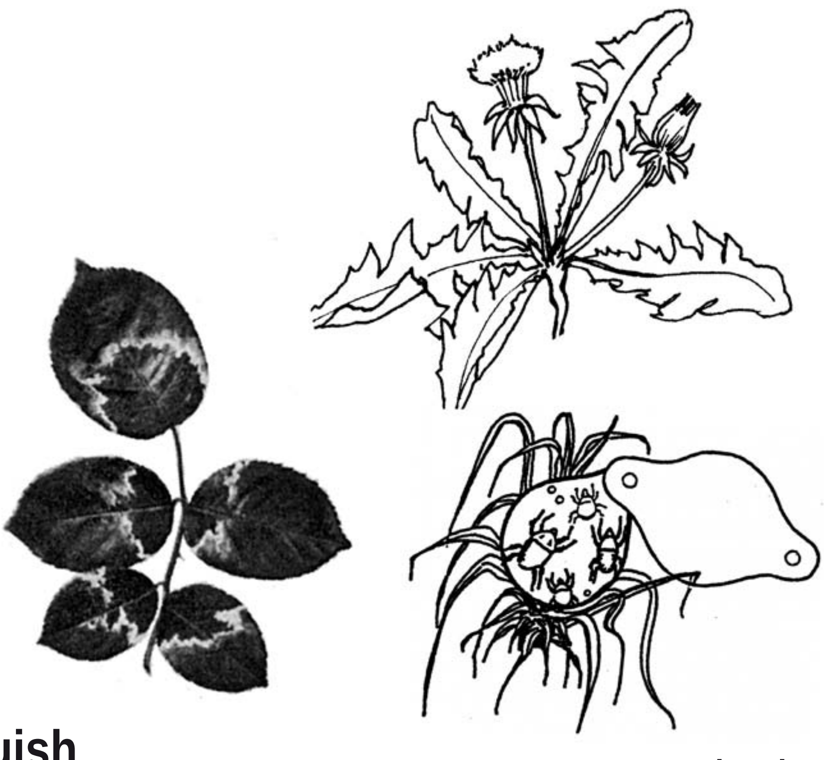
PLANT PROTECTION 1

Pests, Diseases and Weeds

4th edition



Ruth M. Kerruish
Phillip W. Unger

drawings by
Adrienne L. Walkington

PLANT PROTECTION SERIES

PLANT PROTECTION 1

Pests, Diseases and Weeds.

Pests and Diseases

- Insects and allied pests
- Snails and slugs
- Vertebrate pests
- Nematode diseases
- Virus and virus-like diseases
- Bacterial diseases
- Fungal diseases
- Parasitic flowering plants
- Non-parasitic problems

Weeds

PLANT PROTECTION 2

Methods of control.

- Cultural methods
- Sanitation
- Biological control
- Resistant varieties
- Plant quarantine
- Disease-tested planting material
- Physical and mechanical methods
- Pesticides
- Plant Management
- IPM (Integrated Pest Management)
- Organic standards,
- BMP (Best Management Practice)

PLANT PROTECTION 3

Selected Ornamentals, Fruit and Vegetables.

- Annual and herbaceous perennials
- Bromeliads
- Bulbs, corms, rhizomes and tubers
- Cacti, ferns
- Fruit and nuts
- Orchids, palms, roses
- Trees, shrubs and climbers
- Turf grasses
- Vegetables
- Also Australian native plants, Bonsai, Compost, Containers, Garden centres, Greenhouses, Herbs, House plants, Hydroponic systems, Interior landscapes, Manure, Mulches, Nurseries, Plant tissue culture, Postharvest, Potting mixes, Seedlings, Seeds, Soil, Urban bushland, Urban landscapes, Water, Water plants, Xeriscapes.

PLANT PROTECTION 4

How to Diagnose Plant Problems.

- Step 1. The client's enquiry
- Step 2. Identify affected plant
- Step 3. Examine plant parts for signs and symptoms
- Step 4. Visit site, history, questions
- Step 5. Consult references
- Step 6. Seek expert help
- Step 7. Report the diagnosis

PLANT PROTECTION 1

Pests, Diseases and Weeds

4th edition

Ruth M. Kerruish
Phillip W. Unger
with original line drawings by
Adrienne L. Walkington

ROOTROT PRESS ACT

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Front cover: Rose 'mosaic', dandelion, twospotted mites

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It should be recognized that there are differences in soils, climates and seasonal conditions, and that pests, diseases and weeds do not occur uniformly across Australia and may spread to new regions within Australia. New pests, diseases and weeds may enter Australia. Advisors and growers will need to adapt information to suit their particular conditions, regions and situations.

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Organic Federation of Australia (OFA) is the peak body for the organic industry in Australia

www.**ofa**.org.au

and follow the links to obtain the domestic and export organic standards and certifiers.

Biological Farmers of Australia (BFA)
www.**bfa**.com.au

NASAA Certified Organic
www.**nasaa**.com.au

Organic Growers of Australia (OGA)
www.**organicgrowers**.org.au/

Registration of pesticides in Australia is the responsibility of the Australian Pesticides and Veterinary Medicines Authority (APVMA).

APVMA assesses and registers these chemicals to ensure that they perform as claimed and are safe for people, animals and the land. **APVMA** also issues permits for off-label uses. Check on the **APVMA** database that the chemicals you use are registered for use:

www.**apvma**.gov.au

and follow the links to **PUBCRIS** (the Public Chemical Registration Information System).

Many registered products are not available for use by home gardeners

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

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Fig.2.Rust
Fig.3.Hormone herbicide injury
Fig.8.Bean weevil and damage
Fig.11.Codling Moth **E.H.Zeck**
Fig 12.Fruit tree borer damage
Fig.13.Vegetable weevil **E.H.Zeck**
Figs.14,15.Apple leafhoppers and damage
Fig.20.Cottonycushion scale
Fig.21.Apple dimpling bug damage
Fig.22.Woolly aphid damage
Figs.28,29.Case moths
Fig.30.Leafcutting bee damage
Fig.32.Sooty mould
Fig.41.Queensland fruit fly **E.H.Zeck**
Fig.45.Cineraria leafminer damage
Fig.50.Whitestemmed gum moth caterpillar
Fig.51.Painted apple moth caterpillar
Fig.55.Lightbrown apple moth **E.H.Zeck**
Fig.56.Cabbage white butterfly **E.H.Zeck**
Fig.59 Codling moth **W.G.Thwaite**
Fig.60 Codling moth **E.H.Zeck**
Fig.64.Oriental fruit moth **E.H.Zeck**
Fig.66.Fruit-tree borer and damage
Fig.68.Elephant weevil and damage
Fig.69.Beetle borers
Fig.70.Leaf beetle, eggs and larvae
Fig.76.African black beetle **E.H.Zeck**
Fig.77.Fig longicorn and larvae
Fig.78.Bean weevil
Fig.79.Teatree sawfly
Fig.90.Argentine ant **E.H.Zeck**
Fig.91.Citrus gall wasp **E.H.Zeck**
Fig.92.Pear and cherry slug adult
Fig.93.Steelblue sawfly and damage
Fig.94.Leafblister sawfly damage
Fig.97.Gladiolus thrips
Fig.98.Gladiolus thrips damage to corms
Fig.99.Plague thrips **E.H.Zeck**
Fig.101.Green vegetable bug **E.H.Zeck**
Fig.102.Crusader bugs
Fig.106.Green peach aphid **E.H.Zeck**
Fig.107.Woolly aphid damage
Fig.109.Longtailed mealybug and predator
Fig.111.Gumtree scale, frosted scale, soft brown and white wax scale, cottony cushion
Fig.112.Black scale **E.H.Zeck**
Fig.113.Red and white louse scales
Fig 114.San Jose scale **E.H.Zeck**
Fig.116.Greenhouse whitefly
Fig.117.Termite galleries and mound
Fig.118.Timber damaged by termites **E.H.Zeck**
Fig.119.Subterranean termites
Page178.Table35.Termite damage **E.H.Zeck**
Figs.120,121.Australian plague locust and damage
Fig.122.Australian plague locust flights
Fig.123.Grasshopper parasites
Fig.124.European earwig
Fig.125.Springtail
Fig.126.Spider mites **E.H.Zeck**
Fig.127.Grapeleaf blister mite **E.H.Zeck**
Fig.129.Slaters
Fig.130.Snails on trunk of citrus tree
Fig.132.Foliar nematode symptoms
Fig.133.Stem and bulb nematode symptoms
Fig.136.Root knot nematode symptoms
Page278.Ringspot virus symptoms **M.Senior**
Fig.143.Tomato spotted wilt symptoms on dahlia
Fig.144.Tomato spotted wilt-symptoms on arum lily,
Fig.145.Tomato spotted wilt symptoms on nasturtium
Fig.150.Bacterial scab of gladiolus
Fig.152.Fungal leaf spots of mulberry
Fig.156.Bacterial canker of stone fruit
Fig.158.Bacterial leaf and stem rot of pelargonium
Fig.164.Azalea petal blight
Fig.165.Loose smut **M.Senior**
Figs.166,167.Damping off
Fig.168.Lemon scab **M.Senior**
Fig.169.Black spot of grapevine **M.Senior**
Fig.170.Brown rot **M.Senior**
Fig.171.Freckle **M.Senior**
Fig.172.Collar rot of citrus
Fig.173.Red wood rot fungus **M.Senior**
Fig.174.Stem canker of rose
Fig.175.Phytophthora root rot
Fig.176.Rhizoctonia stem rot **M.Senior**
Fig.178.Peach leaf curl defoliation
Fig.187.Downy mildew of lettuce **M.Senior**
Fig.188.Downy mildew of grapevines **M.Senior**
Fig.190.Geranium rust
Fig.191.Bean rust
Fig.200.Peach leaf curl **M.Senior**
Fig.205.Sclerotinia rot, Sclerotium stem rot **M.Senior**
Fig.207.Damping off
Fig.208.Lichens
Fig.209.Wind injury
Fig.211.Sooty mould
Fig.219.Sunburnt trunk
Fig.220.Rind splitting of orange
Fig.222.Cold injury to carnation
Fig.226.Enlarged lenticels on potato tuber
Fig.227.Potato leaf roll
Fig.229.Magnesium deficiency **M.Senior**
Fig.231.Whiptail on crucifer
Fig.244.Mutant orange

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Pagexiii.Plant clinic activities
Fig.1.Christmas beetle
Fig.6.Citrus butterfly caterpillars
Fig.7.Pear and cherry slug damage
Fig.9.Azalea leafminer damage
Fig.10.Citrus gall wasp damage
Page18.Spittle bug
Fig.16.Green peach aphids
Fig.17.Greenhouse whiteflies
Fig.18.Lerps
Fig.23.Black peach aphids
Fig.24.Green house thrips damage
Fig.25.Onion thrips damage
Fig.26.Thrips in dahlia flowers
Fig.27.Callistemon leafrolling thrips damage
Fig.31.Webbing caterpillar damage
Fig.33.Tomato big bid phytoplasma damage
Fig.36 Christmas beetle, corn earwom
Fig.45.Cineraria leafminer damage
Fig.52.Cup moth caterpillar
Fig.54.Leafminer damage to bottlebrush
Fig.57.Corn earworm and damage
Fig.63.Oriental fruit moth damage to peach fruit
Fig.72.Leafeating ladybirds and damage
Fig.73.Predatory ladybirds
Fig.78.Bean weevil damage
Fig.80.Callistemon sawfly larvae
Fig.81.Callistemon sawfly larvae damage
Fig.83.Cypress pine sawfly larvae.
Fig.92.Pear and cherry slug and damage
Fig.94.Leafblister sawfly larvae
Fig.95.Onion thrips damage
Fig.96.Leafrolling thrips damage to callistemon
Fig.98.Gladiolus thrips damage to flowers
Fig.102.Crusader bug damage on wattle
Fig.104.Cabbage aphid damage
Fig.107.Woolly aphids on apple
Fig.108.Lerps and lerp damage
Fig.109.Longtailed mealybug
Fig.111.Wattle tick scale, black scale
Fig.113.San Jose, red and rose scales
Fig.116.Greenhouse whiteflies
Page175.Termite damage to potato
Page178.Table35.Borer and wood rot damage
Page227.Snail damage to cabbage
Page229.Snail damage to gazania - skeletonization
Fig.130.Snail damage to cabbage, kangaroo paw
Page240.Bird damage to roses
Fig.132.Foliar nematode, symptoms(?)
Page273.Hydrangea mosaic
Page275.Ringspots on watermelon
Page 277.Apple mosaic, tomato spotted wilt symptoms
Page278.Tulip flower breaking
Fig.138.Grapevine fanleaf, camellia yellow mottle
Fig.139.Yellow net vein, flat limb
Fig.141.Tomato spotted wilt, capsicum, tomato
Fig.142.Thrips in dahlia flowers
Fig.146.Tomato big bud on tomato
Fig.147.Tomato big bud symptoms on gazania, parsnip
Fig.148.Rose mosaic
Fig.152.Bacterial blight of mulberry
Fig.154.Crown gall symptoms on rhubarb and rose
Fig.156.Bacterial canker of stone fruit
Fig.159.Shothole damage to leaf
Fig.160.Fungal leaf spot on strawberry
Fig.161.Powdery mildew of euonymus
Fig.162.Rust on antirhinum
Fig.163.Petal blight on rose flowers
Fig.177.Damping off
Fig.185.Powdery mildew of euonymus
Fig.192.Gall rust on wattle
Fig.193.Rose rust
Fig.196.Black spot on rose
Fig.197.Anthracnose on rose
Fig.199.Leaf curl symptoms on plum fruit
Fig.202.Wood rot fruiting bodies and damage
Page372.Damping off
Pages380-382.Mistletoe, devil's twine, dodder, broomrape
Fig.212.Wood rot fungus in container
Fig.213.Fairy ring in a lawn
Fig.218.Sunscorch injury to capsicum and tomato
Fig.221.Splitting of skin on tomato
Fig.225.Oedema on umbrella leaf
Fig.227.Leafrolling on rhodendron leaves
Fig.230.Iron deficiency on rhodendron
Fig.232.Blossom end rot on tomato
Fig.233.Simazine injury to *Prunus*
Fig.237.Lawnmower injury to base of tree
Fig.238.Potbound roots
Fig.239.Hail damage to fruit
Fig.240.Chimera on tulip and apple
Fig.241.Fasciation on rose
Fig.242.Variegated leaf on citrus
Fig.243.Burr knots on *Prunus*
Figs.251,252,253.Herbicide injury
Page462.Herbicide injury
Fig.254.Weeds in container

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Page92.Desire codling moth trap

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Fig.148.Rose mosaic

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Fig.84.Gall wasp on Geraldton wax **Wood and Grimm**

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AgBiotech	Monsanto
Agrimm Technologies	Multicrop
Bayer	Organic Crop Protectants
Becker Underwood	Sanoway
Bioglobal	Scotts Australia
Chemtura	SST Australia
Colin Campbells	Syngenta
Crop Care	UPL
Desire	Valent BioSciences
Dow AgroSciences	Yates
Ecogrow	

CONTENTS

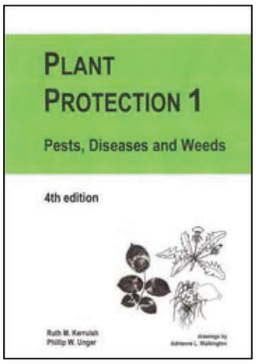
Insects and Allied Pests *(contd)*

Snails and Slugs *227*

PREFACE

This book is the first in a series which combines the basic principles of pests, diseases and weeds into a single, integrated program. Plant Protection is a dynamic field and a systematic understanding of the strategies involved is necessary for the successful management of plants and crops and to permit constant updating. It can readily be used in conjunction with the season-related learning of plant pests, diseases and weeds. In this preface suggestions are made on how this book may best be used.

PLANT PROTECTION 1



Pests, Diseases and Weeds (the **causes** of problems)

PESTS and DISEASES

It can be difficult to know whether one is dealing with a pest or disease. Definitions of these terms are often inconsistent, so pests and diseases have been grouped together and re-divided into 2 new groups:

Parasitic problems include:
- Insects and allied pests
- Snails and slugs
- Vertebrate pests
- Nematode diseases
- Virus and virus-like diseases
- Bacterial diseases
- Fungal diseases
- Parasitic flowering plants

Non-parasitic problems include:
- Living agents, eg fairy rings, lichens
- Non-living agents, eg heat, pollutants

For each group, the following is described:
Distinctive features
Host range
Damage/Symptoms
Pest/Disease cycle
'Overwintering'
Spread
Conditions favoring
IPM and Control methods
Representative problems
Review questions and activities
Selected references

WEEDS

Weeds are less complex to study than pests and diseases and are treated in a traditional manner.

REPRESENTATIVE PROBLEMS

Representative problems have been chosen to indicate possible types of damage, control measures, etc.

Criteria for inclusion of a pest, disease or weed, include economic importance, abundance, interesting or striking appearance.

FACT SHEETS

Information relating to a particular problem is presented in standardized **Fact Sheets** with the following headings/sub-headings:

Common name (of pest, disease or weed)
Cause/Scientific name
Host range/Plants affected/Situation
Description and Damage/Symptoms/Effect
Diagnostics
Pest/Disease/Weed cycle
Overwintering
Spread
Conditions favouring
Integrated Pest Management
Control methods
- Cultural methods
- Sanitation
- Biological control
- Resistant/Tolerant varieties
- Plant quarantine
- Pest/Disease/Weed-tested planting material
- Physical and mechanical methods
- Pesticides

PESTICIDES, BLANK SPACES

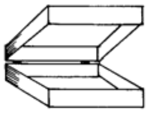
Registered and/or recommended pesticides change from time to time and it is therefore difficult to keep a text current

- **Pesticides are not always listed** as there are many computerized systems which provide up-to-date information on registration and safety, eg some industries such as the grapevine industry publish current recommendations for their particular industry.
  www.apvma.com.au
- **Blank spaces** in some instances, have been left so that where appropriate, currently registered pesticides, new resistant/tolerant varieties, pest management programs and other up-to-date information can be inserted.

WEB SITES

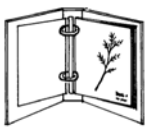
In the online format of this book websites can be accessed by using the Select Text button on the tool bar and pasting them into your search engine. Those that you might want to use regularly can be placed under **'Favourites'** on your computer.

COLLECTIONS



Insect collection

Plant disease and damage collection



Weed collection

THE AIM OF THE COLLECTIONS

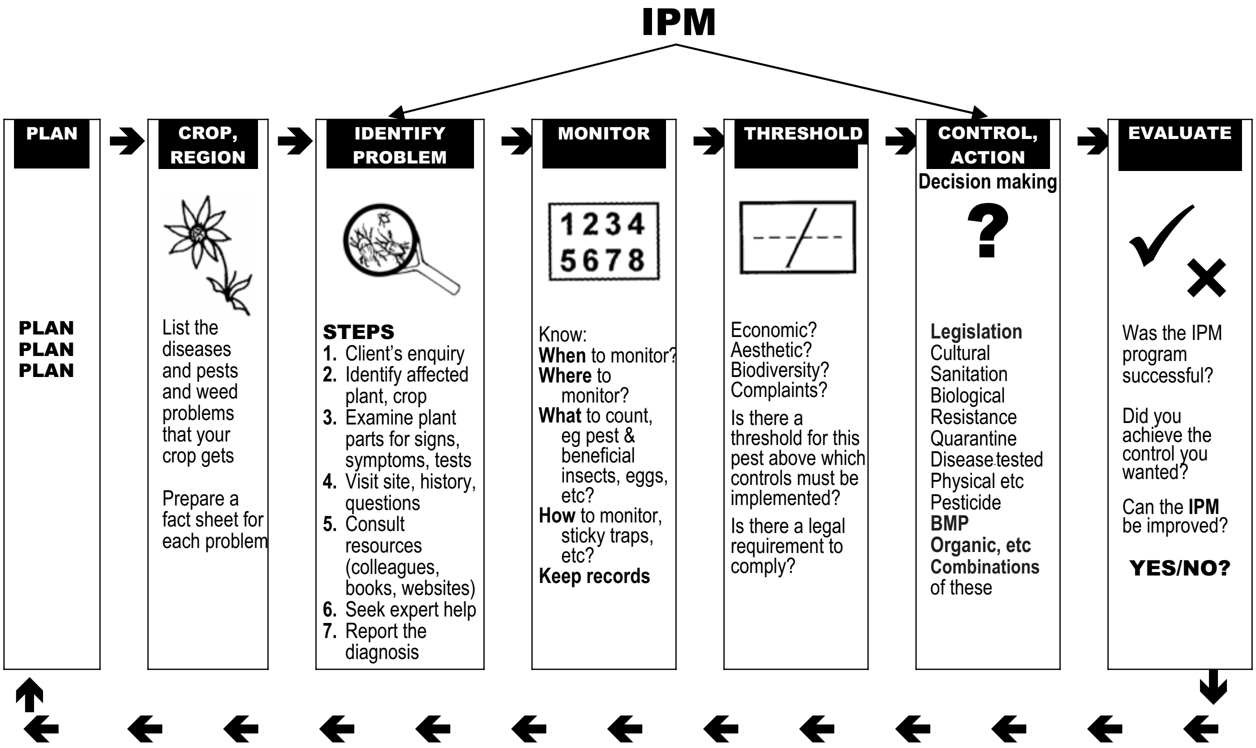
The aim is to help in the systematic study of pests, diseases and weeds and to obtain experience in correctly identifying the causes of plant problems. About **20 specimens** should be prepared for each collection. It is a good idea to swap specimens with other collectors. Instructions can be given for all collections, including details about collecting and preserving them, well before commencing the study of Plant Protection. It is easy to compile collections during the summer. Collections can be a valuable personal reference for many years.

- **Insect collection.** A dry and preserved collection of local pests of economic importance can be prepared and identified. A systematic index should accompany the collection, ie insects should be arranged according to Order. Some specimens may be compulsory; the others collected as desired but be of relevant horticulture interest.
- **Plant disease and damage collection.** A dry herbarium collection of plant diseases and plant damage can be collected and arranged according to the agents which **cause** plant problems, eg insects, snails, nematode diseases, virus diseases, etc (page xi). A systematic index should accompany the collection, ie diseases should be arranged according to their type, eg bacterial diseases, fungal diseases, etc. Some specimens may be compulsory and others of local or personal horticultural interest.
- **Weed collection.** A dry herbarium collection should be prepared and arranged according to specified weed groups. An index should accompany the collection. Collection of the majority of weeds should be compulsory.

WHY IDENTIFY THE PEST, DISEASE OR WEED?

INTEGRATED PEST MANAGEMENT (IPM)

- **Pests, diseases and weeds** are the main causes of plant problems and if they are not **identified** accurately, **control measures** are likely to be ineffective.
- **Identification** of the pest, disease or weed is the **3rd step in IPM**. If dealing with:
  - **Diseases**, the term **IDM** (Integrated Disease Management) is used.
  - **Weeds**, the term **IWM** (Integrated Weed Management) is used.
- **Some** pests, diseases and weeds are **difficult to identify**.



Steps in Integrated Pest Management (IPM).

HOW MUCH OF THE BOOK SHOULD BE STUDIED?

SYSTEMATIC STUDY

- **Causes** of plant problems should be studied systematically, preferably starting with insects and allied pests in autumn, they are easy to collect and study, most people find them interesting.
- However, it is not necessary to cover **all** the problems within each group, but rather that some be selected for more or less detailed study.
- Always include some important **local** pests, diseases and weeds.

PRACTICAL EXPERIENCE

To obtain sufficient practical experience in examining fresh material and diagnosing plant problems, the following activities may be undertaken:

- **Bringing specimens to class.** Students are encouraged to bring specimens for class study and diagnosis.
- **Seasonal pests, diseases and weeds** can be examined when available.
- **Regular testing.** Initially students can examine seasonal specimens according to their cause. After a few weeks and some experience has been acquired, regular weekly or fortnightly self-testing of selected specimens can commence.
- **Field studies.** Take every opportunity to examine problems in the field at different times of the year but especially during spring and autumn, field studies are of most benefit towards the end of the course, when students have acquired some skills. Examine real plant problems at work and in gardens, ask colleagues and friends. Plant clinics and advisory services can be useful aids.
- **Emailing** photographs to diagnostic services.

Many insects and weeds can be readily identified from pictures sent to a diagnostic service – Christmas beetle.

Some diseases have **distinctive** symptoms and a general identification can be made from photos sent to a diagnostic service – **rose 'mosaic'**.

Many diseases can be **difficult** to identify from symptoms and may require fresh material, knowledge of the plant, its history and/or specific tests for identification – the plant is *Choysia*.
What questions might you want to ask?

Fresh material with the enquirer is often best – you can ask questions

Plant clinics can provide a range of plant problems for students that they might not normally see.

Greenhouses are always a great source of pests and diseases.

Trips to look at problems in the field are essential for many situations – though photographs can be **emailed**. ***Left:*** Ash tree dying back due to prolonged drought. ***Right:*** Soil disease of English daisy, a **laboratory test** is required for a positive identification.

DIAGNOSTIC AND INFORMATION SERVICES

Free home garden advice may be provided by your local horticulture college, botanic gardens, garden centres and garden clubs. Talkback radio, Gardening Australia TV and newspapers all provide further opportunities for gardeners to seek advice. On-line fact sheets are a big help for home gardeners. However, a pest still needs to be correctly identified, so plant specimens or their photos may still need to be sent or taken to a garden advisory service. Remember some problems can be difficult to identify from photographs.

Commercial diagnostic services and pest management services are offered by consultants, industry associations, CSIRO and state departments of primary industry. Some are free, others cost recovery.

- Most diagnostic services **specialize** in pests or diseases, soil or water testing, etc.
- There are diagnostic services for some **crops** are available, eg grape, cotton and turf. The **Nursery & Garden Industry** has developed a pest, disease and identification tool for use in the field on handheld PDAs (Personal Data Assistants) and some Smartphones. Some crops have a '**One Stop Shop for Your Crop**' via the internet, eg CropWatch Online for grapevines.
- **Local councils** offer advice on noxious weeds and vertebrate pests, bees, possums.
- The following are examples of some commercial diagnostic services for plant pests, diseases and weeds.

Australia-wide

GrowSearch Australia
An information service for producers of ornamentals, horticultural and nursery crops.
PO Box 327, Cleveland, Qld 4163
☎ (07) 3824 9555 **Fax** (07) 3286 7618
email **growsearch@dpi.qld.gov.au**
www.**dpi**.qld.gov.au/ and search for GrowHelp

Plant quarantine
Plant Health Australia is the lead national coordinating body for plant health in Australia. There are links to the website below at www.**planthealthaustralia**.com.au/

Emergency Plant Response Deed (EPRD)
Underpinning the **EPRD** is **PlantPlan** the agreed technical response plan used by jurisdictions and industry in responding to an EPP incident.

PaDIL (Pest and Diseases Image Library) provides high quality images of exotic organisms, assists with diagnostics, trains and encourages public awareness in quarantine. www.**padil**.gov.au

National Pest and Disease Outbreaks
Outbreak only reports on pests and diseases that are exotic to Australia, and are under eradication programs.
www.**outbreak**.gov.au/

CSIRO Insect Identification Service
Australian National Insect Collection - ACT
ANIC Collection Manager
Clunies Ross Street, Acton ACT 2601
☎ (02) 6246 4281 **Fax** (02) 6246 4264
email **ento-ident@csiro.au**
www.**csiro**.au/**services**/

Biological Crop Protection
Specializes in nematodes, plant diseases, soil-borne diseases, biological control, diagnostic services in nematology, plant pathology and soil biology.
3601 Moggill Rd, Moggill, Qld 4070
☎ (07) 3202 7419
email info@biolcrop.com.au
www.**biolcrop**.com.au

Northern Australia

Northern Australia Diagnostics Network (NADN)
Is concerned with detection, management and control of diseases and pests of horticulture and agriculture in the NT, north WA and north Qld.
www.**tpp.uq**.edu.au/Default.aspx?tabid=722

CRCTPP [Cooperative Research Centre for Tropical Plant Protection)]
Level 5 John Hines Building
The University of Queensland, Qld 4072
☎ (07) 3365 2790
email **j.irwin@uq.edu.au**

Australian Capital Territory

XCS Consulting
A European Wasp and Insect Identification Service.
☎ (02) 6162 1914

New South Wales

Plant Health Diagnostic Service (PHDS), NSW DPI
Plant Pests and Disease Identification
www.dpi.**nsw**.gov.au/

Elizabeth MacArthur Agriculture Institute
Woodbridge Road, Menangle, NSW 2568
☎ (02) 4640 6327 **Fax** (02) 4640 6400

Orange Agricultural Institute
Forest Road, Orange, NSW 2800
☎ (02) 6391 3800, 1800 675 821 **Fax** (02) 6391 3899

Plant Disease Diagnostic Unit Service
Royal Botanic Gardens Sydney
Mrs Macquarie's Road, Sydney, NSW 2000
☎ (02) 9231 8111 www.**rbgsyd**.nsw.gov.au/

Northern Territory

Dept. of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR)
Entomology A range of entomological services is provided to growers, government departments, householders, home gardeners and the general public.

Plant Pathology Branch Identify plant diseases caused by various bacteria, fungi, nematodes, phytoplasmas, viruses and viroids as well as non-living agents. Also develop disease management practices.

Address
Berrimah Farm
Makagon Road, Berrimah, NT 0828
GPO Box 3000, Darwin, NT 0801
☎ (08) 8999 2162 **Fax** (08) 8999 2312
www.**nt**.gov.au/d/Primary_Industry/
email **info.drdpifr@nt.gov.au**

Queensland

Dept. of Primary Industries
Grow Help Australia provides a disease and pest diagnostic service for horticultural crops, testing for disease organisms in plants, seeds, potting mix, soil and water; plant pathogen testing to fulfil nursery accreditation scheme and export requirements; remedial advice.
www.dpi.**qld**.gov.au/26_12360.htm

Grow Help Client Service Officer
Entomology Building
80 Meiers Road, Indooroopilly Qld 4068
☎ (07) 3896 9668 **Fax** (07) 3896 9446
email **growhelp@dpi.qld.gov.au**

HORTUS Technical Services
Laboratory and field testing, pre- and post-plant analysis, fruit testing, potting mixes, quick soil and hydroponic tests, fruit, sap tests and potting mix tests, pest monitoring, training.
410 Langbeckers East Road, Bundaberg, QLD 4670
Locked Bag 3901, Bundaberg, Qld 4670
☎ (07) 4132 50000 **Fax** (07) 4155 6656
www.**croptech**.com.au www.hortus.net.au/

South Australia

SA Research and Development Institute (SARDI)

www.sardi.sa.gov.au/ follow link to Pests and Diseases, then Diagnostic Services

Crop diagnostics provide seed and plant pathology services, virus testing, nematode identification and sampling
☎ (08) 8303 9384

Horticulture Diagnostic Services provide disease diagnosis, virus testing, nematode identification and sampling
☎ (08) 8303 9562 / 8303 9585 **Fax** (08) 8303 9303

Insect Diagnostic Services provides insect identification, biological control advice when requested
☎ (08) 8303 9540 **Fax** (08) 8303 9542

PreDicta B (B=broadacre) is a DNA based soil testing service to identify which soilborne pathogens which pose a significant risk to broadacre crops prior to seeding.
☎ (08) 8303 9393

Tasmania

Dept. of Primary Industries, Parks, Water and Environment

Weeds, pests and diseases
www.dpipwe.tas.gov.au/

Diseases
Senior Pathologist
13 St Johns Avenue, Newtown, Tas 7008
☎ (03) 6233 6864, 1300 368 550 (local call cost)
Fax (03) 6278 2716

Pests
Entomologist
1 Rundle Road, Devonport, Tas 7310
☎ (03) 6421 7636 **Fax** (03) 6424 5142

Victoria

Dept. of Primary Industries

Crop Health Services (DPI – Knoxfield) provides diagnostic services for plant diseases and pests and management recommendations as appropriate. Also provides disease-tested planting material of potatoes, strawberries and other crops and monitoring services.

Crop Health Services
621 Burwood Highway, Knoxfield, Vic 3180
Ferntree Gully Delivery Centre, Vic 3156
☎ (03) 9210 9356 **Fax** (03) 9887 3166
www.dpi.vic.gov.au and search for Crop Health Services

Cropwatch is the division of Fruit Growers Victoria Ltd which provides Integrated Pest and Disease Management (IPDM) and field services to commercial fruit growers on a fee for service basis.
www.cropwatch.com.au/
www.fgv.com.au/cropwatch.htm

Western Australia

Department of Agriculture

AGWEST Plant Laboratories
Provides a range of services including seed certification, weed and insect identification and plant disease diagnosis.
Department of Agriculture and Food Western Australia
3 Baron-Hay Court, South Perth, WA 6151
☎ (08) 9368 3721 **Fax** (08) 9474 2658
email **agwestplantlabs@agric.wa.gov.au**
www.agric.wa.gov.au/

Grain Guard and Hort Guard provide specialist diagnostic service for many plants problems, eg broomrape.

- **PestWeb** - a searchable database that contains identification and control information for insect pests of farms and quarantine significance.
- **Keys to allied pests of extensive agriculture** - an adapted and abridged web version of the popular extension booklet.
- **Identifying and managing aphids in potatoes** - aphid management and identification keys
- **Bruchid pest host database** - a database to outlining bruchid pests, distribution and various host plants.

Pest and Disease Information Service (**PaDIS**)
Free advice and specimen identification
Freecall 1800 084 881 or *email*: **info@agric.wa.gov.au**

Turf Consultants

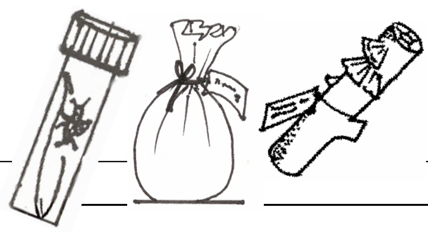
Australian Golf Course Superintendents Assoc. (AGCSATech)
Suite 1, Monash Corporate Centre
752 Blackburn Road, Clayton VIC 3168
☎ (03) 9548 8600 **Fax** (03) 9548 8622
email **info@agcsa.com.au**
www.agcsa.com.au/

Globe Australia
Soil testing and plant diagnostic services
☎ (02) 8713 5555 **Fax** (02) 8713 5550
www.globeaustralia.com.au/turf
www.globeaustralia.com.au/

SportsTurf
Diagnostic Soil, Water and Plant Analysis
Soil, plant tissue and water analysis
Disease, insect and weed identification
Nematode testing
45 Westerfield Drive
Notting Hill VIC 3168
☎ (03) 9574 9066 **Fax** (03) 9574 9072
email **info@sportsturf.com.au**
www.sportsturf.com.au

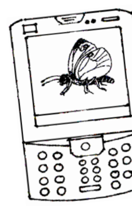
SAMPLES

- Consult the advisory service or website to find out how to sample and send the specimen.
- Samples should be fresh and show early and late stages of damage.
- Insects and fungal fruiting bodies causing damage may be collected.
- For identification of plants/weeds, collect leaves, flowers and seeds where possible.
- If collecting small plants or grasses, collect roots as well.
- Do not wrap specimens in plastic or wet them, specimens rot. Use clean dry paper.
- Photographs, digital images and maps assist diagnosis.
- Soil and water samples must be in secure containers.
- All samples must be clearly labeled.
- Diagnostic forms can be downloaded from the laboratory's website, filled in and attached to the specimen.
- If posting specimens use express post and mark urgent.
- Postal address may be different from delivery address.



Services offered include:
Pest and disease identification
Weed identification
Online diagnostics
Guidelines for control
IPM strategies

Some are highly specialized:
Nematode identification
Seed certification
Soil and water analysis
Soil moisture monitoring
Irrigation advice
Plant tissue analysis
Potting mix test
Sap tests
Fruit tests
Root identification
Environmental monitoring
Specific crops



Diagnostics – online

PDA devices will make it possible to have a complete guide for known crop pests and diseases on every grower's mobile phone, eg the electronic **Pest, Disease, Beneficial & Weed Identification** tool (Nursery & Garden Industry Queensland (NGIQ).

SELECTED REFERENCES

Pests and diseases

Fact Sheets by State/Territory Depts of Primary Industries and the Commonwealth Government are available online:
Bureau of Rural Sciences (BRS) www.daff.gov.au/brs
Australian Capital Territory www.act.gov.au
New South Wales www.dpi.nsw.gov.au
Northern Territory www.nt.gov.au
Queensland www.dpi.qld.gov.au
South Australia www.pir.sa.gov.au
Tasmania www.dpiw.tas.gov.au
Victoria www.dpi.vic.gov.au
Western Australia www.agric.wa.gov.au

Keys Centre for Biological Information Technology (CBIT) Lucid keys www.lucidcentral.org/

Management manuals produced by individual states and industry associations, provide information on pests and diseases of **particular crops** are available as books or online, eg Floriculture; **AUSVEG** which is the national peak industry body representing the interests of Australian vegetable and potato growers www.ausveg.com.au/

American Phytopathological Society (APS) Press, St. Paul, Minnesota produces compendiums on diseases and pests of particular plants. www.shopapspress.org

Bodman, K., Carson, C., Forsberg, L., Gough, N., Hughes, I., Parker, R., Ramsey, M. and Whitehouse, M. 1996. *Ornamental Plants : Pests, Diseases and Disorders.* Q196001. Qld DPI, Brisbane.

Buczacki, S. and Harris, K. 2005. *Pests, Diseases and Disorders of Garden Plants*. 3rd edn. Collins, UK.

Deardorff, D. and Wadsworth, K. 2010. *What's Wrong With My Plant?* Timber Press, USA.

Goodwin, S., Steiner, M. Parker, R., Tesoriero, L., Connellan, G., Keskula, E., Cowper, B., Medhurst, A. and Rodriguez, C. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* Agrilink. QAL0004, NSW DPI. Sydney.

Goodwin, S. and Steiner, M. (eds). 2000. *The Pests, Diseases, Disorders and Beneficials in Ornamentals – Field Identification Guide.* DPI. Will be available digitally for use in the field.

Horst, R. K. (ed.). 2008. *Westcott's Plant Disease Handbook*. 7th edn. eReference, originally published by Springer, NY.

Jones, D. L. and Elliot, W. R. 1986. *Pests, Diseases and Ailments of Australian Plants.* reprinted 1995. Lothian Pub., Melbourne.

Kerruish, R. M. 1997. *Plant Protection 3: Selected Ornamentals, Fruit and Vegetables*. RootRot Press, ACT. avail. online

Kerruish, R. M. 2006. *Plant Protection 4: How to Diagnose Plant Problems*. RootRot Press, ACT. avail. online

McMaugh, J. 1994. *What Garden Pest or Disease is That?* Lansdowne Press, Sydney.

Tesoriero, L. et al. 2009. *Managing Diseases and Pests in Asian Vegetables*. RIRDC, ACT.

Yates. *Yates Garden Guide*. cur. edn. Angus and Robertson, Sydney. There is also a pest guide.

Pests

CSIRO entomology www.ento.csiro.au/education/about.html
Introduction to Entomology http://bugs.bio.usyd.edu.au/
Aust. Ento. Supplies www.entosupplies.com.au
Victorian Museum www.mov.vic.gov.au/
Australian insect farm www.insectfarm.com.au/about.htm

Broadley, R. and Thomas, M. . *The Good Bug Book : Beneficial Insects and Mites Commercially Available in Australia for Biological Pest Control.* ABC/Qld DPI/RIRDC.

Hadlington, P. W. and Johnston, J. A. 1998. *An Introduction to Australian Insects*. Revised edn. UNSW Press, Kensington, NSW.

Zborowski, P. and Storey, R. 1995. *A Field Guide to Insects in Australia.* Reed Books, Port Melbourne.

Diseases

The Australasian Plant Pathology Society (APPSnet) www.australasianplantpathologysociety.org.au/
The American Phytopathology Society (APSnet) www.apsnet.org/
Lucid disease keys - First microscope key to microbes *An initial guide for the identification of microbes observed with the light microscope*. www.lucidcentral.org/
NIASA. *The Nursery Industry Accreditation Scheme, Australia.* www.ngia.com.au/

Agrios, G. N. 2005. *Plant Pathology*. 5th edn. Academic Press, NY.

Brown, J. F. and Ogle, H. J. 1997. *Plant Pathogens and Plant Diseases.* Rockvale Pubs., Armidale, NSW.

Committee on Standardization of Common Names for Plant Diseases of The American Phytopathological Society, 1978-2007 (compiled by). *Common Names of Plant Diseases*. APSnet online Resources. www.apsnet.org/

Cooke, T., Persley, D and House, S. (eds) 2009. *Diseases of Fruit Crops in Australia*. CSIRO Publishing, Melbourne.

Fahy, P. C. and Persley, G. J. 1983. *Plant Bacterial Diseases : A Diagnostic Guide.* Academic Press, North Ryde, NSW.

Keane, P. J., Kile, G. A., Podger, F. D. and Brown, B. N. (eds). 2000. *Diseases and Pathogens of Eucalypts.* CSIRO Pub., Collingwood, Vic.

Persley, D., Cooke, T. and House, S. 2010. *Diseases of Vegetable Crops in Australia.* CSIRO Pub., Melbourne.

Weeds

Fact Sheets by State/Territory Depts of Primary Industries and the Commonwealth Government are available online
Weeds in Australia www.weeds.gov.au
Weeds Australia www.weeds.org.au
National Weeds Lists www.weeds.gov.au/weeds/lists/index.html
Lucid weed keys www.lucidcentral.org/
Field Guides – **WEEDeck**, Regional **Ute Guides**

Auld, B. A. and Medd, R. W. 1986. *Weeds : An Illustrated Botanical Guide to the Weeds of Australia.* Inkata Press, Melbourne.

Parsons, W. T. and Cuthbertson, E. G. 2001. *Noxious Weeds of Australia*. 2nd edn. CSIRO, Melbourne.

Biological control/Organic standards/IPM

List of suppliers www.goodbugs.org.au/
Organic Federation of Aust (OFA) www.ofa.org.au for organic certifiers, draft national standard, publications
AS 6000—2009. Organic and Biodynamic Products www.standards.org.au/ www.ofa.org.au/
Organic Growers of Australia www.organicgrowers.org.au/
NASAA Certified Organic www.nasaa.com.au
Organic Crop Protectants www.ocp.com.au/
Australian Organic Journal www.australianorganic.com.au/
Biological Farmers of Australia (BFA) for publications, standards, producers, registered products directory, contacts www.bfa.com.au
Companies, eg Becker Underwood, Bioglobal, Bugs for Bugs, Ecogrow

Caldwell, B., Rosen, E. B., Sideman, E. A, Shelton, A. M. and Smart, C. D. 2000. *Resource Guide for Organic Insect and Disease Management.* www.nysipm.cornell.edu/organic_guide/

Quarantine

Australian Quarantine and Inspection Service (AQIS) www.daff.gov.au/aqis search for DAFF online
PaDIL Pest and Disease Image Library has diagnostic photographs and information www.padil.gov.au/
Target lists of weeds, insects, plant and animal pests and diseases. www.daff.gov.au and search for target lists

Pesticides

Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
Herbiguide, Albany, WA
Croplife Australia www.cropelifeaustralia.org.au/
MSDS www.msds.com.au/
Company websites, Industry Pest Control Guides
Regional Pest and Disease Guides

Journals

Plant Protection Quarterly www.weedinfo.com.au/ppq_toc
Farm Online www.farmonline.com.au
Aglinks www.aglinks.com.au/
Acres Australia www.acresaustralia.com.au/
Rural Press www.ruralpress.com/
IPMnet www.ipmnet.org
Cropnet www.cropnet.com

PESTS AND DISEASES

Twospotted mites (*Tetranychus urticae*) can be seen with a hand lens.

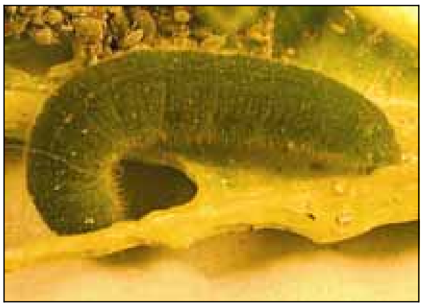
Steelblue sawfly (*Perga* spp.) larvae (spitfires) rest during the day in clumps and feed on eucalypt leaves at night.

Peach leaf curl (*Taphrina deformans*) is a fungal disease affecting some stone fruits.

WHAT ARE PESTS AND DISEASES?

PESTS AND DISEASES

A PEST is an organism that at any given time or place, is undesirable.



Cabbage white butterfly caterpillar chewing broccoli leaves. The cabbage white butterfly is the worst butterfly pest in the world.
Photo©CIT, Canberra (P.W.Unger).

A DISEASE is any condition of a plant that interferes with its normal structure, functions or economic value.

Fungal leaf spots on strawberry
Photo©NSW Dept of Industry and Investment (M.S.Senior).

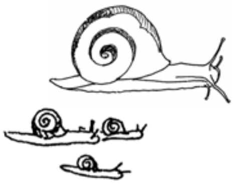
DIFFERENCE BETWEEN A PEST AND A DISEASE

IT CAN BE DIFFICULT TO KNOW whether one is dealing with a pest or disease, as definitions of these terms are often inconsistent. Pests and diseases have been grouped together and re-divided into 2 new groups:

- **Parasitic** pests and diseases
  - Insects and allied pests
  - Snails and slugs
  - Vertebrate pests
  - Nematode diseases
  - Virus and virus-like diseases
  - Bacterial diseases
  - Fungal diseases
  - Parasitic flowering plants
- **Non-parasitic** pests and diseases
  - Living agents, eg lichens
  - Non-living agents, eg environment

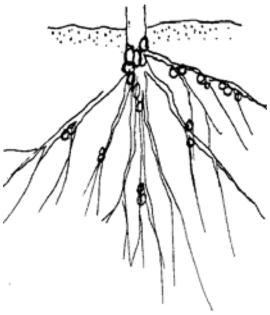
PARASITIC PESTS AND DISEASES

Cabbage white butterfly (*Pieris rapae),* caterpillars feed on cabbages, stock, etc.

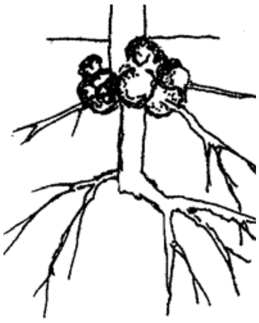


Snails and slugs damage a wide range of plants

Fruit bats (flying foxes) can be pests of fruit.



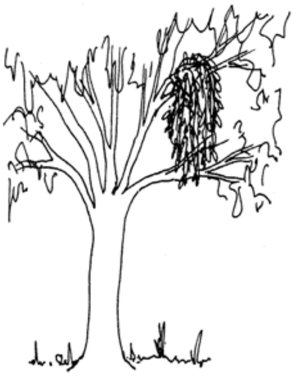
Root knot nematodes (*Meloidogyne* spp.) cause galls up to **20 mm** across to develop on roots.



Crown gall (*Agrobacterium* sp.) causes galls **20-300 mm** across to develop at the crown of Rosaceous plants.

Rose mosaic (a complex of virus diseases).

Black spot of rose (*Marsonnina rosae*).



Mistletoe on a tree.

WHAT ARE PARASITIC PESTS AND DISEASES?

PARASITIC PESTS AND DISEASES

PARASITIC PESTS AND DISEASES are caused by LIVING agents (plants and animals) which damage plants by obtaining their food from them. Parasitism occurs where one organism benefits to the detriment of the other. Parasitic pests and diseases of plants commonly include:

- Insects and allied pests
- Snails and slugs
- Vertebrate pests
- Nematode diseases
- Virus and virus-like diseases
- Bacterial diseases
- Fungal diseases
- Parasitic flowering plants

Other organisms such as algae and protozoa may also be parasitic but are not as commonly encountered.

Fig. 1. Christmas beetle feeding on a eucalypt leaf. Photo©CIT, Canberra (P.W.Unger).

Fig. 2. Rust pustules on the under surface of a geranium leaf. Photo© NSW Dept. of Industry and Investment.

NON-PARASITIC PESTS AND DISEASES

NON-PARASITIC PESTS & DISEASES are caused by:

- **LIVING agents** (plant and animals) which damage plants mechanically, or in some way **other than** by obtaining their food from them. Examples include leafcutting bees, dogs, cats, children, fairy rings, lichens and slime moulds.
- **NON-LIVING agents** such as heat, frost, drought, waterlogging, lightning, pesticide injury, deficiencies and pollution. This group is **almost infinite** in number and type.

Although **non-living agents** cause plant damage in their own right, some create an environment favourable to the development of a **parasitic** problem, eg the fungus *Phytophthora* produces spores which can swim in water and infect poorly developing plant roots in over-watered potting mixes.

Fig. 3. Hormone herbicide (2,4-D) injury to grapevine leaves. Thickened veins, reduced interveinal leaf area, pronounced saw-toothed leaf margins. Photo© NSW Dept. of Industry and Investment.

Insects and Allied Pests

Insect

Mites

Spider

Springtails

Millipede

Centipede

Slater

BIOLOGY

Phylum Arthropoda, Class Insecta

Insects are the most abundant and most diverse of all animals. More than 86,000 species of insects have been identified in Australia and probably a similar number are awaiting discovery. It is likely that some may become extinct without ever having been discovered!

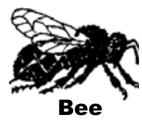
CSIRO Insects and Their Allies www.**ento**.csiro.au/**education**/about.html

SOME BENEFICAL INSECTS

Wasp laying an egg in a scale insect

POLLINATORS OF MANY PLANTS

- Bees, wasps, flies, beetles and other insects are important pollinators of crops.



Bee

FOOD SOURCE OF MANY ORGANISMS

- Bats, birds, fish, frogs and lizards feed on many different types of insects.
- Humans and animals feed on honey, bogong moths, witchetygrubs (wood-boring larvae, sometimes called bardee grubs), termites can be roasted.
- Plants such as the Venus fly trap, feed on flies.

FEED ON AND RECYCLE ANIMAL AND PLANT WASTES, DEAD ANIMALS

- Garden maggots in compost heaps digest and biodegrade organic matter.
- Dung beetles bury and decompose dung.

PARASITES AND PREDATORS OF MANY PLANT AND ANIMAL PESTS

- Red scale of citrus can be controlled biologically by parasitic wasps.
- Insects may also transmit biological control agents, eg mosquitoes transmit the myxomatosis virus used to control rabbits.

PRODUCE ITEMS USED BY HUMANS

- Beeswax, shellac, dyes, silk, medicines, royal jelly, red food colouring products are all used in today's society.

AESTHETIC VALUES

- Beautiful insects especially butterflies are collected.
- Wings of dead butterflies in some parts of Africa are used as an art form to create pictures. Butterflies and beetles are used as head or body decorations.

SOME HARMFUL INSECTS

Weevil chewing leaves

MOST INSECTS AND ALLIED PESTS ARE NOT 'PESTS'!

- **Less than 0.1%** of the nearly 1 million known species are harmful.

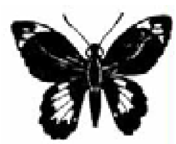
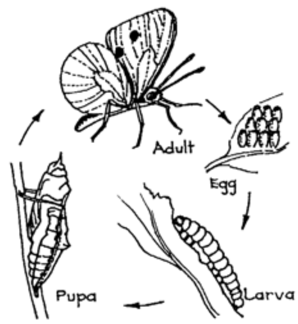
'PESTS' OF PLANTS AND ANIMALS

- Plants may be damaged by aphids, fruit flies, scales and other insects.
- Stored products by grain moths, grain beetles.
- Paper, leather and textiles by beetles, cockroaches, silverfish, moths.
- Animals by blowflies, fleas.
- Humans by fleas, scabies, mosquitoes, ticks, lice, bedbugs.
- Many insects are nuisance pests, eg bush flies, many ants.
- Some '**stinging'** insects, eg bees, wasps, and some ants inject poisoning and paralyzing liquids via a modified egg-laying structure. Some '**biting'** pests pierce the skin to feed on blood; many dogs are infested with ticks each year and some may die from tick paralysis.
- Arachnophobia is a fear of spiders.

TRANSMIT DISEASES OF PLANTS AND ANIMALS

- Plants, eg tomato spotted wilt virus is spread by thrips.
- Humans, eg malaria (a protozoa) is spread by a species of mosquito which pierces the skin ('bites') to feed on blood.

Why are insects successful?

PROLIFIC REPRODUCTION RATE	**A QUEEN TERMITE CAN DEPOSIT MORE THAN 2000 EGGS PER DAY** and she can live for more than 10 years! It has been estimated that a single green peach aphid in one year could give rise to a population of more than 10 million aphids! Although many do not survive, enormous numbers do. Many insects have a short life cycle, there are exceptions, eg the life cycle of some cicadas may be as long as 17 years, some moth borers may tunnel in wood for as long as 2-5 years in trees before pupating.
OCCUR IN EVERY ENVIRONMENT	**INSECTS ARE FOUND ON BOTH LAND AND WATER** under most climatic conditions.
MANY POSSESS WINGS	**WINGS ARE NOT FOUND** in any other invertebrate animal. This is one of the decisive factors in the supremacy of insects on land and in air.  **Large citrus butterfly**
PROTECTIVE EXOSKELETON	**INSECTS AND OTHER ARTHROPODS** such as mites, spiders, millipedes and slaters have a hard protective **external** skeleton (an exoskeleton). Humans have an **internal** bony skeleton.
SMALL SIZE	**THE GENERALLY SMALL SIZE OF INSECTS** is probably one of their most important characteristics in the struggle for existence. The majority are 125 mm or less in length, but there is considerable variation, the smallest being less than 0.25 mm and the largest about 260 mm in length.
COMPLETE METAMORPHOSIS	**METAMORPHOSIS** is the process of change from egg to adult. Insects in the most abundant orders have a **complete metamorphosis** which means that: • They hatch from the egg in a form **totally dissimilar** to the adult. • Each stage of development may be **specialized**, eg moths and butterflies: – Larvae are specialized for feeding. – Adults for reproduction and spread.  **Cabbage white butterfly**
POLYMORPHISM	**POLYMORPHISM** (the occurrence of **3 or more distinct types of adults in a single species)** is common among insects, eg adult honeybees may be either a: • Queen (the reproductive) • Drone (male), or a • Worker
CAMOUFLAGE	**CAMOUFLAGE** assists many avoid predators, eg some look like green or brown leaves, twigs, others merge with the colour of bark, some caterpillars have 'eye spots' to frighten predators, some are spiny (page 13).
FINDING FOOD	**MANY WAYS OF FINDING FOOD**, eg large eyes identify movement, eggs are laid in their larval food source, forelegs may be modified to catch prey, stinging.
SENSORY SOPHISTICATION	**SENSORY PROCESSES**, eg smell, taste, sight, hearing and feeling surpass most other organisms.

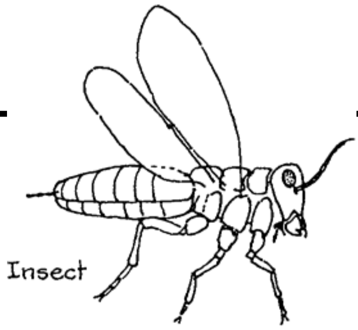
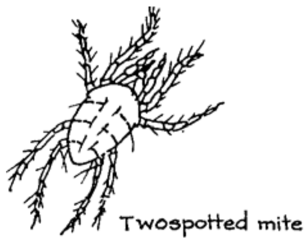
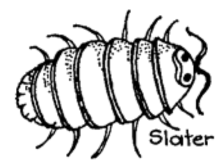
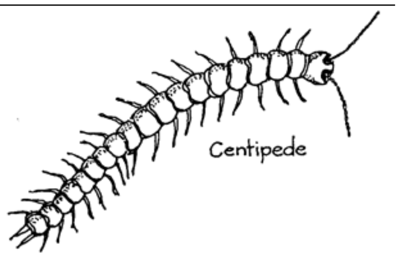
What are insects?

Insects belong to the **Class Insecta** in the **Phylum Arthropoda**, the largest phylum in the Animal Kingdom. Other classes in the Phylum Arthropoda are listed below.

PHYLUM ARTHROPODA
(Insects and Allied Pests)

The most important distinguishing features common to **adults** of the Phylum Arthroproda are:

1. Body is divided into segments.
2. Hard outer covering on body and limbs, with flexible joints for movement.
3. Paired limbs.
4. Bilateral symmetry (each side of the body is a mirror image of the other).

CLASS INSECTA	**INSECTS** 1. Three body segments. 2. Three pairs of legs on thorax. 3. Antennae present (1 pair). 4. Wings either present or absent.	
CLASS COLLEMBOLA	**SPRINGTAILS** 1. Three body segments. 2. Three pairs of legs on the thorax. 3. Furcula on abdomen for jumping. 4. Wingless.	
CLASS ARACHNIDA	**MITES,** TICKS, **SPIDERS,** SCORPIONS 1. Two body sections. 2. Four pairs of legs. 3. No antennae. 4. No compound eyes. 5. Simple eyes present.	
CLASS MALACOSTRACA	PRAWNS, CRABS, BARNACLES, **SLATERS** 1. Two body sections. 2. Five or more pairs of legs. 3. Antennae present. 4. Usually sea dwellers, sometimes on land.	
CLASS DIPLOPODA	**MILLIPEDES** 1. At least 11 body segments. 2. Body round. 3. Two pairs of legs to each segment, no poison fangs. 4. Antennae present.	
CLASS CHILOPODA	**CENTIPEDES** 1. At least 19 body segments. 2. Body long and flattened. 3. One pair legs to each segment, first pair modified to form poison fangs. 4. Antennae present.	

External anatomy of adult insects

BODY	**HARD COVERING** • The hard covering is called an **exoskeleton.** **SEGMENTATION PROVIDES MOBILITY** • The body is segmented into the **head**, **thorax** and **abdomen**. • Segmentation and mobility allows some insects and allied pests, eg funnelweb spiders, to adopt **threatening positions**. **BILATERALLY SYMMETRICAL AND MORE OR LESS ELONGATED** • Each half is a **mirror image** of the other.
HEAD	**SEGMENTATION AND MOBILITY** • Segments of the head are **fused.** • There is a **joint** between the head and thorax. **ANTENNAE** • There are **2 antennae** (1 pair) for smelling, feeling, occasionally tasting and hearing. **EYES** • **Compound** and/or **simple** eyes. **MOUTH** • **Chewing**, **sucking**, siphoning, sponging, lapping, etc.
THORAX	**SEGMENTATION AND MOBILITY** • The thorax is segmented into 3 parts to provide **mobility**. **WINGED OR WINGLESS** • If winged, **1 or 2 pairs** (most insects have 2 pairs of wings). • If 2 pairs, **1 pair** attached to each of the **2nd and 3rd thoracic segments**. **THREE PAIRS OF JOINTED LEGS** • Legs are **flexible** with a hard covering. • **One pair** is attached to each of the **3 thoracic segments**. **SPIRACLES** • Spiracles (for **breathing**) may be present or absent.
ABDOMEN	**SEGMENTATION AND MOBILITY** • The abdomen is segmented into up to 11 segments to provide **mobility**. **LARGE ABDOMEN** • The abdomen is **large** compared with the head and thorax. **SPIRACLES** • Spiracles (for **breathing**) may be present or absent, often 1 pair per segment. **OTHER APPENDAGES** • Cerci at the end of the abdomen (for **feeling)** may be used during mating (page 16).

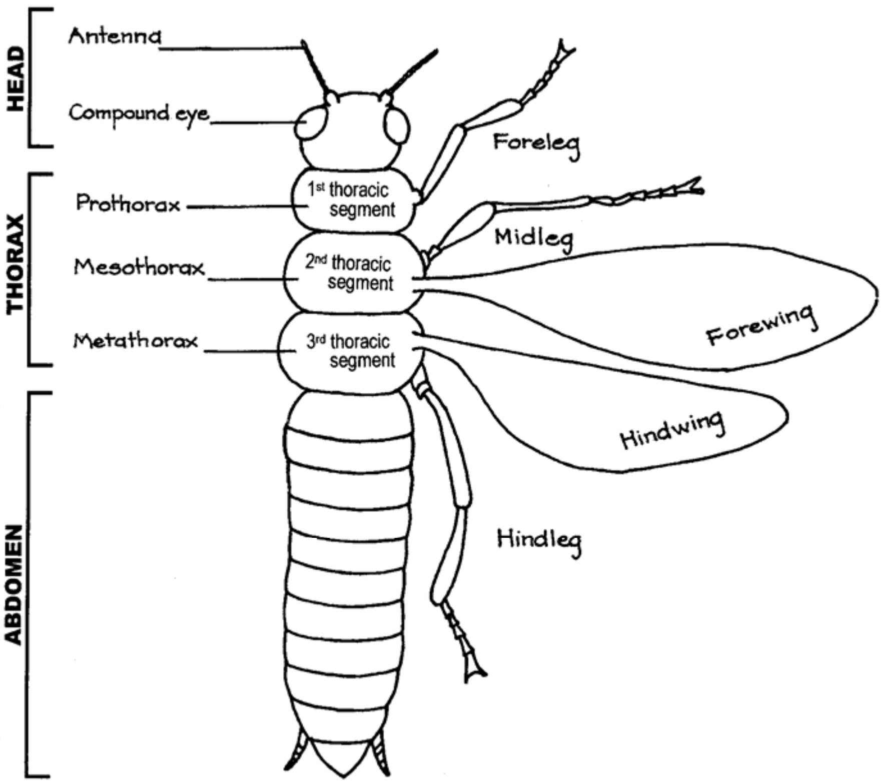


Fig. 4. Diagrammatic drawings of an insect from above.

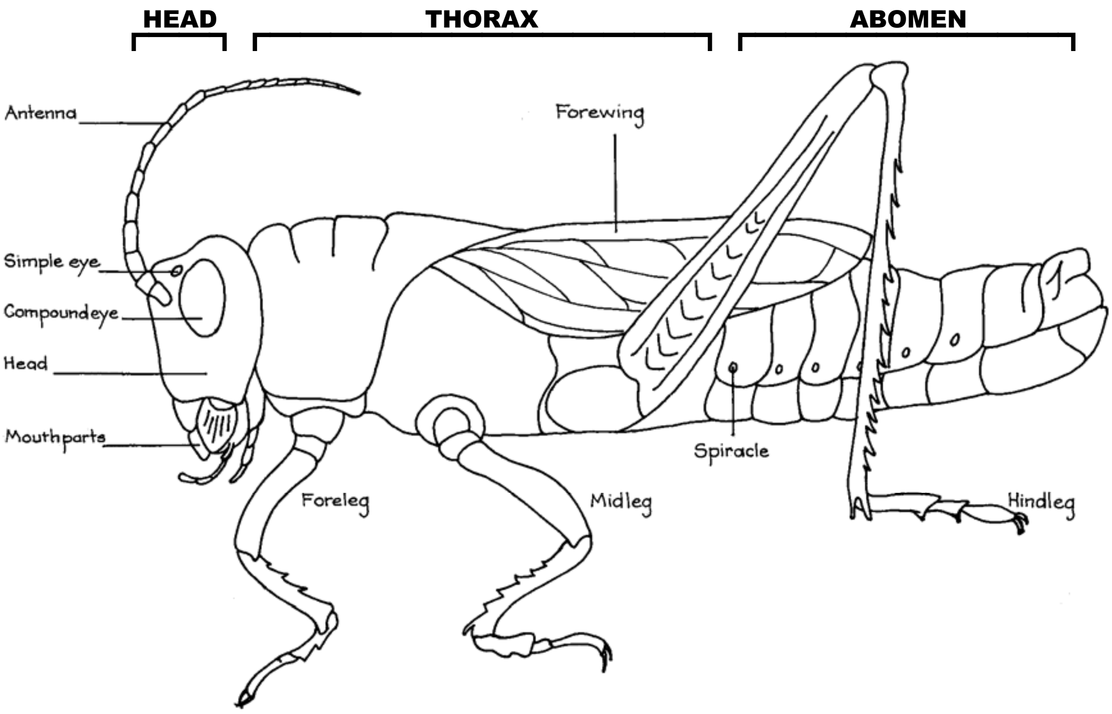
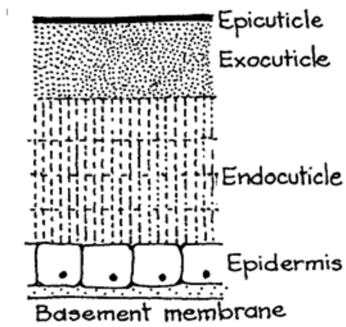


Fig. 5. Diagrammatic drawing of a young locust (nymph) from the side.

INTEGUMENT
(Body covering)

The shape of an insect is determined by its tough outer covering, the **integument**. This forms a skeleton (an exoskeleton) within which lie all the soft tissues.

The integument plays an important part in insect development and physiology and in relation to the action of insecticides. It is made up of the **cuticle**, **epidermis** and the **basement**:

CUTICLE	**THE CUTICLE IS USUALLY HARD, DENSE, INELASTIC AND IMPERMEABLE** to liquids and is variable in thickness. The cuticle consists of: **THE EPICUTICLE**, which is thin and waxy, gives the characteristic impermeable nature to the cuticle, and protects the insect from water loss. Silica gel is sometimes used to control cockroaches. It physically destroys the wax so that the insects dry out and die. **THE EXOCUTICLE** is thicker and gives rigidity to the cuticle. It is composed of hard chitin and other substances and may contain pigments. **THE ENDOCUTICLE**, is never pigmented and is the most flexible and elastic portion of the cuticle.  **Cuticle** When the cuticle is first formed it is soft and pliable, but certain layers of it soon harden (see above). The cuticle hardens in sections or plates with flexible unsclerotized cuticle between. The cuticle of many larvae, eg caterpillars, remains soft all over the body.
EPIDERMIS	**THE EPIDERMIS** is a continuous single layer of living cells which secrete the substances forming the cuticle. It also contains specialized cells which produce surface hairs and glandular secretions. These are found on the surface of the cuticle.
BASEMENT	**BASEMENT MEMBRANE** The basement membrane is a very thin layer separating the epidermis from the body cavity.
COLOUR	**COLOUR CAN HAVE MANY USES** • **Camouflage.** Stick insects resemble either sticks or leaves, their colour, shape and swaying movement make them very difficult to see against a background of trees and shrubs. • **Discouraging predators.** The brightly coloured spots of many ladybirds and the red stripe of female redback spiders warn off predators which might eat them. 'Eye'spots on the wings of some moths and on the rear of some caterpillars confuse predators. Birds learn to avoid insects that are brightly coloured or taste unpleasant. • **Catching prey.** Larvae of some predatory glow-worms produce light which glows from the tip of the abdomen and attracts prey. • **Mating.** Colour and light are used to gain the attention of females during mating.

HEAD

SEGMENTATION

Movement

SINGLE HARD HEAD CAPSULE

- Although originally formed of 6 segments, the head is compacted into a single hard head capsule.
- There is usually a narrow ‘neck’ region behind the head which allows the head to move.

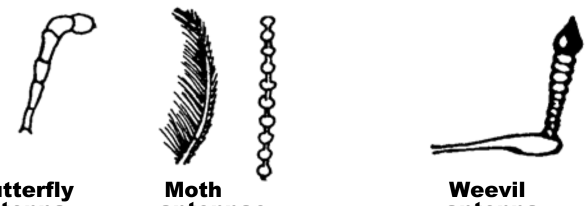
ANTENNAE

Smelling
Feeling
Tasting
Hearing

ONE PAIR OF ANTENNAE

The antennae arise from the front of the head, usually situated between or in front of the compound eyes. Antennae are:

- Used for smelling, feeling and occasionally for tasting and hearing.
- Mobile and can move in all directions.
- Made up of few or many segments.
- Variable in size and shape.



Butterfly antenna (clubbed) **Moth antennae** (variable) **Weevil antenna** (elbowed)

EYES

MOST INSECTS HAVE BOTH COMPOUND AND SIMPLE EYES

- However, only one or other may be present.

COMPOUND EYES

- Most insects have **1 pair**.
- They are usually **conspicuous** shiny objects on the side of the head, eg in flies, and are round, convex or kidney-shaped.

1 pair large compound eyes

- Compound eyes are composed of **minute hexagonal panes** fitted closely together. Each pane admits a point of light, a bit of the total scene that the insect sees. Nerves carry the information to the brain and all the bits of the picture are then pieced together to form the whole picture (like a television picture). The more panes an insect has the sharper the picture, eg flies have 4,000 and **dragonflies more than 20,000 panes**.
- Insects **cannot move their eyes** but they can move their heads.
- They have **no eyelids**, their eyes are always open.
- They can see a sharp image up to **1 meter**, further is a blur.
- They can quickly see **movement**.
- They can discriminate **colors**, see colors we cannot see, eg ultraviolet and infrared.

3 tiny simple eyes arranged in a triangle between 1 pair of large compound eyes

SIMPLE EYES (ocelli)

- Each adult insect has up to **3 simple eyes**, each with only **1 lens**, usually arranged in a **triangle** on the top of the head. It is doubtful if any of them see a clear image but they are able to distinguish **light from darkness** and may discern faint images. The simple eyes found in larvae are called ‘stemmata’.
- Larvae of insects with a **complete metamorphosis** do not have compound eyes, they have **6 simple eyes** on the side of their head.

‘ Eyespot’ on grapevine hawk moth caterpillar

‘EYESPOTS’

Eyespots on caterpillars and insect wings are not real eyes, they are for decoration to frighten predators.

HEAD *(contd)*

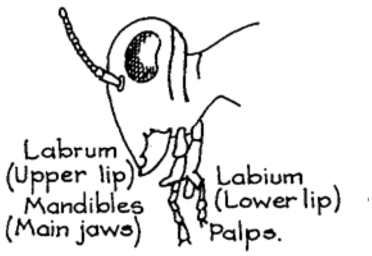
MOUTH PARTS

The mouth of an insect is surrounded by mouth parts which differ in appearance depending on their method of feeding. They may be jaw-like for chewing or tube-like for sucking. In many insects which have a complete metamorphosis, the mouth parts are different in the larval and adult stages. The stages of insects which damage plants **have mouth parts belonging to the first three types** illustrated below:

Many variations

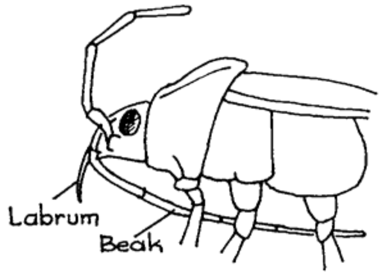
1. CHEWING (biting mouthparts).

Solid food, eg beetles, grasshoppers.



2. PIERCING and SUCKING.

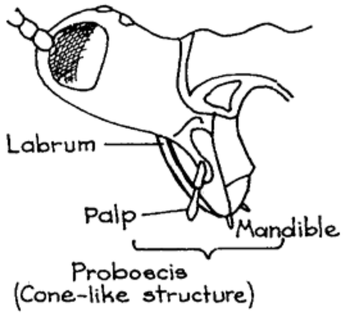
Liquid food, eg bugs, aphids, lerps, mealybugs, scales, whiteflies.



Many variations

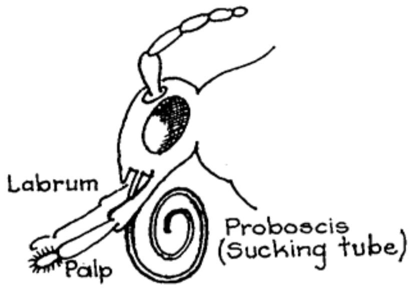
3. RASPING and SUCKING.

Liquid food, eg thrips.



4. SIPHONING.

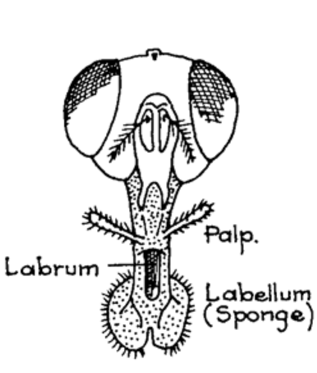
Liquid food, eg butterflies, moths.



Many variations

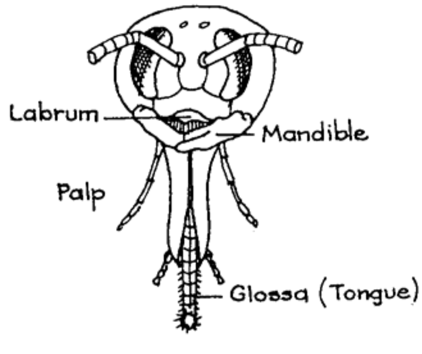
5. SPONGING.

Liquid food, eg flies; the mouth parts of mosquitoes are modified so they can pierce the skin and feed on blood.



6. CHEWING AND LAPPING.

Solid and liquid food, eg honeybees.



THORAX

The **thorax is made up of 3 segments** (from front to rear):

1 pair of legs on each → **PROTHORAX (1st)**, **MESOTHORAX (2nd)**, **METATHORAX (3rd)**

MESOTHORAX (2nd), **METATHORAX (3rd)** ← 1 pair of wings and 1 pair of spiracles on each

All 3 thoracic segments may not be visible from above, eg beetles.

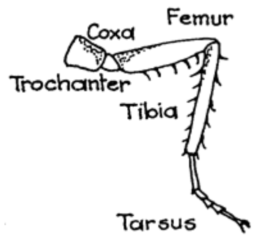
LEGS

ADULT INSECTS HAVE 6 LEGS (3 PAIRS)

- There is 1 pair on each segment of the thorax.

LEGS ARE JOINTED AND HAVE 5 PARTS

- Coxa (articulates with the sternum).
- Trochanter (often overlooked, tiny).
- Femur (the stoutest part).
- Tibia (usually long and slender).
- Tarsus of 1-5 segments, in adults the last tarsal segment usually has a pair of claws, larvae usually have one claw.



Moths, mantids and grasshoppers have **ears** on their legs

Some legs (and bodies) are covered with **sensory hairs**

Mole cricket, front leg modified for digging.

LEGS ARE OFTEN MODIFIED FOR SPECIAL PURPOSES, not necessarily for locomotion:

- Digging, eg mole crickets.
- Catching prey, eg praying mantids.
- Cutting leaves, eg leaf-cutting bees.

WINGS

MANY, BUT NOT ALL INSECTS HAVE WINGS

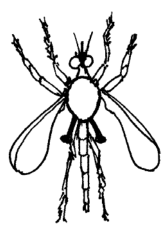
- There is 1 pair on the **mesothorax** and 1 pair on the **metathorax**.

WING STRUCTURE

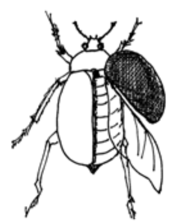
- Wings are usually formed of **2 layers of thin membrane** strengthened by a framework of tubular veins, the spaces between being known as cells.
- In the early stages of development wings are present as **wing buds** which are filled with blood and supplied with trachea (air tubes).
- Wings are **articulated to the sides** of the thorax and connected internally to strong muscle bands.
- **Wing venation** is used for identification especially, in wasps and flies.

VARIATIONS include:

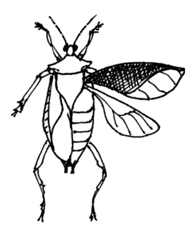
- Some adults have **no wings**, eg female painted apple moth.
- Some insects with wings **cannot fly**, eg German cockroach.
- Hind wings modified to form clubs **(halteres)**, eg flies.
- Forewings modified to form hardened wing covers **(elytra)**, eg beetles.
- Forewings have a **thickened front portion**, the rest of the wing being gauzy, eg true bugs (green vegetable bug).
- Surface of wings may be covered with **hairs or scales**, eg butterflies.
- Wings may be **coupled together**, eg butterflies.



Fly, hind wings club-shaped (halteres).



Beetle, forewings hardened (elytra).



Bug, forewing with thickened portion.

Sound and communication

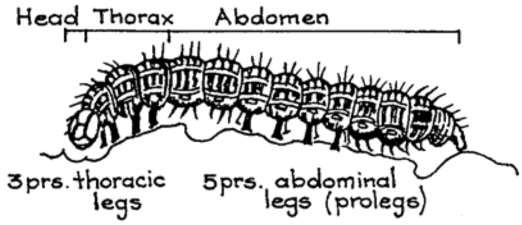
- **Some grasshoppers and beetles** rub their rear leg and forewing together.
- **Some male crickets** chirp on hot summer nights by rubbing specialized parts of their forewings to attract females.
- **Honey bees'** wings stroke over 11,000 times per minute, to make their distinctive buzz.
- **Mosquitoes** beat their wings in flight to make the buzz we hear. Males have bushy antennae which are designed to pick up on the wing beat of their mates.
- **House flies** beat their wings up to 200 times per second to make their familiar buzz.

ABDOMEN

The **abdomen** is made up of a number of segments joined by flexible membranes. Up to 11 segments may be present though the number is often less. In addition, several segments may be much reduced or modified for **mating** so that in some cases there may only be 4-5 segments.

<table>
<tr><td>PROLEGS</td><td>
LARVAE OF SOME INSECTS HAVE PROLEGS

Moth, butterfly and some sawfly larvae have prolegs.
Prolegs develop on the abdomen and are not true jointed legs.
They assist with walking and attachment to their host plant.



Grape vine moth caterpillar
NUMBER OF PROLEGS VARY

Larvae of butterflies and moths have up to 5 pairs.
Larvae of some sawflies have 6-8 pairs.

</td></tr>
<tr><td>SEXUAL APPENDAGES</td><td>
CERCI
Some insects have a pair of cerci located at the tip of the abdomen. They are used for feeling and are often used during mating.


Earwigs
OVIPOSITORS

Some females, eg wasp parasites, have long ovipositors (tubes) for depositing their eggs deeply in tissue. They usually arise from beneath segments 8 and 9.
In bees, wasps and some ants, the ovipositor is also a stinging organ.

Parasitic wasp
CLASPING OR HOLDING ORGANS

These occur in male insects, are used during mating and are usually on the 9^{th} segment.
If the 5th pair of prolegs on moth larvae are well developed they may also be called claspers. Caterpillars of the doubleheaded hawk moth are huge (up to 12 cm long). The terminal claspers are very large and at first glance could be mistaken for the head, hence the insect's common name.

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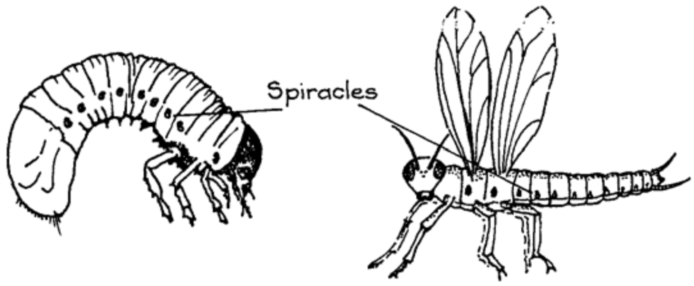
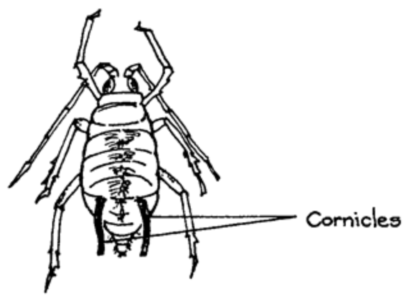
ABDOMEN *(contd)*

SPIRACLES **Breathing**	**COMMONLY 8 PAIRS OF SPIRACLES** • One pair to each segment. • Used for respiration. **SPIRACLES ARE APERTURES** • Spiracles allow oxygen to enter the body and carbon dioxide to pass out. They can open and close. • The spiracles are the openings which lead into a system of air tubes or trachea which are spirally strengthened to retain their shape. They branch and become smaller in diameter until they are called 'tracheoles' which end blindly within cells in all parts of the body. Oxygen and carbon dioxide diffuse across the thin walls of the tracheoles.  **Scarab grub (larva)** **Grasshopper (adult)**
ANUS	**END OF THE ABDOMEN** • The anus is usually situated at the end of the abdomen. **MATERIAL EXCRETED** Several different types of materials are excreted through the anus including: • Frass • Honeydew • Spittle **MORE INFORMATION?** • Excretions are detailed on the following page.
CORNICLES	**CORNICLES ARE TUBE-LIKE STRUCTURES** arising from the **upper side** of the **5th and 6th** abdominal segment. • They secrete a defensive fluid. • Cornicles are present on many species of **aphids**.  **Green peach aphid** (view from above).
SOUND	**MALE CICADAS HAVE A PAIR OF PLATES OR DRUMS** on either side of their abdomen which they vibrate to make their familiar sound. They also have ears on the abdomen.

Insect excretions

FRASS

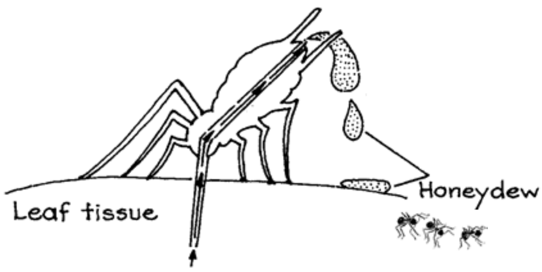
FRASS is the undigested food and waste particles passed out through the anus. It may be solid or liquid.

- **Solid frass** is produced by **many** insects, eg beetles, caterpillars, sawfly larvae. Because the faeces of some insects are characteristically shaped this feature can be used for identifying these insects, for example cup moth larvae which may be feeding high up in a tree. Pellets of excreta found on the lower leaves of pot plants or on benches in glasshouses often indicate that caterpillars are feeding higher up in the foliage. Solid frass and undigested residues of eaten wood may fill tunnels in which the larvae of borers have been feeding.
- **Liquid frass** is produced by **some insects**, eg flies, thrips:
  - The ‘fly specks’ found on ceilings and light globes are the dried liquid excreta of the common house fly.
  - The small black spots on the undersurfaces of viburnum leaves is the liquid excreta of the greenhouse thrips.

HONEYDEW

SOME SUCKING HEMIPTEROUS INSECTS PRODUCE HONEYDEW, eg

- Aphids
- Leafhoppers
- Lerp insects
- Mealybugs
- Soft scale insects
- Whiteflies



Aphid sucking plant sap and excreting honeydew


Ants

HONEYDEW EXCRETED THROUGH THE ANUS may be produced in enormous volumes, up to several times the weight of the insect in 24 hours.

THE EXTREMELY HIGH CARBOHYDRATE CONTENT, which may exceed 80% of the total weight of fresh excreta, makes it very attractive to other insects such as **ants**, which may tend certain species as we would tend cows.

- **Composition of honeydew varies** with the seasonal composition of the plant sap. In addition to the constituents of the plant sap which pass straight through the alimentary canal of the insect, there is a variety of sugars and nitrogenous compounds which are synthesized in the body of the insect.
- **Honeydew may be produced in such large quantities** that plants and paths beneath infested plants become sticky.
- **Black sooty mould fungus** may grow on the honeydew causing further disfigurement.

SPITTLE


Exposed spittle bug with froth above.

1st STAGE NYMPHS OF SPITTLE BUGS PRODUCE SPITTLE

- **As soon as the nymphs begin feeding** they almost immediately commence excreting the frothy spittle which gives the insects their name.
- **Spittle is formed** from excess plant fluids (with the addition of some internal secretions) and discharged through the anus. The excretion is stirred into a stable froth by abdominal contractions which force bubbles of air from specialized air canals on the abdomen into the liquid.
- **Spittle (froth) completely covers the insect** and protects it from desiccation and attack by natural enemies.

Insect secretions

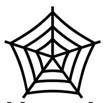
WAX GLANDS

THE SECRETION OF WAX BY THE EPIDERMAL GLANDS is a normal process of cuticle formation in all insects. However, in some insects profuse discharges of wax occur.

- **Beeswax** is the natural secretion of the worker honeybee that is poured out in thin scales or flakes from glands that open on the underside of the abdomen. Its production directly follows the consumption and digestion of a quantity of honey, a kilogram of wax resulting from the consumption of from 2-10 kg of honey in about 24 hours!
- **Several insects belonging to the Order Hemiptera** also secrete wax profusely, including the tiny lac scale insect which is native to India and Burma and produces the substance from which shellac (a varnish) is made. Woolly aphids and mealybugs secrete large quantities of waxy materials.

SILK, WEBBING

Leaf curling spider curls a dead leaf with silk to form a hiding place.



Spider web

SILK AND WEBBING are produced by many **insects, mites and spiders**.

- **Silk is used by caterpillars of moths and butterflies** for many purposes, including cocoon construction to protect the pupa, case making for sheltering caterpillars, binding leaves together and for lowering themselves for dispersal, eg leafrolling caterpillars. The silk is produced in special glands and comes out via the mouth. The Chinese untangled the silk from the pupa of the silkworm cocoons to give the world silk.
- **Webbing is also produced by 'spider' mites**, eg twospotted mite, from glands which open into the mouth. In heavy infestations, the fine silk threads form a web over the entire plant. The mites crawl over the webbing and fasten their eggs to it.
- **All spiders** use silk to cover their eggs. The use of silk to form various types of webs to capture food is widespread. Young spiders (spiderlings) use silk for dispersal (ballooning).

ODOURS, TASTE

DERMAL GLANDS, which secrete unpleasant odours which have a **protective** function, are common in bugs in the Order Hemiptera, eg bronze orange bug and the crusader bug.

- **Stink bugs** give out a particularly disagreeable smell when disturbed, hence their common name.
- **Birds learn to avoid** brightly colored insects that taste unpleasant.
- **Social insects**, eg ants, bees and wasps, use odours to communicate with each other.

ATTRACTANTS

PHEROMONES are substances produced by external glands on insects which produce specific reactions in other individuals of the same species.

- **The best known pheromones are the sex attractants** which are commonly found in moths and flies and used in pest control.

POISON GLANDS

Stingers are used to lay eggs, for self-defence and stinging

MANY ANTS, BEES, WASPS AND SOME ANTS secrete venom from glands and inject it through a modified ovipositor or a stinger as a mechanism of self-defence. Honey bees have a large barbed stinger.

Barbed stinger which the honey bee uses for self-defence.

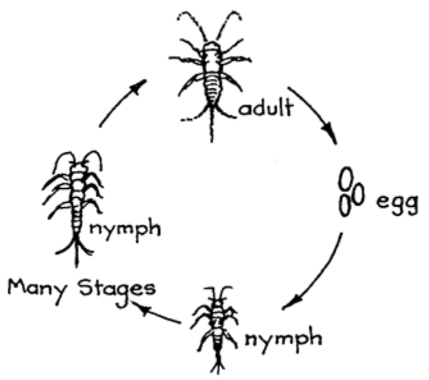
Worker bee

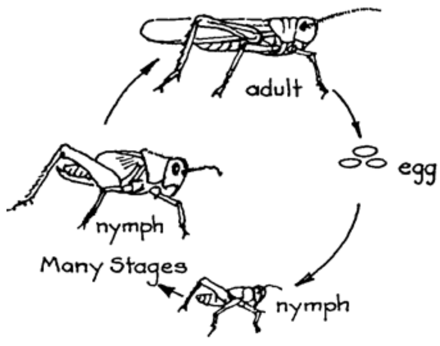
SPIDERS BITE and some simultaneously inject venom via their fangs into their victim.

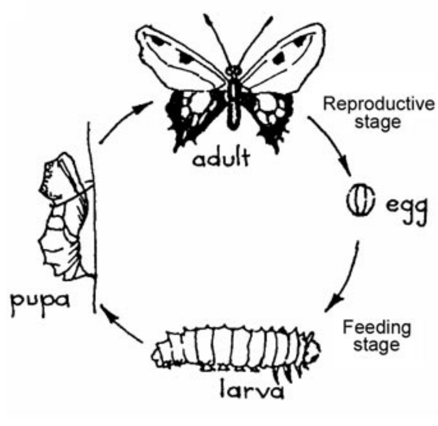
Life cycles and growth

METAMORPHOSIS

All insects develop from eggs and the process of change from egg to adult is known as **metamorphosis**. A complete cycle from egg to egg may take as little as 7 days, eg whitefly, to as long as 17 years, eg some cicadas! There are basically 3 types of metamorphosis:

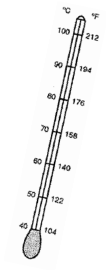
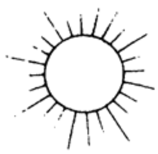
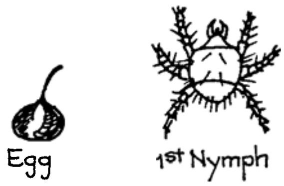
<table>
<tr>
<td>NO METAMORPHOSIS
Also known as:
Ametabola
Apterygotes</td>
<td>

Silverfish</td>
<td>The insect (usually called a nymph) hatches from the egg in a form closely resembling the adult.
The only external change during growth and moulting is an increase in size.
The insects in this group are wingless, eg silverfish.</td>
</tr>
<tr>
<td>INCOMPLETE
OR
GRADUAL
METAMORPHOSIS
Also known as:
Hemi-metabola
Exopterygotes</td>
<td>

Grasshopper</td>
<td>The insect (usually called a nymph) hatches from the egg in a form only generally resembling the adult.
The early nymphal stages have no functional wings, but have external wing buds which gradually increase in size at each moult.
Wings (when present) develop externally, eg grasshoppers.</td>
</tr>
<tr>
<td>COMPLETE
METAMORPHOSIS
Also known as:
Holo-metabola
Endopterygotes</td>
<td>

Citrus butterfly</td>
<td>The insect (usually called a larva) hatches from the egg in a form totally dissimilar to the adult.
Wing buds develop internally beneath the cuticle of the larva and are only visible externally in the pupal and adult stage.
Wings develop internally, eg butterflies.</td>
</tr>
</table>

DIAPAUSE

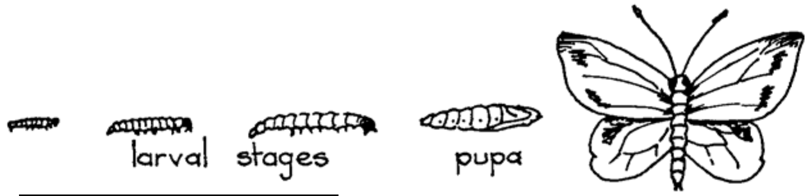
ARRESTED DEVELOPMENT	**DIAPAUSE IS A STATE OF ARRESTED DEVELOPMENT** • It is principally an **adaptation**, synchronizing the life cycle of the insect with the seasonal changes in its environment. • Insects may stop developing even though most conditions are favorable. **DIAPAUSE MAY OCCUR IN ANY STAGE OF THE LIFE CYCLE**, eg egg, larva, pupa or adult and is usually constant for a particular species: • European red mite - Egg stage • Oriental fruit moth - Larval stage • Australian plague locust - Egg stage
ENVIRONMENTAL CONDITIONS  	**THERE IS A RANGE OF CONDITIONS** which insects may need before a diapause is broken, including: **TEMPERATURE** • Winter eggs of the **European red mite** require 150-200 days at temperatures of less than l0°C before hatching occurs in spring, just before the time of apple bloom, so that there is plenty food for the nymphs.  **European red mite** **LIGHT** • In the **oriental fruit moth** diapause of the larva is controlled by temperature and daily exposure to light (photoperiod). • **Knowledge of the photoperiodic response**, which appears to be rather general in diapausing insects, has proved useful in rearing insects in the laboratory and **predicting pest outbreaks**, etc.

GROWTH

WHICH STAGES GROW?

ADULT INSECTS DO NOT GROW IN SIZE

- **Only nymphal and larval stages grow** and they do so by means of stages (also called **instars**).



Only larval stages grow.

Only nymphal stages grow.

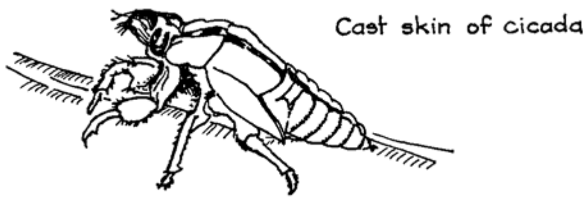
MOULTING

CUTICLE

- Because the cuticle of an insect is hard and rigid it cannot grow or stretch once it is formed. The cuticle must, therefore, be shed at intervals and replaced by a larger one as the insect grows.
- Before the cuticle is shed a new one is formed beneath it and the insect, covered in a new soft cuticle, emerges from the old cuticle.

MOULTING

- The act of casting the skin is called a 'moult'. After a moult the insect enters a new stage, that is, the 1st stage, then the 2nd stage and so on.
- The number of moults which can occur during the life of an insect varies from 3-20 but it is usually a fixed number for any particular species.



Adult cicada moulting.

WHAT CONTROLS MOULTING?

HORMONES

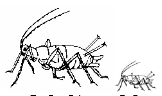
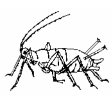
- Growth of an insect is controlled by hormones produced within the nervous system and special glands.

BROKEN LIMBS

INSECTS CAN REPLACE BROKEN LIMBS

- These are gradually regenerated **at each successive moult** so that a limb lost in an early stage will be more developed than one lost during a later stage.

REPRODUCTION

MALES AND FEMALES 	**MOST INSECTS HAVE MALES AND FEMALES** • Male insects produce sperm and females produce eggs. • Most insects occur as approximately equal numbers of males and females which mate, females then lay eggs. • In social species, eg termites, most individuals are not sexual and reproduction is carried out by only a small number in the colony. • Female egg-laying tubes (ovipositors may be modified for digging or serrated for cutting leaves (to insert eggs) or used as a stinger.
HOW DO EGGS HATCH?  **Adult aphid** **Live nymph**	**EGGS ARE LAID AND HATCH LATER** (oviparity) • Larvae and nymphs emerge **some time after eggs are deposited**. • This is the **usual type** of egg hatching, eg **moths** and **butterflies**. **EGGS ARE LAID AND HATCH IMMEDIATELY** (oviviparity) • Eggs contain **fully developed larvae and nymphs** which emerge immediately after the egg is laid. • Examples include **various flies** and **coccids.** **LIVE YOUNG ARE BORN (**viviparity**)** • Eggs mature and hatch **within the female body**. • Common in **aphids**, **scales** and **many flies.**
REPRODUCTIVE CAPACITY	**INSECTS HAVE TREMENDOUS REPRODUCTIVE CAPACITY** • **1 pair** of San Jose scale insects can produce **1 million offspring** each year!
PARTHENOGENESIS  **Butterfly**  **Bee**  **Aphid**	**REPRODUCTION WITHOUT FERTILIZATION OF EGGS** • Parthenogenesis may take place in any type of egg hatching (see above) and occurs in many different types of insects. **SPORADIC** • Parthenogenesis may take place only **occasionally** although males occur regularly. • **Male and female butterflies and moths** may be produced from unfertilized eggs. **CONSTANT** • Parthenogenesis may take place **regularly** as a normal phenomenon, eg in aphids, stick insects and some wasps. • **Male honeybees** are regularly produced from unfertilized eggs and females from fertilized eggs. **CYCLIC** • Parthenogenesis **alternates** with normal sexual reproduction in a regular sequence throughout the year. • Common in **aphids**.
HERMAPHRODITE	**INDIVIDUALS WITH BOTH MALE AND FEMALE REPRODUCTIVE ORGANS** • Individuals possess **both** functional male and female reproductive organs, eg **cottonycushion scale.**
COLOUR AND LIGHT	**MATING** • Colour and lights can be used to gain attention of females for mating, eg **female tropical butterflies** display bright colors to attract a male.

TYPES OF LARVAE

JUVENILE STAGES

LARVAE

- The **juvenile stages of insects** with a complete metamorphosis are called **larvae**. It is often difficult to distinguish one larval type from another and many keys have been compiled to aid in their identification.

FEATURES USED IN IDENTIFYING LARVAE

FEATURES include:

- Presence or absence of a **segmented body**.
- Presence or absence of an **obvious head capsule**.
- Presence or absence of **antennae**.
- Presence or absence of **true legs on the thorax**.
- **Length** of the **true legs on the thorax**.
- Presence or absence of **prolegs on the abdomen**.
- Presence or absence of **various appendages**, eg fleshy lobes at the end of the body.
- **Pattern of hairs** around the anus, eg scarab grub larvae.

INSECTS WITH A COMPLETE METAMORPHOSIS

Remember, these orders also have beneficial members, eg parasitic flies and wasps, predatory ladybirds.

THOSE WHICH MAY DAMAGE PLANTS include:

- **Order Diptera** (flies).
  Larvae are usually called **maggots**, some maggots damage plants and animals, others are beneficial.

  Maggots

- **Order Lepidoptera** (butterflies, moths).
  Larvae are usually called **caterpillars**, most caterpillars are **plant feeders**, also sometimes called:

  Armyworms, Cutworms, 'Borers'

- **Order Coleoptera** (beetles, weevils).
  Some larvae damage plants, others are beneficial. Larvae are sometimes called:

  'Borers', 'Grubs', 'Weevils'

- **Order Hymenoptera** (ants, bees, wasps, sawflies).
  Some larvae damage plants, others are beneficial. Larvae are sometimes called:

  'Slugs', 'Spitfires'

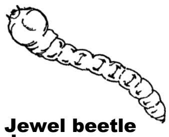
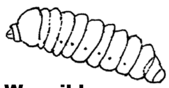
THOSE WHICH ONLY HAVE BENEFICIAL members include:

- **Order Neuroptera** (lacewings).
  Larvae feed on aphids and other insects. Larvae are sometimes called:

  Antlions, Aphidlions

Lacewing larva

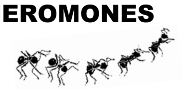
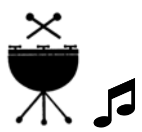
Table 1. Examples of different types of larvae.

LARVAE	INSECT ORDERS: LEPIDOPTERA Butterflies, moths	DIPTERA Flies	COLEOPTERA Beetles, weevils	HYMENOPTERA Ants, bees, sawflies, wasps
WITHOUT LEGS • Sense organs reduced • Live among plentiful food so do not need legs to seek food		All fly larvae  **Fruit fly maggots**	Some beetle or weevil larvae  **Longicorn beetle larva**  **Jewel beetle larva**  **Weevil larva**	Ants, bees and some wasps  **Citrus gall wasp larva**
WITH LEGS – **Thoracic legs only** • More or less well developed thoracic legs • Abdominal appendages usually absent • Head capsule and appendages usually well developed **LONG LEGS**			Active predators  **Ladybird beetle larva**	
WITH LEGS – **Thoracic legs only** – **SHORTER LEGS**			Some beetle larvae  **Scarab grub**	Some sawfly larvae  **Steelblue sawfly larva (spitfire)**
WITH LEGS – **Thoracic and abdominal legs** • **Well developed segmentation** • Thoracic and abdominal legs (prolegs) well or moderately well developed • Usually live on or near food	All moth and butterfly larvae  **Grapevine moth caterpillar.** Ring of hooks on end of prolegs			Some sawfly larvae  **Callitris sawfly larva** No ring of hooks on end of prolegs
WITH LEGS – • **No abdominal segmentation** • Only rudimentary appendages • No spiracles • Larvae emerge from egg into high nutrient food, eg eggs, or bodies of other insects				Some parasitic wasps

Blood system

YELLOW-GREEN FLUID	The blood of insects is a yellowish to greenish fluid. It is generally not confined to tubular arteries and veins as in humans but bathes all the internal organs and fills the body cavity.
CIRCULATION	Insect blood is circulated by the pumping action of a tube-like heart which is located in the abdomen or thorax. The blood carries nutrients to the organs and transports waste from them. It carries very little oxygen or carbon dioxide.

Nervous system, communication

RECEPTORS	**INSECTS HAVE RECEPTORS** • For **seeing, feeling, tasting** and **hearing.** • **Insects respond** to these stimuli by appropriate behavior, eg moving. These functions rely on electrical messages sent along threadlike nerves. • An **insect's nervous system** consists of a brain, various ganglions (groups of nerves) and other nerve structures.
PHEROMONES  **Pheromones** guide ants along a trail	**PHEROMONES** are produced by special glands and are used to communicate or control behaviour or development of other insects. • Insects can detect pheromones over long distances. • Ants, bees and wasps use pheromones for communication within a group. • Pheromones are easy to put in lures for monitoring insect presence, populations or for control.
TOUCH, TASTING, SMELLING 	**HAIRS ON VARIOUS PARTS OF AN INSECT BODY** may be sensitive to **touch** or **chemical substances**. • **Movement of hair** electrically stimulates nerves **within** the hair. • **The open ends of hairs** on mouthparts, antennae or parts of the legs may be **sensitive to chemicals** and are called **chemo-receptors**. • **Feathery antennae** of many male moths detect chemicals given out by females. • **Butterflies and flies taste** their food by walking on it.
HEARING 	**INSECTS HAVE EARS** • **Ears are thin areas of cuticle** supplied with special nerve endings. • **Their position varies**, eg some **grasshoppers** have an ear on each foreleg, **cicadas** have ears on the abdomen, some **moths** have ears on the thorax.
SOUND PRODUCTION 	**MANY INSECTS PRODUCE SOUNDS** usually by rubbing specialized parts of the body together. • **Some male crickets** chirp on hot summer nights by rubbing specialised parts of their forewings together to attract the females. • **Male cicadas** make a loud well known mating call by vibrating a pair of cuticle plates (drums), one on either side of the abdomen which amplifies the sound. It may also warn off predators. Each species has a distinct song. • **Mosquitoes** make sound by beating their wings in flight. • Some **grasshoppers and beetles** rub their rear leg and forewing together. • Some insects make squeaky sounds by rubbing parts of their mouth together, others just tap on the ground or branch on which they are standing.
INSECTICIDES 	**NERVOUS SYSTEM** Most older insecticides were developed to affect the nervous system of insects. The best known ones being the **organophosphates**, eg **Rogor**® (dimethoate), **Malathion**® (maldison) and the **carbamates**, eg **carbaryl**.

PLANT DAMAGE

Host range

Insects and allied pests vary tremendously in the range of plants on which they can feed. It is important to know whether a pest can infest other plants and if so, which ones.

VERY WIDE HOST RANGE

INSECTS WITH A VERY WIDE HOST RANGE include:

- African black beetle
- Australian plague locust
- Black scale
- Black vine weevil
- European earwig
- Greenhouse whitefly
- Green peach aphid
- Lightbrown apple moth
- Looper caterpillars
- Longtailed mealybug
- Onion thrips
- Plague thrips
- Twospotted mite
- Western flower thrips

Twospotted mites may attack a wide range of plants, including ornamentals, fruit and vegetables.

A GROUP OF PLANTS, A FAMILY OR A FEW GENERA

INSECTS WITH A RESTRICTED HOST RANGE include:

• Argentine stem weevil	- Cool season grasses, eg bent, also wheat
• Codling moth	- Pome fruits, eg apples and pears
• Gladiolus thrips	- Gladiolus, carnation, arum lily, calla lily, *Monbretia*, ‘red-hot’ poker and tiger flower
• Oak leafminer	- Oak, beech, Spanish chestnut
• Oriental fruit moth	- Stone fruits
• Pumpkin beetle	- Cucurbits and related plants
• Rose scale	- Blackberry, loganberry, raspberry, rose
• Webbing caterpillars	- Mainly *Leptospermum*, *Melaleuca*, also *Astartea, Baeckea, Kunzea*, *Thryptomene*
• Woolly aphid	- Apple, crab apple, occasionally other hosts, rarely pears

A GENUS, A FEW SPECIES WITHIN A GENUS OR SOME VARIETIES

INSECTS WITH A VERY RESTRICTED HOST RANGE include:

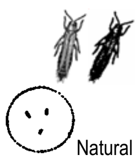
• Azalea lace bug	- Azalea, rhododendron
• Azalea leafminer	- Azalea
• Citrus gall wasp	- Citrus (especially lemon and grapefruit)
• Couchgrass scale	- Couchgrass
• Fern scale	- Ferns
• Grapeleaf blister mite	- Grapevine (some varieties only)
• Grape phylloxera	- Grapevines (some varieties only)
• Gumtree scale	- Eucalypt (some species only)
• Leafblister sawfly	- Eucalypt (some species only)
• Steelblue sawfly	- Eucalypt (some species only)

How insects damage plants

BY DIRECT FEEDING

Weevil chewing leaves

Aphid sucking plant sap



Natural size

Thrips rasp plant surfaces and suck up plant sap

CHEWING DAMAGE

LEAVES	**Eaten**, eg various caterpillars **Leafmining**, eg oak leafminer (larvae feed inside leaves) **Skeletonized**, eg pear and cherry slug
FLOWERS BUDS	**Eaten**, eg lightbrown apple moth, budworms (*Helicoverpa*)
FRUIT	'**Worms', weevils**, eg fruit fly (larvae feed inside fruit)
STEMS BARK	**Borers**, eg fruit-tree borer (larvae feed inside trunks, branches) **Galls**, eg citrus gall wasp (larvae feed inside stems)
ROOTS	**Eaten**, eg scarab grubs

PIERCING & SUCKING DAMAGE

LEAVES	**Galls**, eg pimple psyllid (of callistemon) **Leaf distortion**, eg cabbage aphid **Leaf spots**, eg acacia-spotting bug **Wilting**, eg longtailed mealybug **Yellow stippling**, eg lace bugs, leafhoppers, twospotted mite, whiteflies
FLOWERS BUDS	**Distortion**, eg green peach aphid
FRUIT	**Distortion**, eg apple dimpling bug
STEMS BARK	**Dieback**, eg San Jose scale **Galls**, eg woolly aphid
ROOTS	**Galls**, eg woolly aphid

RASPING & SUCKING DAMAGE

LEAVES	**Distortion**, eg western flower thrips, callistemon leafrolling thrips **Silvering**, eg gladiolus thrips, greenhouse thrips
FLOWERS BUDS	**Speckling**, eg gladiolus thrips, western flower thrips
CORMS	**Rotting**, eg gladiolus thrips

INDIRECT DAMAGE

Saunder's case moth

- **Presence of insect itself,** eg San Jose scale on fruit being exported to certain countries may cause the entire consignment to be condemned.
- **Transmission of virus and other diseases**, eg aphids transmit many chrysanthemum viruses, thrips transmit tomato spotted wilt virus.
- **Frass**, eg caterpillars.
- **Honeydew**, eg aphids.
- **Sooty mould** growing on the honeydew produced by aphids.
- **Larva and nymph skins**, eg aphid nymph skins.
- **Spittle**, eg froghoppers (spittle bugs).
- **Bag shelters**, eg many native moths, Saunder's case moth.
- **Webbing**, eg webbing caterpillars.
- **Tainted fruit**, eg stink bug.
- **Mechanical injury**, eg leafcutting bee.

DIRECT FEEDING DAMAGE
Chewing damage

Fig. 6. Citrus butterfly caterpillars chew lemon leaves.
Upper: Large citrus butterfly caterpillar (up to 65mm long).
Lower: Small citrus butterfly caterpillar (up to 40mm long).
Photo©CIT, Canberra (P.W.Unger).

Fig. 7. Pear and cherry slug larva (up to 13 mm long) chewing the surface of a cherry leaf **(skeletonization)**.
Photo©CIT, Canberra (P.W.Unger).

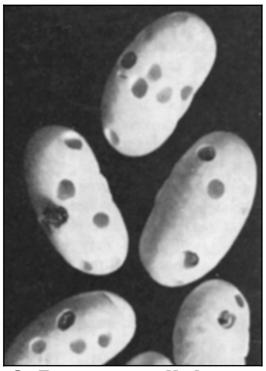


Fig. 8. Bean weevil damage.
Larvae feed inside bean seed creating cavities which are covered by thin skin through which the adult emerges.
Photo©NSW Dept of Industry and Investment.

Fig. 9. Azalea leafminer damage. Undersurface of azalea leaves showing mines, the tiny caterpillars feed between the upper and lower leaf surfaces. Later they roll the leaf tips under to form a chamber in which they later pupate. Photo©CIT, Canberra (P.W.Unger).

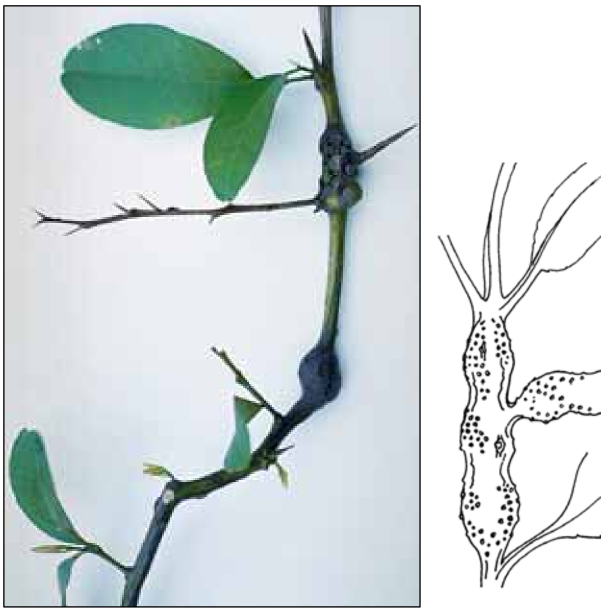


Fig. 10. Citrus gall wasp damage. *Left:* Swellings on a stem of a citrus tree produced by the larvae feeding inside the stem. Photo©CIT, Canberra (P.W.Unger). ***Right:*** Galled twig showing exit holes of adult wasp.

Fig. 11. Codling moth damage.
Caterpillar (larva) chewing inside an apple near the core. Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Chewing damage *(contd)*

Fig. 12. Fruit-tree borer. Larval damage to trunks. ***Left:*** External damage to trunk. ***Right:*** Tree split longitudinally to show internal damage, note tunnel is only about 10 cm long. Photos©NSW Dept. of Industry and Investment.

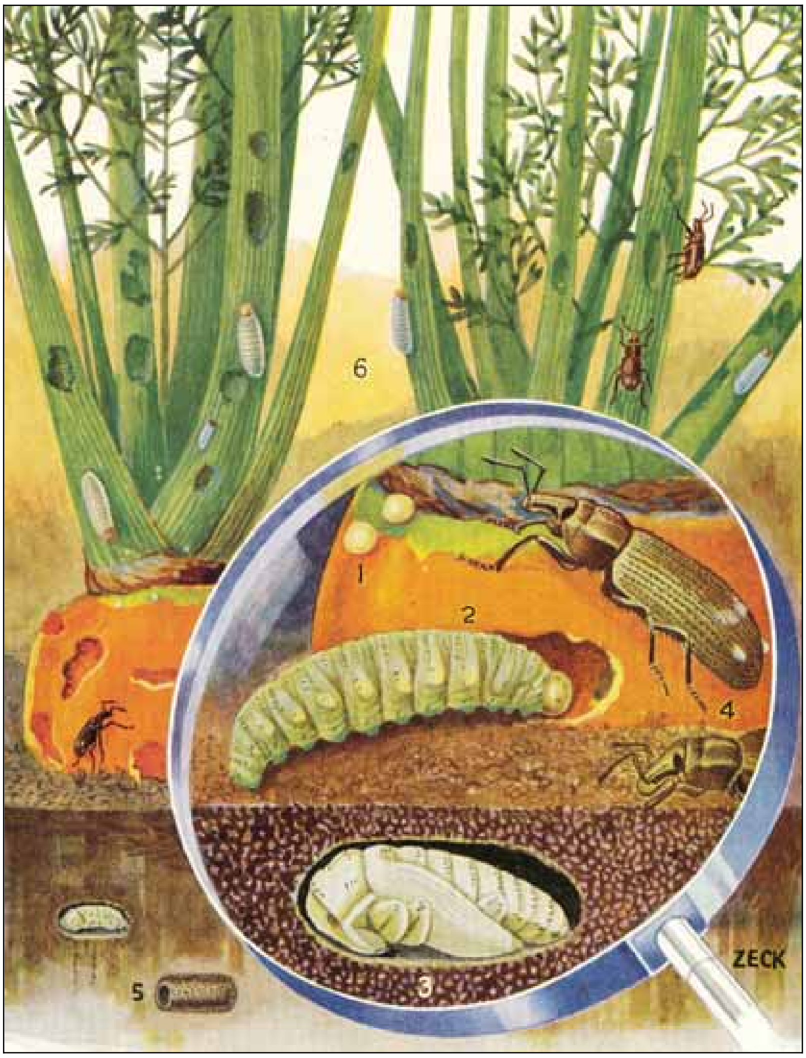


Fig. 13. Vegetable weevil (*Listroderes difficilis*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x5:
1. Eggs
2. Larva
3. Pupa (or chrysalis) in earthen cell
4. Weevil (or adult)

Actual size:
5. Earthen cell from which adult has emerged
6. Carrots damaged by larvae and adults

Piercing and sucking damage

Fig. 14. Apple leafhopper damage to crabapple leaves. ***Left:*** Healthy foliage ***Right:*** Foliage spoilt by leafhoppers. Photos©NSW Dept. of Industry and Investment.

Fig. 15. Apple leafhoppers resting on the undersurfaces of apple leaves (50% natural size). Photo©NSW Dept. of Industry and Investment.

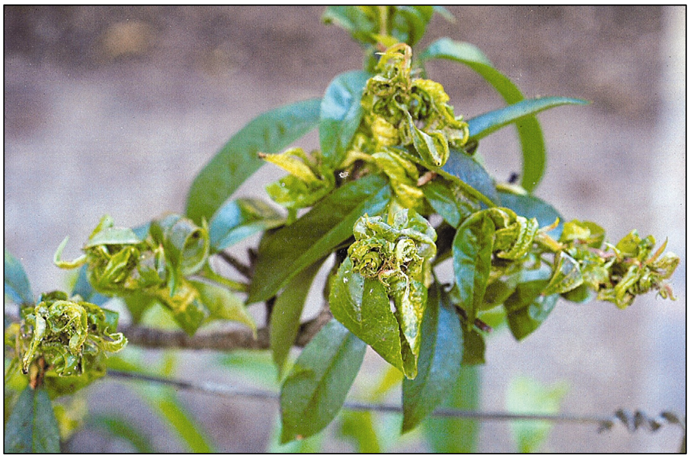


Fig. 16. Green peach aphid damage. The sucking of the aphids causes leaves to curl. Do not confuse with the fungal disease peach leaf curl (page 358). Photo©CIT, Canberra (P.W.Unger).

Fig. 17. Greenhouse whiteflies on the undersurfaces of a tomato leaf. Photo©CIT, Canberra (P.W.Unger).

Fig. 18. Lerps on eucalypt foliage. Discolored areas of the leaf develop where lerps have been feeding. Photo©CIT, Canberra (P.W.Unger).

Fig. 19. Acacia-spotting bug damage to *Acacia* leaves. ***Left:*** Damage to leaves with **no** marked veinal structure. ***Right:*** Damage to leaves **with** a marked veinal structure.

Piercing and sucking damage *(contd)*

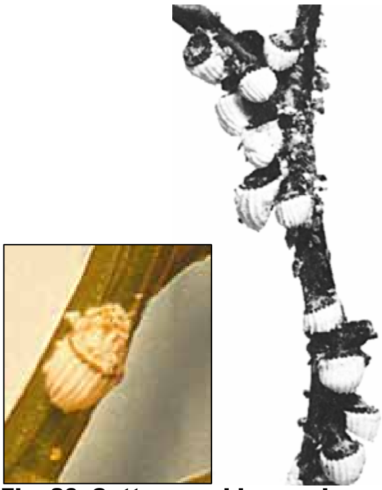


Fig. 20. Cottonycushion scales on wattle and citrus stems. Photo©NSW Dept. of Industry and Investment.

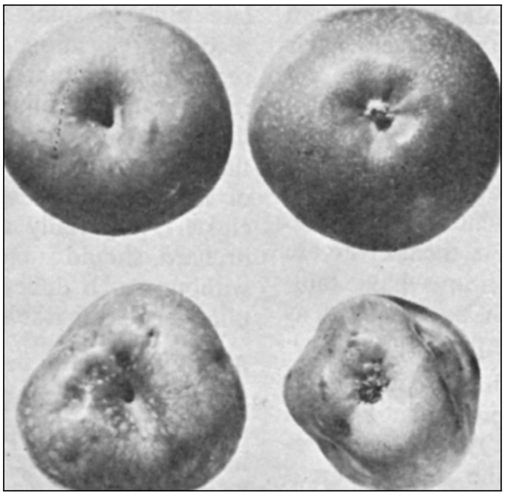


Fig. 21. Apple dimpling bug damage to apple. ***Upper:*** Healthy apples. ***Lower:*** Damaged apples. Photo©NSW Dept. of Industry and Investment.

Fig. 22. Woolly aphid injury.
A: Galls produced on roots.
B: Healthy undamaged twig.
C and D: Damaged apple twigs.
Photos©NSW Dept. of Industry and Investment.

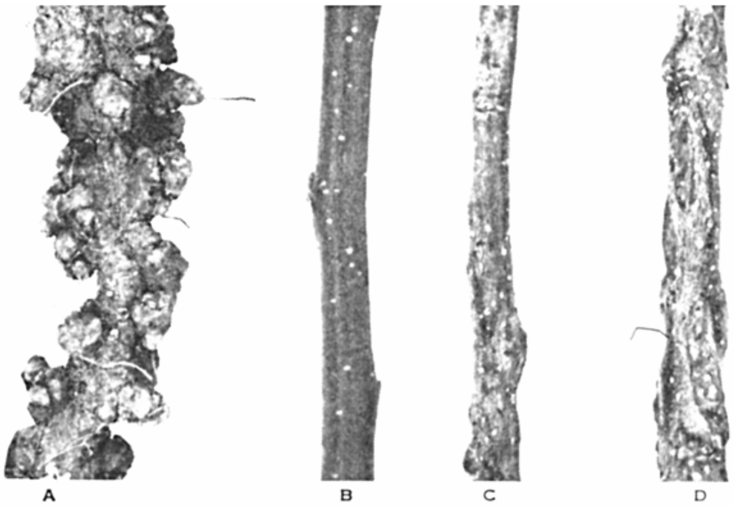


Fig. 23. Black peach aphids feeding on new spring growth of peach. Photo©CIT, Canberra (P.W.Unger).

Rasping and sucking damage

Fig. 24. Greenhouse thrips injury to the leaves of viburnum (*Viburnum tinus*) showing silvering of leaves and spots of dark excreta mainly on the undersurface. Photo©CIT, Canberra (P.W.Unger).

Fig. 25. Onion thrips injury to onion leaves. Photo©CIT, Canberra (P.W.Unger).

Fig. 26. Thrips in dahlia flowers. Photo©CIT, Canberra (P.W.Unger).

Natural size about 1 mm long.

Fig. 27. Callistemon leaf-rolling thrips injury to *Callistemon* leaves. Photo©CIT, Canberra (P.W.Unger).

INDIRECT DAMAGE

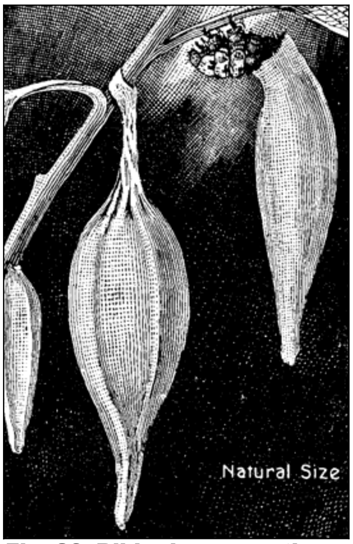


Fig. 28. Ribbed case moth. Pupa, larva and case. Photo©NSW Dept. of Industry and Investment.

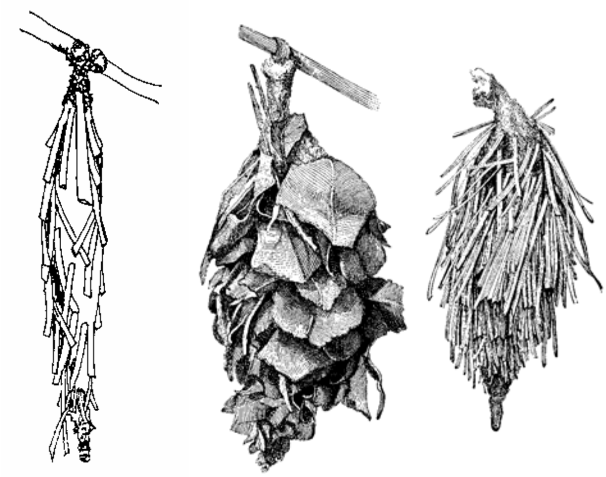


Fig. 29. Leaf case moths showing leaf fragments and pine needles used to cover their pupal cases. Photo©NSW Dept. of Industry and Investment.

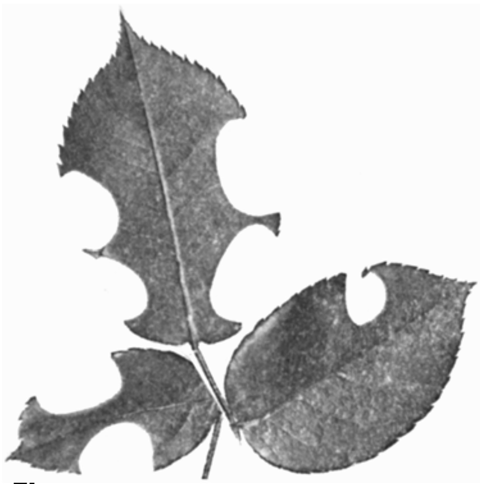


Fig. 30. Leafcutting bee damage to rose leaves. Bees cut circular pieces from leaf edges with their mandibles and use the pieces to line their nests. Photo©NSW Dept. of Industry and Investment.

Fig. 31. Webbing caterpillar damage to melaleuca. Caterpillars spin silky webbing which becomes coated with pellets of excreta and plant debris. Photo©CIT, Canberra (P.W.Unger).

Fig. 32. Sooty mould fungus on orange leaf. Black sooty mould grows on the honeydew excreted by some sap sucking insects, eg aphids. Photo©NSW Dept. of Industry and Investment.

Fig. 33. Tomato big bud phytoplasma. ***Left:*** **Common brown leafhopper** (about 1 mm long) transmits the tomato big bud phytoplasma. ***Right:*** Healthy chrysanthemum on left and infected plant on right (greening of flower parts). Photo©CIT, Canberra (P.W.Unger).

Pest cycle

The **LIFE CYCLE** of an insect is the **stage or succession of stages** in growth and development that occurs between the appearance or re-appearance of the same stage, eg the adult.

The **PEST CYCLE** describes **where each stage of the life cycle occurs**, eg host, seed, soil, the length of each stage, the number of generations, its seasonal occurrence and so on. The range of insect pest cycles is almost **infinite** so that only a few common examples of where stages may occur are presented. Many insects spend some part of their life cycle in the **soil**.

HOST ONLY

SOME INSECTS SPEND NEARLY ALL THEIR LIFE in a **close parasitic relationship with their hosts** with perhaps only very short stages occurring away from the host, eg

- Bean weevil (seeds)
- Black scale (stems, leaves)
- Green peach aphid (buds, leaves, shoots)
- Longtailed mealybug (leaf bases, flowers, fruit)
- Twospotted mite (mainly leaves, herbaceous stems)

HOST, HOST DEBRIS, LITTER, ETC

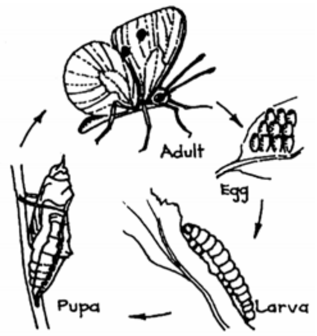
Codling moth larva in fallen fruit

SOME INSECTS CONTINUE TO DEVELOP IN SEED, HOST PLANT DEBRIS, LITTER, eg

- Citrus gall wasp (in galls of pruned stems)
- Codling moth larvae (in fallen fruit)

CATERPILLARS OF MANY MOTHS AND BUTTERFLIES MAY PUPATE on host plants, host plant debris or on general litter:

- Cabbage white butterfly
- Codling moth



Life cycle of the cabbage white butterfly

DEBRIS FROM SOME PLANTS MUST BE DESTROYED, eg

- Prunings of citrus containing mature citrus gall wasp larvae and/or pupae should be burnt to prevent adult wasps from emerging.

HOST AND SOIL

Pupa of scarab grub in soil

LARVAE OF MANY INSECTS feed on or in **leaves** and other plant parts but **pupate in the soil**, eg

- Corn earworm, grapevine moth
- Pear and cherry slug
- Steelblue sawfly

EGGS, LARVAE, NYMPHS AND ADULTS of some insects may occur **in or on the soil** but feed on roots, stems, trunks, seed and other plant parts, eg

- African black beetle
- Cutworms and armyworms
- Mole crickets

WHY IS KNOWLEDGE OF THE PEST CYCLE IMPORTANT?

FOR IMPLEMENTATION OF EFFECTIVE CONTROL MEASURES, eg

- Planning **IPM (Integrated Pest Management)** programs (page 39). After **identifying** the pest, knowledge of the **pest cycle** is essential as the pest scout needs to know where to look for the pest, eg on leaves or bark.
- Does the **seed or other propagation material** need to be treated?
- Could **sanitation** and other non-chemical methods be useful controls?
- **When should pesticides be applied?** When the pest is under the bud scales during winter or when it is feeding on the new leaves in spring?

Overwintering, oversummering

'Overwintering' describes how the **pest carries over from one season to the following one**, ie either **over winter** (for pests active in summer) or **over summer** (for pests active in winter).

KNOWLEDGE ESSENTIAL FOR CONTROL MEASURES

Where does the pest overwinter? Stem, fruit, seed, leaf, root, host debris, soil?

SOME INSECTS 'OVERWINTER' IN SEVERAL STAGES, eg

- In coastal areas, the Queensland fruit fly can 'overwinter' as **maggots** in fruit and as **adults**.

MANY INSECTS MAY 'OVERWINTER' IN SEVERAL PLACES, eg

- Cabbage white butterfly as pupae on attached to the **host** or **nearby object**.
- Codling moth on the trunk of the **host** and on **litter** on the ground.

KNOWLEDGE OF STAGES AND PLACES

Knowledge of the **stages** which 'overwinter' (adults, eggs, etc) and the **places** where they occur (host, alternate weed hosts, seed, plant debris, soil, etc) is used to **develop control measures.** For pests which 'overwinter' on/in:

- **Deciduous hosts**, dormant sprays can be applied, eg
  Grapeleaf blister mite
  Rose scale
- **Alternate hosts**, these may be removed and destroyed - important for effective control, eg
  Cineraria leafminer (host plants, weed hosts, eg sow thistle)
  Gladiolus thrips (volunteer gladioli plants from previous crops)
- **Propagation material**, pest-free cuttings and seed must be selected, eg
  Chrysanthemum gall midge (on chrysanthemum cuttings)
  Bean weevil (in bean seed)
- **Litter and trash from the crop**, removal and destruction of such plant residues contribute to their control and may be compulsory, eg
  Codling moth
  Fruit fly
- **Soil**, control measures of some type may be required.

ON THE HOST PLANT

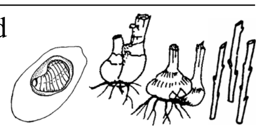
- Azalea leafminer - Larvae in cocoons under leaves
- Black scale - Nymphal stages
- Cabbage white butterfly - Larvae in pupae
- Codling moth - Larvae in cocoons on trunk
- Grapeleaf blister mite - Adult mites under bud scales
- Oriental fruit moth - Larvae in cocoons on trunk
- Mealybugs - Eggs on roots, stems, other plant parts

ALTERNATE HOSTS

- Cineraria leafminer - Host plants, including weed hosts
- Greenhouse thrips - Host plants including weed hosts

SEED, OTHER PROPAGATION MATERIAL

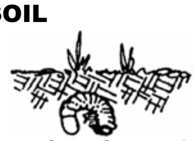
- Rice weevil - Eggs, larvae, pupae in seed
- Bulb mites - Mites, eggs on bulbs
- Scale - Adults, eggs on cuttings, nursery stock



HOST DEBRIS, LITTER, ETC

- Codling moth - Larvae in cocoons on stable litter
- Driedfruit beetle - Adults or larvae in fallen fruit
- Oriental fruit moth - Larvae in cocoons in mummified fruit and on stable litter
- Twospotted mite - Adult females shelter in litter and trash

SOIL

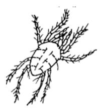


Scarab grubs remain dormant in winter

- Grapevine moth - Larvae in cocoons
- Pear and cherry slug - Larvae in cocoons
- Plague locust - Eggs in soil
- Steelblue sawfly - Larvae in cocoons
- Corn earworm - Pupae
- Scarab beetles - Larvae

Spread

Many control measures are designed to prevent spread of a pest either within a crop, within a state, between states or into and out of Australia. This principle is the basis of quarantine. Computer software packages can predict the spread of pests, diseases, weeds and beneficial organisms. They can also define areas at risk from colonization by pests and alternative control strategies including appropriate quarantine measures.

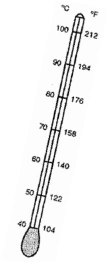
FLIGHT  Moth	**MOST ADULT INSECTS HAVE WINGS AND SO CAN FLY** • **Some insects can fly great distances,** eg – Wanderer butterfly, Australian plague locust. – Monarch butterflies, the world's largest migrant butterfly has a wing span of up to 10 cm, migrates between North America and Mexico. – Bogong and corn earworm moths migrate long distances in the eastern states of Australia. • **Some are not very strong fliers,** eg – Azalea leafminer (adult moths can only fly about 1 metre). – Gladiolus thrips ability to spread through a crop is assisted by wind. – Codling moths only fly about 100 metres but are also assisted by wind.
WIND 	**FLIGHT MAY BE ASSISTED BY WIND, AIR CURRENTS, STORMS,** eg • Twospotted mites may be spread on windblown leaves. • Storms and hurricanes over-ride weather systems, eg monarch butterflies can be blown off course, eg from North America to Britain. • Currant-lettuce aphid is thought to have been to blown by wind to Tasmania from New Zealand.
CRAWLING	**WINGLESS ADULT INSECTS, NYMPHS AND LARVAE** of many insects, spread by crawling, eg • Weevil larvae and adults • Locust nymphs • Mite nymphs and adults • Moth and butterfly caterpillars  **Mite**  **Caterpillar**
INFESTED PLANT MATERIAL  **Cuttings**	**EGGS, NYMPHS OR LARVAE, PUPAE AND ADULT INSECTS** may be transported on or in any part of a plant, eg • Bulbs - Bulb mites, bulb flies • Fruit - Fruit fly, codling moth • Nursery stock - Twospotted mite, scale insects • Packing cases - Codling moth • Cut flowers - Thrips • Seeds - Rice weevil  **Rice weevil larva in seed**
SOIL 	**INSECTS WHICH MAY BE TRANSPORTED IN SOIL,** eg • Root mealybugs in containers. • Black vine weevil larvae and adults in containers.
HANDS, SHOES, CLOTHING, VEHICLES	**OVERSEAS PASSENGERS MAY CARRY INSECTS** • On their clothing, hand baggage and other items. 
ANIMALS	**OTHER INSECTS, SNAILS, BIRDS, ETC** • Ants may carry scales from plant to plant.  **Ants**
WATER	**SOME ARE COMMONLY CARRIED ON WATER,** eg • Springtails. 

Conditions favouring

CONDITIONS FOR DEVELOPMENT

GENERAL CONDITIONS

- Most insects prefer **warm and humid weather**.
- Some insect pests are favoured by lush growth, eg nitrogenous fertilizers.
- Weather the **previous** season can be as important as that in the **current** season, eg plague thrips cause most plant injury after unusually moist autumns and winters, which favour survival of pupae in the soil.
- The significance of a disease outbreak also depends on the stage of crop development, eg seedling, or just before harvest; or its place in a cropping sequence, eg continuous cropping favours certain pests (and diseases).



TEMPERATURE

- Nearly all insects become **inactive** at temperatures below 4-15^{o}C (no insect damage occurs below 4^{o}C). Many insects can **hibernate** at temperatures much lower than this.
- **No insects can survive** for long at 60-65^{o}C. Generally 3 hours at 51-56^{o}C will kill most insects.
- The **body temperature** of insects is closely related to the temperature of the surrounding environment. The growth of an insect increases as temperature increases until the optimum temperature for a particular type of insect is exceeded, at this point the growth rate rapidly declines.

MOISTURE

- Moisture may or may not be essential for some stages of insect development. For example moths and butterflies cannot emerge from pupae unless moisture is present.
- Rain, can kill off large numbers of some insects, eg thrips.

SPECIFIC REQUIREMENTS

MANY INSECT PESTS HAVE SPECIFIC REQUIREMENTS, eg

- Cineraria leafminer - Cool and moist (a late winter and spring pest)
- Gladiolus thrips - Hot and dry
- Greenhouse whitefly - Warm and moist (glasshouse/outdoor pest)
- Redlegged earth mite - Cool and moist (winter pest)
- Twospotted mite - Hot and dry/hot and humid (glasshouse/outdoor pest)
- Woolly aphid - Cool and moist (mostly a spring and autumn pest)

CLIMATE CHANGE

CHANGES WHICH MIGHT TAKE PLACE IN SOME REGIONS

- Some pests may spread to new areas, eg fruit fly to Tasmania.
- Some pests may be more or less serious in certain regions.
- New pests may emerge.

WARNING SERVICES

MAY NEED TO BE REGULARLY UPDATED

- Warning services for insect pests, eg are based on temperature, rain, humidity, length of leaf wetness etc.
- Fact Sheets and other information about pests require constant updating.

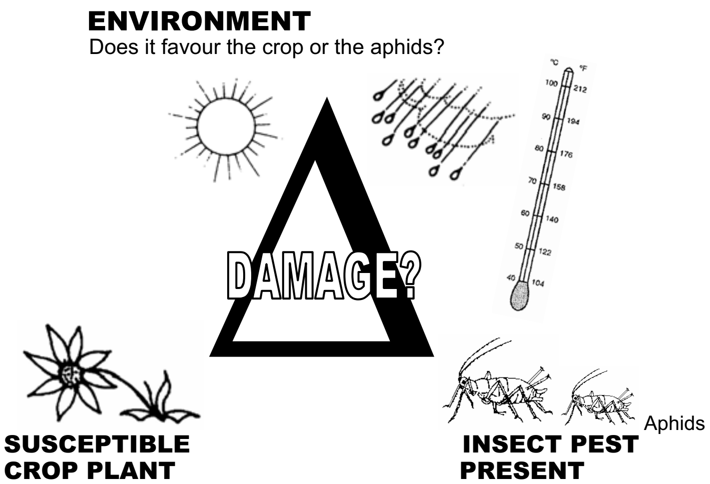


Fig. 34. Pest triangle.

INTEGRATED PEST MANAGEMENT (IPM)

MAIN STEPS

IPM is not a specific set of rules, there is no central program for everyone

IPM maximizes the use of **non-chemical** controls and **optimizes/minimizes** the use of chemical methods while taking into account all environmental factors, economics, etc. **IPM** provides improved long term control and **slows/prevents** the development of pesticide resistance. As the effect of a pest on a crop is influenced by **many factors**, eg weather, natural enemies, crop variety, etc, a range of controls is usually needed.

PLAN
PLAN
PLAN

1. **Plan** well in advance to use an **IPM** program that fits your situation. Some expertise is needed to use an **IPM** plan. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides.

2. **Plant/crop/region.** Know the problems which occur on your crop or in your region. **IPM** programs are available for pests on a range of crops in particular regions. Check if an **IPM** program is available for **your pest/crop**, eg
   - **IPM** programs are available for some **pests**, eg twospotted mite, corn earworm (*Helicoverpa*) and Western flower thrips **(WFT)** on particular crops.
   - **Many commercial crops** have computer programs and websites which incorporate and provide information on **IPM** programs. Best Management Practice **(BMP)** programs are available for cotton, grape, citrus, nursery crops. CropWatch provides commercial **IPM** services for fruit growers in southern Victoria; Scientific Advisory Services provides **IPM** for tropical horticulture.

3. **Identification** of the pest(s) must be confirmed. Consult a diagnostic service if necessary (page xiv). Successful **IPM** depends on **sound knowledge** of pests, their beneficials, their life cycles, spread, conditions favouring, population distribution, etc. Obtain a fact sheet for each pest.

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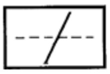
5678

4. **Monitoring** indicates **seasonal** trends, the **best time** to **start control** if necessary, and the effectiveness of earlier control measures. Record findings. You must:
   - Know **when** it must be done, eg before sowing, before flowering. **Warning services** based on weather, calculate when outbreaks may occur.
   - Check **where** they are to be monitored, eg leaves, soil, flowers. Checking the top 15cm of soil before planting for earth mites, black field crickets, scarab grubs.
   - Decide **what** has to be monitored, eg eggs, larvae or adults of **pests** and **beneficial** insects and/or damage. Check if they are still alive and established.
   - Know **how** to monitor, eg sticky traps, lures? Use a x10 hand lens.



5. **Threshold.** The level of pest numbers or damage at which treatment is necessary to manage a pest problem. How much damage can you accept? Have any insect and/or damage thresholds been established? If so, what are they, eg economic, aesthetic, environmental? It may be **nil** for quarantine purposes.

?

6. **Action/Control/Decision making.** Many control methods will be **preventative**, eg pest-tested planting material, seed treatments. Take appropriate action at the correct time when a prescribed threshold is reached. There may be **legal** and/or **organic standard** requirements. Potential damage may not warrant any action.
   - For **pests not yet in Australia or in some states**, quarantine can prevent entry.
   - **For new arrivals** spread can be minimized by early detection. Response Programs assist control of specified pest outbreaks. Noxious pest legislation and other regulations are most effective during these early stages of invasion, when eradication could be attempted. Available pest control methods do not eradicate pests unless they have been selected for a national or state eradication program.
   - **For established pests** the best we can hope for is containment using appropriate control methods strategically and early. Eradication is generally impossible.

✓x

7. **Evaluation.** Review **IPM** program. Make improvements if necessary which may involve continued monitoring. Remember the aim is **not** to eradicate pests (unless legislated for), but to maintain populations below that which causes economic, aesthetic, and/or, other effects. Be prepared to accept some damage if appropriate.

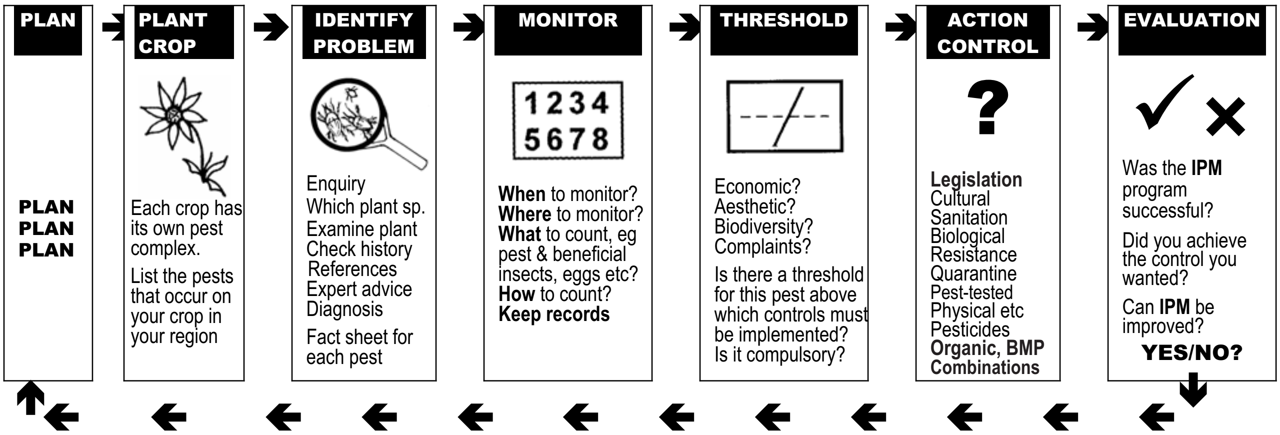


Fig. 35. Steps in IPM.

Control methods

LEGISLATION

LEGISLATION, REGULATIONS	Legislation and various regulations affect many aspects of pest control and examples are described under each method of control.

CULTURAL METHODS

LEGISLATION 	Cultural methods may be compulsory in some states/territories/regions of Australia for some pests of some plants. For example, a banana plant must not be planted or cultivated in a Banana Plant Quarantine Area (**BPQA**) in certain areas of Queensland without an inspector's approval, unless the plant (a) is to be planted and cultivated in a residential plantation, or (b) is an approved cultivar for the **BPQA**.
WHAT ARE CULTURAL METHODS?	Cultural methods involve ordinary day-to-day horticultural practices. They are usually used in conjunction with other methods and are **preventative** and are an essential part all plant management programs.
CONDITIONS FAVOURABLE TO THE HOST CROP 	**PLANT VIGOUR, ETC** • **Balanced irrigation/fertilizer regimes**. – **Trees attacked by borers** show a marked improvement if their vigour is stimulated by watering, fertilizing and judicious pruning. – **Plants attacked by sucking insects**, eg mealybugs and aphids, can tolerate attacks better if there is adequate soil moisture. – **Avoid excessive plant vigour**, eg oriental fruit moth injury to shoots is more common on lush growth due to excessive fertilization, watering or pruning. • **Genetically modified crops** may be able to grow faster, mature earlier.
CONDITIONS UNFAVOURABLE TO THE PEST 	**CONDITIONS** • **Weather**, eg gladiolus thrips is favoured by hot dry weather. Efficient irrigation can significantly reduce the amount of damage. • **Cultivation** of soil exposes insects, eg scarab grubs, to birds, desiccation or mechanical damage. Some larvae and pupae can be buried so deeply that they cannot emerge or be brought to the surface and desiccate. Note that minimum tillage may result in an increase of some pests. • **Crop rotation** aims to reduce pest numbers by depriving them of **food**. Is more successful in controlling diseases than insect pests. – **Continual cropping** of the same crop risks a buildup of pest problems specific to that crop. Rotation crops should **not** be related to the following crop or a potential weed. – **Crop rotation can assist** in the control of insect pests if the pest is either wingless or can only attack a single group of plants. **Potato moth** only attacks potato, other Solanaceous plants and weeds. **Lucerne seed wasp** can be reduced with **lucerne-free** rotations. – **Most established soil pests** can be reduced by a period of **fallow** between cultivation of pasture and sowing the crop. – **Brassica break crops** such as canola or mustard when ploughed in release toxic bio-fumigants and may suppress some soilborne insect pests. • **Harvesting and planting dates**, eg **early maturing stone fruit varieties** can be harvested before the development of damaging fruit fly populations. • **Warning services** based on modeling programs provide information on conditions favourable to the pest, eg **moisture, temperature, wind, etc.** • **Climate change.** Research is determining how changes in moisture, temperature, etc will affect the distribution and severity of current and emerging insect pests. • **Windbreaks** to protect predators.
REPELLENT AND BAIT PLANTS Purchase one of the many books available on companion plantings	**COMPANION PLANTS** • **Repellent plants** are reputed to repel certain pests, eg garlic aroma can repel some species of aphids. One must know which species of aphids is repelled and the situations where it is effective, eg in a vegetable patch or in a rose garden. • **Bait or trap plants** attract certain pests and once on that plant they can then be readily destroyed by picking or spraying. **Corn earworm moths** prefer to feed on chickpeas rather than cotton. Patches of chickpeas in cotton crops could be slashed to stop further development. • **Beneficial insect attractants**. Coriander attracts hoverflies which feed on aphids and small caterpillars and so reduce pest infestation in cabbages.

SANITATION

LEGISLATION

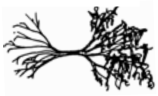
LEGISLATIVE REQUIREMENTS include:

- **Sanitation measures** are often part of an overall management program and be compulsory in some situations, eg
  - Codling moth
  - Mediterranean and Queensland fruit flies
- **Method of disposal** may also be prescribed by legislation, eg
  - Mediterranean and Queensland fruit flies
  - Citrus gall wasp

WHAT IS SANITATION?

Sanitation is aimed at eliminating or reducing the amount of infested material in a garden, nursery, orchard, glasshouse or other situation, **preventing** spread of pests to other healthy plants or produce.

CROP DEBRIS, LITTER



FRUIT, PLANTS

- **Infested fruit on the tree and all fallen fruit** (healthy and infested) must be removed and destroyed at regular intervals as prescribed by **legislation**, eg codling moth, fruit fly.
- **Promptly remove and destroy all plant debris**. Some insects 'overwinter' on crop debris and litter surrounding host plants, eg
  - Mealybugs can survive on crop debris.
  - Cabbage white butterfly as pupae attached to the food-plant debris.
- **Destroy old crops** by ploughing in as soon as harvest is complete. As the plants breakdown so do the most of the organisms that were attacking it. The ploughed-in plant material must be fully broken down before the new crop is planted or pests will move onto the new crop.

DESTRUCTION OF HOST PLANTS

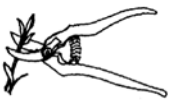
Cineraria leafminer may overwinter on weed hosts, eg sowthistle

IT MAY BE NECESSARY TO DESTROY HOST PLANTS

- **Roguing** is the removal and destruction of infested plants **in a crop** that could spread infestation to healthy plants within the crop, eg
  - **Insect populations that develop on a few plants** can provide a source of infestation for the whole crop.
  - **Indoor and glasshouse plants** may be so badly infested with mealybugs that chemical and other methods of control are likely to be ineffective. Their destruction would be a necessary part of a control program.
- **Many plant pests 'overwinter'** on weed hosts, alternate hosts, volunteer seedlings and crops and are a source of infestation for commercial plantings as they dry off. Destruction of these hosts before they seed is essential for control, exceptions might be where these hosts support predators. Weed hosts of some plant pests include:

Cape weed	- Brown vegetable weevil
Sowthistle, other Asteraceae	- Cineraria leafminer
Weeds, other herbaceous plants	- Twospotted mite
Grass, herbage	- Rutherglen bug
Unwanted and unharvested fruit trees	- Codling moth, fruit fly

PRUNING



SEVERELY INFESTED PORTIONS OF PLANTS

Pruning of severely infested parts of plants and destroying them is frequently an effective way of coping with some pests, eg

- Callistemon tip borer
- Oriental fruit moth
- Scale infestation on ferns

HYGIENE

WHERE APPROPRIATE (depends on the crop)

- Clean and disinfect **benches and floors** regularly in glasshouses.
- Clean equipment before **moving** it to clean areas.
- Thoroughly clean **containers and packing equipment** prior to re-use.
- **Clean and sterilize** secateurs, pruning tools and harvest utensils.
- **Restrict movement** by vehicles and people (insects adhere to clothes).
- Handle pest-free plants **before** handling infested plants. Wash hands.

BIOLOGICAL CONTROL

LEGISLATION, ETC

The **Biological control Act 1984 (Cwlth)** regulates the choice of target pests, biological control agents which can be researched, approval for release and persons releasing the agents. Target list of Biological Control Agents:
www.**daff**.gov.au/

- **Suppliers of biological control agents:**
  Australasian Biological Control (ABC) www.**goodbugs**.org.au/
  Biological Farmers of Australia/Organic Standards www.**bfa**.com.au/
  Organic Crop Protectants www.**ocp**.com.au/
  Toxicity of commonly used chemicals to some beneficial species www.**goodbugs**.org.au/
- **AS 6000—2009. Organic and Biodynamic Products** (Standards Australia) outlines the minimum requirements to be met by growers and manufacturers wishing to label their products 'organic' or 'biodynamic' (page 49).

WHAT IS BIOLOGICAL CONTROL?

CLASSICAL BIOLOGICAL CONTROL may be defined as the deliberate use of a pest's natural enemies to control a pest. In practice:

- Several biological control agents may be released to control a single pest, eg biological control of insects and mites may be brought about by other insects and mites, diseases, pheromones and genetic engineering.
- Insecticides **not toxic to predators** assist control. Fungicides, and other pesticides used to control other pests and diseases must also be non-toxic to predators.
- Some industries, eg cotton, have guides on the impact of individual insecticides on natural predators of major cotton pests. By focusing on conserving the natural enemies of major cotton pests, eg *Helicopverpa*, mites, aphids, mirids and tipworms, it is possible to significantly reduce insecticide use without impairing productivity.
- Biological control agents are **most effective** when used in **IPM** programs.

BY INSECTS OR MITES

Many predators and parasites can be purchased for release

PREDATORS

Predatory insects and mites feed on **many** other insects or mites (prey). Common predators include **ladybirds and mites**. Predators can supplement their diet by feeding on pollen, nectar and fungi.

- **General predators**, eg
  Ants, eg green ants
  Assassin, pirate and damsel bugs
  European and paper nest wasps
  Lacewing larvae (various spp.)

Ladybirds feed on aphids, scales

- **Predatory ladybirds**, eg

Ladybirds (various species)	- Aphids
Red chilocorus (*Chilocorus circumdatus*)	- Armoured scales
Ladybird (*Rodalia cardinalis*)	- Cottonycushion scale
Cryptolaemus beetle (*Cryptolaemus montrouzieri*)	- Mealybugs (many species)
Native ladybird (*Rhizobius lindi*)	- San Jose scale

Twospotted mite (about 0.5mm long)

Chilean predatory mite (about) 0.7mm long

- **Predatory mites**, eg

Chilean predatory mite (*Phytoseiulus persimilis*)	- Twospotted mite
Predatory mite (*Typhlodromus occidentalis*)	- Thrips
Predatory mite (*Hypaspis* spp.)	- Black vine weevil, thrips pupae, fungus gnats
Predatory mite (*Neosiuilus cucumeris*)	- Thrips
Predatory mite (*Amblyseius victoriensis*)	- Rust mites, broad mite
Predatory mite (*Amblyseius montdorensis*)	- Mealybugs, thrips

PARASITES

Parasitic insects feed and live in, or on, a **single** insect. The most common parasitic insects are **wasps and flies** which lay their eggs in adults, larvae and eggs of pest insects. The wasp eggs hatch inside its host and the larva ultimately consume and kill the pest. In the future it may be possible to alter the **DNA** of wasps so they can parasitize a range of insect pests.

Wasp laying egg in a scale insect

- **Wasps**, eg

Wasp (*Aphidius rosae*)	- Rose aphids
Wasp (*Encarsia formosa*)	- Greenhouse whitefly nymphs
Wasp (*Trissolcus basalis*)	- Green vegetable bug eggs
Wasp (*Aphytis* spp.)	- Red scale
Wasp (*Aphelinus mali*)	- Woolly aphids
Wasp (*Apunta* spp.)	- Cabbage white butterfly caterpillars
Wasp (*Trichogramma* spp.)	- Moth eggs
Wasp (*Trichogrammatoidea cryptophebiae*) (MacTrix)	- Macadamia nutborer eggs
Wasp (*Aphidius colemani*)	- Aphids, eg green peach aphid
Wasp (*Metaphycus helvolus*)	- Soft brown scale, black scale
Greenhouse thrips parasite (*Thripobius semiluteus*)	- Greenhouse thrips

BIOLOGICAL CONTROL *(contd)*

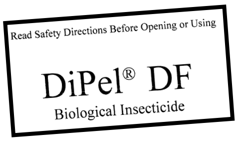
BY DISEASES

Also known as:
Microbial agents
Microbial pesticides
Biological pesticides
Biocontrol agents

VIRUSES

Some viruses only attack insects, eg beetles, grasshoppers, caterpillars. Viruses can be genetically engineered to increase the speed at which they kill infected insects (page 88).

- **Gemstar®**, **ViVUS Gold** (*Heliothis* virus) is used in IPM programs for **corn earworm** (*Helicoverpa armigera*) and **native budworm** (*H. punctigera*) in cotton and certain fruit, vegetable, ornamental, field crops. The virus is ineffective against large caterpillars, taking so long to kill the infected host caterpillars that much crop damage can occur in the mean time. The virus must be eaten.
- **Other insect viruses**, include:
  Cabbage white butterfly virus
  Codling moth virus
  Lightbrown apple moth virus
  Potato moth virus

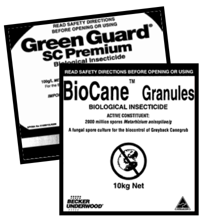


BACTERIA

- ***Bacillus thuringiensis (Bt)***, a soilborne bacterium, is marketed as a 'biological pesticide' to control leaf eating caterpillars with a **high gut pH**. The caterpillars **eat** the bacterial spores which contain a toxin that causes septicaemia killing them. Different strains of ***Bt*** attack different insects (page 59). New strains of ***Bt*** are still being developed. Research is continuing on whether insects may develop resistance to ***Bt. Bt.*** used to control caterpillars of the gypsy moth in Chicago may also kill caterpillars of many other species.

Dipel®, various (***Bt*** subsp. *kurstaki*)	- Some leafeating caterpillars, has some activity against mosquitoes.
XenTari®, various (***Bt*** subsp. *aizawai*)	- Caterpillars, eg corn earworm or cotton bollworm (*Helicoverpa armigera*), diamondback moth (*Plutella xylostella*)
Cybate®, Vectobac® (***Bt*** subsp. *israelensis*)	- Mosquito larvae
Novodor® (***Bt*** subsp. *tenebrionis*)	- Chrysomelid and tenebrionid beetle pests in plantation eucalypts, elm leaf beetle (under research)

- **Spinosad** (derived from soil bacteria)
  Entrust® Naturalyte® Insect Control, Success®, Tracer® (spinosad) - Certain insect pests of certain crops, eg cotton, vegetables, fruit, ornamentals
- **Many other bacteria** are being researched overseas including **Wolbachia** bacteria which could be used to modify natural populations of the dengue fever mosquito (*Aedes aegypti*) to prevent it transmiting the virus to humans. ***Bacillus firmus*** is an insect pathogen of some caterpillars.



FUNGI

- **Green muscardine fungus** (*Metarhizium* spp.) can be purchased, eg
  BioCane® (*Metarhizium* sp.) - Greyback canegrub
  GreenGuard® (*Metarhizium* sp.) - Locusts, grasshoppers
  BioBlast® (*Metarhizium* sp.) - Termites (in the USA)
  www.beckerunderwood.com.au/
- **Other fungi which kill a range of insects** include *Verticillium lecanii, Beauveria bassiana, Entomophthora*, *Paecilomyces* spp. Overseas also *Aschersonia aleyrodis* is being researched to suppress whiteflies.

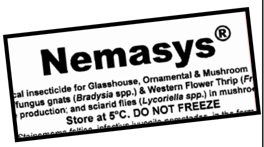
50 MILLION INFECTIVE JUVENILES

NEMATODES Entomopathogenic nematodes (ENs)

Some nematodes are symbiotically associated with bacteria which they carry within their intestinal tract, often within a specialized vesicle. The **nematodes seek out natural openings on insects** and move into the bloodstream where they release the bacteria causing septicaemia. Most insects are susceptible and given enough nematodes they will die, eg

www.beckerunderwood.com.au/
www.ecogrow.com.au/

Beddingia siricidola	- Sirex wasp in *Pinus radiata*
Heterorhabditis bacteriophora	- Black vine weevil
Heterorhabditis zealandica	- Argentine stem weevil, certain scarab grubs, bill bug weevil
Steinernema carpocapsae	- Banana borer weevil, cutworm, armywom, house termites, cat flea
Steinernama feltiae	- Currant borer moth caterpillars
Steinernema feltiae	- Fungus gnats, mushroom fly



BIOLOGICAL CONTROL *(contd)*

STERILE INSECT RELEASE METHOD

SIRM (Sterile Insect Release Method)

Male insects are sterilized and released, so that although mating takes place there are no offspring. **SIRM** has been used against some fly pests, eg

- **Old world screw-worm fly** (*Chrysomya bezziana*) is a pest of livestock in Papua New Guinea. **Male screw-worm flies** are reared in large numbers and sterilized by exposure to gamma radiation. Large numbers are released. When they mate with wild females there are no offspring.
- **Fruit flies.** Large scale breeding and release of sterile males is carried out to control fruit flies in Australia.
- Sometimes called **SIT (Sterile Insect Technique).**

BIOLOGICAL CHEMICALS, BAITS, TRAP CROPS ETC

Moth lure

Like all technologies mating disruption must be managed well

Plastic dispensers containing pheromone

PHEROMONES, BAIT AND FOOD SPRAYS, TRAP CROPS

Pheromones are chemical substances produced and released by insects which affect, in some way, other individuals of the same species. **Sex attractants** are the most common types of pheromones used in pest control, eg

- **Pheromones** are widely used in survey work to **monitor** presence of a pest so that pesticides are only applied when necessary, eg
  - **Codling moth** lures used for monitoring attract **male** codling moths only. Regular weekly counts provide a reliable means of monitoring population levels ensuring the accurate timing of chemical or non-chemical controls. Lures are also available for monitoring other moths, eg **LBAM**, **OFM**, pantry moths.
  - **Fruit fly lures**, eg **Dak.pot** contains a pheromone to attract **male Queensland fruit flies (QFF)** and an insecticide, usually maldison, to kill them. Another lure contains capilure + dichlorvos which attracts **male Mediterranean fruit fly (MedFly)**.
- **Mating disruption**. Pheromone dispensers are tied around new wood in spring and release so much female pheromone that males become **confused** and can't mate. Widely used instead of insecticide sprays to manage some moths, eg
  - Codling moth (Isomate® C-S Pheromone, Disrupt-CM)
  - Lightbrown apple moth (Isomate® LBAM Plus Pheromone)
  - Oriental fruit moth (Disrupt-OFM, Isomate® OFM Rosso-S Pheromone)

- **Pest baits plus insecticides**
  - **Fruit fly protein baits + insecticide**, eg **Eco-Naturalure®, Naturalure®** fruit fly bait concentrates contain protein/sugar-based bait + **spinosad** (derived from soil bacteria) to attract and control both **QFF** and **Medfly**. They have the **BFA registered product logo** on their labels.
  - **Magnet®** (attractants and feeding stimulants, plus an insecticide, sold separately) for *Helicoverpa* moths which are killed when they contact or ingest it, preventing egg laying. Other attractants, eg **BioATTRACT Heli**™ (kairomone bait) are being researched for use in the management of *Helicoverpa* and certain other moths.
- **Predator lures and food sprays** can be applied to insect-infested crops or to draw predators away from crops if they are to be sprayed. Many predators and parasites of plant pests also feed on nectar, honeydew or pollen. Commercial products can be applied to crops to provide food to attract, conserve and buildup natural enemies, eg
  - **Envirofeast®** (yeast-based) attracts more than 20 species of beneficial insects into cotton crops to feed on *Helicoverpa* spp. and mites.
  - **Predalure®** (oil of wintergreen) attracts predatory insects into gardens, eg green lacewing (*Chrysoperia carnea*), ladybirds (*Coleomegilla maculata*) and various syrphids (hover flies) target pests such as aphids, mealybugs, scales, small caterpillars, greenhouse whitefly (*Trialeurodes vaporariorum*) and twospotted mite (*Tetranychus urticae*).

Envirofeast

Predalure

- **Trap crops** are an option for area-wide management of *Helicoverpa* on some crops, eg cotton. Moths are attracted to particular trap crops, eg chickpeas, where they can be destroyed. Precise strategies depend on whether the trapping is carried out in spring or summer.

RESISTANT, TOLERANT VARIETIES

LEGISLATION

ENVIRONMENTAL ACTS, PESTICIDE ACTS, ETC may regulate their use, eg

- **GM** crops must be approved for release.
- **Prescribed growing of resistant varieties** which do not require pesticide sprays in buffer zones close to urban settlements or in pest-free quarantine areas.
- **Phylloxera**, a root-and foliage-feeding aphid, is one of the world's most devastating pests of grapevines is slowly spreading in Australia and can only be controlled through the use of resistant root stock and quarantine measures.

WHAT DOES RESISTANCE/ TOLERANCE MEAN?

A FEW DEFINITIONS

- **The use** of resistant and tolerant plant varieties is an increasingly important solution to insect and other plant problems.
- **Host resistance/tolerance may be based** on chemicals present in the host plant, colour or morphological features, such as thorny and hairy surfaces that make it difficult for insects to feed on foliage, etc.
  - **Traditional cross breeding**. The parent plant is crossed (hybridized) with a cultivated or wild species which has the desired resistant genes.
  - **Genetic engineering**. Genes for resistance are transferred into susceptible crop varieties, thereby reducing the time required to develop new resistant varieties.
  - **Some pests may adapt** to resistant or tolerant species and if large plantings are planned, some non-resistant or non-tolerant varieties should be included.

Immune	Cannot be infected by a given pest or pathogen.
Resistant	Possessing qualities that hinder the development of a given pest, pathogen; may be affected little or not at all.
Tolerant	The ability of a plant to sustain the effects of a pest or disease without dying or suffering serious injury or crop loss. **Even slightly tolerant varieties can be useful.** Acceptable levels of damage on these varieties (thresholds of damage) can be defined before sprays need to be applied, eg green mirids on cotton.

SOME EXAMPLES

UNLIMITED RANGE OF TOLERANCE AND RESISTANCE IN NATURE

- **Some species of eucalypts** are more or less tolerant to pests such as gumtree scale, lerp and Christmas beetle attack. But **provenances and individual trees** within each eucalypt provenance may differ in their tolerance to Christmas beetles.
- **Genetic engineering** is increasingly being used to modify crops so they have some resistance or tolerance to certain insect pests and other plant problems reducing pesticide use, eg
  - **Probably the best known** is Ingard® cotton (***Bt*** cotton) which has been genetically modified to produce its own insecticides, ie to produce protein from ***Bt*** which is toxic to cotton bollworms (*Helicoverpa* spp.), the major caterpillar pests of cotton, but not toxic to beneficial or other organisms.
  - **Peas** have been genetically engineered to have resistance to the pea weevil (*Bruchus pisorum*) which is a major pest of peas.


Christmas beetles favour certain eucalypts.


Corn earworm, cotton bollworm is a major pest of sweetcorn, cotton, ornamentals.


Pea weevil severely damages field peas.

Fig. 36. Resistant/tolerant hosts is the only long term solution to these pests.

PLANT QUARANTINE

LEGISLATION

THE QUARANTINE ACT (1908) AND AMENDMENTS is the **legal base** for quarantine in Australia. Australia's quarantine function is delivered by:

- **Australian Quarantine and Inspection Service (AQIS)** which undertakes quarantine operations and ensures compliance with quarantine policy. Prohibited imports include insects and products on, or in which they might be carried. Soil is a prohibited import.
- **Biosecurity Australia** which develops quarantine policy and advises the Government. Biosecurity has a plan of action if pests enter Australia.

www.daffa.gov.au/**aqis**

AUSTRALIAN PLANT QUARANTINE SERVICE AQIS

INSECT PESTS NOT YET IN AUSTRALIA include:

Some insect pests of plants not as yet in Australia include:

- Colorado potato beetle
- European corn borer
- Japanese beetle, Khapra beetle
- Leafmining insects of chrysanthemum
- New Zealand grass grub
- Rice stem borers

For **target lists** of insects, plant pests and diseases and weeds, visit:
www.daff.gov.au/aqis/quarantine/naqs/**target-lists**

PaDIL (Pests and Diseases Image Library) is a good reference for exotic pests:
www.**padil**.gov.au/

INSECT VECTORS NOT YET IN AUSTRALIA include:

- Asian citrus pysllid (a vector for the bacterial disease citrus greening)

PESTS WHICH HAVE ARRIVED in Australia within the last 10 years include:

- Aphids, eg currant lettuce aphid, Monterey pine aphid
- Mites, eg olive bud mite, southern red mite
- Thrips, eg banana thrips, fig thrips, melon thrips, Western flower thrips
- Whiteflies, eg ash whitefly, cabbage whitefly, spiralling whitefly
- Others, eg elm leaf beetle, mango leafhopper, red imported fire ant

PESTS WHICH OCCUR IN AUSTRALIA BUT NOT IN OTHER COUNTRIES

Export fruit, plant material and other items infested with such pests may not be permitted entry to countries where the pest does not occur, such pests include:

- Various species of fruit flies
- San Jose scale, many pests of eucalypts

INTERSTATE & REGIONAL PLANT QUARANTINE

QUARANTINE WITHIN AUSTRALIA (domestic quarantine)

Insect pests subject to quarantine measures within Australia include:

- Azalea leafminer
- Citrus leafminer, citrus gall wasp
- Mediterranean and Queensland fruit flies
- Argentine ant, red imported fire ant
- Western flower thrips, melon thrips
- Codling moth
- Elm leaf beetle
- Grape phylloxera
- European red mite
- Sorghum midge

Wendy Unger

For more information on interstate quarantine visit:
www.**quarantinedomestic**.gov.au/

LOCAL PLANT QUARANTINE

Restrict movement by vehicles and people

SOME INSECTS DO NOT FLY VERY FAR, SOME ARE WINGLESS

One of their main methods of spread of such pests is by the movement of infested plant material and they are often **re-introduced** into glasshouses and nurseries by this means, eg on cuttings, in soil, vehicles, clothes many insects may be found on clothes, shoes, vehicles, containers.

- Azalea leafminer moths can only fly about 1 meter.
- Mealybugs and mites crawl.
- Adult female scales which are stationary.
- Isolate new introductions until pest-freedom is assured.
- There is no legislation to control this level of quarantine.

PEST-TESTED PLANTING MATERIAL

HIGH HEALTH
VIRUS-TESTED
ELITE STOCK

LEGISLATION

Legislation regulates production, the supply line and sale of pest-tested planting material to growers, eg

- Horticultural Stock and Nurseries Acts
- Seed Acts

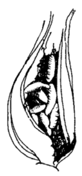
WHAT IS PEST-TESTED PLANTING MATERIAL?

Insect pests and mites (and diseases) may be carried **in, on or in association with, bulbs, cuttings and other vegetative propagation material**. They may also be carried in **seeds and in soil**. Many terms have been used in the past to describe 'tested planting material', eg virus-tested, disease-tested, high health, elite stock, etc.

ALWAYS PLANT PEST-TESTED PLANTING MATERIAL (if available)

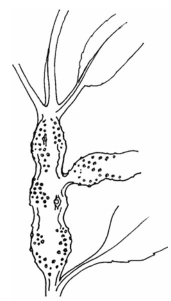
- **Planting material is only free** from the pests (and diseases) for which it has been **tested** and found to be **free** from. It may carry other pests (and diseases) for which it has **not been tested**. Efforts are made to ensure that pest-tested planting material is as **free from** as many other pests, diseases and weeds as possible, and is of good horticultural quality.
- **To get rid of the specified pests**, disease-tested planting material has either **undergone treatment** or been grown in special **areas free from** the specified pests **(area freedom)**. In either case the planting material is tested again (or continually) before sale to ensure that it really is free of the specified pests.
  - **Treatments** include hot water, insecticides.
  - **Area-freedom.** Crops grown for seed may be grown in areas that are free of the target pest, eg Western flower thrips, grape phylloxera. These areas are **defined by legislation**.
- **Certification Schemes** aim to provide **seed** or **vegetative propagation** material conforming to cultural characteristics and guaranteed-free from specified pests, diseases and weeds to the grower.
- **Suppliers.** Contact your crop association.

INSECT PESTS ASSOCIATED WITH PROPAGATION MATERIAL



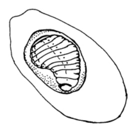
Bulb fly maggots

- **Ornamental plants**
  Azaleas cuttings, plants - Azalea leafminer, azalea lace bug
  Chrysanthemum cuttings - Chrysanthemum gall midge, cineraria leafminer
  Daffodil bulbs - Bulb flies, bulb mites
  Gladiolus corms - Gladiolus thrips
  Rose nursery stock - Rose scale



Citrus gall wasp damage

- **Fruit trees**
  Citrus nursery stock - Citrus gall wasp, citrus leafminer, scales
  Stone fruit nursery stock - San Jose scale, aphids
  Pome fruit nursery stock - San Jose scale, woolly aphid
  Currants - Currant borer moth larvae
  Grapevine rootstock - Phylloxera



Rice weevil damage

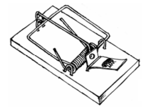
- **Vegetable and field crops**
  Bean seed - Bean weevil
  Potato tubers - Potato moth
  Lucerne seed - Lucerne seed wasp
  Rice seed - Rice weevil

PREVENT RE-INFESTATION

PREVENT RE-INFESTATION by **not** introducing infested bulbs, tubers, nursery stock, cuttings, etc, which may carry pests that may attack your crop.

- Pest-tested planting material is usually **not resistant** to attack by the pests (and diseases) it has been freed from and so may be re-infested.
- Only **introduce** pest-tested planting material into **pest-free areas** and plant into **pest-free media or soil**.

PHYSICAL & MECHANICAL METHODS



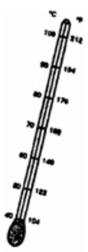
LEGISLATION

Legislation provides for the proper construction of insect-proof quarantine houses, post harvest treatments of fruit for fruit flies and many other treatments of plant materials.

WHAT ARE PHYSICAL & MECHANICAL METHODS?

These control methods have become prominent in recent years because of the development of **resistance to pesticides**, the need to **avoid pesticide residues** and for **economic reasons**. Unfortunately, many are difficult to apply on a large scale, are only partially effective, offer no long term protection and some are labour intensive.

PHYSICAL METHODS




Sticky trap

TEMPERATURE

- **Heat.** Treatment at **50-60°C** for varying periods generally kills all stages of insect pests. **Hot water treatments** are used to kill bulb mites and bulb flies. Some nurseries **pasteurize** soil and potting media with steam reduced to **60°C for about 30 minutes**, soil still retains living beneficial micro-organisms and is undamaged structurally. Insect pests, some diseases and some weed seeds are killed.
- **Cooling.** Low temperatures are useful for retarding insect development but **freezing temperatures** are usually required to **kill** them. Seed may be held in cold storage to prevent or slow down insect development. Postharvest cold disinfestation treatments of citrus eliminate possible fruit flies.

OTHER PHYSICAL METHODS

- **Humidity.** Insect development is retarded at relatively low humidities. Grain is usually dried before storage until its moisture content is **less than 12%.**
- **Light** is attractive to many insects especially nocturnal species. Probably the best known light trap is the **electric grid light trap** found in butcher shops and delicatessens. Insects attracted by the **ultraviolet** light are electrocuted.
  - **Yellow sticky traps** are attractive to a wide range of small flying insects both pest and beneficial (blue is attractive to thrips and shoreflies). Used to monitor insects for timing sprays but can reduce numbers to some extent.
  - **Solar-powered UV light** attracts insects into traps of various kinds, eg drums of swirling water where they drown.
- **Gases.** Long term storage of grain in pits began with the Pharaohs, where exclusion of air killed insects in the grain. Today **oxygen** levels in silos can be lowered and replaced by **carbon dioxide or nitrogen**.
- **Inert abrasive and absorptive dusts** act by **abrading or absorbing the waxy cuticle** of insects which then dehydrate and die. Inert dusts, eg mineral earths, diatomite, are used to protect stored grain from insect pests. The use of inert dusts is not new; the ancient Egyptians used a type of inert dust.
- **Physical shocks.** Some stages of insect development, eg pupae, are very sensitive to physical shocks and **grain turning** can significantly reduce the insect populations in stored grain products.
- **Irradiation** is used to eliminate pests and from foodstuffs and commodities **increasing their storage life**. Used for some non-food items in Australia.

MECHANICAL METHODS


Fly swat


Tree banding - codling moth, fruit tree root weevil and white cedar moth


Moths are attracted to the pheromone on a sticky surface

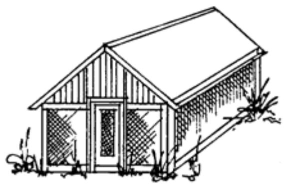
OPERATIONS

Hand operations include **swatting flies,** collecting slow-moving insects and destroying them. Collect weevils and cutworms by torchlight at night.


Collecting insects by hand

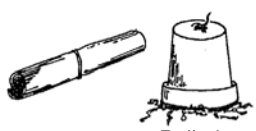
BARRIERS

Insect-proof greenhouses prevent aphids from attacking plants and spreading virus diseases. They are used routinely for plant quarantine purposes. **UV-resistant** fabrics (which must comply with various Standards), include anti-insect nets which can generally protect crops from pests and increase yields, control temperature, light.


Insectproof greenhouse

TRAPS

Most traps work by appealing to a pest's need for **food, shelter or sex**, eg earwigs are attracted to rolled newspapers by their need for shelter. **Bands of cardboard** tied around trunks trap larvae that climb tree trunks. **Fruit fly pheromones** attract certain male and/or female fruit flies which are then killed by insecticide in the trap.


Earwig shelter traps. Rolled newspaper and shredded paper in upturned flower pot

INSECTICIDES, MITICIDES

LEGISLATION

AS 6000—2009. **Organic and Biodynamic Products** (Standards Australia) outlines minimum requirements to be met by growers and manufacturers wishing to label their products organic or biodynamic

LEGISLATION

- **Commonwealth legislation** provides for a national system of pesticide **registration** up to the point of sale. Registration is the responsibility of the Australian Pesticides and Veterinary Medicines Authority (**APVMA**).

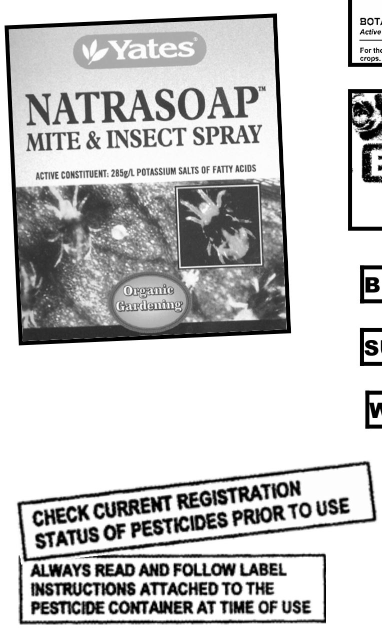
> **APVMA** www.**apvma**.gov.au/ and search **PUBCRIS** for registered chemicals
> or purchase **Infopest** **www.dpi.qld.gov.au/infopest**
>
> To check for products **permitted in organic systems**
> **AS 6000—2009. Organic and Biodynamic Products** www.**standards**.org.au/
> Organic Federation of Australia (OFA) www.**ofa**.org.au/
> Biological Farmers of Australia www.**bfa**.com.au/
> National Association for Sustainable Agriculture, Australia **(**NASAA**)** www.**nasaa**.com.au/
> Organic Growers of Australia (OGA) www.**organicgrowers**.org.au/

- **State/Territory/Regional legislation** currently regulates the **use** of pesticides. However, it is intended that there be a national system. All persons using pesticides **commercially** must undergo **training** in the safe handling and use of pesticides.

INSECTICIDE APPLICATIONS

- **Insecticide applications** (page 50).
- **Non-systemic and systemic insecticides** (movement in **plants** (page 51).
- **Summary and examples** (page 52).
- How are insecticides **absorbed by insects?** (page 53).
- **Non-selective and non-selective insecticides** (page 54).
- **When** should insecticides be **applied?** (page 55).
- **Resistance** (page 56).
- **Insecticide Mode of Action Groups** (Table 2, page 57).
- **Bio-insecticides, spray oils, soaps, pheromones** (Table 3, page 61).
- Fumigants (page 267).

> Contact **CropLife Australia** for updates of **Insecticide Mode of Action Resistance Groups**
> www.**cropelifeaustralia**.org.au/



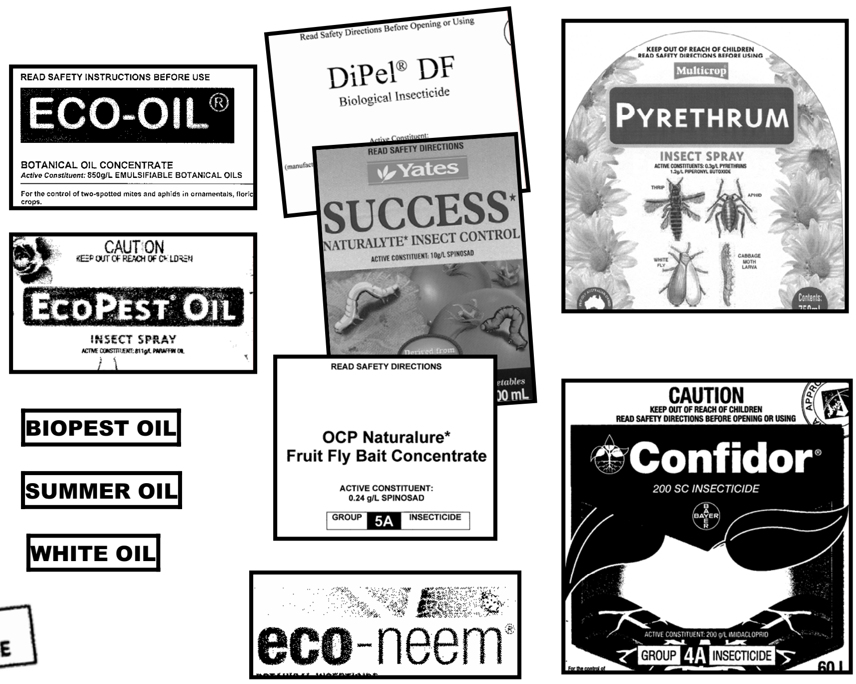
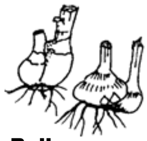


Fig. 37. Some insecticide labels.

INSECTICIDE APPLICATIONS.

New equipment and improved methods for delivery of insecticides are continually being developed.

INSECTICIDES MAY BE USED TO TREAT


Bulbs, corns

ALL PLANT PARTS, eg
- Foliage and stems
- Trunks and limbs
- Flowers, fruit and seeds
- Roots, cuttings, seedlings
- Bulbs, corms, tubers, etc
- Air space
- Seeds prior to planting
- Stored seed, grain
- Potting mixes and soil

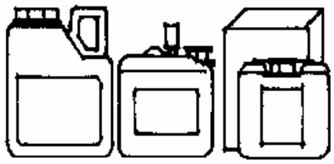

Seeds Cuttings Nursery stock

FORMULATIONS

Some formulations combine fertilizers with insecticides

LIQUIDS, eg
- Emulsifiable concentrates
- Suspension concentrates
- Liquid concentrates
- Micro-encapsulated suspensions

SOLIDS, eg
- Baits
- Dusts
- Granules
- Powders


The formulation is the product purchased

OTHERS, eg
- Aerosols
- Fumigants
- Slow release generators

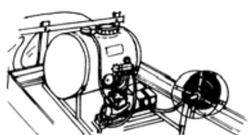
APPLICATION EQUIPMENT

Knapsack

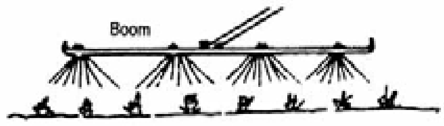

Trolleypak

Application equipment ranges from expensive large units to small ready-to-use convenient container-applicators, eg

SPRAY EQUIPMENT, eg
- Hydraulic sprayers, eg knapsacks, trolleypaks, trailer sprayers, booms
- Air blast sprayers
- Mist blowers
- Rotary atomizers
- Electrostatic sprayers
- Fog generators
- Aeroplane sprayers

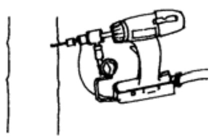

Truck sprayer


Trailer sprayer



Boom sprayer

OTHER EQUIPMENT, eg
- Dusters
- Granule dispensers
- Tree injection
- Soil injectors


Tree injection

Many pests and some diseases reside on the undersides of leaves. Some spray equipment has nozzles that can rotate 360 degrees allowing the undersides of leaves to be sprayed with ease.

SELF-DISPENSING APPLICATORS, eg
- Hose-ons
- Dusters
- Guns
- Aerosols

Hose-one Duster Gun Aerosol

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

NON-SYSTEMIC & SYSTEMIC INSECTICIDES
Contact & translocated insecticides – Movement in plants

NON-SYSTEMIC INSECTICIDES

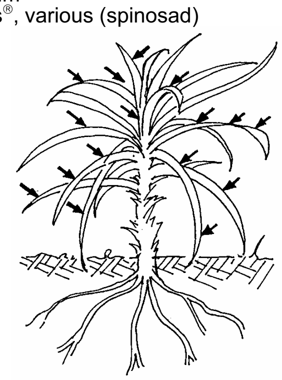
Contact

NON-SYSTEMIC INSECTICIDES ARE NOT ABSORBED BY THE PLANT.

- They are only effective at the site of application. **Contact sprays** are only effective on insects, eg scales and mealyugs that are actively moving over the plant. Adult scales and mealybugs that have developed their waxy covering are difficult to kill with contact pesticides.
- They are sometimes called **'preventative'** as they are often applied before the insect has actually been found but where it is expected.
- Contact sprays may be devastating to beneficial insects.

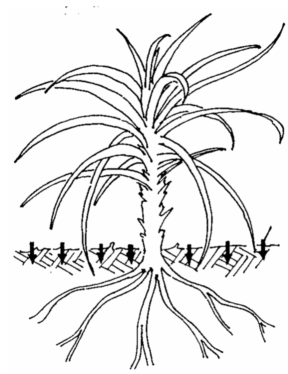
NON-SYSTEMIC – FOLAGE, eg

Dipel®, various (*Bacillus thuringiensis*)
Malathion®, various (maldison)
Mavrik®, various (tau-fluvalinate)
Pyrethrum
Success®, various (spinosad)



NON-SYSTEMIC - SOIL, eg

Garlon®, various (triclopyr)
Lorsban®, various (chlorpyrifos)
Malathion®, various (maldison)



SYSTEMIC INSECTICIDES

Translocated

SYSTEMIC INSECTICIDES ARE ABSORBED BY THE PLANT.

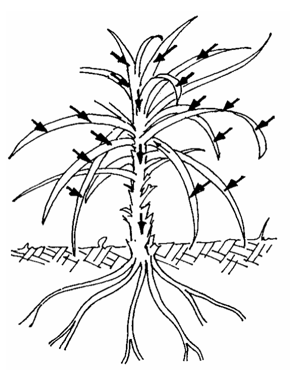
- They are carried (**translocated**) through the sap stream to parts remote from the site of application where they control sap-sucking pests, eg aphids, mites, which are actively feeding. Once the pest has stopped feeding it is too late to control it. They can be effective against some insects already inside the plant.
- The whole plant surface **need not be treated**, eg systemic insecticides may be applied as foliage, root and soil or as tree injection treatments.
- **New developing foliage may be protected** from insect attack
- Systemic insecticides are **not** necessarily evenly distributed within the plant. Know **how** a particular product moves within the plant. **Penetrants** are insecticides that just penetrate the cuticle, eg Lebaycid® (fenthion) will kill fruit fly eggs laid immediately under the skin of fruit.
- May control a pest **more slowly** than contact non-systemic insecticides.

Excessive residues may still occur if with-holding periods are not observed. Washing the outside of fruit does not remove internal residues. If surface residues disappear quickly, they will result in **minimum risk to non-target organisms**

SYSTEMIC - FOLIAGE, eg

Taken up by LEAVES

Confidor®, various (imidacloprid)
Folimat®, various (omethoate)
Pirimor®, various (pirimicarb)
Rogor®, various (dimethoate)



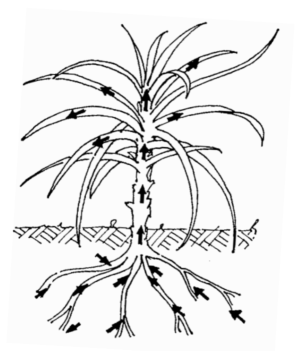
Systemic insecticides applied to foliage do not generally move downwards to the roots

Once applications of systemic pesticides have been absorbed by the plant foliage they **cannot** be washed off by rain or irrigation.

SYSTEMIC – APPLIED TO SOIL, eg

Taken up by ROOTS

Gaucho®, Merit®, Premise®, various (imidacloprid)
Nemacur®, various (fenamiphos)
Temik® (aldicarb)



When applied to the **soil**, systemic pesticides dissolve in soil water and are taken up by the roots and **translocated upwards** to varying degrees within the plant. The soil must be kept moist for continued uptake. Some systemic insecticides applied to roots and trunks are translocated upwards into the foliage to control **foliage-feeding insects**.

SUMMARY & EXAMPLES

Fig. 38. INSECTICIDES & MITICIDES

Foliage

NON-SYSTEMIC Contact

Abamectin® (*abamectin*)
Azamax®, Neem® (*azadirachtin*)
Dipel® (*Bacillus thuringiensis*)
Derrist® dust (rotenone)
Entrust®, Success® (spinosad)
Insegar® (fenoxycarb)
Dursban® (chlorpyrifos)
Lebaycid® (fenthion)
Malathion® (maldison)
Mavrik® (tau-fluvalinate)
Oil sprays (petroleum, paraffinic, botanical)
Omite® (propargite)
Pyrethrin
Apollo® SC (clofentezine)
Natrasoap® (soap sprays)

SYSTEMIC

Confidor® (imidacloprid)
Crown® (acetamiprid)
Calypso® (thiacloprid)
Actara®, Cruiser®, Meridian® (thiamethoxam)
Regent® (fipronil)
Tempo® (betacyfluthrin)
Orthene® (acephate)
Rogor® (dimethoate)
Folimat® (omethoate)
Pirimor® (pirimicarb)

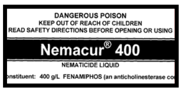
Soil

NON-SYSTEMIC

Biogreen® (*Metarhizium*)
Biocane® (*Metarhizium*)
Nematodes (various)
Dursban® (chlorpyrifos)
Malathion® (maldison)

SYSTEMIC

Confidor® Guard Soil (imidacloprid)
Merit® (imidacloprid)
Initiator® (imidacloprid)
Nemacur® (fenamiphos)



Trunks of trees

Dormant woody primarily to control scales
Lime sulphur
Oil sprays (petroleum, paraffinic)
Rogor® (dimethoate)

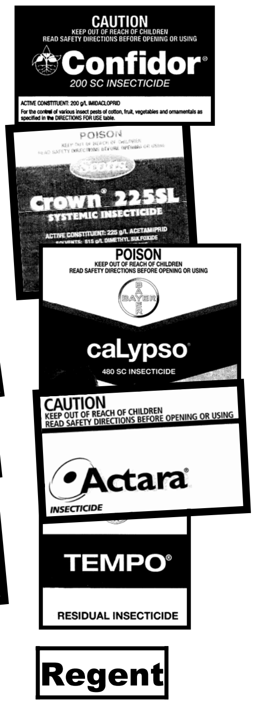
Seed dressings

Gaucho® (imidacloprid)
Rogor® (dimethoate)

Bulbs Corms Roots

Malathion® (maldison)
Sulphur

Fruit



Some products have been approved for use in organic systems (**BFA REGISTERED PRODUCT**).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

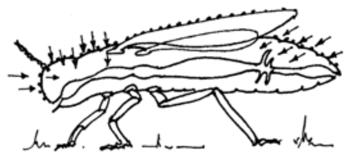
HOW ARE INSECTICIDES ABSORBED BY INSECTS?

CONTACT ACTION

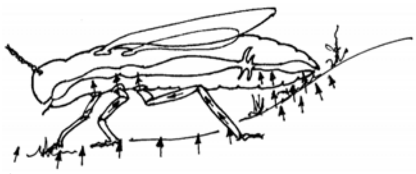
HAS TO PENETRATE THE SKIN, CUTICLE OR FEET.

Contact insecticides are applied directly onto the insect or to the area to be protected. Insecticides with contact action include:

- Bugmaster® (carbaryl)
- Confidor® (imidacloprid)
- Dursban® (chlorpyrifos)
- Insegar® (fenoxycarb)
- Lebaycid® (fenthion)
- Malathion® (maldison)
- Mavrik® (tau-fluvalinate)
- Pirimor® (pirimicarb)
- Rogor® (dimethoate)
- Petroleum oils (smothers insects)
- Vegetable oils (smothers insects)
- Soaps (dissolves insect wax)



Insects are wetted by spray, eg aphids (adapted from Gerozisis and Hadlington 2001).



Crawling insects walk on treated surfaces, eg codling moth, cockroaches (adapted from Gerozisis and Hadlington 2001).

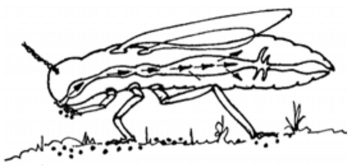
STOMACH ACTION

HAS TO BE EATEN BY THE PEST BEFORE IT IS EFFECTIVE.

Stomach insecticides are useful against foliage chewing insects. Insecticides with stomach action include:

- Bugmaster® (carbaryl)
- Confidor® (imidacloprid)
- Derris® Dust (rotenone)
- Dipel® (*Bacillus thuringiensis*)
- Dursban® (chlorpyrifos)
- Insegar® (fenoxycarb)
- Lebaycid® (fenthion)
- Mavrik® (tau-fluvalinate)
- Naturalyte® (spinosad)

Insect eats treated plant surface or poisonous baits, eg caterpillars (adapted from Gerozisis and Hadlington 2001).



Insect ingests insecticide during grooming, eg termites (adapted from Gerozisis and Hadlington 2001).

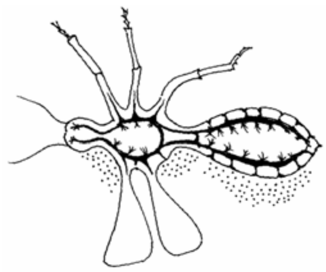
FUMIGANT ACTION

Knockdown insecticide spray is designed for use against flying insects. It acts quickly causing sprayed insects to fall, eg pyrethrin

ACTS THROUGH INHALATION OR ABSORPTION OF VAPOUR.

Nearly all insecticides have some degree of volatility but for most this is a very low level. Some, however, can be highly volatile and are breathed in via the spiracles and are said to have respiratory, inhalation or fumigant action, eg

- Dichlorvos
- Pyrethrin
- Sulphur® (sulphur)



Insect breathe in insecticide, eg flying insects (adapted from Gerozisis and Hadlington 2001)

MANY MODES OF ACTION

MANY HAVE MORE THAN ONE MODE OF ACTION, eg

- Bugmaster® (carbaryl) - Contact and stomach action
- Derris® Dust (rotenone) - Contact and stomach action
- Lebaycid® (fenthion) - Contact and stomach action
- Ambush® (permethrin - Contact and stomach action
- Mavrik® (tau-fluvalinate) - Contact and stomach action
- Confidor® (imidacloprid) - Contact and stomach action
- Pirimor® (pirimicarb) - Contact and fumigant action
- Sulphur - Contact and fumigant action
- Insectigas® (dichlorvos) - Contact, stomach and fumigant action
- Slay-afe® (pyrethrin) - Contact, stomach and fumigant action

NON-SELECTIVE AND SELECTIVE INSECTICIDES
Broad & narrow spectrum insecticides

There is a wide range between the two extremes of non-selective and selective products, also some insecticides can be used selectively, eg fruit fly baits (spinosad).

NON-SELECTIVE INSECTICIDES

Broad spectrum ⟷

ACTIVE AGAINST A WIDE RANGE OF PEST AND BENEFICIAL INSECTS

- **Extensive repeated use** of non-selective insecticides may result in upsurges of pest species due to the reduction in populations of parasitic and predatory insects, eg the use of **cabaryl** repeatedly to control codling moth on apples may result in outbreaks of **twospotted mite**.
- **Other non-selective insecticide/miticides** include:

Confidor® (imidacloprid)
Folimat® (omethoate)
Lebaycid® (fenthion)
Maldison® (malathion
Mavrik® (tau fluvalinate)
Regent® (fipronil)
Rogor® (dimethoate)
Success®, Entrust® (spinosad)
Talstar® (bifenthrin)

SELECTIVE INSECTICIDES

Narrow spectrum ⟷

ONLY ACTIVE AGAINST SOME SPECIES OR SOME STAGES OF INSECTS

- Selective insecticides may not kill off natural enemies preventing upsurges of new pests and so are useful in **IPM** programs.
- Some are bio-pesticides, eg Dipel® (*Bacillus thuringiensis*), and are less toxic, not many are available.
- Some may have to be applied more frequently.
- A wider range of pesticides may have to be stored and applied.
- Examples of selective insecticides/miticides include:

Fruit fly lures and baits (many)	- Fruit fly (adults)
Isomate™ C-S Pheromone (tiers)	- Codling moth (adults)
Dipel® (*Bacillus thuringiensis*)	- Some leafeating caterpillars
Insegar® (fenoxycarb)	- Codling moth
Vivus® (virus)	- Corn earworms (*Helicoverpa* spp.)
Pirimor® (pirimicarb)	- Aphids (nymphs and adults)
Greenguard® (*Metarhizium* sp.)	- Locusts and grasshoppers
Omite® (propargite)	- Mites (adults and nymphs)
Apollo® (clofentenzine)	- Mites (ovicide, nymphs)
Calibre® (hexythiazox)	- Mites (ovicide)
Pyranica® (tebufenpyrad)	- Mites (all stages)
Avid® (abamectin)	- Mites, native budworm on cotton
Aramite®, Floramite® (bifenazate)	- Mites

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

WHEN SHOULD INSECTICIDES BE APPLIED?

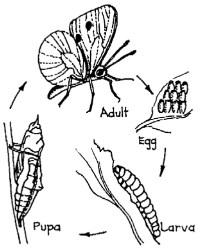
Follow label **directions for use** and **insecticide resistance warnings**. Companies may restrict application and/or number of applications of certain chemicals on crops being grown for their use.

GROWTH STAGE OF HOST

Insecticides must be applied to the appropriate part of the host.

Foliage | Flowers | Dormant woody plants | Seeds, cuttings | Bulbs, corms | Roots, soil

SUSCEPTIBLE STAGE IN PEST LIFE CYCLE



Cabbage white butterfly

SOME PESTS ARE SUSCEPTIBLE TO INSECTICIDES at only at certain stages of their life cycle, eg

Aphids	- Nymphs and adults on plants
Black scale	- Nymphs (crawlers) on plants (see below)
Cabbage white butterfly	- Larvae (caterpillars) on plants
Cineraria leafminer	- Larvae (fly maggots) in mines
Codling moth	- Adult moths
Pear and cherry slug	- Larvae (slugs) feeding on the plant
Scarab grubs	- Young larvae (grubs) in soil
Steelblue sawfly	- Larvae (spitfires) in the host

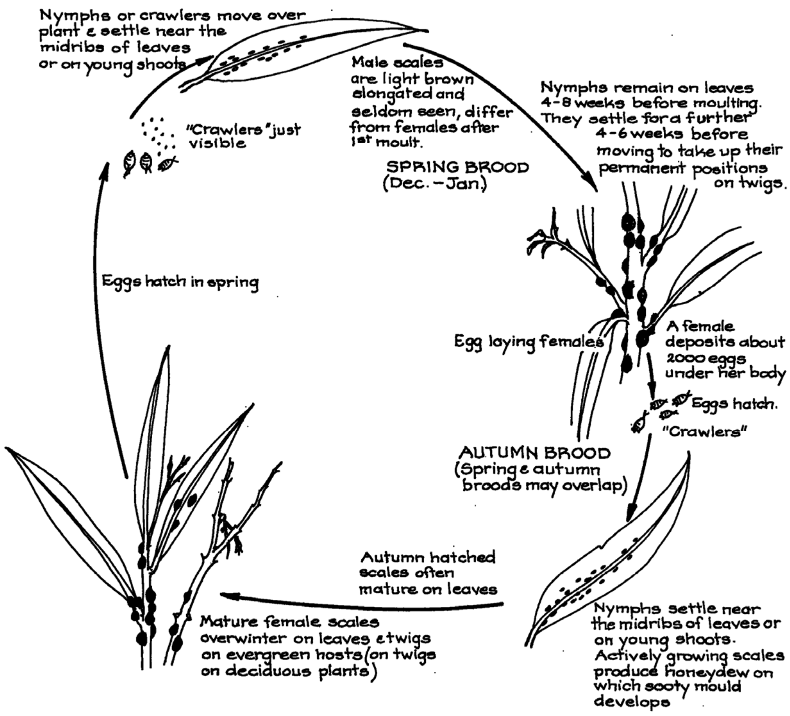
MONITOR THE SUSCEPTIBLE STAGE(S)

- Know which **stage of pest** (eggs, larvae, adults), on which **part of the plant** (flowers, leaves, stems etc), and what **sampling techniques** to use.
- Better **selection and application** of pesticide will provide more effective control and greater safety to workers and the environment.
- **Correct timing**, eg time of year season etc.

NUMBER AND INTERVAL BETWEEN APPLICATIONS

BLACK SCALE *(an example)*

- **Number of applications**. Many insecticides do not kill all stages of an insect. **Black scale** on **evergreen hosts** is controlled by spraying the susceptible 'crawler' stage in spring and/or autumn. However, insecticides used to kill the 'crawler' stage, may not kill adults or eggs, therefore a **2nd application** about 10-14 days later after the **1st spray**, is often required to kill the 'crawlers' emerging from eggs which were still unhatched at the time of the **1st spray** (pages 164-166).
- **Interval between applications** depends on the particular insecticide, its persistence and other factors. If persistence is too short the **pest** may not be controlled, if too long, the **environment** may be adversely affected.



Black scale (*Saissetia oleae*)

RESISTANCE

WHAT IS RESISTANCE?

Insecticide resistance is the ability of a pest to survive doses of insecticide that would normally provide control. The pest is not adequately controlled.

- **At least 50% of world pest**s have developed some resistance to any one major group of pesticides. It is so extensive that it is difficult to find effective chemicals for some pests. Use of the few remaining effective ones has been restricted in an attempt to prolong their useful life.
- **Using the same insecticide continually** to control the same pest will lead to the development of resistance by the pest.
- **In Australia**, insects and mites which have developed resistance to a range of insecticides/miticides include:
  Corn earworm (*Helicoverpa armigera*)
  European red mite (*Panonychus ulmi*)
  Green peach aphid (*Myzus persicae*)
  Twospotted mite (*Tetranychus urticae*)
  Western flower thrips (*Frankliniella occidentalis*)

RESISTANCE MANAGEMENT STRATEGIES

Use **IPM** programs which include non-chemical control methods to preserve beneficial insect and mites. Some insects, eg members of the Order Hymenoptera do not seem to develop resistance to insecticides. Seek advice about ways of reducing and managing resistance.

- **Insecticide Resistance Management Strategies.** Commercial crops.
  - **CropLife Australia** has classified insecticides into **Insecticide Mode of Action Groups** which indicate the mode of action of the insecticide on a metabolic process in the pest, ie **how it kills or suppresses the pest** (page 57, Table 2) . Some biological insecticides are **not** classified by **CropLife Australia** (page 61, Table 3). Contact **Croplife Australia** for updates and classification and click on **Resistance Management**:

    www.**croplifeaustralia**.org.au/
  - **To minimize the development of resistance** and prolong the life of existing insecticides, observe **1, 2, 3.... groups** on **commercial insecticide labels**. Follow resistance warnings. Rotate insecticides between different groups as recommended. Remember, persons using commercial insecticides must undergo training. **Home garden products available from garden centres are not required to have insecticide mode of action groups on them**.
  - **CropLife Australia** has also prepared management strategies for some pests and for some crops to minimize the development of resistance.
    - **Pest** resistance management strategies developed for some **pests** include corn earworm (*Helicoverpa armigera*), Western flower thrips **(WFT)** (*Occidentalis frankliniella*).
    - **Crop-Pest** Resistance Management Strategies have been developed, eg for cole crops - diamondback moth.

Classification by Croplife Australia is according to **how a pesticide kills the insect, fungus or weed** and is used for resistance management.

It does **not indicate toxicity,** it is true that some groups are more toxic than others as indicated by the signal headings on their labels (see page 237).

- **Follow label instructions and warnings.** which include resistance strategies. Application of some insecticides for control of some pests is **restricted** in order to prevent or delay the likelihood of resistance developing. **"Example"** and **"Company"** are used in the following general instructions to avoid using specific insecticide or company names.

> **GENERAL INSTRUCTIONS**
>
> GROUP **4A** INSECTICIDE
>
> **Insecticide Resistance Strategy**
> For insecticide resistant management, **Example** is a group 4A insecticide. Some naturally occurring insect biotypes resistant to **Example** and other Group 4A insecticides may exist through normal genetic variability in any insect population. The resistant individuals can eventually dominate the insect population if **Example** and other Group 4A insecticides are used repeatedly. The effectiveness of **Example** on resistant individuals could be significantly reduced. Since occurrence of resistant individuals is difficult to detect prior to use, **Company** accepts no liability for any losses that may result from the failure of **Example** to control resistant insects.
>
> **Resistance Management Strategies**
> Strategies are outlined on the label for various pests or crops; there may be industry management strategies which must be followed. For further information contact your local supplier, company representative or local agricultural department agronomist.

Applications may fail for reasons other than resistance, eg
- Incorrect identification of the pest.
- Wrong insecticide may have been used.
- Equipment not calibrated properly.
- Applied at wrong time.
- Weather was unsuitable for application.

INSECTICIDE MODE OF ACTION GROUPS

• Insecticides are classified by **Croplife Australia** into mode of action groups which assist in **resistance management**. • The following tables are a summary guide only, and not a substitute for reading a currently registered label, the MSDS and obtaining up-to-date advice. • The tables also provide an overall picture of the types of insecticides available for crop protection. • **Mark insecticides you use at work.**	Contact **Croplife Australia** for a full list of insecticides, updates of the classification and further information: www.**croplifeaustralia**.org.au Check **Pubcris** for current **registration** status: www.**apvma**.gov.au/ **Infopest** can be purchased www.dpi.**qld**.gov.au/

Table 2. Insecticide Mode of Action Groups (2009) *some examples*

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS CONTROLLED, SUPPRESSED**
1 Acetylcholinesterase inhibitors Nerve action *all members of this class may not be cross resistant*	**1A** Carbamates	**BUGMASTER, VARIOUS** carbaryl (not approved for use on food-producing plants in the home garden)	Non-systemic Contact action Stomach action may thin apples	Certain, turf, fruit, ornamentals, vegetables, field crops, non-crop	**Broad spectrum** beetles, bugs, caterpillars, wireworms, grasshoppers, pear & cherry slug
		APHIDEX, VARIOUS pirimicarb	Slightly systemic Contact action Fumigant action	Ornamentals, fruit, vegetable, pasture, field crops	**Aphicide** certain aphids
	1B Organo Phosphates	**FOLIMAT** omethoate	Systemic Contact action	Cotton, certain ornamentals, some fruit & vegetables	**Broad spectrum** sucking insects, eg aphids thrips, lace bugs, whiteflies **Miticide** twospotted mite, others
		LEBAYCID, VARIOUS fenthion	Slightly penetrant Contact action Stomach action	Ornamentals, fruit, some vegetables, Long residual	**Broad spectrum** fruit flies, codling moth, lightbrown apple moth, oriental fruit moth, others
		MALATHION maldison	Non-systemic Contact action	Ornamentals, fruit, vegetables, field crops, pasture	**Broad spectrum** aphids, lace bugs, scales, fruit fly, oriental fruit moth, beetles, grasshoppers etc
		ROGOR, VARIOUS dimethoate	Systemic Contact action Some fumigant	Ornamentals, fruit, vegetables, field crops, turf, pasture	**Broad spectrum** sucking insects, aphids, thrips, fruit fly maggots, leafminers, mites, etc
2 GABA-gated chloride channel antagonists Nerve action	**2A** Cyclodiene organo-chlorines	**ENDOSAN, THIODAN** endosulfan Restricted product	Non-systemic Contact, stomach action, some fumigant action	**Only to be sold to or used by an authorized person**	**Broad spectrum** long persistence
	2B Phenyl-pyrazoles (Fiproles)	**COSMOS, GOLIATH, VARIOUS** fipronil	Systemic Contact action Stomach action Seed treatments	Bananas, wine grape, turf, field crops, vegetables, ornamentals, forestry	**Broad spectrum** thrips, caterpillars, beetles, Argentine stem weevil, fruit fly lures
3 Sodium channel modulators Nerve action (more than 200products in this group)	**3A** Pyrethroids Pyrethrins	**MAVRIK, VARIOUS** tau-fluvalinate often formulated with the fungicide myclobutanil	Non-systemic Contact Stomach action Suppresses mites	Ornamentals, apples, stone fruit, cauliflower, tomato	**Broad spectrum, eg** *Helicoverpa*, cabbage moth, cabbage white butterfly, aphids, thrips.
		BAYTHROID, VARIOUS cyfluthrin	Non-systemic Contact action Stomach action	Certain vegetables, ornamentals, turf	**Broad spectrum** caterpillars eg *Helicoverpa*, weevils, turf pests
	derived from chrysanthemum flowers	**SLAY-AFE, VARIOUS** pyrethrin + piperonyl butoxide (may be formulated with garlic, eucalyptus, etc)	Non-systemic Contact, stomach & fumigant action rapid knockdown, air borne for up to 4 hrs	Ornamentals, gardens, indoors, buildings (short residual)	**Broad spectrum** most flying insects, aphids, flies, whiteflies, household insects
		TALSTAR, VARIOUS, MAXGUARD bifenthrin may be formulated with other insecticides	Non-systemic Contact action Stomach action	Ornamentals, fruit, turf, field crops	**Broad spectrum** surface feeding insects eg ants, turf pests **Miticide** many species of mites
	3B No registered actives	No registered actives			
4 Nicotinic acetycholline receptor agonists Nerve action	**4A** Neonicotinoids (an important group of insecticides because of their effectiveness and wide target range)	**CONFIDOR, MERIT, GAUCHO, PREMISE, INITIATOR, VARIOUS** imidacloprid	Systemic Contact action Stomach action anti-feedant, residual activity up to 70 days	Ornamentals, trees, turf, fruit, field crops, vegetables, buildings, poles, establishing eucalypts; **seed treatments** (certain insect pests & prevent spread of barley yellow dwarf virus in cereals)	**Broad spectrum** **sucking insects**, eg thrips, aphids, whiteflies; ***not*** mites; **chewing insects**, eg scarab grubs, billbug
		CROWN, VARIOUS acetamiprid	Systemic Contact action Residual	Ornamental plants, cotton, potatoes, potting mixes	**Broad spectrum** **sucking insects**, eg aphids, mealybugs, scales, thrips, lace bug, whiteflies; **fungus gnats, shore flies**
	contd next page	**CALYPSO** thiacloprid	Systemic does not affect predatory mites	Some pome & stone fruits, some ornamentals	**Broad spectrum** **sucking insects** (apple dimpling bug, aphids); **chewing insects** (codling moth, oriental fruit moth)

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 2. Insecticide Mode of Action Groups (2009) *some examples*

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS CONTROLLED, SUPPRESSED**
4 *(contd)*	**4A** Neonicotinoids *(contd)*	**ACTARA, CRUISER, MERIDIAN** thiamethoxam	**Systemic Contact Stomach**	Turf; citrus, cotton, tomato, maize sorghum, sweetcorn, sunflower	**Broad spectrum** soil & sucking insects, eg larvae of various scarabs, billbug; wireworm, earwigs, thrips, aphids
	4B No registered actives	No registered actives			
5 Nicotinic Acetyl choline receptor allosteric activators Nerve action	**Spinosyns** **Eco-naturalure is a BFA** CERTIFIED PRODUCT FOR ORGANIC GARDENS	**ECO-NATURALURE, TRACER NATURALYTE, VARIOUS** spinosad (derived from soil bacteria)	**Contact action Stomach action** baits & sprays, may kill certain wasp parasites and some lacewings	Certain herbs, fruit & nut crops, vegetables, ornamentals, field crops, tea tree, eucalypts	**Insecticide** *Helicoverpa,*, loopers, other caterpillars, pear & cherry slug, beetles, Queensland and Mediterrean fruit flies.
		DELEGATE spinetoram		Pome & stonefruit	**Narrow spectrum** lightbrown apple moth, loopers and oriental fruit moth
6 Chloride channel activators Nerve action	**Avermectins Milbemycins** (from *Streptomyces* sp.)	**ABAMECTIN, VERTIMEC, VARIOUS** abamectin (fermentation product of soil micro-organism	**Non-systemic Contact action Stomach action** slow acting, good persistence effective against insects resistant to other insecticides	Ornamentals, roses, apple, pears, citrus, cotton, tomatoes, strawberries, minimum impact on beneficials	**Miticide** motile stages only, no ovicidal activity **Insecticide** leafminers, native budworm
		MILBEKNOCK, ULTIFLORA milbemectin Any on the surface is degraded by sunlight	**Non-systemic** but absorbed by young leaves, taken up by feeding mites and remains active for many weeks	Strawberries, ornamentals including roses, chrysanthemums, carnations	**Miticide** twospotted mite
7 Juvenile hormone mimics Growth regulation	**7A Juvenile hormone analogues**	**RIZACON, GRAIN-STAR, VARIOUS** methoprene	**Insect growth regulator,** prevents insects from maturing to adults, eg inhibits larval moulting	Stored cereal grains, also dogs, cats	**Narrow spectrum** stored grain pests; fleas, etc
	7B Fenoxycarb	**INSEGAR, VARIOUS** fenoxycarb	**Insect growth regulator Contact action Stomach action** ovicidal, inhibits larval moulting	Apples, pears	**Narrow spectrum** codling moth, lightbrown apple moth, aids in control of San Jose scale
	7C Pyriproxyfen	**SUMILARV** pyriproxyfen **To be used by licensed pest control operators only**	**Insect growth regulator Contact action Stomach action**	Buildings, houses, restaurants, puppies, cats kittens	**Narrow spectrum** cockroaches, fleas (retards growth of insect larvae, ovicidal)
8 Miscellaneous non-specific (multi-site) inhibitors	**8A Alkyl halides**	**METHYL BROMIDE** methyl bromide	see Fumigants page 267 **All fumigants must only be supplied to and used by professional and registered fumigators**		
	8B Chloropicrin	**VARIOUS** chloropicrin	see Fumigants page 267		
	8C Sulfuryl fluoride	**VARIOUS** sulfuryl fluoride	see Fumigants page 267		
9 Selective Homopteran feeding blockers	**9A** No registered actives	No registered actives			
	9B Pymetrozine	**CHESS** pymetrozine	**Systemic Contact action Stomach action** long lasting	Certain brassica vegetables, potatoes, stone fruit, cotton	**Narrow spectrum** aphids (can remain alive for 2-4 days but stop feeding in a few hours)
10 Mite growth inhibitors Growth regulation	**10A Clofentezine**	**APOLLO** clofentezine	**Contact action** ovicide, larvicide, not adults, control for up to 80 days, slow acting	Certain pome & stone fruits, bananas, hops, ornamentals	**Miticide** European red mite, bryobia mite, strawberry mite, twospotted mite
		CALIBRE hexythiazox)	**Non-systemic Contact action Stomach action** Ovicidal, not adults	Ornamentals, apple, pear, stone fruit, strawberry	**Miticide** European red mite, twospotted mite
	10B Etoxazole	**PARAMITE** etoxazole	**Contact action, Translaminar Residual activity** of 4-5 weeks; not adult mites. Adults lay sterile eggs, stops existing eggs and nymphs developing	Pome fruit, stone fruit, table grapes, cotton	**Miticide** twospotted mite, bean spider mite, European red mite

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 2. Insecticide Mode of Action Groups (2009) ***some examples***

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS CONTROLLED, SUPPRESSED**
11 Microbial disruptors of insect midgut membranes (includes transgenic crops expressing *Bt* toxins) BIOLOGICAL INSECTICIDES	***Bacillus thuringiensis* or *B. sphaericus* and the insecticidal proteins they produce**	**AQUABAC, VECTOBAC, VARIOUS** *Bt.* subsp. *israelensis*	**Stomach action**	Salt marshes, still water, waste water	**Narrow spectrum** larvae of mosquitoes
		VECTOLEX *Bacillus sphaericus*	**Stomach action**	Salt marshes, still water, waste water	**Narrow spectrum** larvae of mosquitoes
		XENTARI *Bt.* subsp. *aizawai*	**Stomach action** young caterpillars stop feeding, starve to death, slow acting	Cole crops (cabbage, cauliflower, broccoli, Brussel sprouts)	**Narrow spectrum** cabbage moth, cabbage white butterfly, cabbage-centre grub, cabbage cluster caterpillar
		COSTAR, DIPEL, DELFIN, VARIOUS *Bt.* subsp. *kurstaki*	**Stomach action** young caterpillars stop feeding, starve to death, slow acting	Ornamentals, cotton, vegetables, vines, fruit trees, field crops, forestry, turf	**Narrow spectrum** leafeating caterpillars of *Helicoverpa* spp., & certain other moths & butterflies
		NOVODOR *Bt.* subsp. *tenebrionis*	**Stomach action** **Mite growth regulator**	elms, experimentally on eucalypt	**Narrow spectrum** various chrysomelid & tenebrionid beetles, eg elm leaf beetle
		TRANSGENIC CROPS *Bt.* crop proteins: Cry1AcCry2Ab			**Narrow spectrum**
12 Inhibitors of mitochondrial ATP synase) Energy metabolism	**12A** **Diafenthiuron**	**PEGASUS** diafenthiuron	**Non-systemic** **Contact action** **Stomach action** Effective against all stages of mite	Cotton	**Insecticide** cotton aphid, suppresses silver leaf whitefly **Miticide** twospotted mite
	12B **Organotin miticides**	**TORQUE** fenbutatin-oxide	**Non-systemic** **Contact action** only motile forms, no ovicidal activity, not toxic to most beneficial mites	Certain ornamentals, fruit & hops	**Miticide** twospotted mite, European red mite, bryobia mite, citrus mites, etc
	12C **Propargite**	**OMITE** propargite (cyclosulfine)	**Non-systemic** **Contact action** motile stages only	Ornamentals, fruit, vegetables,	**Miticide** spider mites, European red mite, passionvine mite, false spider mites
	12D **Tetradifon**	**MASTA-MITE** tetradifon (formulated with dicofol)	**Non-systemic** **Contact action** All stages of mites	Certain fruit trees, vegetables, ornamentals	**Miticide** certain mites
13 Uncoupler of oxidative phosphorylation via disruption of the proton gradient Energy metabolism	**Chlorfenapyr**	**INTREPID, SECURE** chlorfenapyr	**Stomach action** More effective against small larvae (< 4 mm), may be highly persistent	Cotton, brassica vegetables, apples peaches, pears	**Insecticide** bollworms (*Helicoverpa* spp.), cabbage white butterfly, diamond back moth **Miticide** twospotted mite
14 Nicotinic acetyl-choline receptor chanel blockers Nerve action	No registered actives	No registered actives			
15 Inhibitors of chitin biosynthesis, type 0, Lepidopteran Grow regulation	**Benzoylureas**	**ALSYSTIN** triflumuron	**Stomach action** Larvicide interferes with insect moulting (chitin formation)	Mushroom casing/compost; many other situations	**Broad spectrum** larvae of sciarid flies & other insects
16 Inhibitors of chitin biosynthesis type 1 Homopteran Grow regulation	**Buprofenzin**	**APPLAUD** buprofezin (adult insects not controlled, no effective on eggs, persists long time)	**Insect growth regulator (IGR)** **Contact action** **Stomach action** (treated insects lay sterile eggs)	Citrus, grapes, pears, mango, persimmons, custard apple, passionfruit	**Narrow spectrum** **Hemiptera**, eg mealybugs, scales, ***not*** Lepidoptera, Diptera. Hymenoptera
17 Moulting disruptor, Dipteran Grow regulation	**Cyromazine**	**VETRAZIN, VARIOUS** cyromazine	**Contact action** larvicide	Sheep, animal housing, feedlots, poultry manure	**Narrow spectrum** larvae of many flies
18 Ecdysone receptor agonists Grow regulation	**Diacylhydrazines**	**PRODIGY** methoxyfenoxide	**Stomach action** **Contact action** (accelerates moulting, feeding ceases almost immediately)	Pome fruit, certain other fruits and crops	**Narrow spectrum** lightbrown apple moth and other Lepidoptera caterpillars

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 2. Insecticide Mode of Action Groups (2009) *some examples*

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS CONTROLLED, SUPPRESSED**
19 Octopamine receptor agonists Nerve action	**Amitraz**	**AMITRAZ, OPAL, VARIOUS** amitraz	**Non-systemic** **Contact action** **Vapour action** **Repellent action**, all stages of mites, ovicidal	Cotton; cattle, deer, goats, pigs, sheep	**Insecticide** *Helicoverpa* on cotton **Miticide** ticks on animals
20 Mitchondrial complex 111 electron transport inhibitors (coupling site 11) Energy metabolism	**20A** **Hydramethylnon**	**AMDRO** hydramethylnon Professional pest control operators	**Stomach action**	Non-crop, residential & commercial buildings, turf, gardens	**Insecticide** ants, cockroaches
	20B No registered actives	No registered actives			
	20C No registered actives	No registered actives			
21A Mitchondrial complex 1 electron transport inhibitors Energy metabolism	**21A** **METI acaricides**	**PYRANICA** tebufenpyrad	**Non-systemic** **Contact action** **stomach action** effective against all mite stages	Apples, pears. peaches, ornamentals	**Miticide** twospotted mites, European red mite
		SANMITE pyridaben	**Non-systemic** all stages of mites, good residual activity	Apple, pear, stone fruit, grapes, bananas, roses	**Miticide** certain mites
	21B **Rotenone**	**DERRIS DUST** rotenone (found in **roots** of 63 species of legumes)	**Non-systemic** **Contact action** **stomach action** very toxic to fish	Ornamentals, vegetables, vines	**Broad spectrum** aphids, thrips, caterpillars, mostly home garden use
22 Voltage-dependent sodium channel blockers Nerve action	**22A** **Indoxacarb**	**STEWARD, AVATAR, VARIOUS** indoxacarb	**Non-systemic** **Contact action** **stomach action**	Cotton, certain vegetables, field crops; buildings	**Narrow spectrum** *Helicoverpa* spp., certain other insects; also cockroaches
	22B No registered actives	No registered actives			
23 Inhibitors of acetyl CoA carboxalase Lipid synthesis, growth regulation	No registered actives	No registered actives			
24 Mitochondrial complex IV electron transport inhibitors Energy metabolism	**24A** **Phosphine**	**VARIOUS** phosphine aluminium phosphate magnesium phosphate	see Fumigants page 267		
	24B	No registered actives			
25 Vacant				CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE	
26 Vacant				ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE	
27 Vacant					
28 Ryanodine receptor modulators Nerve & muscle action	**Diamides**	**ACELEPRYN, ALTACOR, CORAGEN** chlorantraniliprole (branded as RynaXypyr®)	**Stomach action** **Translaminar activitiy**	Vegetables, pome & stone fruit, grapes, turf (good control of turf pests)	**Narrow spectrum** **certain Lepidopteran caterpillars**, eg codling moth, **certain beetles**, eg African black beetle
UN Compounds of unknown or uncertain mode of action[1]	**Azadirachtin** **Eco-neem is a BFA CERTIFIED PRODUCT FOR ORGANIC GARDENS**	**AZAMAX, ECO-NEEM, NEEMAZAL** azadirachtin (seeds of *Azadirachta indica*) (see Fumafert® pages 267, 344)	**Stomach action** **Contact action** slightly trans-laminar, Inhibits larval moulting, repellent & antifeedant	Ornamentals, floriculture, potting soil for floriculture & horticulture **Do not use on plants that produce food for human or animal consumption**	**Broad spectrum** certain aphids, whiteflies, fungus gnats, twospotted mite
	Bifenazate	**ACRAMITE, FLORAMITE** bifenazate	**Non-systemic** **Contact action**	Pome & stone fruits	**Miticide** twopotted mite, bryobia mite, European red mite
	Dicofol	**KELTHANE** dicofol	**Non-systemic** **Contact action** Eggs, motile stages. Long residual	Certain ornamentals, fruits, vegetables, field crops	**Miticide** organo-phosphate resistant mites, no insecticide activity

[1]A compound with an unknown or controversial mode of action or an unknown mode of toxicity will be held in group 'un' until evidence becomes available to enable that compound to be assigned to amore appropriate mode of action group

Table 3. Bio-insecticides, spray oils, soaps, pheromones, etc. (some are agricultural biological products)

TYPE	THE PRODUCT		SOME USES Read label, obtain advice from company	
	Trade name Active constituent	Mode of action	CROPS, SITES TREATED	PESTS CONTROLLED
BIO-INSECTICIDES	**BIOCANE GRANULES** *Metarhizium* sp.	Fungal disease of insects	Sugarcane □new plant crop	**Selective insecticide** greyback canegrub
	GREEN GUARD *Metarhizium* sp.	as above	Agricultural areas, pastures, crops, forage crops, non-crop areas	**Selective insecticide** grasshopper, locusts
	Nematode *Beddingia siricidicola*	Nematode disease of insects	*Pinus radiata*.	**Selective insecticide** sirex wasp
	Nematode *Heterorhabditis bacteriophora*	as above	Ornamentals	**Selective insecticide** black vine weevil
	Nematode *Heterorhabditis zealandica*	as above	Turf	**Insecticide** Argentine stem weevil, African black beetle, black-headed cockchafer, Argentine scarab, bill bug
	Nematode *Steinernema carpocapsae*	as above	Bananas, etc	**Insecticide** banana borer weevil, cutworm, armyworm, house termites, cat flea
	Nematode *Steinernema feltiae*	as above	Currants; seedlings, hydroponically grown flowers, mushroom houses	**Insecticide** currant borer moth, fungus gnat, mushroom fly, western flower thrips
	GEMSTAR *Helicoverpa* NPV (zea)	Virus disease of *Helicoverpa* spp.	Various crops including cotton	**Selective insecticide** *Helicoverpa* spp.
SPRAY OILS **Petroleum oils**	**WINTER OIL, DORMANT OIL, STIFLE, VARIOUS** petroleum oil Winter Spray Oil	**Contact action** **Smothers pests**	**Used only on dormant** deciduous pome and stone fruit tree & vines	**Insecticide** especially scale insects & insects
	SUMMER OIL, PEST OIL, WHITE OIL, VARIOUS petroleum oil Summer Spray Oil	**Contact action** **Smothers pests**	**Used on plants in foliage.** Certain fruit, ornamentals, special oils developed for some crops, bananas, citrus, grapes	**Insecticide/Miticide/** especially scale insects, mites, citrus leafminer, also aphids, mealybugs, whiteflies **Fungicide** certain banana diseases & powdery mildews
Paraffinic oils	**BIOPEST, ECOPEST OIL, VARIOUS** paraffinic oil paraffinic oils must contain at least 62% paraffinic chains BioPest Paraffin Oil	**Contact action** **Smothers pests** . EcoPest Oil	**Used on plants in foliage.** Fruit trees, eg citrus, pome fruit & stone fruit, grapes, certain vegetables, field crops roses, ornamentals	**Insecticide/Miticide/** mites, scales, citrus leafminer, also aphids, mealybugs, whtieflies **Fungicide** certain banana diseases & powdery mildew
Botanical oils, vegetable oils Oil seeds, eg soybean, canola, cotton	**ECO-OIL, VARIOUS** botanical oils ECO-OIL®	**Contact action** suffocates pests, waxy cuticle is denatured dehydrating insects, repellent activity	**Used on plants in foliage** Certain ornamentals, fruits, vegetables	**Insecticide/Miticide/** scales, mites, aphids, whiteflies, citrus leafminer

OILS ARE USED AS:

1. **Spray oils for pest control** are mixed with water and applied to plants as a high volume spray for managing certain pests and diseases. They kill insects by smothering them so a good film of oil has to be applied to leaves, fruit, twigs and branches. Some insects avoid spray oils so that feeding by some sap-sucking insects, eg aphids, which spread virus diseases, is reduced; spray oils can also inhibit viruses spread mechanically by humans. They can provide some control of leaf spots, powdery mildews, rust diseases. Spray oils are suited to **IPM** programs.
2. **Spray adjuvants/spray additives to improve the effectiveness** of insecticides, herbicides and fungicides (page 455). Some spray oils used for pest control are also used as spray additives.

SAFETY AND EFFECTIVENESS:

1. **How safe will it be to the plant and environment**, eg dormant or winter (only applied when plants are dormant), summer or white (may be applied when in leaf), superior oils (applied year round without toxicity).
2. **How effective it will be in helping control** sedentary or semi-sedentary pests and fungal diseases. Paraffinic oils are effective and considered to be superior over vegetable, pine and other mineral oils for **controlling a rage of pests and diseases** (Sacoa www.**sacoa**.com.au/)
3. **For more information on spray oils:**
   Beattie and Hardy 2005, Walsh et al. 2008
   Precision Spray Oils™ www.**caltex**.com.au/**cropprotection/**
   SACOA Spray Oils www.**sacoa**.com.au

Table 3. Bio-insecticides, spray oils, soaps, pheromones, etc. (some are agricultural biological products) *(contd)*

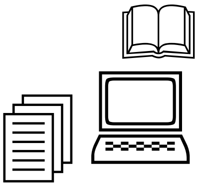
TYPE	THE PRODUCT		SOME USES Read label, obtain advice from company	
	Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS, CONTROLLED, SUPPRESSED**
SYNERGISTS	**VARIOUS** piperonyl butoxide	**Synergist**, formulated with pyrethrum to enhance its performance		
SOAPS	**NATRASOAP, BUGGUARD, VARIOUS** potassium salts of fatty acids (soap sprays)	**Contact action** Dissolves the waxy covering of the insect	Pot plants, vegetables, fruit trees, ornamentals.	**Insecticide** sedentary or semi-sedentary soft-bodied insects, eg aphids, thrips, mealybugs, whiteflies, scale crawlers, mites
PHEROMONES **Insect control**	**ISOMATE CTT** pheromone insect confusion agent (tiers)	**Mating disruption** Large quantities of female pheromones are released from tiers confusing male moths, preventing mating	Apples, pears,	**Single species insecticide** codling moth
	ISOMATE C as above also **ISOMATE C-S**	As above	Apples, pears	**Single species insecticide** codling moth
	ISOMATE C/OFM TT as above	As above	Pome fruit	**Single species insecticide** codling moth, oriental fruit moth
	ISOMATE OFM ROSSO as above also **ROSSO-S**	As above	Peaches, nectarines	**Single species insecticide** oriental fruit moth
	ISOMATE LBAM PLUS as above	As above	Apple, grapes	**Single species insecticide** lightbrown apple moth
FOOD SPRAYS, LURES, ATTRACTANTS Reduce pesticide usage	**AMINOFEED, ENVIRO-FEAST, PRED FEED** **AminoFeed, Mobait** (yeast-based) **Envirofeast**, **PredFeed** (sugar based)	**Attracts** > 20 species of beneficial insects which feed on pests. Must be a source of beneficial insects or a 'refuge' from where they can be attracted	Cotton. Used in **IPM** programs	**Beneficial insect sustenant** *Helicoverpa* spp. & spotted mites
	PREDALURE oil of wintergreen	**Attractant** for beneficial insects		**Beneficial insect sustenant**
	BIO-ATTRACT HELI™ kairomone bait	**Attractant** for *Helicoverpa* moths		**Pest insect attractant** adult *Helicoverpa* & certain other moth pests
	MAGNET **attractant/feeding stimulant** (alpha-pinene, anisyl alchohol, butyl salicylate cineole (eucalyptol). D-limonen phenylacetaldehyde) **+ insecticide**	**Attractant** for *Helicoverpa* moths which are killed when they contact or ingest it preventing egg laying	Cotton; blanket coverage is not necessary; timing is critical.	**Pest insect attractant** *Helicoverpa* spp. moths
	CARPOPHILUS MASS TRAPPING SYSTEM	**Attractant** for *Carpophilus* beetles	Stone fruit (currently under APVMA Research Permit 9971/11344)	**Pest insect attractant** *Carpophilus* spp.
FUNGICIDE GROUP M2	**SULPHUR**	**Protectant** (non-systemic) **Contact, some fumigant action**	Ornamentals, fruit, vegetables	**Fungicide/Miticide/ Insecticide** see Fungicides (page 341)
ABRASIVE DUSTS	**DRYACIDE** silica	**Contact action,** kills insects by desiccation	Grain sheds, buildings, ware-houses, equipment, silos, stored grain	**Insecticide** controls organo-phosphate-resistant strains of insects
INORGANIC METALS	**VARIOUS** borax as borax boron as boric acid	**Contact action** Ingested when the insect cleans itself, absorbed through insect cuticle	Commercial and domestic buildings slow acting requiring 7-10 days for control	**Insecticide** ants, cockroaches, silverfish
OTHERS	**FUMAFERT** mustard seed, neem cake	Has soil bio-fumigant properties which aid in the control of some **soil, insects, diseases** and **nematodes** (page 267).		
	EXPERIMENTAL eg vegetable products, eucalyptus oil, tea tree oil, melaleuca oil, the addition of fertilizers, etc	**Contact action,** smothering effects, may kill adults & nymphs feeding, eg aphids, mirids and mites in some crops, also some scarab grubs and lawn armyworms ; may modify feeding and egg laying behaviour of insects on some plants		
Some may be toxic to humans, animals, bees and other beneficials	**Bay laurel** (*Laurus nobilis*) - leaves - ants, mice **Cinnamite** (cinnamon oil) (*Cinnamomum zeylanicum*) - all stages of aphids, mites, powdery mildew (roses) **Garlic** (*Allium sativum*)) - often mixed with pyrethrum - aphids, flies, etc **Quasia** (*Quasia amara*) - wood and bark - aphids caterpillars **Rhubarb** (*Rheum rhabarbarum*) - leaves - aphids **Ryania** (*Ryania speciosa*) - roots, leaves and stems - codling moth, thrips			

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

IDENTIFICATION & CLASSIFICATION

HOW EASY IS IT TO IDENTIFY INSECTS?



SOME ARE EASY TO IDENTIFY IN A GENERAL WAY

Become **familiar** with the **pest and beneficial insects** which occur in **your crop** and be able to identify them accurately. This is part of all **IPM** programs.

- **Identifying insects, mites**, and the damage they cause, is usually easier than sorting out problems associated with diseases and plant nutrition.
- **Scarab grub larvae** in lawns are readily recognized as such. Other easy to recognize pests include aphids on roses, sawflies on eucalypypts.
- **Books and computer programs** illustrate groups of insects, eg flies, locusts, thrips and flies; also pests affecting crops in particular regions, eg vegetables, brassicas, turf, nurseries (page 224). Pocket guides are available for use in the field. Eventually complete guides for known crop pests and diseases will be available via mobile phones for farmers and growers.

INSECT KEYS

Although insect keys for identifying **adults, nymphs, larvae and pupae** of insects generally to orders and families, and for identifying **special groups of insects**, eg moth and butterfly larvae on brassica crops, have been compiled, in practice, their use by the non-expert can be difficult. Reasons include:

- The **small size** of some insects and allied forms.
- Difficulty in recognizing, in some instances, whether the insect is an **adult** or immature stage, eg a nymph.
- Some closely allied pest forms **resemble insects** at some stages.
- The large **number** and **diversity** of insect species in Australia.
- **Keys** for identifying insects are on **CSIRO's** and **Lucidcentral's** websites:
  www. entocsiro.au/ education   www. lucidcentral.org/
  State websites have keys for identifying insects and damage on some crops.

XPERT

NEED EXPERT HELP?

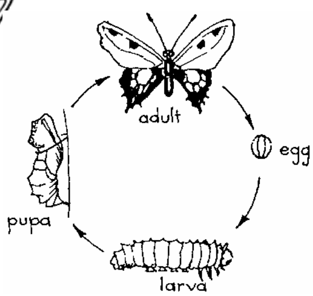
- Although some insects such as scarab grubs are readily recognized as such, it can be difficult to identify the precise **species** which is needed for implementing effective control measures in commercial turf.
- Similarly identifying the precise species of fruit fly damaging you crop.
- **DNA** fingerprinting complements **structural features** to identify exotic pests.
- A wide range of soil pests and diseases can now be identified from a single soil sample using new Australian soil testing techniques.
- Contact a diagnostic service for assistance (page xiv).

CLASSIFICATION

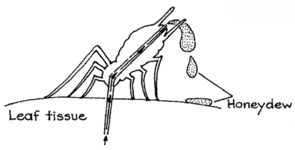
Classification of insects (Class Insecta) to orders and families is based on a wide range of features, including:

- **Wing features**, eg
  - Winged or wingless
  - Number of pairs of wings
  - Size
  - Texture, scales, etc
  - Thickenings
  - Venation, vein patterns

- **Life cycle**, eg
  - No metamorphosis
  - Incomplete metamorphosis
  - Complete metamorphosis



- **Mouthparts**, eg
  - Chewing
  - Piercing and sucking
  - Rasping and sucking
  - Lapping



- **Antennae**, eg
  - Clubbed
  - Feathery

- **Abdomen**, eg
  - Ovipositors, cerci
  - Hairs
  - Constrictions

- **Tarsi segments**, eg
  - Number

- **Body shape**, eg
  - Flattened
  - Small size
  - Wedge-shaped

Thrips
(< 3 mm long)

Orders of Insects

Fig. 39. Insect orders of interest to horticulture.

CLASS INSECTA - Insects

1. Three body segments.
2. Three pairs of legs on thorax.
3. Antennae present (1 pair).
4. Wings present or absent.

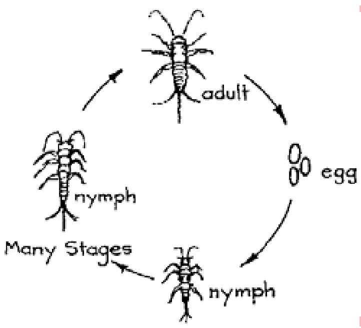
WINGLESS
(primitively wingless)

WINGED ADULTS
(some secondarily wingless)

NO METAMORPHOSIS

ORDERS

THYSANURA
(silverfish, not really a horticultural pest)



WINGS DEVELOP INTERNALLY
COMPLETE METAMORPHOSIS
(larvae dissimilar to adults)

ORDERS

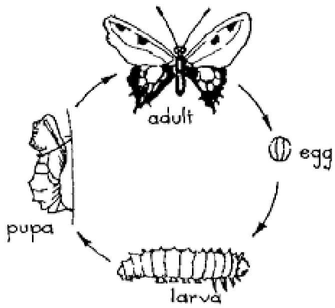
DIPTERA
(flies, gnats, midges, mosquitoes)

LEPIDOPTERA (butterflies, moths)

COLEOPTERA
(beetles, weevils)

HYMENOPTERA
(ants, bees, sawflies, wasps)

NEUROPTERA (lacewings)



WINGS DEVELOP EXTERNALLY
INCOMPLETE METAMORPHOSIS
(nymphs similar to adults)

ORDERS

THYSANOPTERA
(thrips)

HEMIPTERA (bugs)
(bugs; hoppers; lerps, mealybugs, scales, whitefly)

ISOPTERA
(termites, white ants)

ORTHOPTERA
(crickets, grasshoppers, katydids, locusts)

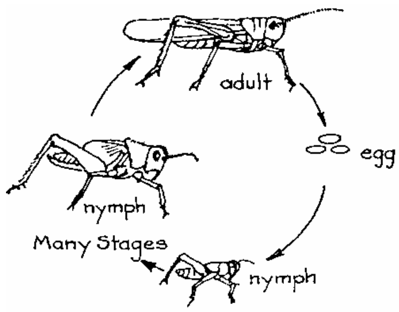
DERMAPTERA
(earwigs)

BLATTODEA
(cockroaches)

PHASMATODEA
(leaf insects, stick insects)

MANTODEA
(mantids, praying mantids)

ODONATA
(dragonflies, damselflies)



Insects and their Allies
www.ento.csiro.au/education/insects_allies.html

ORDER DIPTERA

Flies, gnats, leafminers, midges, mosquitoes

NO. SPECIES IN AUSTRALIA

More than 8,000 species have been identified in Australia.

www.ento.csiro.au/education/insects/**diptera**.html
www.brisbaneinsects.com/brisbane_**flies**/index.html
Lucid key *On The Fly - The Interactive Atlas and Key to Australia Fly Families*
www.**lucidcentral**.org/

SOME DISTINCTIVE FEATURES

Members of this order are fairly similar in appearance.

ADULT **Wings**
1. **One pair** of membraneous forewings. Do not confuse flies with wasps which have 2 pairs of wings.
2. **Hindwings** reduced to small club-like structures (**halteres**) are used as stabilisers during flight.
3. Some species are **wingless**.

Eyes **Usually large compound eyes**, each eye has up to 4000 lens. Can see movements quickly.

Mouth
1. **Varies among different families**, but usually used for sucking up liquid (except for carnivorous types).
2. **In some families**, eg mosquitoes, the mouth has been adapted for piercing.

LARVA **Legs** **No true legs**, often called a **'maggot'**.

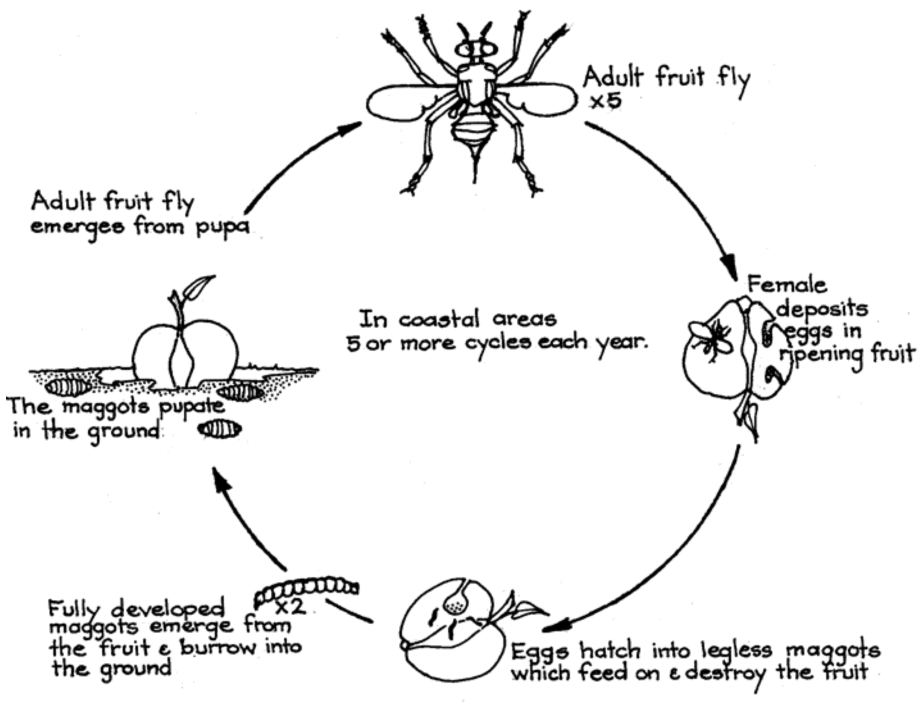
Head Mostly very reduced head capsule.

LIFE CYCLE

There is a **complete metamorphosis** - egg, larva (maggot), pupa and adult (fly).

Queensland fruit fly
4-5 mm long

Many variations, eg bean fly, cineraria leafminer, fungus gnats, garden maggots



METHOD OF FEEDING

ADULT **Sucking** and sometimes **piercing**. Feeds on liquids.

LARVA **Liquid diet.** Some predatory larvae have **mandibles**, eg hover flies. Larvae eat the food they hatch on (carefully selected by the mother fly).

PLANT DAMAGE

DIRECT FEEDING DAMAGE

Larvae (maggots) are responsible for most plant damage.

LEAVES **Leafmining,** eg pittosporum leafminer, cineraria leafminer
Galls, eg chrysanthemum gall midge

FRUIT **Maggot damage**, eg fruit fly, ferment fly, metallic-green tomato fly

STEMS **Galls**, eg chrysanthemum gall midge
Borers, eg bean fly

BULBS **Maggot damage**, eg bulb flies

INDIRECT DAMAGE

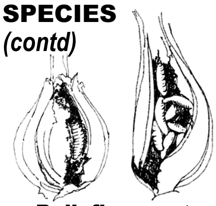
- During feeding, fruit fly **maggots** introduce **decay organisms**, eg bacteria and fungi, causing fruit rots.
- **Fruit may be disfigured** by the egg laying of female fruit flies (‘stings’).

INJURIOUS HAIRS/BRISTLES, etc.

- Some flies are **blood suckers**, eg mosquitoes, and are pests of **humans** and **animals**.

LIST OF SOME SPECIES

	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (maggots) (not exhaustive)
	FERMENT FLIES (Family Drosophilidae)		
Do not confuse with fruit flies	Ferment fly, vinegar fly	*Drosophila* spp.	Associated with decaying fruit, etc. **Used in genetics**
	FRUIT FLIES (Family Tephritidae)		
Major fruit fly pests of commercial fruit. (many minor or non-pest species commonly found in traps)	**Mediterranean fruit fly** (**Medfly**)	*Ceratitis capitata*	Fruit in **WA**
	Queensland fruit fly (**QFF**)	*Bactrocera tryoni*	Fruit in **Qld, NSW, Vic**
	Lesser Queensland fruit fly	*B. neohumeralis*	Most commercial and many native fruit, Qld, north **NSW**
	Cucumber fly	*B. cucumis*	Cucurbits, tomato (**Qld, NSW**)
	Jarvis’s fruit fly	*B. jarvisi*	Fruit (**Northern Australia**, **Qld, NSW**)
	Banana fruit fly	*B. musae*	Banana, papaya, quince, **Qld**
	Mango fly	*B. frauenfeldi*	Banana, mango, citrus, guava
Some destructive fruit flies overseas not currently present in Australia Fruit fly monitoring is carried out in far north Queensland and the Torres Strait, WA, etc	Malaysian fruit fly	*B. latifrons*	Malaysia, Solanaceous crops
	Melon fly	*B. cucurbitae*	PNG, serious vegetable pest
	Asian papaya fruit fly	*B. papayae*	PNG, northern Torres Strait Eradicated from **Qld** in 1999
	Carambola fruit fly	*B. carambolae*	Sumbawa, Indonesia
	Oriental fruit fly	*B. dorsalis* complex	Vietnam, **destructive pest of fruit**
	Mexican fruit fly	*Anastrepha ludens*	Central & south America, USA, Canada. Citrus, mango, etc
	Natal fruit fly	*Ceratitis (Pterandrus rosa)*	Africa, Indian ocean, many fruit
	New Guinea fruit fly	*B. trivialis*	PNG (Western Province)
	Philippines fruit fly	*B. philippinensis*	Philippines. Commercial fruit. Eradicated from Darwin, 1999
	Breadfruit fly, jackfruit fly	*B. umbrosa*	Torres Strait, PNG, Indonesia, detected in traps in NT
	GALL MIDGES (Family Cecidomyiidae)		
	Chrysanthemum gall midge	*Rhopalomyia chrysanthemi*	Chrysanthemum
	Sorghum midge	*Contarinia sorghicola*	Serious pest of sorghum
	Citrus blossom midge	*Cecidomya* sp.	Citrus flowers
	Wattle gall fly	*C. acaciae- longifolia*	Wattle
	Eucalyptus gall midge	*Harmomyia omalanthi*	Eucalypt
	Mushroom white cecid	*Heteropeza pygmaea*	Mushrooms

LIST OF SOME SPECIES *(contd)*	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (maggots) (not exhaustive)**
 **Bulb fly** maggots	**GARDEN MAGGOTS (several families)**		
	Garden maggot Garden soldier fly	*Bibio imitator* *Exaireta spinigera*	**Adults** feed on nectar, **larvae** feed on decaying organic matter in compost heaps, etc
	HOVER FLIES (Family Syrphidae)		
	Lesser bulb fly Narcissus bulb fly	*Eumerus tuberculatus* *Ampetia equestris*	Bulbs Bulbs
	LEAFMINER FLIES (Family Agromyzidae)		
Moth, sawfly and beetle larvae may also mine in leaves	Bean fly	*Ophiomyia phaseoli*	Maggots bore into stalks and stems of beans and related plants, but **not** broad beans
	Beet leafminer	*Liriomyza chenopodii*	Beet, spinach, wall flower and chickweed
	Cabbage leafminer	*L. brassicae*	Crucifers
Not known in Australia	Vegetable leafminer	*L. sativae*	Fruit, vegetables and ornamentals
	Celery fly	*Melanagromyza apii*	Larvae bore into celery stalks
	Cineraria leafminer nasturtium	*Chromatomyia syngenesiae*	**Asteraceae** eg cineraria, gazania, chrysanthemum, lettuce, weeds, eg sow thistle, capeweed
	Pittosporum leafminer	*Phytobia pittosporphyllii*	*Pittsporum* spp., *P. undulatum*
	Soybean fly	*Malanagromyza sojae*	Soybean
	MIDGES (Family Chironomidae)		
	Seedling bean midge	*Smittia macleayi*	Beans, cucurbits
	Rice bloodworm	*Chironomus tepperi*	Rice
	FUNGUS GNATS (several families)		
 **Fungus gnat** maggot	Fungus gnats Black fungus gnats	Family Mycetophilidae Family Sciaridae	Organic matter, decaying fungi in roots, root hairs
	Mushroom sciarids	*Lycoriella* spp., Sciaridae	All stages of mushrooms
	SHORE FLIES (Family Ephydridae)		
	Rice leafminer	*Hydrellia* sp.	Rice, other plants
	Shore fly	*Scutella australiae*	Algae in greenhouses
	OTHERS (Many families)		
	Atherigona	*Atherigona orientalis*	Damaged tomato fruit, rotting plant and animal matter
	Couchtip maggot	*Delia urbana*	New turf, especially couch
	Eucalyptus flies	Family Fergusoninidae	Eucalypt
	Metallic-green tomato fly	*Lamprolonchaea brouniana*	Tomato fruit. Do not confuse maggots with those of ferment or fruit flies
	Onion maggot	*Delia platura*	Onion, bean, brassicas, cucurbits
	Mosquitoes	Family Culicidae	Vector of human diseases, eg malaria, Ross River fever
	BENEFICIAL FLIES		
Biological control agents	Elm leaf beetle fly	*Erynniopsis antennata*	Elm leaf beetle (*Pyrrhalta luteola*)
	Bathurst burr seed fly	*Euaresta bullans*	Bathurst burr
	Groundselbush gall fly	*Rhopalomyia californica*	Groundsel bush
	St John's Wort midge	*Zeuxidiphosis giandi*	St John's Wort
	Lantana seed fly	*Ophiomyia lantanae*	Lantana
	Mediterranean fly	*Sarcophaga penicilliata*	Pointed snail (*Cochlicella acuta*), proposed biological control agent
Natural controls	Hover flies	Family Syrphidae	Some species are pollinators, larvae of some species are aphid **predators**
	Snail-killing flies	Family Sciomyzidae	**Predators** or **parasites** of snails
	Robber flies	Family Asilidae	**Predators** of many insects
	Tachinid flies	Family Tachinidae	**Parasitic** on eggs of caterpillars, beetles, grasshoppers. Eggs laid on outside of insects, larvae feed inside
	Crane flies	Family Tipulidae	Larvae feed on decaying plant material

Fruit flies

Fruit flies are a major world-wide pest of fruit. Control measures are compulsory under legislation. In some areas, eg Tablelands of NSW, fruit fly is often a sporadic pest and in some seasons is not a problem. Some of the exotic fruit fly present in countries to Australia's north could have devastating effects on many Australian crops (page 66). There is a Fruit Fly Research Centre (University of Sydney). Papaya fruit fly outbreaks cost millions of dollars in lost trade, control, treatment and eradication.

Scientific name

Fruit flies (Order Diptera, Family Tephritidae). There are more than 100 species of fruit flies in Australia about 16 species attack commercial fruit (page 66). **Queensland fruit fly (QFF)** (*Bactrocera tryoni*) is the pest species in **eastern Australia** and **Mediterranean fruit fly (Medfly)** (*Ceratitis capitata*) **MFF** is the pest species in **WA**. Many fruit flies are native species and are not economic pests. In the **NT** the major fruit flies are *B. aquilonis* and *B. jarvisi*, both with wide host ranges.

Host range

QFF attacks a wider range of fruit than **MFF**.
Fruit and nuts, eg pome fruits (loquats early in the season, apple, pear, quince), stone fruits (apricot, peach, nectarine), avocado, banana, citrus (especially grapefruit), fig, grape, most exotic fruit, walnut, a variety of tropical and cultivated fruits.
Ornamental fruits, eg crabapple, peach, japonica, fruiting berries, *Clivia* spp.
Vegetables, eg tomato, capsicum.
Native fruits, eg kangaroo apple, lilly-pilly, native guava.

Description & damage

Adults are small colorful flies, wings are mostly banded or spotted. The head is distinct, the abdomen tapers to a point and the female has a prominent ovipositor. Species differ slightly in size and appearance. **MFF** are **4-5 mm** long with a yellow body marked with white, brown, blue and black, mottled wings and pale green eyes. **QFF** are about **7-8 mm** long (a little larger than the common housefly) and are reddish brown with yellow markings on the thorax, wings are clear with a narrow dark band along the front margins and a transverse stripe near their base. **MFF** are not as mobile as **QFF**. **Maggots** (larvae) are about **8-9 mm** when fully grown (last stage larvae) and are white to creamy-white. They have a pointed head with a pair of small black hook-like jaws, no legs, and a squarish rear end. Maggots are capable of 'skipping' or 'jumping' up to 15 cm. **In their natural environment** fruit flies have a positive role as plant pollinators and as a source of food for birds and vertebrates

Only fruit is damaged.

- **Stings** (egg laying punctures) vary depending on the type of host attacked and are difficult to detect in some fruits, eg mango, papaya. Stings are made by the ovipositors of female fruit flies, small punctures may be visible, sunken areas, sap may be present and premature ripening adjacent to the sting. Stings may also appear as small black marks on the skin, which become discolored. They may be surrounded by a ring of tissue that fails to colour as the fruit ripens, rot may occur close to the sting.
- **Maggots** feed in fruit.
- **Fruit may rot** due the introduction of decay organisms after stinging and maggots feeding.
- **Fruit may fall** following stinging and decay.
- **Fruit may be inedible** or downgraded to juice grade.
- **Location and degree of damage** varies with type of fruit, number of larvae in fruit and the climatic conditions, eg
  - **Apple and pear.** A discolored area may develop around each sting. Burrowing by hatched maggots in the fruit soon become noticeable. Decay can readily be detected by hand.
  - **Loquat** 'stings' are similar to those in apple. Loquats are the main host of early infestations.
  - **Citrus** are not good hosts. The citrus acid in fruit pulp and oil in rind kills many eggs and maggots. The area around the sting may yellow, punctures may ooze. Later, water-soaked areas around the sting may develop green mould (*Penicillium* spp.).
  - **Stone fruit** may appear intact and sound but maggots are easily detected when fruit is opened. Decay is associated with their activity especially around the stone.
  - **QFF** will lay eggs in all varieties of persimmon and passionfruit but maggot development is rare.
  - **Home garden tomatoes** may be heavily infested in autumn. Commercial tomato crops are seldom attacked except when grown in urban areas.
- **Postharvest losses** include that from:
  - Further development of maggots.
  - Presence of fruit flies and their damage. Affected fruit may be unsaleable or downgraded at market.
  - Growers may be required to perform postharvest treatments.
  - Quarantine restrictions being imposed by domestic or export markets. Affects export earnings.

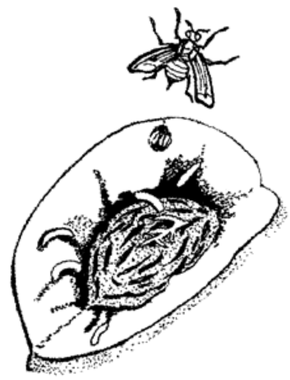


Fig. 40. Queensland fruit fly (*B. tryoni*).
Upper: Fruit fly, actual size.
Lower: Maggots in a peach.

Diagnostics

- **Obtain local information** on fruit fly species which occur in your area. Posters of Fruit Flies of Australia and the world may be purchased from Scientific Advisory Services www.saspl.com.au/
- **Plant Health Australia** is developing a web-based remote microscope system to improve Australia's fruit fly diagnostic capability.
- **Morphological differences** between **adults**, eg size, colour of abdomen. Experts may be required to differentiate adults of different species. Gene technology identifies **strains**.
- **Eggs and larvae** of fruit flies look alike. Experts are required to differentiate species.
- **On some hosts**, fruit fly maggots can be confused with those of **ferment flies** (*Drosophila* spp.) which only attack **ripe** fruit. On other hosts, eg tomato, fruit fly maggots may additionally be confused with those of green tomato fly or athergona (tomato fly).

Pest cycle

There is a **complete metamorphosis** (egg, maggot, pupa and adult) with up to 5 or more generations each year. Adults live for long periods, mate at dusk and are often seen during the day basking on the sunny side of trees feeding on bacterial colonies which are more plentiful under humid conditions. The adult female lays eggs **under the skin** of the fruit. Hatching occurs in 2-3 days and the maggots burrow (tunnel) and feed in the pulp (flesh) for 10 days or more. When mature they leave the fruit and burrow into the **soil** and pupate to form a smooth, light brown pupa. Depending on the temperature the adult fruit fly emerges from the **pupa** 2-8 weeks later, mates within a week and females begin laying eggs and the cycle starts again. The complete cycle of the **QFF** from egg to adult takes about **5 weeks** in hot weather while **MFF** may take as few as **4 weeks**. The life cycle of **MFF** in WA is generally similar to that of the **QFF**.

'Overwintering'

- Fruit flies can be **active all year round** in warm moist areas.
- Fruit flies usually 'overwinter' as **inactive adults** but are killed by cold winters, as are pupae in the ground. It is likely that the pest is introduced into these cooler regions each spring and summer in infested fruit.

Spread

- **By movement of infested** fruit and vegetables. **Airline passengers** carrying a few pieces of fruit are one of the main means for spread of fruit flies from one country to another.
- **Adults are strong fliers** and assisted by wind, can travel many kilometers. Cyclonic winds may carry fruit flies into northern Australia.
- **QFF** extends southwards in Victoria every year.
- **Pest Free Areas (PFAs). Medfly** and **QFF** do not occur in these **PFAs** and are incapable of naturally dispersing to these **PFAs** from infested areas, due in part to the hostile conditions experienced in the **PFAs** and surrounding lands. Introductions usually occur through transport by humans which is strictly controlled by legislation.

Conditions favouring

- Warm moist conditions, especially after good falls of summer rain. Hot dry weather reduces numbers of emerging adults.
- Fruit become susceptible to fruit fly some weeks **before** harvest and maturity.
- Infestations usually begins with earlier ripening fruits, eg loquats. **QFF** mainly attacks summer fruits, particularly **later maturing** varieties and is more severe during mid to late summer.
- Tree-ripened fruit. As the season progresses, fruit fly populations, the attractiveness of fruit to fruit fly and the risk of damage all increase.

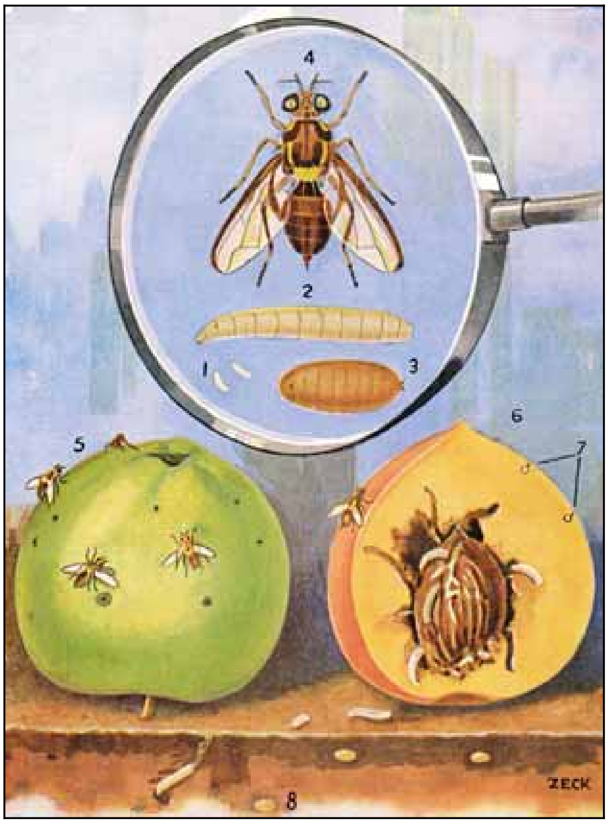


Fig. 41. Queensland fruit fly (*Bactrocera tryoni*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x5
1. Eggs
2. Larva or maggot
3. Pupa
4. Adult fruit fly

Actual size

5. Apple showing punctures or stings where eggs have been deposited
6. Peach showing decay and tunnels of the maggots
7. Egg clusters beneath the skin
8. Pupa in the ground

Conditions favoring *(contd)*

Climate change (Sutherst 2000).

As the limiting effects of rainfall are largely offset by **irrigation**, the southern distribution of **QFF** is limited by **temperature**. It is expected that the impact of **QFF** on Australian horticulture will progressively **increase** over the next few decades. With longer and more favorable fly seasons leading to more generations per year and reduced winter deaths, it is likely that **QFF** populations will increase and become established over a wider area. Potential consequences include:

- **Threat** to the sustainability of area freedom in the current **Fruit Fly Exclusion Zones (FFEZ).**
- **Increased** damage and control costs for commercial growers in endemic areas except northern Australia.
- **Increased damage to backyard growers** especially in **SA** and **Vic**. Thus the **QFF** poses a real threat to southern states under modest projected increases in temperature to the extent that the likely cost increases raises doubts about the ability of some industries in southern areas and remain viable.

Management (IPM)

There is a National Fruit Fly Strategy (NFF).
www.**planthealthaustralia**.com.au/**fruitfly**

1. **Plan in advance and obtain advice** for your situation. Control measures **vary** according to where you live, whether you are a commercial grower or home gardener, etc.
2. **Crop, region.** Seek advice from **local authorities** to ensure your plan is for your fruit crop in your region.
3. **Identify** the fruit flies likely to be found in you area. Understand their life cycle, host range, how they 'overwinter', spread, etc. Is your fruit fly a pest species? Consult a diagnostic service if needed (page xiv).
4. **Monitor presence of male** fruit flies using synthetic pheromone traps in an area so that baits or cover sprays may be timed more precisely. Use correct lure as some fruit flies are not attracted to lures. Many fruit flies caught in traps are native species. **Exotic fruit flies** are trapped in northern Australia and in other in pest-free areas. Fruit Fly Hotlines in SA may be contacted by the public who find **maggots** in fruit from gardens or bought from a shop.
   - Fruit should also be checked for **stings** (egg laying activities) by female fruit flies.
   - Control activities can then be directed towards either the eggs and maggots in fruit, or towards the adults.
   - **Fruit flies** may be so serious that monitoring may be irrelevant, eg on guava in some areas.
   - **Male annihilation.** Traps with pheromones to attract **male fruit flies** and an insecticide, help to reduce numbers but do not satisfy quarantine regulations.
5. **Thresholds**. There is nil tolerance in a **FFEZ** and for many export markets. To control and eradicate **QFF** and **MedFly** in a **FFEZ**, treatment measures are prescribed. Thresholds **are** available for some species of fruit fly, they vary with the crop. How much damage can you tolerate economically or aesthetically before you implement control measures? Growers in some regions must consider whether likely damage is sufficient to warrant spraying.
6. **Take appropriate action** when a threshold is reached (depends on whether it is a quarantine, commercial grower or home garden problem. Keep up-to-date with official advice, information and legal obligations. If in a **FFEZ**, immediately report sightings of fruit flies to local authority/department of agriculture. Costly suppression or eradication programs may be under-taken by government/agricultural agencies.
   - Treat other nearby susceptible fruit crops**.**
   - Both cover sprays and bait sprays may be used concurrently in commercial orchards.
   - Pre and post harvest treatments may be required to gain entry to southern and export markets.
   - Contingency plans are in place for exotic fruit flies should they be detected in any part of Australia.
   - Programs are available for organic growers, eg *Organic Farming : Managing Fruit Fly in Citrus* www.**dpi.vic**.gov.au/
7. **Evaluation**. Review your monitoring and treatment records. Decide whether an improved program is needed for next season.

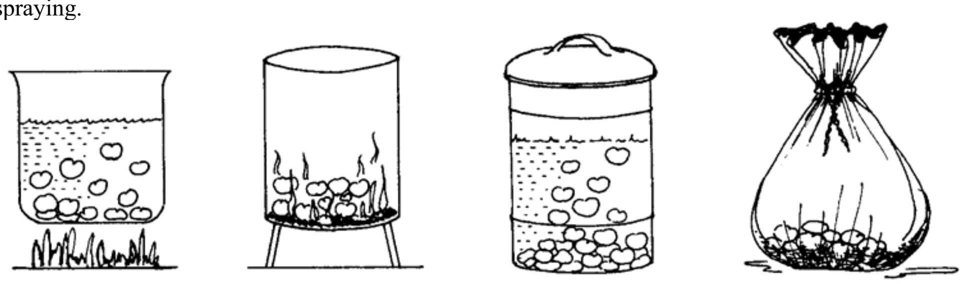
Control methods

Each state/region has particular requirements for the control of fruit flies and the local regulatory authorities should be contacted for information on control or if fruit fly is suspected. Control measures for quarantine officers, local councils, commercial growers and home gardeners vary according to the region in which you live, ie if it is a **fruit-fly free zone (FFEZ)**, if fruit fly is a **major** economic cost for commercial growers, if it is an area where **exotic** fruit flies may enter, or if it is in an area where fruit fly is a **sporadic** problem not requiring control in some seasons.

Legislation.
It is the responsibility of the occupier of land to prevent infestation by fruit fly. Each State/ Territory has particular requirements for the control of fruit flies. Consult the appropriate local authority for current regulations for the area in which you live, these usually include sanitation measures, quarantine regulations and insecticide applications. There are also import/export quarantine regulations. Search for fruit fly at: www.**aqis**.gov.au/

Cultural methods.

- Some climatic areas are **not suited** for the continued development of fruit fly.
- Grow **early maturing varieties** and harvest before fruit fly populations build up.
- **Some** commodities can be harvested at a mature stage **before** they are susceptible to fruit fly.
- **Prune trees** to a manageable size to facilitate picking, spraying and baiting.
- **Cultivate soil** around trees and keep weed-free.



Boil fruit for at least 10 minutes. | Burn. Is this permitted? | Immerse fruit in water inside covered container for at least 3 days. | Secure fruit inside a plastic garbage bag. Expose bag to sun for at least 3 days.

Fig. 42. Sanitation measures for treating fruit infested with fruit fly maggots.

Sanitation reduces breeding sources

You are required by **law** in prescribed areas to:

- **Remove** unwanted or regularly unharvested fruit trees and orchards around sheds, boundary fences. There may be specific requirements in some regions for some crops, eg quince.
- **Treatment of alternative fruiting hosts** and removal of wild hosts in and around orchards help reduce numbers.
- **Collect and destroy immediately** all ripe, **fallen** fruit and tomatoes. Remove all infested fruit from **trees and tomato plants** at intervals not exceeding 3 days, to eliminate breeding sites. Remove any late hanging fruit. Keep ground beneath trees and around tomato crops free from long grass and weeds. Destroy fruit by either:
  - Boiling for at least 10 minutes. Take care.
  - Burning (if permitted).
  - Soaking for at least 3 days in water topped with kerosene. Dispose of fruit after treatment.
  - Placing in water in a covered container for 3 days.
  - Securing fruit inside a plastic garbage bag and exposing the bag to sun for 3 days, and disposing in the garbage. Suitable for home gardeners. Could this be buried in the soil?
  - Treating with an approved insecticide, **prior** to burying. Do **not bury untreated fruit** as this does not kill the maggots and adult flies can emerge from pupae as deep as **1 meter**.
  - **Slash** between rows to destroy fruit.
  - **Practice** good packing shed hygiene with thorough inspections to remove any infested fruit.
  - **Special arrangements** may be negotiated with organic growers in eradication areas to remove all fruit from a property not treated. Remember it is only possible to grow organic fruit because neighbours co-operate in fruit fly eradication.

What are your local regulations?

Biological control

- **Natural controls.** Fruit flies also infest the fruit of native plants; native parasites and predators, some of which can be mass reared and released to help provide control of fruit fly populations.
  - **Parasitic wasps** commonly lay eggs in fruit fly eggs and maggots but do not significantly reduce fruit fly numbers.
  - **Predators** of adult fruit flies include the assassin bug, praying mantises, spider and birds.

- **SIT (Sterile Insect Technique)** is the large scale breeding and release of **sterile male flies** which mate with wild female flies in the field producing **non-viable eggs** leading to **eradication**. The method is species specific. Fruit flies are sterilized by exposing pupae to gamma radiation.
  - Used for most outbreaks of **QFF** in SA following an initial **baiting** program. May be available for **Medfly** control in SA and with **baiting** techniques to eradicate **MedFly** in WA.
  - **Medfly** is harder to eradicate than **QFF** because it is less responsive to **bait**.
- **New lures** for female *Bactrocera* spp. of fruit flies being researched will improve monitoring and so protect current markets for fresh produce.

Resistant varieties

Late ripening fruits are very susceptible. Early ripening fruits act as a source of infestation of later ripening fruits.

Plant quarantine

- **Australian Quarantine & Inspection Service (AQIS)** controls the entry of exotic fruit flies (page 66) into Australia, using a combination of X-ray units, detector dogs, physical inspection and quarantine surveillance (trapping, regular host fruit surveys of high risk species, eg guava, mango).
  - **Northern Australian Quarantine Strategy (NAQS)** trapping program detects exotic fruit fly incursions in the Torres Strait and from Asia, eg Asian Papaya fruit fly, melon fruit fly and *Bacterocera trivialis* which are directly related to weather patterns. This **warning detection program** uses traps baited with lures to detect lure-responsive exotic fruit flies. Exotic fruit flies in the Torres Strait are eradicated.
  - **Fruit is imported** from fruit-fly pest free areas overseas, based on results of trapping, climatic data and verification visits to pest-free areas, etc.
- **Interstate & Regional Plant Quarantine** Checkpoints throughout Australia prevent spread of fruit fly into fruit fly-free regions.
  - **Tasmania** and **NZ** are free from **Medfly** and **QFF**, as is **SA**.
  - **Medfly** occurs in **WA** except in the **Ord River Irrigation Area** which has area freedom status.
  - **QFF** is present in **NT, Qld, NSW** and **Vic**.
  - The **Fruit Fly Exclusion Zone (FFEZ)**. Comprises parts of NSW, Victoria and SA (Fig. 43).
    www.agric.**nsw**.gov.au
  - **Maintenance** of the **FFEZ** and other **Fruit Fly Free Areas** involves:
    - ❑ Roadblocks to confiscate fresh fruit and vegetables. Warning signs and disposal bins are located on most roads leading into the **FFEZ**.
    - ❑ Fruit fly traps to detect outbreaks (monitoring).
    - ❑ Eradication of detected outbreaks.
    - ❑ Control of movement of infested fruit by regional Quarantine Regulations **within** Australia.
    - ❑ Coordination and management of the **FFEZ** by the **TriState Fruit Fly Committee** involving Commonwealth, NSW, Vic, SA and industry.
  - **Recognition of fruit fly free areas** by overseas countries means that fruit can be exported without need for costly treatments, eg citrus to Japan.
  - **Pest Quarantine Areas** for fruit fly incursions, eg papaya fruit fly in Queensland, limited its spread and facilitated monitoring and eventual eradication.

Fig. 43. Fruit Fly Exclusion Zone (FFEZ). Quarantine areas marked with dots, other quarantine areas are prescribed as necessary.

If you find maggots in fruit or vegetables in areas considered free of fruit fly contact your local Department of Agriculture for advice.

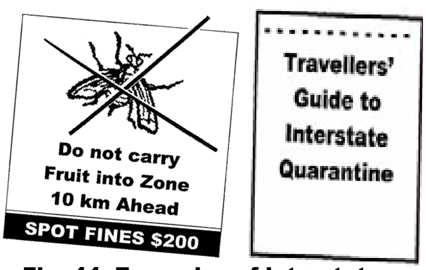


Fig. 44. Examples of interstate quarantine leaflets.

- **Growers sending fruit interstate and overseas**.
  - Must **comply** with the **Conditions of Entry** restrictions of the receiving State or Country. These indicate the required treatments or inspections for fruit fly. A guarantee of fruit fly-free status may be achieved by quarantine and phytosanitary measures. Many countries have a nil tolerance. Outbreaks of papaya fruit fly in Australia caused NZ to ban imports of Australian bananas – lifting the ban was conditional on the bananas being harvested, packed and exported in the unripe mature-green state.
  - Must **contact** their nearest Department of Agriculture/Primary Industry about required **post-harvest** treatments/inspection procedures.
  - Search for exotic fruit flies www.daff.gov.au/aqis

Physical & mechanical methods

- **Postharvest.** Fruit may be disinfested by heat, eg hot water dipping and circulating hot air, by cold disinfestation treatments and irradiation.
- **Exclusion products.** Mesh enclosures (about 2 mm diameter) **exclude** fruit flies, some other insect pests, and birds. High value ripening fruit, eg avocado, grapes, can be **bagged** by gardeners and growers, eg PestGuard Bags, Fruit Sleeves.

Insecticides

- **Fruit on trees**. Control **adults** using cover and/or bait sprays **after** monitoring, they are compulsory by law in most States/Territories.
  - **Cover sprays**, eg dimethoate, are usually systemic insecticides that are applied to the whole tree to kill the various stages of fruit fly (adults, eggs and larvae present in fruit). On some crops, fruit flies are controlled by insecticide sprays used against other pests.
    - ❑ **Penetrant sprays**, eg fenthion, are effective in areas where baits are not. Sprays quickly kill adult flies on foliage and fruit, and eggs and just hatched maggots immediately under the skin of the fruit.
    - ❑ **Disadvantages of cover sprays.**
      - May be very disruptive to parasites and predators. Their use may increase other pests.
      - Do not prevent adults laying eggs in the fruit. Egg laying punctures may be unacceptable blemishes.
      - Lebaycid® (fenthion) is very toxic to birds.
      - Some sprays, eg Rogor® (dimethoate) may cause leaf and fruit drop in apricots and early peaches
  - **Protein bait sprays**, a mixture of protein, water and insecticide, can be spot sprayed onto trees and other sites in an orchard. Protein attracts both **male and female fruit flies** which are killed as they feed. Female fruit flies require protein for egg laying and are especially attracted. Baiting is more effective when carried out in the morning when fruit flies are active. Mark trees which have been bait sprayed.
    - ❑ **Advantages of bait sprays**
      - Effective against both male and female fruit flies.
      - Applied to foliage or boards, not fruit. Less costly.
      - Less disruptive to natural controls, honey bees.
      - Only small quantities of insecticide are used.
      - Helicopters can be used to over wide areas.
      - Most effective in isolated or semi-isolated areas for orchard or community baiting schemes.
      - Not all trees may need to be treated.
    - ❑ **Disadvantages of bait sprays**
      - Only kills adult flies, does not prevent development of eggs and maggots already in the fruit. If fruit is infested supplementary cover sprays may be needed.
      - May not provide adequate control under high fly pressure or in highly susceptible crops.
      - Are applied more frequently than cover sprays.
      - Less effective for a few trees or in orchards near urban areas with high fruit fly populations.
      - Not rainfast, re-application is necessary after heavy or continuous rain to maintain effectiveness.
      - May mark commercial fruit, eg mango.
- **Fruit postharvest** may need disinfestation to comply with quarantine regulations.

Table 4. Fruit flies – Some lures and insecticides.

What to use?	Comments (CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE)
TRAPS TO DETECT AND MONITOR ADULTS	
TRAPS - LURE MINUS INSECTICIDE **Fly Bye Fruit fly lure, Wild May fruit fly attractant** (4-(p-hydroxyphenyl)-2-butanone acetate) attract and kill male **QFF** **Many recipes for home made wet traps**, eg 2 L water +half cup sugar +1 teaspoon of imitation vanilla essence +2 tablespoons cloudy ammonia, hang 2 bottles in each tree as soon as trees are in bloom. **Household products**, eg vegemite, marmite, sugar) **Insectrap** is a non-toxic, sticky, yellow trap that attracts and traps Diptera insects, it also traps citrus gall wasps.	**Traps are used to detect and monitor** the presence of fruit flies in an area so that baits or cover sprays may be timed precisely. **Lures** used to attract adult fruit flies include pheromones, food (protein/sugar) or coloured spheres coated with a sticky gel (blue best for QFF and yellow for Medfly). **Depending on the type of trap** used, flies get caught on a sticky surface, killed by insecticide, dehydrate or drown in liquid bait.
TRAPS – LURE PLUS INSECTICIDE **Different lures/insecticides are used in different traps** **Group 1B**, eg **Biolure + maldison** attracts female **Medfly** **Capilure + dichlorvos** attracts male **Medfly, QFF, papaya fruit fly** **Dak pot Lure & Insecticide (maldison) Trap, Q-Fly Lure, Searles Fruit Fly Wick Attractant, Eco-naturalure** attract male **QFF** **Methyl eugenol + maldison** attracts many exotic male **fruit flies** **Trimedlure + insecticide** attracts male **Medfly** **Group 2B**, eg **Cue-lure + fipronil** attracts male **QFF**, lesser **QFF,** some exotic species, attracts male within radius of 400 meters or more. **Wet or food traps** (protein or sugar +insecticide) attracts both male and female **Medflies**, other flies as well.	**Lure plus insecticide traps** for detection/monitoring are used in conjunction with a baiting program or cover sprays (or a combination of both) to effect control of the targeted fruit fly. Regular monitoring of the crop for egg-laying by female flies should be employed in addition to the use of lures. **These traps** are a mixture of usually a male attractant (pheromone or food attractant) and an insecticide to kill the attracted fruit fly. Lures are usually placed in trees and can be applied as gels, impregnated fibre board blocks, absorbent wicks and strings or traps, placed at high densities in the areas where the targeted species is known to occur. The aim is to reduce the populations to such an extent that no mating occurs, but their main function is monitoring. They do not satisfy quarantine regulations. May be used in area-wide management strategies.
FOLIAGE BAITING (LURE PLUS INSECTICIDE) **Group 1B**, eg **Dak-pot fruit Fly Attractant** (yeast, for use with a suitable insecticide, usually maldison). State/territories provide specific information on foliage baiting. **Group 5**, eg **Eco-naturalure Fruit Fly Bait Concentrate, Naturalure Fruit Fly Bait Concentrate, Yates Nature Way Fruit fly** (protein/sugar-based bait +spinosad), controls fruit flies including **QFF and Medfly.**	**Foliage baits** are a mixture of a food attractant and an insecticide. Both male and female fruit flies are attracted and die after coming in contact with the insecticide or ingesting it. Follow label instructions on **where and when to apply**, etc. Wash all fruit after harvest to remove any residues. Foliage baiting may not be as effective as cover spraying under severe pest pressure or frequent rain. Must be applied more often.
COVER SPRAYS **Group 1B**, eg chlorpyrifos, dimethoate, fenthion, maldison, trichlorfon)	**Cover sprays** are used to spray the entire tree (foliage/fruit) to kill fruit flies resting in the tree, maggots and eggs in the fruit. Time of application varies with species, other insects present at time of spraying will be killed.
POSTHARVEST DIPPING OF FRUIT **Group 1B**, eg dimethoate, fenthion	There may be dipping requirements for commercial certification of produce against fruit flies.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Cineraria leafminer

An example of a leafminer

Leafminers generally do not kill plants.

Scientific name

Chromatomyia syngenesiae (Order Diptera, Agromyzidae). Minor pest in NSW, Victoria, SA. Other leafminers are listed on page 67

Host range

Mainly Asteraceae and related plants. eg **Ornamentals,** eg cineraria, chrysanthemum, gazania, gerbera, *Helichrysum*, also mist flower, nasturtium.
Vegetables, eg lettuce.
Weeds, eg capeweed, prickly lettuce, sowthistle.

Description & damage

Adult flies are small inconspicuous grayish-black flies **2-3 mm** long. They may be seen walking over the leaves of host plants during winter and spring but they often go unnoticed. They may fly slowly making short hopping flights of about 1 meter at a time. **Female flies feed** by repeatedly puncturing the **undersurfaces** of young leaves with their ovipositors and sucking up the sap which flows from the wound. These punctures appear as bleached spots on the upper surface of the leaf. On some varieties of chrysanthemum these spots can be confused with early stages of white rust. **Larvae** are creamy-white, legless and **4-5 mm** long when fully fed. They have no head and there is usually only one larva or maggot per mine. **Pupae** are elongate, barrel-shaped, light brown and about **2.5 mm** long and can be easily seen through the undersurface of the leaf at the end of tunnels. A single leaf may contain several pupae.

Leaves. Foliage is spoilt. Maggots tunnel between the upper and lower surfaces of leaves. Initially the mines appear as pale, narrow, thread-like **lines** but as the maggots grow, the mines become wider and more obvious and may eventually reach **1.5 mm** in across. A trail of insect excreta can often be seen in the mines when held up to the light**. Pupae** are easily seen in the mines through the leaf undersurface.

General. The **appearance of foliage** is spoilt and in cinerarias and other species which become heavily infested, plants may wilt and **growth** may be severely retarded. If the leafmining of the maggots destroys most of the leaves **plants may die**. Very often, however, affected plants will still produce a good crop of flowers.

Diagnostics.

- Meandering leaf mines on leaves of susceptible varieties.
- Larvae and/or pupae can be seen through lower leaf surfaces when held up to the light.
- The only leafmining insect that attacks these plants in Australia at present.
- Lucid keys www.**lucidcentral**.org/
  - *Key to the World Genera of Eulophidae Parasitoids (Hymenoptera) of Leafmining Agromyzidae (Diptera)*
  - *Liriomyza Parasitoids in South East Asia*
  - *Polyphagous Agromyzid Leafminers Identification Key Tutorial* is available at:

keys.**lucidcentral**.org/keys/v3/**leafminers**/tutorial.htm

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with several generations each season. The life cycle from egg to adult takes about **3-4 weeks.** Female flies lay eggs singly within the leaf tissues on the undersurfaces of leaves and the puncture marks or **'stings'** may be seen as small scars on the leaf surface. Eggs hatch in about **4-5 days** and the larvae feed and tunnel within the leaves between the upper and lower epidermis for **15-18 days** (Goodwin et al 2000). When fully grown they pupate at the end of the tunnel. Adult emerge **10 days** later.

Fig. 45. Cineraria leafminer (*Chromatomyia syngenesiae*). Damage caused by maggots. ***Left:*** Cineraria. Photo©NSW Dept of Industry and Investment. ***Right:*** Marguerite daisy. Photo©CIT, Canberra. (P.W.Unger)

'Overwintering'

On host plants, pupae may be seen in the tunnels on the undersurface of the leaf.

Spread

By adults flying, by propagation, eg cuttings from infested plants and by the movement of infested plants, plant parts, infested plant debris.

Conditions favouring

Cool humid weather during late winter, spring and early autumn. Fine meandering lines initially appear on leaves during late winter and spring. There seem to be more of a problem in coastal areas such as Melbourne and Sydney.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Access/prepare a plan** which fits your situation based on previous records of cineraria leafminer damage to susceptible varieties.
2. **Crop, region.** Know and mark all susceptible varieties in your area/garden which may require treatment.
3. **Identification** of pest must be confirmed by a diagnostic service if necessary (see page xiv).
4. **Monitor.** Examine leaves for mines and larvae during late winter and early spring depending on the region (page 39). Record your findings.
5. **Threshold.** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic? Do you need to calculate your own threshold? Commercial growers often have a threshold of appearance of the first mines. This will vary with season and region.
6. **Take appropriate action** when any decided threshold is reached. Prune out any infested leaves and apply insecticides as soon as mines are detected and when **maggots are still mining** in leaves but have not pupated. Repeat applications may be required until warm weather arrives. Record treatment dates, etc. Home gardeners usually settle for sanitation measures. Remember if pupae have formed in the leaves it is too late to spray.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required, ie growing less susceptible varieties. Continue to examine leaves to ensure treatment has been successful or there is a need for further treatment.

Control methods

Cineraria leafminer can be difficult to manage.

Cultural methods. Fertilize and water affected plants. Overseas adding potassium silicate to fertilizer mixes with potted chrysanthemums (200ppm or higher) saw a significant reduction in leafminers emerging from treated plants versus the control. This may be a good cultural tool for suppressing leafminers.

Sanitation. Occasional shoots which are infested may be pruned off and destroyed in such a way that adult flies cannot emerge from the pupae within the leaf tissues. All prunings from infested plants should be destroyed. Control weeds and volunteer hosts.

Biological control. Overseas, parasitic wasps may control cineraria leafminer on chrysanthemum. Check with Australasian Biological Control for possible biocontrol agents. List of suppliers www.goodbugs.org.au

Resistant varieties. Varieties vary in resistance. The florists chrysanthemum (*C. sinense*) seems to be **resistant**. Margarite chrysanthemums (*Chrysanthemum frudi*) and shasta daisy (*C. maximum*) are **susceptible**.

Plant quarantine. There are other leafmining insects which are major pests of chrysanthemum and other Asteraceae **overseas**. Serpentine leafminer (*Liriomyza trifolii*) is probably the most important. Chrysanthemum and gypsophila imported from areas where it occurs are subjected to mandatory treatment. Other leafminers overseas include *L. huidobrensis, L. sativae* and *Amauromyza maculosa.*

Pest-tested planting material. Avoid taking cuttings from infested plantings. If this is unavoidable, select plants for propagation which are apparently damage-free.

Insecticides.
See Table 5 below.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 5. Some insecticides for leafminers generally.

What to use?	When and how to apply?
FOLIAGE SPRAYS **Group 1B**, eg Rogor® (dimethoate) **Group 4A**, eg Confidor® Guard Soil Insecticide (imidacloprid) - citrus leafminer on citrus **Group 5** eg Success™ 2 Naturalyte™ Insect Control (spinosad) See also page 128 **Spray oils**, eg petroleum oils, paraffinic oils, botanical oils **Remember, check the plant and the leafminer the product is registered for use on**	If using a spray: • Use a **penetrant or systemic** chemical to kill larvae inside leaves. • If maggots have **pupated**, it is too late to spray. Hold several leaves up to the light, if most tunnels have a small round hard pupa at the end, then pupation has taken place and spraying is not effective. • **Several sprays** at approximately weekly intervals may be necessary **if** larvae are still active and further infestations occur, ie in late winter and early spring **if** weather is cool and wet. • Ensure that **both sides of the leaves** are wetted thoroughly with spray.

Fungus gnats

Fungus gnats are becoming an increasingly widespread and **damaging nursery pest**.

Scientific name

Fungus gnats (Order Diptera, Family Mycetophilidae) and **black fungus gnats** (Family Sciaridae), eg glasshouse sciarids (*Bradysia* spp.) are widespread pests. Do not confuse fungus gnats with **shore flies** (Family Ephydridae) and their larvae which are often minor pests in greenhouses (Goodwin et al 2000).

Host range

Flies (adults) are short-lived and do not feed on plants. **Maggots** (larvae) feed on decaying fungi and other organic matter in soil and potting media. They also feed on roots and stems of most seedlings, cuttings and soft-foliaged mature plants such as carnation, gerbera, poinsettia and most hydroponic crops. **Shore fly maggots** feed on algae living on media surfaces while the adults imbibe liquids and leave faecal spots on foliage.

Description & damage

Adult flies are mosquito-like, slender, gray or black and about **2-5 mm** long. They have long slender dangling legs, long antennae and 1 pair of wings with a **Y-shaped vein** at the tip. They are weak fliers, hover in groups around plants or run over the surface of seedling and cutting trays and pots at dusk and can be a nuisance indoors around potted plants. **Larvae** (maggots) are mostly small, thread-like, active, almost transparent (internal organs can be seen), legless, about **5-8 mm** long with small dark heads (Fig. 46) and can be found wriggling on or near the surface of soil and potting mixes. Maggots may leave a tiny slimy glistening trail on the soil/mix surface. They may gain access to roots through the base of pots. **Pupae** are **3-6 mm** long, brown, cylindrical and are found in soil or potting media.

Roots of seedlings, cuttings and young plants may be damaged by large numbers of **maggots**. Roots may be scarred and root hairs eaten off, causing wilting and secondary attack by disease organisms. Maggots may also feed on the **callus** of cuttings, preventing striking or slowing down root development. Larger maggots may tunnel into **stems** of seedlings and cuttings just below the soil surface killing them.

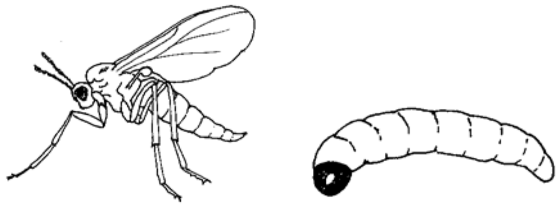


Fig. 46. Fungus gnat (Mycetophilidae).
Left: Adult (fly), 2-5 mm long, mosquito-like.
Right: Larva (maggot), 5-8 mm long, obvious head.

General.

- **Leaves** yellow, plants lack vigour. Reduce plant growth rate and yields – the root damage reduces nutrient and water uptake.
- **Spread disease.** Feeding **maggots** can ingest and spread fungal spores of root rot fungi. *Pythium, Fusarium, Thielaviopsis* (*Chalara*) and *Verticillium* are carried in their gut and retained through to the adult fly to be spread elsewhere.

  Adults can also spread grey mould (*Botrytis*) which attacks foliage. **Shore flies** and their larvae can also transmit *Phytophthora* and *Pythium* spp.
- **Customers complain** about flies and maggots, poor presentation of damaged plants at point of sale. Shore flies may also reduce marketability. Flies irritate **staff**.

Diagnostics.

- **Fungus gnats** are often confused with shore flies. They are mosquito-like and often found running on the soil surface, maggots have a distinct head (Fig. 46). **Shore flies** look like house flies, stout, with 5 pale spots on their wings, maggots have no distinct head (Fig. 47). Adults can be caught on sticky yellow traps but they can be difficult to identify. You may need to get advice. Use a x 10 lens and record counts.
- **Damage by larvae** is often unnoticed because they can be difficult to find in media or within plant stems. Reduced growth is hard to quantify.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with several overlapping generations each season in greenhouses. Development varies with temperature. At **24°C** egg to adult fly life cycle is about **3 weeks**. Adults mate soon after they emerge from pupae in the soil and within 2-3 days the female lays **100-200 small white eggs** in cracks on continually wet soil surfaces, particularly around the base of plants or in plant debris. These eggs hatch after 4-6 days into maggot-like larvae which feed for **2-3 weeks** on media and plant roots then **pupate** in soil or potting media.

'Overwintering'

Possibly as pupae. Fungus gnats may breed continuously at temperatures above 24°C, in greenhouses and in surrounding drains, etc.

Spread

- By adults flying.
- By movement of contaminated soil or media in pots or plant material.

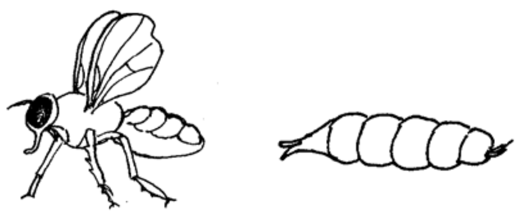


Fig. 47. Shore fly (Ephydridae).
Left: Adult (fly) 3-4 mm long, 5 pale spots on wings.
Right: Larva (maggot), 6-8 mm long, no obvious head.

Conditions favouring

- Soil or media which is continually wet, over watered, poorly drained. Highly moisture-retentive potting mixes.
- Persistent pest in protected nurseries.
- Soil or potting media rich in organic matter.
- Low light, high humidity, misting systems.
- At 24°C reproduction is continuous.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** if fungus gnats are an ongoing problem which includes better management of media, drainage, humidity and fertilizers.
2. **Crop, area.** Mark plants or areas where control is required. Proper application and use of nematodes will vary with crop and production system.
3. **Identification** of adults and larvae must be confirmed. Consult a diagnostic service if necessary (see page xiv). Locate main breeding areas, be familiar with its life cycle, method of spread, etc.
4. **Monitor** pest and/or damage and record results which will indicate when peak populations occur (page 39).
   - **Trap adults** on yellow sticky traps.
   - **Monitor maggots** by placing potato discs on moist potting media. Larvae are attracted to the discs and tunnel underneath or into the discs.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic? Do you need to calculate your own threshold for crops at risk?
6. **Action**. Implement appropriate treatment, when any threshold has been exceeded. Early treatment prevents damage. If using nematodes apply initially at planting and shortly thereafter or if yellow card counts are < 50/trap/week (guide only).
7. **Evaluation**. Continue monitoring to ensure control measures have been effective. **Records** compiled over several seasons help develop control thresholds relevant to the month and stage of crop growth.

Control methods

Cultural methods.

- The **only permanent cure** is to avoid over-fertilizing and overwatering. Improve drainage. Allow media to dry out as much as possible without injuring plants before watering will kill many maggots. Maggots do not like dry media.
- Avoid using potting media **high** in organic matter such as peat. Plants may need to be repotted using **less** organic matter.
- Avoid storing media where it can get wet and attract adult flies. They will colonize it and then enter the production cycle.
- Shore flies are controlled in a similar manner.

Sanitation.

- Remove and destroy badly infested containers.
- Keep areas below benches, walkways, corners and surrounding areas free of pools of water, fertilizer, spilled potting media, unwanted pot plants, plant debris and weeds. Disinfect surfaces; remove algae (shore fly).

Biological control

- **Natural controls** include predatory mites, beetles and parasitic wasps.
- **Commercially available agents**. Many variables can affect the performance of bio-control agents, eg pesticides used for other pests, improper storage and incorrect use.
  List of suppliers www.**goodbugs**.org.au/
  - **Nematodes** (*Steinernema* spp.) are applied as a drench or spray drench to growing media after planting. The nematodes seek out natural openings on the fungus gnat larvae present among the roots of plants. When inside they release bacteria which causes septicaemia in the maggots. After 2 weeks the nematodes have multiplied inside the maggots which rupture releasing more nematodes to search for more maggots. Store at 5°c do not freeze.
    Becker Underwood www.**beckerunderwood**.com/
    Ecogrow Environmental www.**ecogrow**.com.au

Nemasys®

50 MILLION INFECTIVE JUVENILES

  - **Cybate**®, **Vectobac**® (*Bacillus thuringiensis* var. *israelensis*), bacteria which produce a crystalline protein is registered for the control of mosquito larvae and possibly could be useful in the future against fungus gnat larvae.
  - **Predatory soil-dwelling mites** (*Hypoaspis* sp.) feed on larvae of fungus gnats. Introduce soon after planting before fungus gnats become established.
  - **Predatory rove beetles** (*Dalotia (Atheta) coriaria*) feed on shoreflies in addition to thrips and fungus gnats.

Physical & mechanical methods.

- Vermiculite (50 cm) or sand on top of soil discourages adult flies from egg-laying.
- Sticky yellow boards trap adult flies.
- Light traps also capture large numbers of flies.
- Screening greenhouses to exclude adult flies.
- Properly compost potting media to kill maggots.
- Pasteurization of media, if practical.
- Increasing light levels and ventilation reduce favourable breeding conditions.

Insecticides.

- Foliage sprays and dusts may control adult flies while soil drenches control maggots (Table 6).
- Compost-incorporated insecticides and insect growth regulators **(IGRs)** have been used overseas with good results. **IGRs** interfere with molting of maggots killing them. More target specific, not broad spectrum. Often have shorter restricted-entry intervals. Choose one which does not injure roots/plant bases.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 6. Fungus gnats – Some insecticides and bio-control agents

What to use?	When and how to apply?
TO CONTROL ADULTS **Group 3A**, eg pyrethrins	Adult flies must be killed **before** egg laying.
TO CONTROL LARVAE **Group 1A**, eg Mesurol® spray (methiocarb) **Group 4A**, eg Crown® (acetamaprid) **Group 15**, eg Dimlin® Insect Growth Regulator (diflubenzuron) **Group UN**, eg Azamax®, Eco-neem®, Neemazole® (azarachtin) **Bio-control agents (nematodes)**, eg *Steinernema. feltiae*, *S. carpocapsae*	Drench soil, potting mix or compost in which infested plants are growing. Apply when larvae are first seen. Drench media **thoroughly**.

Garden maggots

Scientific name

Minor pests, Order Diptera:

Bibionid fly (*Bibio imitator*)
Garden Soldier fly (*Exaireta spinigera*)

Host range

The adults are nectar-feeding and the maggots feed on decaying organic matter, so are often found in overwet compost heaps.

Description & damage

Gardeners find the wriggling masses of maggots repulsive and usually want to get rid of them immediately!

Bibionid fly. **Female flies** are about **12 mm** long, the middle of the head is red and the rest black. The thorax and the base of the wings are smoky-brown and the abdomen orange. **Maggots** (larvae) are legless, dull gray-brown, and about **14 mm** long when fully-fed. Their more or less cylindrical bodies are covered with a number of protuberances, those near the end of the abdomen being the longest.

Garden soldier fly. **Flies** are about **13 mm** long and have a narrow glossy black body. Wings are black and white, the hind pair being very long. When at rest the legs are spread out and the wings folded together down the back. **Maggots** (larvae) are about **15 mm** long when fully-fed and are dull brown. Their broad, flattened bodies which measure about 3 mm across bear a number of fine hair-like protuberances.

Roots. Where plants are deep rooted, the loosening of the soil by the maggots has little effect on them. However, with **shallow-rooted** plants some injury may occur due to the drying out of the loosened soil.

General. The maggots look unsightly but often do not seem to do much damage to plants. They mostly indicate less than ideal growing conditions.

Diagnostics. The large size of the maggots, their unattractive 'hairiness' and habit of clustering together in overwet areas, make them easy to recognize.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with several generations each season.

'Overwintering'

Various stages depending on the region.

Spread

By adults flying. Probably also by movement of compost from place to place.

Conditions favouring

Overwet compost, excessive rains, poor drainage, organic fertilizers.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan**. There is limited need for an IPM program in this case.
2. **Crop, region.** Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv). Locate breeding areas and be familiar with appearance of maggots, their life cycle and habits.
4. **Monitor** pest and/or damage and **record** results as recommended.
5. **Thresholds.** Have any aesthetic thresholds been established? Do you need to calculate your own threshold?
6. **Action**. Take appropriate action when any threshold is reached or when shallow-rooted plants are affected. Reduce moisture.
7. **Evaluation.** Review program to see if garden maggots were controlled and recommend improvements if necessary.

Control methods

Control of these maggots in the soil or compost is not usually desirable or necessary.

Cultural methods. Reduce moisture in compost and provide adequate drainage.

Sanitation. If it is thought they may be disturbing the roots of shallow rooted plants, their habit of clustering together makes them easy to remove.

Fig. 48. Garden soldier fly (*Exaireta spinigera*).
Left: Adult (fly) about 12 mm long.
Center: Larvae (maggots) about 15 mm long.

ORDER LEPIDOPTERA

Butterflies, moths

NO. SPECIES IN AUSTRALIA

In excess of **20,000 species** in Australia. The **second largest** of the insect orders after the Coleoptera. Some butterflies are listed as endangered species in some states and Butterfly Action Plans have been put in place (Piper 2001). Butterflies are included in the Flora for Fauna project (page 81).

www.ento.csiro.au/education/insects/**lepidoptera**.html
www.brisbaneinsects.com/brisbane_**moths**/index.html
Lepidoptera larvae of Australia http://**nla.**gov.au/**nla.arc-**114644

SOME DISTINCTIVE FEATURES

Moths vary in size more than any other insect group. A **Hercules moth** has a wingspan of **30 cm** while that of a **leafminer** may be only **3 mm**

ADULT

Wings 1. Two pairs large wings. A few moths are wingless.
2. Densely covered with minute overlapping **scales**.

Mouth Mouthparts in the form of an **elongated tube**, **coiled** like a watch spring when at rest. There are a few exceptions.

Eyes Large compound eyes. One occeli above each eye.

As a rule of thumb:

BUTTERFLIES are **day flying** with **clubbed antennae**, **brightly colored**. Wings **vertical** when at rest. There are a few exceptions.

MOTHS are **night flying**, antennae are **other** than clubbed, often feathery in males, often **drab** when colored. Wings **flat** when at rest. There are a few exceptions.

Larvae are commonly known as caterpillars

LARVA

Legs **3 pairs** of legs on **thoracic segments** and up to **5 pairs of unsegmented prolegs** on **abdominal segments**. Prolegs have a ring of fine hooks on the end.

Mouth **Chewing**.

PUPA Often in a **silken cocoon** (moths) usually a chrysalis (butterflies).

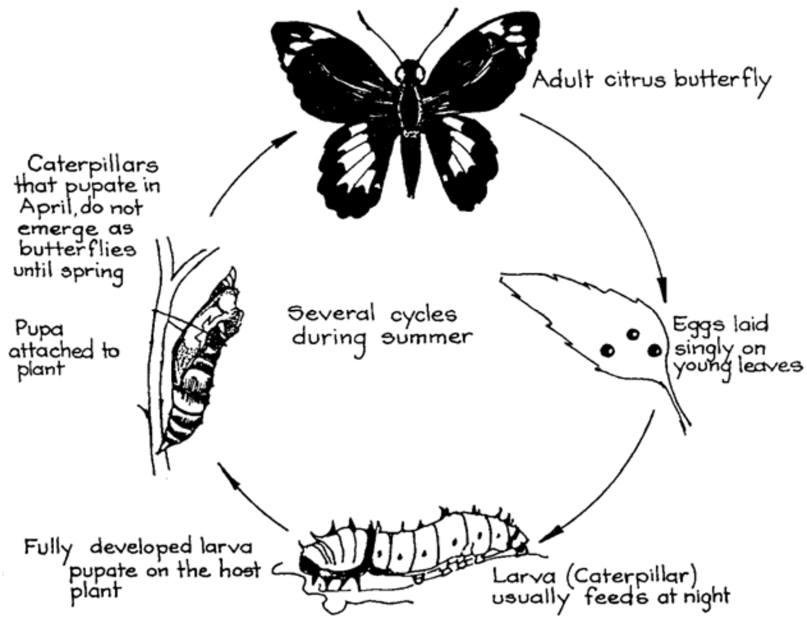
LIFE CYCLE

There is a **complete metamorphosis** - egg, larva (armyworm, bagworm, bollworm, borer, budworm, caterpillar, cluster grub, cutworm, grub, inchworm, looper, 'worm'), pupa and adult.

Large citrus butterfly

Males have a wingspan of up to 120 mm

Many variations, eg codling moth, moth borers, cutworms



METHOD OF FEEDING

ADULT **Feeds only on nectar or other liquids** of flowering plants using a long coiled tube (proboscis). Some adults do **not** feed at all.

LARVA **Chewing mouthparts**, feeds almost exclusively on plant tissue. Vast majority feed on foliage or wood. Some are carnivorous, feeding on other caterpillars and soft-bodied insects, eg ant larvae.

PLANT DAMAGE

Caterpillars eat all plant parts

DIRECT FEEDING DAMAGE

Only the **larvae** (caterpillars) damage plants.

LEAVES
- **Leaves eaten,** eg cabbage white butterfly, citrus butterflies, painted apple moth
- **Leafmining,** eg oak leafminer, azalea leafminer
- **Skeletonization,** eg autumn gum moth, gumleaf skeletonizing moth

FLOWERS BUDS
- **Eaten**, eg painted apple moth, budworms (*Helicoverpa* spp.)

FRUIT
- **Surface chewing damage**, eg lightbrown apple moth
- **'Worm' damage,** eg codling moth, oriental fruit moth, corn earworm (tomato grub)

STEM, BARK ROOTS
- **Borers**, eg oriental fruit moth, callistemon tip borer, fruit-tree borer, Australian goat moth

SEEDLINGS SHOOTS
- **'Grubs', 'worms'** eg cutworms, armyworms

INDIRECT DAMAGE

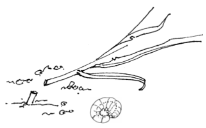
- **Frass** (excreta produced by larvae, anything else left behind), may:
  - **Disfigure** a plant.
  - **Aid** in diagnosing a problem.
- **Formation of structures**, eg bag shelters, case moths, leaf rolls and webbing.
- **May introduce decay organisms**, eg brown rot of stone fruit may be spread by caterpillars of the oriental fruit moth.

INJURIOUS HAIRS/BRISTLES, etc.

- **Larvae and cocoons** may be covered with **hairs that irritate**, eg white stemmed gum moth.

LIST OF SOME SPECIES

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (caterpillars) (not exhaustive)
ADMIRALS, BROWNS (Family Nymphalidae)		
Common brown butterfly	*Heteronympha merope*	Grasses
Meadow argus butterfly	*Junonia villida calybe*	Antirrhinum
Oleander butterfly	*Euploea core corinna*	Oleander
Wanderer butterfly, monarch butterfly	*Danaus plexippus* Migratory in North America but not obviously so in Australia	Asclepiadaceae, eg cotton bushes (*Asclepias* spp.), moth plant (*Araujia hortorum*), *Calotropis gigantean*
BORERS (several families)		
Callistemon tip borer	Lepidoptera	Callistemon, melaleuca
Currant borer moth	*Synanthedon tipuliformis*	Currant, gooseberry, raspberry
Fruit-tree borer	*Maroga melanostigma*	Wide range of trees, shrubs
Small fruit-tree borer	*Cryptophasa albacosta*	Wide range of trees, shrubs
Oriental fruit moth	*Graphiolita molesta*	Stone fruit
Tomato stemborer	*Symmetrischema plaesiosema*	Tomato
Goat moths, wood moths (Family Cossidae)		
Australian goat moth	*Culama caliginosa*	Various trees
Giant wood moth	*Xyleutes cinereus*	Eucalypts
Wattle goat moth	*X. encalypti*	Wattles
Witjuti grub	*Xyleutes* sp.	*Acacia kempeana*

LIST OF SOME SPECIES *(contd)*	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (caterpillars) (not exhaustive)**
	CASE MOTHS, BAGWORMS (Family Psychidae)		
	Saunders' case moth, large bagworm (Qld)	*Oiketicu elongatus*	Eucalypt, teatree, melaleuca, citrus, ornamentals
	Others	*Clania* spp., *Hyalarcta* spp	Teatree, pine, many garden plants eg roses
	CUP MOTHS (Family Limacodidae)		
Larvae have 'stingers'	Chinese junks (larvae)	*Doratifera* spp.	Eucalypt, brush box, apricot, guava
	CUTWORMS, ARMYWORMS, NOCTUIDS, SEMI-LOOPERS (Family Noctuidae)		
	Armyworms	*Leucania* spp., *Spodoptera* spp., *Persectania* sp.	Grasses, cereals
 **Cutworm** damage	Common cutworm, Bogong moth Black cutworm Brown cutworm, pink cutworm	*Agrotis infusa* *A. ipsilon* *A. munda*	Newly sown crops, transplanted seedlings cereals, fodder and field crops, vines, weeds, ornamentals
	Corn earworm, cotton bollworm, tomato grub, tobacco budworm	*Helicoverpa armigera*	Sweetcorn, sorghum, tomato, pea, strawberry, cotton, many other crops
	Native budworm	*H. punctigera*	Tomato, linseed, other plants
	Loopers	*Chrysodeixis* spp.	Wide range, ornamentals, field, vegetable, weeds
	Grapevine moth	*Phalaenoides glycinae*	Vines, fuchsia, *Hibbertia* sp., *Glycine, Gnaphalium*
	Gumleaf skeletonizer	*Uraba lugens*	Eucalypts
	HAWK MOTHS (Family Sphingidae)		
	Australian privet hawk moth	*Psilogramma menophron menophron*	Jasmine, native olive (*Olea paniculata)*
	Convolvulus hawk moth	*Agrius convolvuli*	Convolvulus and other plants
	Grapevine hawk moth	*Hippotion celerio*	Grapes
	Vine hawk moth	*Theretra oldenlandiae*	Grapes, related plants, sweet potatoes
	LEAFBLOTCH MINERS (Family Gracillariidae)		
Moth leafminers may belong to other families, eg silkyoak leafminer (see below)	Azalea leafminer	*Caloptilia azaleella*	Azaleas
	Citrus leafminer	*Phyllocnistis citrella*	All citrus, finger lime.
	Oak leafminer	*Phyllonorycter messaniella*	Oak, beech, chestnut
	Wattle leafminer	*Acrocercops plebeia*	Wattle
	LEAFROLLER MOTHS (Family Tortricidae)		
	Codling moth	*Cydia pomonella*	Pome fruit
	Lightbrown apple moth	*Epiphyas postvittana*	Wide range, fruit trees, citrus, grapes, ornamentals, weeds
	Oriental fruit moth (peach tip moth)	*Grapholita molesta*	Stone fruit, sometimes apples
	Silkyoak leafminer	*Peraglyphis atimana*	Grevillea
	PYRALID MOTHS (Family Pyralidae)		
	Webbing caterpillars, teatree caterpillars	*Catamola* spp., other genera	Wide range, small leafed Myrtaceae, eg *Astartea, Leptospermum, Kunzea, Melaleuca, Thryptomene*
	Cedar shoot caterpillar, cedar tip borer	*Hypsipyla robusta*	Bores into tips of red cedar (*Toona australis*)
	Pasture webworms	*Hednota* spp.	Cereals and pasture grasses
	European corn borer	*Ostrinia nubilalis*	Overseas, maize, other crops
Not known in Australia, monitored in northern Australia	Redbanded mango caterpillar	*Deanolis sublimbalis*	Mango fruit, other fresh fruit
Biological control agents	Cactoblastis	*Cactoblastis cactorum*	Imported to biologically control prickly pear
	Waterhyacinth moth	*Sameodes albiguttalis*	Water hyacinth

LIST OF SOME SPECIES *(contd)*	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (caterpillars) (not exhaustive)**
	LOOPERS, INCHWORMS (Family Geometridae)		
	Autumn gum moth	*Mnesampela privata*	Eucalypts
	Grevillea looper	*Oenochroma vinaria*	Grevillea
	STORED GRAIN MOTHS (several families)		
	Angoumois grain moth	*Sitotroga cerealella*	Stored grain (**primary** pest) – attacks sound grain
	Indian meal moth	*Plodia interpunctella*	Stored grain (**secondary** pest) – attacks damaged grain
	SWALLOWTAILS (Family Papilionidae)		
	Large citrus butterfly, orchard butterfly	*Princeps aegeus*	Plants belonging to the Rutacae family eg citrus, *Acronchia, Halfordia*, native limes, also *Choisya, Zieria,* wilga
	Small citrus butterfly	*Eleppone anactus*	
Endangered butterflies. These have been given protection under the **Fauna Conservation Act**	Cairns birdwing butterfly	*Triodes euphorion*	Native *Aristolochia tagala* *A. deltantha,* introduced *A. elegans*
	Richmond birdwing butterfly	*T. richmondius*	Native vine (*A. praevenosa)*
	Ulysses butterfly	*Princeps ulysses joesa*	*Euodia elleryana, E. bonwickii,* introduced citrus.
	TUSSOCK MOTHS (Family Lymantridiidae)		
Causes severe irritation	Mistletoe browntail moth	*Euproctis edwardsii*	Mistletoe (on eucalypts only)
	Painted apple moth	*Teia anartoides*	Wide range of native plants, ornamentals, fruit trees, vegetables, weeds
	White cedar moth	*Leptocneria reducta*	White cedar
Not known in Australia	Asian gypsy moth	*Lymantria dispar*	Ornamental plants, deciduous trees, eucalypts, pine, fruit trees
	OTHERS (Many families)		
	Cabbage moth	*Plutella xylostella*	Brassicaceae, flowers, vegetables, weeds
	Cabbage white butterfly	*Pieris rapae*	Brassicaceae, flowers, vegetables, weeds
	Emperor gum moth	*Opodiphthera eucalypti*	Wide range of native trees, also citrus, olive, pepper trees.
	Potato moth, tobacco leafminer (Qld)	*Phthorimaea operculella*	Potato, tomato, tobacco, related weeds, eg thornapple
	Processionary caterpillar, bag-shelter moth	*Ochrogaster lunifer*	*Acacia pendula*
	Scribblygum moth	*Ogmograptis scribula*	Scribblygum
	Silkworm	*Bombyx mori*	Mulberry
Endangered moth	Golden sun moth	*Synemon plana*	Grasslands
Cause severe irritation	Whitestemmed gum moth	*Chelepteryx collesi*	Eucalypts. Do not handle caterpillars, pupae, etc

Fig. 49. Flora for Fauna is an initiative of the Nursery and Garden Industry **(NGIA)** and is supported by the Natural Heritage Trust. The program identifies and promotes a range of plants that are known to attract, feed or shelter Australia's native fauna, initially birds and butterflies, and to a lesser extent frogs, lizards, possums, fruit bats, etc. A **Flora for Fauna** plant list is available on their websites

www.floraforfauna.com/

Flora For Fauna

Individual native plants will be labeled with the Flora for Fauna label. Some will also be labeled:

Plant for Butterflies

BUTTERFLIES AND MOTHS

Summary - Some exceptions

	SOME DISTINCTIVE FEATURES	PLANT DAMAGE (caterpillars)
BUTTERFLIES 	**ADULT** **Flight** Day flying **Colour** Bright **Antennae** Clubbed **Wings** Vertical when at rest **LARVA** **Legs** **3 pairs legs** on the **thorax** and up to **5 pairs prolegs** on the **abdomen**	**DIRECT FEEDING DAMAGE.** **LEAVES** Leaves eaten, eg citrus butterflies **FLOWERS BUDS** Chewing damage, eg grass blue butterfly **FRUIT** 'Worm' damage, eg pea butterfly **SEEDLINGS SHOOTS** Chewing damage, eg cabbage white butterfly **INDIRECT DAMAGE.** • Frass, eg cabbage white butterfly
MOTHS 	**ADULT** **Flight** Nightflying; moths are attracted to lights at night; a few day-flying moths are brightly coloured, eg grapevine moth **Colour** Often drab coloured **Antennae** Not clubbed **Wings** Wings flat when at rest **LARVA** **Legs** As for butterflies	**DIRECT FEEDING DAMAGE.** **LEAVES** Leaves eaten, eg cup moth Leafmining, eg oak blotch miner Skeletonization, eg gumleaf skeletonizer **FLOWERS BUDS** Chewing damage eg corn earworm **FRUIT** 'Worm' damage, eg codling moth Surface chewing, eg lightbrown apple moth **STEMS BARK** Borers, eg fruit-tree moth borer **SEEDLINGS SHOOTS** Chewing damage, eg cutworms **INDIRECT DAMAGE.** • Frass, eg all caterpillars • Formation of structures, eg case moths • Introduction of decay organisms, eg oriental fruit moth

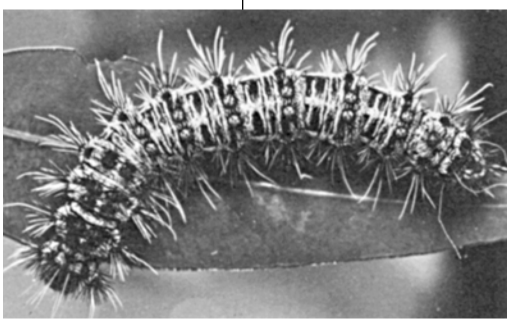


Fig. 50. Whitestemmed gum moth caterpillar (*Chelepteryx collesi*). Photo©NSW Dept of Industry and Investment.

Fig. 51. Painted apple moth caterpillar (*Teia anartoides*). Photo©NSW Dept of Industry and Investment.

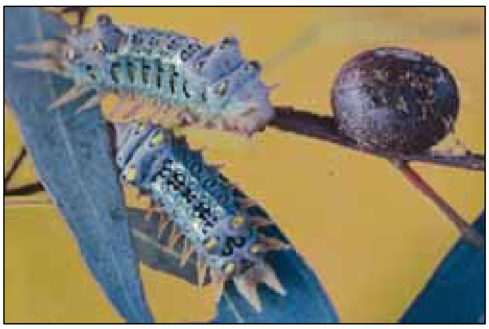


Fig. 52. Cup moth caterpillar (*Doratifera* spp.) and its cup-shaped cocoon with lid. Photo©CIT, Canberra (P.W.Unger).

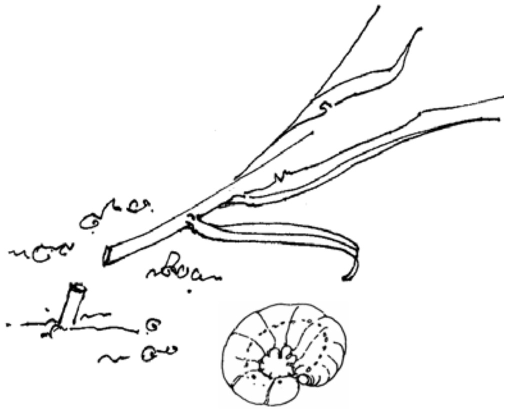


Fig. 53. Cutworm damage (Family Noctuidae).
Left: **Stem** of seedling chewed off just above ground level during the night. They also chew holes in leaves, buds and fruit near the ground.
Right: **Cutworm** (caterpillar) is smooth-bodied, 30-40 mm long at maturity and may be olive-green to brown or almost black. When disturbed they quickly curl up. Cutworms hide in soil near damaged plants during the day.

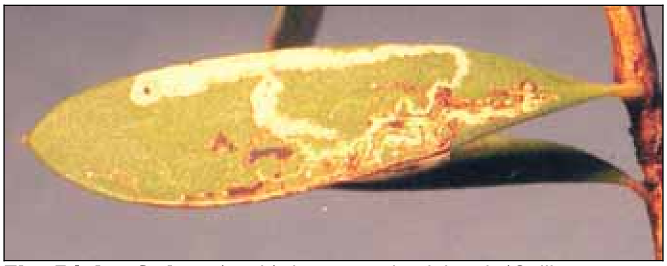


Fig. 54. Leafminer (moth) damage to bottlebrush (*Callistemon* spp.) leaves. Note meandering mines made by the larva feeding between the upper and lower leaf surfaces. Leafmining insects tend to be host specific and may attack both exotic and native plants.
Photo©CIT, Canberra (P.W.Unger).

Fig. 55. Lightbrown apple moth (*Epiphyas postvittana*).
Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x 4
1. Group of eggs laid on leaf
2. Caterpillar, slender, green; when disturbed it wriggles and drops down on a silken thread. It feeds on buds, flowers and leaves in protected places by webbing or rolling leaves or flowering parts together
3. Pupa
4. Adult moth, adults are bell-shaped and vary in color. Females are pale about 20 mm long, males are smaller and show variable colour patterns

Actual size

5. Eggs on leaf
6. Caterpillar on citrus leaf
7. Empty pupal shell from which moths have emerged
8. Adult moth resting on leaf
9. Apple showing injury by caterpillar feeding on the surface
10. Caterpillar damage to citrus leaf

Cabbage white butterfly

An example of a leafeating caterpillar

Scientific name

The introduced cabbage white butterfly (*Pieris rapae*, Order Lepidoptera) is the **most serious** economic butterfly pest in Australia. Its status as a pest varies depending on the crop and the region.

Host range

Butterflies visit a wide range of flowers to feed on nectar. Caterpillars feed on Brassicas (crucifers) and some other species.
Ornamentals, eg stock, wallflower, geranium, mignonette, nasturtium, spider flower (*Cleome*).
Vegetables, eg broccoli, cabbage, cauliflower, Brussel sprouts, radish, mustard, kale and turnip.
Field crops, eg canola, rape.
Weeds, eg shepherd's purse, wild mustard.

Description & damage

Butterflies, although popularly referred to as 'white' butterflies, are usually a general gray-white and have a wingspan of **40-50 mm**. Hindwings beneath are yellow and the forewings are paler. Females have 2 black spots on the upper surface of each forewing, while males have only one spot. Both sexes have one black spot on each hindwing.
Larvae (caterpillars) are velvety green, covered with fine short hairs **20-30 mm** long when fully grown with a faint yellow stripe down the back and along each side. They are well camouflaged, their color closely resembles that of the plant on which they are feeding. Caterpillars generally feed at night and frequently rest during the day with their bodies extended along leaf midribs and are not readily seen. Tell-tale droppings often reveal the location of caterpillars. **Pupae** are about **18 mm** long, light gray, yellow or green and are attached to the host plant or some nearby object.

Leaves/heads. **Young** caterpillars feed mainly on leaf **undersurfaces** while older caterpillars feed from the **uppersurfaces** and eat large irregular holes from the outer leaves of broccoli or cauliflowers. Greenish-brown pellets of excrement are caught in the angles of leaves. Only leaf ribs and veins of seedling leaves may be left.

General. So much of the leaf tissue is generally eaten by these caterpillars that the growth of plants is seriously interfered with and the heads of cabbages or cauliflowers are stunted or do not form at all. Leafy vegetables are rendered unfit for human consumption.

Diagnostics. Do not confuse **damage** with that caused by:

- Other caterpillars seen on the plant or on the ground which attack brassicas, eg cabbage moth, cluster caterpillar, diamondback moth, etc. Some are more damaging than others. Different species vary greatly in size. **Keys** assist identification of caterpillar pests of brassicas.
- Snails and slugs which chew holes, leave snail droppings and slimy glistening trails.
- Bird damage, eg silver eyes, which feed on seedlings.
- Over-mature cabbages which split overnight.
- Caterpillar **droppings** of various species can be found under infested plants.
- If still unsure seek advice.

Pest cycle

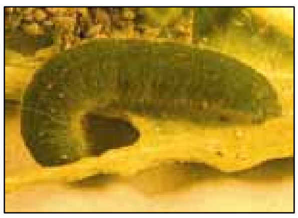
There is a **complete metamorphosis** (egg, larva, pupa and adult), with at least 2 generations each season. Females lay pale yellow eggs singly, usually on the **undersides of the outer leaves**, which provide food for young caterpillars. When fully grown they pupate on the food-plant, some nearby object, or even on debris on the ground. The pupa is attached by its tail to a silken pad; its body is supported by a fine silken girdle around the middle. Females may live for up to 4 weeks during which time they lay several hundred eggs.

Fig. 56. Cabbage white butterfly (*Pieris rapae*).
Photo©NSW Dept of Industry and Investment (E.H.Zeck).

1. Egg (x10)
2. Larva or caterpillar (x2.5)
3. Pupa or chrysalis (x2.5)

Actual size

4. Eggs on leaf
5. Larva or caterpillar
6. Pupae attached to plant
7. Adult butterfly



‘Overwintering’

Usually in the pupal stage which is attached by its tail to the food-plant or nearby object.

Spread

- By butterflies flying assisted by wind, strong fliers may be found many kilometers from host plants.
- Movement of infested host plants carrying eggs, caterpillars or pupa.

Conditions favoring

- Warm weather at any time of the year.
- Most active in spring/early summer, autumn.

Management (IPM)

Best practice kits which incorporate Lucid™ keys for diagnosing problems in *Brassica* vegetable crops and linked to best practice management strategies are available for commercial crops.

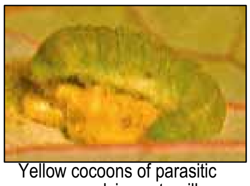
1. **Obtain/prepare a plan** that fits your situation. **IPM** programs are available for caterpillars and aphids on commercial Brassica crops. Obtain local information.
2. **Crop, region. IPM** management programs are available and vary with the region and the particular crop, eg broccoli, cauliflower cauliflower or cabbage.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** the crop regularly as recommended and record results, eg
   - **When and how often** to monitor, eg weekly.
   - Stage of **host** development, eg seedling to 5 cm head, 5-10 cm head. Number of plants inspected.
   - Stage of **pest** development, eg egg, caterpillar, adult. Also monitor **beneficial** insects.
   - Extent of pest **damage**.
5. **Threshold** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic? Do you need to calculate your own threshold? Will it be different for each variety of Brassica and for each growth stage?
6. **Action.** Depends on decided threshold, especially to **seedbeds** and in the field. Home gardeners usually control caterpillars when they are first observed.
7. **Evaluate IPM** program to see how well it worked. Review records of monitoring, threshold, spray applications, release of bio-control agents, etc, for success of treatment and future **IPM** improvements.

Control methods

Sanitation.

- If only a few plants caterpillars can be hand picked, but they are green and hard to find.
- Remove weed hosts, keep crops weed-free.
- Destroy, eg plough or dig in, infested crop plant material to prevent development of the pest.

Biological control.



Yellow cocoons of parasitic wasps on dying caterpillar.

- **Natural controls**.
  - **Many parasitic and predatory** insects, birds, spiders, virus, bacterial and fungal diseases attack eggs, caterpillars, pupae and butterflies, reducing caterpillar numbers but not economic control.
  - **Some companion plants**, eg dill, are reputed to attract parasitic wasps; sage is reputed to repel the cabbage white butterfly.
- **Introduced wasp parasites**, eg
  - **CWB** pupal parasite (*Pteromalus puparum*).
  - **CWB** parasite (*Cotesia glomerata*).
  - *Apanteles glomeratus* and *A. rubecula* parasitise caterpillars. Their cocoons are seen on fully grown caterpillars which stop feeding and die (see above).
- **Biocontrol agents for purchase** eg
  - ***Trichogramma* wasps** parasitize **CWB** eggs.
  - **Dipel**® (*Bacillus thuringiensis* ***(Bt)***) is a bacterium which is eaten by young caterpillars feeding on leaves. A toxin is released which kills **CWB** caterpillars. It has short residual activity but is slower acting than chemical insecticides. Caterpillars may take several days to die so it must be applied when caterpillars are small. It is **not** suitable for emergency treatment. It is a registered pesticide and marketed under a range of trade names (see below).

Resistant varieties.

- All brassicas seem to be susceptible, but red cabbage has fewer of the taste components which attract adult butterflies. **CWB** feet carry hairs that allow it to **recognize chemicals** in the foliage on which it alights; it lays a single egg underneath a susceptible leaf.
- Overseas, some Brassicas may be bred to produce ***Bt*** avoiding the need to spray.

Pest-tested planting material.

- Ensure purchased seedlings are caterpillar-free!

Physical & mechanical methods.

- In severe infestations home gardeners can place light fine woven mesh or other material over rows of seedlings to exclude butterflies. Seedlings grow and lift up the mesh. Many also provide protection from sun, light frosts and hail. Ensure adequate light penetration and air circulation.
- **Screen** greenhouse vents to exclude butterflies.

Insecticides.

- Many insecticides are registered to control **CWB** caterpillars. Thoroughly spray to penetrate foliage and cover **leaf undersurfaces**.
- Control caterpillars while they are small. Older ones are less susceptible and may require application of synthetic insecticides.
- **Croplife Australia Resistance strategies** are on labels and should be carefully followed.

Table 7. Cabbage white butterfly – Some insecticides and bio-control agents.

What to use?	When and how to apply?
FOLIAGE APPLICATIONS **Group 1A**, eg carbaryl (not on food-producing plants in home gardens) **Group 1B**, eg Orthene® (acephate); Malathion® (maldison) **Group 2B**, eg Regent® (fipronil) **Group 3A**, Decis® (deltamethrin); Mavrik® (tau-fluvalinate); Sum-alpha®, Flex® (esfenvalerate) **Group 5**, eg Entrust®, Success®, Tracer® (spinosad) **Group 6A**, eg Proclaim® (emectin) **Group 11**, eg Dipel® (*Bacillus thuringiensis* subsp. *kurstaki*), Xentari® (*Bt* subsp. *aizawai*) **Group 13**, eg Secure® (chlorfenapyr) **Group 21B**, eg Derris® Dust (rotenone) **Group 28**, eg Belt® (flubendiamide) **Biocontrol agents**, include **Groups 5** and **11** above **Others**, eg garlic oil; chilli/garlic	CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE **Spinosad** is derived from soil bacteria. ***Bacillus thuringensis (Bt)*** is slow-acting. • Apply to small caterpillars. • Stomach poison, caterpillars have to eat it. • Selective, only controls leaf-eating caterpillars. • Generally **several applications** are required.

Corn earworm

Cotton bollworm, tomato grub, tobacco budworm

Scientific name

Corn earworm (*Helicoverpa armigera,* Family Noctuidae, Order Lepidoptera) is said to be the world's worst agricultural pest. It is a **major** pest in NSW, Vic and WA and costs Australian growers more than $200 million each year. Related pests include:

Native budworm (*H. punctigera*)
Cape gooseberry budworm (*H. assulta*)
Indian weed caterpillar (*Heliothis rubrescens*)

Host range

Many different commercial crops, eg
Ornamentals, eg calendula, carnation, dahlia, everlasting, hollyhock, snapdragon.
Vegetables, eg bean, pea, sweetcorn, tomato.
Fruit, eg young apple, peach, strawberries.
Field crops, eg clover, cotton, linseed, maize, soybean, sunflower, pasture, grasses, winter cereals.
Weeds, eg capeweed, deadly nightshade, fat hen, Scotch thistle, stinging nettle.

Description & damage

Moths (adults) are stout, brownish, with a wingspan of about **40 mm**. There are distinctive dark markings on fore and hindwings. Moths hide among foliage during the day and fly at dusk, feed on nectar and lay eggs on young growth. **Eggs** are easily seen as they are about **0.5 mm** in diameter, dome-shaped, flattened at the base and ribbed. They are initially whitish but change to brownish shortly before hatching when the head and body of the caterpillar can be seen.

Fig. 57. Corn earworm, cotton bollworm, tomato grub (*Helicoverpa* spp.). ***Upper:*** Caterpillars (about 40 mm long) boring into sweetcorn cobs; ***Lower:*** Caterpillars boring into tomato fruit. Photo©CIT, Canberra (P.W.Unger).

Caterpillars (larvae, bollworms, budworms, earworms) grow to **40-50 mm.** Initially pale green or cream they change to shades of green, fawn, yellow, or red-brown depending on the foliage on which they are feeding. Brown or black stripes run along the body. Small larvae have bristle-like hairs, large caterpillars are smooth. There is no webbing.

Pupae are brown, about **2 cm** long and are found in soil.

Damage.

- **Young caterpillars** feed on **young leaves** but soon move to **buds, flowers, young fruit or seeds** and eat their way in.
- **Older larvae** burrow into **flower buds and fruit**. Caterpillars may wander from fruit to fruit. Entry holes of tiny caterpillars are easily over-looked but as the caterpillars grow, entry holes are bigger and more easily seen (Fig. 57).
- **Damage** may continue **postharvest**.
- In the laboratory caterpillars can eat through plastic.

Diagnostics. Holes in buds and flower heads indicate infestation. Caterpillars are distinctive.

- State fact sheets assist with identification.
- It may be necessary to seek specialized help to distinguish corn earworm from native budworm and other caterpillars (page xiv).
- To **confirm** that *H. armigera* is present and not *H. punctigera* (which is easily controlled with insecticides), CSIRO has developed a test which involves squashing eggs and larvae on to Lepton™ membranes, a particular colour change indicates *H. armigera.* Mainly used by diagnostic services.
- Scientists are sequencing the moth's genome (unraveling its 14,000 genes) which they think will discover its weaknesses, and the development of specially designed insecticides.

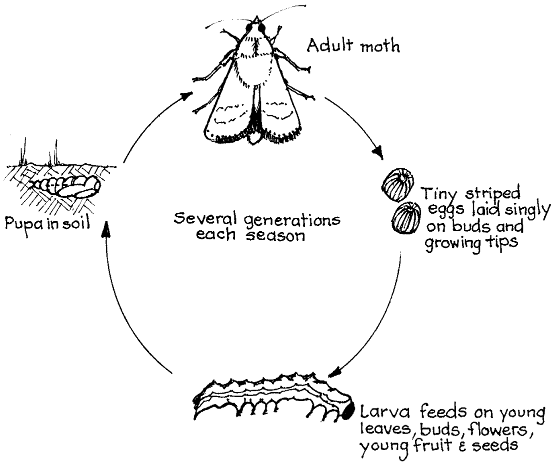


Fig. 58. Corn earworm life cycle.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with several overlapping generations each growing season. In warmer areas there are 10 or more generations/year. Each female moth lays about 1000 eggs which are white, dome-shaped, finely striped about 0.5 mm across, singly on upper parts of plants, eg growing tips, sepals, petals, young fruits and flower buds. Eggs change to yellow then brown prior to hatching. When fully grown larvae leave the host and burrow 8-10 cm below the soil surface to pupate. Pupal stage may be as long as 2-3 weeks in warm weather and up to 6 weeks in cooler conditions. Life cycle from egg to adult can be about 4-6 weeks in summer or up to 12 weeks in cool weather.

'Overwintering'

As pupa in soil. Moths do not emerge from pupae formed in mid to late autumn until the following spring and early summer. In cooler areas they have fewer generations. The pupae enter a **diapause** (resting state) in autumn and adult moths emerge in spring.

Spread

Moths can fly only for short distances up to 50 meters but can be carried up to 100 km, by wind to new hosts in bloom. They are attracted to lights. Movement of infested produce.

Conditions favoring

- Warm, moist, weather. Damage may be severe and widespread during periods of good summer rainfall when moisture stimulates emergence of moths and food plants are plentiful. Long dry cool spells delay emergence of moths.
- Amount of damage varies from year to year.
- Corn earworm *(H. armigera*) is more common in coastal, sub-tropical and northern areas. Native earworm (*H. punctigera*) is widely distributed throughout the inland and southern states.
- Usually there are 2 main periods of infestation, spring-early summer and autumn. Most common in late summer to autumn.
- Plentiful hosts starting to flower and fruit.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation. Growers should obtain local information on scouting and recommendations on control.
2. **Crop, region**. Recognize variations and regional susceptibility. **Resistance and Best Management Strategies** for *Helicoverpa* have been developed for some crops, eg cotton, sweetcorn.
3. **Identify** the exact *Helicoverpa* species causing the damage. Consult a diagnostic service if necessary (page xiv). Fact sheets for your crop.
4. **Monitor** pest and/or damage and **record** results as recommended (page 39), before deciding to use a biological or chemical insecticide or release beneficials.
   - Monitor **adults** using **pheromone traps** to detect presence of moths and indicate population size.
   - Monitor for **very small larvae** and **eggs** regularly at the appropriate times depending on weather, especially after heavy rainfall.
   - Trap crops associated with cotton crops can be used for predicting *Helicoverpa* populations.
5. **Thresholds** which differ, depending on the crop and/or crop value, precise species of caterpillar, region, season, climate, planting date, have been developed for some crops. How much damage can you accept? Remember that the threshold is the break even point where the cost of control equals the cost of likely damage, so you are **no worse of** if you spray and no worse of if you don't.
6. **Action**. Spraying thresholds are unlikely to be more than guidelines for timing sprays. Examine crops at least twice per week during danger periods. Before deciding to spray consider:
   - Likely extent and severity of infestation.
   - Ability of crop to either tolerate caterpillar damage without any significant loss or to replace leaves or fruiting parts lost to caterpillars.
   - Estimated value of likely loss if crop is left untreated against anticipated cost of treatment.
   - Only spray eggs and very small caterpillars (up to 5 mm long). Larger caterpillars are unlikely to be controlled.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required based on records of infestation in the current and previous seasons. Seek advice if necessary.

Control methods

Cultural methods. Cultivation will damage pupae, survivors may be eaten by birds, mice or earwigs. Hot wet conditions favour disease in larvae and may sharply reduce populations. Heavy rainfall may wash eggs off leaves; heat may kill up to 50% of the eggs and larvae.

Sanitation. Attack in corn cobs can be prevented by cutting the tips off cobs and the silks after the latter are brown and beginning to dry out. For small infestations caterpillars can be hand-picked off the plant. Remove alternative weed hosts. Destroy infested plant material and debris to prevent development of the pest.

Biological control.

- **Natural controls** are of limited effect:
  - **Predators** feed on eggs and larvae. Most abundant predators are birds, ladybird beetles, pirate bugs, black mired bugs and spiders which eat about 60% of eggs on unsprayed plants. **Night stalker spiders** are season-long predators of *Helicoverpa* eggs on cotton. **Ants** are early season predators of *Helicoverpa* eggs at the edges of cotton fields in Australia and in the USA are being considered for the biological control of insect pests of cotton.
  - **Parasitic** wasps and flies parasitize eggs, larvae and 'overwintering' pupae.
  - **Diseases** (viral, bacterial, fungal) infect caterpillars and are favoured by hot wet conditions. Some myco-insecticides (based on fungi) are being researched for commercial use against *Helicoverpa* spp.
- **Commercially available** agents include:
  - **Parasitic wasps** (*Trichogramma pretiosum*). Parasitized eggs may be purchased and released. Eggs attacked by *Trichogramma* turn black 3-4 days of attack. *Trichogramma* can be:
    - ❑ **Encouraged** in crops by avoiding broad spectrum insecticides or using pesticides **not** toxic to *Trichogramma* www.goodbugs.org.au/
    - ❑ **Purchased**. *Microplitis* wasps also parasitize larvae. List of suppliers www.goodbugs.org.au/
    - ❑ Released after *Helicoverpa* eggs have been **collected** from sorghum and maize crops and assessed for levels of parasitism.
  - **Food attractants.** Natural enemies in bush around crops can be attracted to the crops by **Envirofeast**® (yeast-based) which attracts > 20 species of beneficial insects into cotton crops to feed on *Helicoverpa* spp. For Envirofeast to work effectively a source of beneficial insects or a 'refuge' to draw them from is essential.

– **Diseases**
- **Dipel**®, (*Bacillus thuringiensis* (***Bt***), a bacterium which produces a toxin that kills caterpillars. It is marketed as an insecticide. Small caterpillars are easier to kill.
- **Gemstar**® (*Helicoverpa* virus) may be applied by commercial growers of cotton, sorghum, chickpea. Slow-acting.

– **Trapping moths**
- **Moth attractants. Magnet**® (lure which is a blend of plant volatiles attractive to insects and feeding stimulants plus an insecticide sold separately) attracts *Helicoverpa* moths which are killed when they contact or ingest it, preventing egg laying, reducing the need for insecticides. Other products are being researched. Less than 2% of the crop area may need to be treated. Other products are being researched for use in Australia, eg **BioATTRACTHeli** (attractant which consists of kairomones and sugar feeding stimulants) attracts adult *Helicoverpa*, armyworm and certain other moth pests; when combined with an insecticide registered for that crop, reduces moth numbers.
- **Trap cropping** is an option for area-wide management of *Helicoverpa* on some crops, eg cotton. Moths are attracted to particular trap crops, eg chickpeas, where they can be destroyed. Precise strategies depend on whether the trapping is carried out in spring or summer.

Resistant/tolerant varieties.

- **Genetically engineered plants** reduce the need for spraying.
  - **Ingard**® **cotton** (***Bt*** cotton), engineered to contain an insect-specific toxin produced by ***Bt***, was released in 1997. *Helicoverpa* caterpillars feeding on **Ingard cotton** will die. Cotton varieties are now available which not only incorporate the ***Bt*** genes but also genes for herbicide resistance (Roundup Ready), and resistance to *Fusarium* and other diseases (Bollgard II). Beneficial insects, mammals and birds are not affected and there has been a 50% reduction in pesticide use.
  - **Refuge crops** are used in the cotton industry to help prevent *Helicoverpa* resistance to ***Bt*** cotton (genetically modified). Susceptible moths in these refuge crops can mate with resistant moths from the ***Bt*** cotton crop, diluting overall resistance levels. Refuge crops can also support beneficial insects, and secondary pests of cotton.
  - **Other hosts** are being researched so that virus particles can be synthesized in leaves to control *Helicoverpa* spp.

Pest-tested planting material.

- Seedlings and cuttings may carry eggs and very small caterpillars, soil may support pupae.
- Only plant pest-free seedling and cuttings.

Physical & mechanical methods.

- Screen vents in greenhouses to exclude moths.
- Cut off infested tops of corn cobs after harvest before marketing.

Insecticides.

- ***Helicoverpa* Resistance Management Strategies** have been developed. Check label. *H. armigera* has developed resistance to many insecticides, eg carbamates, pyrethroids, etc.
  - **CropLife Australia Resistance Strategy.** In some areas certain insecticides may only be used at certain times of the year on some crops.
  - Despite increasing difficulty in managing *H. armigera* with conventional chemical insecticides due to **resistance** problems and the increasing public concern about environment safety, chemical insecticides continue to be the most widespread commercially used method of controlling *Helicoverpa* spp.
- **To preserve beneficial insects** avoid using insecticides early in the season or use selective materials such as ***Bt***.
- **Number and frequency** of sprays depends on duration and intensity of egg laying and weather, particularly temperature.
- **Systemic insecticides** are not particularly effective against caterpillars.
- **Small caterpillars** are **easier to kill** when using Dipel®. Where large caterpillars (> 13 mm long) or large numbers of caterpillars are feeding consider applying a synthetic insecticide.
- **Control** *Helicoverpa* caterpillars when they are about to **emerge from the eggs** (black-brown in colour) before they can cause much damage. Once they are sheltered they are difficult to contact with insecticides.
- **Thorough spray penetration** of foliage is essential for good control.
- **Other research options** under investigation include applying **semio-chemicals** (behaviour modifying chemicals) to cotton plant surfaces. Improving the effectiveness of spray oils.

Table 8. Corn earworm – Some insecticides and bio-controls agents.

What to use?	When and how to apply?
FOLIAGE SPRAYS	
Group 1A, eg carbaryl (not on food-producing plants in home gardens)	
Group 1B, eg Rogor® (dimethoate); Orthene®, Tracer (acephate)	
Group 3A, eg Cymbush® (cypermethrin); Mavrik® (tau-fluvalinate); pyrethrins; Ambush® (permethrin); Baythroid®, Bullock® (alpha-cyfluthrin); Talstar® (bifenthrin); Decis® (deltamethrin); Karate® (lambda-cyhalothrin)	
Group 5, eg Entrust®, Success®, Tracer® (spinosad)	
Group 6, eg Affirm®, Proclaim® (emamectin)	
Group 11, eg Dipel®, Costar® (*Bacillus thuringiensis* various strains); **INGARD** cotton	CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE
Group 13, eg Secure® (chlorfenapyr)	
Group 19, eg Opal® (amitraz)	ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE
Group 21B, eg Derris® Dust (rotenone)	
Group 22A, eg Steward® (indoxacarb)	
Group 28, eg Belt® (flubendiamide)	
Spray oils, eg Canopy® (paraffinic oil)	Steward® (indoxacarb) may temporarily affect beneficial insects but populations quickly recover.
Biocontrol agents, include Gemstar®, Vivus® (*Helicoverpa* virus); see also **Groups 5** and **11** above	
House & Garden Sprays, eg bioallethrin, bioresmethrin	Biocontrol agents can be used to kill caterpillars with minimal impact on beneficial insects

Codling moth

An example of an internal-feeding caterpillar in fruit

The codling moth is the **key pest** of pome fruit in eastern Australia. Unless effective control measures are applied the total crop may be lost.

Scientific name

An introduced moth (*Cydia pomonella,* Order Lepidoptera).

Host range

Ornamentals, eg crabapple.
Fruit and nuts, eg apple, pear, quince, nashi. Also uncommonly, walnut, stone fruits, persimmon, pomegranate and hawthorn.

Description & damage

Moths (adults) when at rest with wings folded are brownish-gray in general appearance and about **12 mm** long. On closer examination, the fore part of the wing is found to be pale grayish-brown with faint narrow cross stripes. The rest of the forewing is dark chocolate brown. Metallic glints can be seen in the color pattern when the moth is examined under a hand lens. **Caterpillars** (larvae) are **12-20 mm** long when fully grown, are cream to pinkish in colour with a brown head. **Cocoons** are tough, white and stick firmly to the bark of the fruit tree. **Pupae** are dark, orange-brown and about **1 cm** long.

Damage to fruit. Only the fruit are damaged. In unprotected crops, caterpillars may tunnel into 50-100% of the fruit on a tree.

- The tiny caterpillar enters the fruit mainly near the calyx end. More damage occurs when they leave to pupate. If the fruit is split open tunnels are seen to run to the core and seeds on which the caterpillar feeds. Caterpillars tend to be cannibalistic so that usually only one caterpillar is found in the center of each infested fruit.
- When the caterpillar is fully grown, it tunnels to the surface of the fruit and emerges through a round exit hole.
- Damage on the outside is visible as small holes or punctures (Fig. 59). Later the holes become more obvious and masses of black frass protrude usually with gummy exudate.
- Sometimes, 'stings' occur on the surface of the fruit where a caterpillar has died after entering, or failed to enter the fruit successfully.
- Damaged fruit often drop prematurely.

Diagnostics.

- Codling moth larvae are the **only** caterpillars that commonly tunnel to the core of apples and usually there is only one caterpillar per fruit.
- Do not confuse with caterpillars of the oriental fruit moth **(OFM)** which only rarely attack pome fruits or with **fruit fly maggots** which are much smaller and numerous.

Fig. 59. Codling moth (*Cydia pomonella*). External signs of attack by caterpillars Photo©NSW Dept of Industry and Investment (W.G.Thwaite).

Fig. 60. Codling moth (*Cydia pomonella*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

1. Eggs (about x4).
2. Caterpillar (about x3).
3. Cocoon spun in crack in bark cut open to show pupa.
4. Adult moths in resting position (about x4).

Actual size

5. Eggs on leaf.
6. Cocoon showing empty pupal skin from which a moth has emerged.
7. Moths resting on leaf.
8. Apple showing damage caused by the caterpillar feeding inside

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult), with 2 generations each season and often a partial 3rd generation (Fig. 61 below). Multiple generations in warmer districts. The 1st (spring) generation moths start to emerge early in October, reaching a peak about mid-November. Eggs are laid on leaves and fruit at dusk when the temperature is **16°C or higher** and the air is calm. They hatch in 5-10 days, young caterpillars soon entering into fruit to feed around the core. They become fully fed in about 4 weeks when they crawl down at night from the fruit to shelter under loose bark, in crevices around the trunk and main limbs to spin cocoons in which they later pupate. They may fall to the ground in infested fruit and then look for stable litter, eg packing cases, on which to pupate. The 1st pupation occurs during the 1st week in December and continues throughout December and January. Moths emerge in about 15 days and reach peak numbers in late January. Larvae from this generation 'overwinter' in a fully fed state in cocoons and pupate in mid-September. A partial 3rd generation sometimes occurs, infesting late varieties in April.

'Overwintering'

Because adult moths are not very mobile, the **main source of infestation** in spring (the 1st brood moths) in an orchard or on a tree is the over-wintering **cocoons** in cracks and under loose bark on trunks, broken limbs, on stable litter on the ground, paling fences, packing cases, etc. A few 'strays' will wander in from surrounding orchards, just as a few of the native population will depart, but their numbers are negligible.

Spread

- By adults flying at dusk. In most orchards female moths will not spread over more than 5-10 trees, but males will fly as far as 180 meters.
- Transfer of fruit infested with caterpillars.
- Transfer of cocoons on packing containers or any other suitable carrier. Because the spread of codling moth to new areas is by the movement of infested fruit (larvae) or fruit boxes (cocoons) or any other suitable carrier, preventing this is an essential part of quarantine.

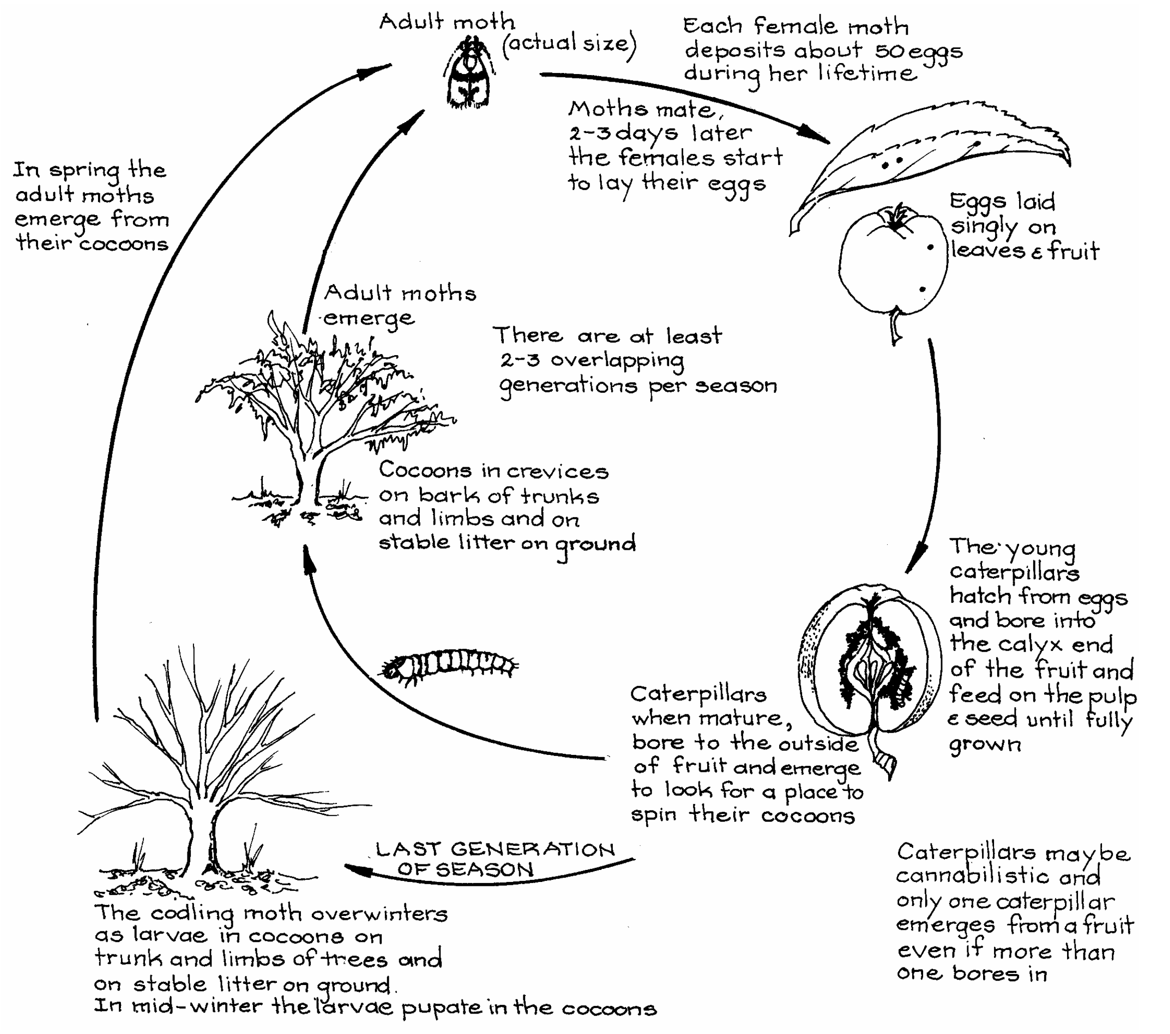


Fig. 61. Pest cycle of codling moth (*Cydia pomonella*).

Conditions favouring

- Warm, dry weather in late spring and early summer speeds development of eggs and larvae. Warm autumns increase risk of late infestation.
- Optimum temperature 28-30°C (cycle 4 weeks).
- Each stage of the life cycle has specific temperature requirements for development, eg
  - Moths do not mate or lay eggs until the temperature exceeds 16°C and air is calm. Moths will not emerge from pupae, take flight or mate at < 16°C.
  - Eggs hatch, larvae feed and grow and pupate at a minimum threshold of 10°C.
  - Adult males fly at a minimum threshold of 13°C.
- Good pupating sites on the tree itself.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** based on your legal obligations in your State/Territory. Growers should obtain local information on scouting and control recommendations.
2. **Crop, region**. Be aware of pest favourable climates, proximity of other susceptible crops, etc.
3. **Identification** of codling moth larvae must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage and record results as recommended. Monitoring offers direct savings associated with the cost of sprays, long term benefits of reducing the numbers of sprays and slows down development of resistance to chemicals.
   - **Orchards without MD** (mating disruption) need pheronome traps or codling moth warning systems (pages 44, 92). Check infestation at thinning time (if present review program).
     - **Monitor male moths.** Synthetic female pheromones are used to attract male moths to sticky traps where they are counted regularly so that the number of routine pesticide applications can be reduced and timing improved.
     - **Early warning systems** have been developed which issue recommendations on the best time to spray based on **codling moth populations** and **daily temperatures** recorded by the grower. The system depends on establishing the first emergence of moths from 'overwintering' sites and then recording daily temperatures. Records are sent to the local Departments of Agriculture/ Primary Industries which enters them into a computer model which gives a prediction of when egg laying will commence and optimum date(s) for spraying with an insecticide.
   - **Orchards with MD** need to be monitored by suitably trained staff or a consultant.
     - **Monitor male moths** with sticky male pheromone traps before moth activity starts so that **MD** dispensers can be placed in orchards at the correct time. However, **MD** interferes with trap readings.
     - **Monitor fruit for damage** by scouting from early December to harvest, depending on district.
5. **Thresholds**. There may be nil quarantine requirement, eg in WA. How much damage can you accept? Take advice.
6. **Action**. Decisions about some methods of control, eg mating disruption (**MD**), need to be made long before monitoring has indicated a need for an insecticide application. Seek expert advice if unsure.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required. Record damage at harvest to help with management decisions for next season.

Control methods

Successful control requires careful hygiene, mating disruption, insecticide selection and application, resistance management and monitoring, etc.
www.**bioglobal**.com.au/

Legislation. Control measures are compulsory under State/Territory legislation such as Plant Diseases Acts or their counterparts which require a grower of apples, pears and quinces in some areas to carry out certain sanitation treatments and to apply a minimum number of pesticide applications.

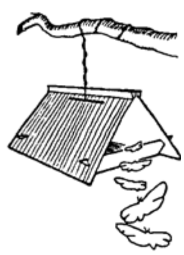
Sanitation. You may be required by **law** to:

- Collect all fallen fruit and remove all infested fruit from trees at intervals **not exceeding 7 days** (for fruit fly the interval is 3 days). Keep ground beneath trees free from long grass and weeds. Treat fruit to be destroyed by boiling, burning or placing in a special insect-proof pit.
- Remove and destroy 'overwintering' sites, eg unwanted trees, unwanted litter and plant debris (boxes, tree props).
- Scrape loose bark and cocoons from the trunk and limbs of the tree during December and again at the end of February and during winter.
- At end of season check bulk bins and other handling equipment for cocoons in cracks and crevices, if found destroy larvae.
- Home gardeners in isolated areas could remove and destroy all fruit as it develops for 1 year.

Biological control/Natural controls.

- **Natural controls** do not appear to reduce codling moth populations significantly.
  - **Codling moth virus** can devastate localized populations of codling moth larvae. This virus has been developed into a commercial product overseas but local trials in Australia have been disappointing.
  - A **parasitic nematode** has shown promise for control of 'overwintering' larvae.
  - **Earwigs and mirid bugs** prey on codling moth eggs but neither gives significant control.
  - **Wasps**, eg *Trichogramma*, parasitize codling moth eggs. In Australia the rate of parasitism is too low for commercial use.
- **Commercial use**. Male moths are attracted to females by strong scent (pheromones).
  - **Female pheromone lures** have been used for decades to **attract male moths** to sticky traps where they are counted regularly. This ensures better timing of insecticide applications, reducing pesticide usage.


Picking up fruit


Monitoring male moths, some traps attract both male and female moths


Mating disruption (tiers are attached to twigs)

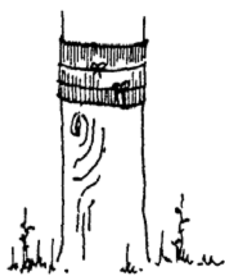

Cocooning sites

Fig. 62. Codling moth (*Cydia pomonella*). Sanitation, biological methods (pheromones for monitoring, mating disruption) and physical methods assist control.

– **Desire traps (InSense Duo Lure)** have both female pheromones (sex scents) that attract male moths and a karimone (food scent) that attracts female moths. Many male and female moths are caught on replaceable sticky pads and fewer eggs are laid. Contact Desire Pest Management: http://**insense**.com.au/products.htm

Desire Codling moth trap. Photo©Insense

– **Mating disruption (MD)** is used in large orchards (pages 44, 91 Fig. 62). The orchard is saturated with synthetic female pheromone emitted from slow-release dispensers (tiers). This prevents male moths from using pheromones emitted from female moths to locate and mate with the females **(confusion strategy)**. However, **MD** interferes with the use of pheromone traps for monitoring moth populations to determine if there is a need to supplement **MD** with other treatments. Like all technologies mating disruption must be managed well. New attractants are being researched.

– **Nematodes**, *Steinernema carpocapsae* (Millenium®) can be applied to 'overwintering' larvae. Timing of application is based on favourable weather conditions. www.**beckerunderwood**.com/

Resistant varieties. All apple and pear varieties seem to be equally susceptible. Late ripening apples may be particularly susceptible.

Plant quarantine.

- **AQIS** (Australian Quarantine & Inspection Service). It is illegal to bring fruit into Australia.
- **Interstate and regional quarantine.**
  – Codling moth does **not** occur in WA. The movement of infested fruit and packing cases is strictly controlled by Interstate and Regional Quarantine Regulations within Australia.
  – **In WA and other areas** where codling moth does **not** occur. If infested fruit is found (an apple or other pome fruit with a frass-filled tunnel reaching to the core) take it to the nearest agricultural office for identification. Fruit from the eastern states must be declared at checkpoints and airports. Monitoring is carried out to detect any incursions.
- **Local quarantine.** As moths only fly short distances do not bring in fruit, fruit cases, etc into isolated properties where codling moth does not occur.

Physical & mechanical methods.

- **In home gardens**, artificial cocooning sites such as bands of clothe or corrugated cardboard tied with wire around tree trunks, allows 'overwintering' larvae to be trapped and destroyed.
- **Exclusion products**, eg 'Apple Pouches' are available for purchase!

Insecticides.

- **Successful codling moth control** with chemical pesticides depends on competent spraying. Since 1 mated female can produce > 1000 **2nd brood** caterpillars, good spraying will not only produce a clean crop, but will reduce the 'overwintering' population in the orchard.
- **Sprays are directed to killing the moths** (not caterpillars which almost immediately burrow into fruit out of reach of pesticides). The aim is to put a thin layer of spray on the upper surfaces of as many leaves and young fruit as practicable. The better the coverage, the more effective will be the spray. When moths alight on leaves and young fruit in the evening, they absorb the chemical through their feet.
- **Some insecticides** used to control codling moth may **kill the natural enemies** of two-spotted mite, woolly aphid and other pests, so that further sprays are required to control these pests, eg carbaryl. Select insecticides which will control codling moth but not affect natural controls and any biological control agents used to control other pests.
- **Some insecticides**, may disfigure some varieties of fruit if applied before, during or shortly after adverse conditions. Check the label.
- **Resistance** to many insecticides used to control codling moth has occurred.
  – Implement sanitation measures.
  – Prune trees to ensure good spray coverage.
  – Check sprayer calibration, get advice if unsure.
  – Use **mating disruption** if the block meets minimum requirements regarding size www.**bioglobal**.com.au/
  – Follow **Croplife Australia** resistance management strategies.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 9. Codling moth – Some insecticides and bio-controls.

What to use?	When and how to apply?
STICKY TRAPS **Used for monitoring** attract **male** codling moths only. **May assist control**. Desire codling moth kits attract both male and female codling moths for one season.	Regular weekly counts provide a reliable means of monitoring population levels ensuring the accurate timing of chemical or non-chemical controls.
MATING DISRUPTION (MD) TIERS Isomate® C Pheromone Insect Confusion Agent Isomate® C-S Pheromone Insect Confusion Agent Isomate® CTT Pheromone Insect Confusion Agent Isomate C/OFM TT Pheromone Insect Confusion Agent Disrupt-CM Mating Disruption Agent	• Suitability depends on size and layout of blocks. Seek advice from district horticulturist if necessary. • May be necessary to supplement **MD** with insecticide and sanitation measures. • Apply dispensers at the recommended times during each season, rate per hectare, height and distribution.
IF PREDATORY MITES ARE BEING USED	• Only use pesticides recommended by the supplier to control codling moth, twospotted mite and other pests.
COVER SPRAYS **Group 1A**, eg carbaryl (not on food-producing plants in home gardens) **Group 1B**, eg Lebaycid® (fenthion), others **Group 3A**, eg Gringo®, Talstar®, various (bifenthrin) **Group 4A**, eg Calypso® (thiacloprid); Sumarai (clothianidin) **Group 5**, eg Entrust®, Success®, Tracer® (spinosad); Delegate® (spinetoram) **Group 7B**, eg Insegar® (fenoxycarb) **Group 18**, eg Mimic® (tebufenozide) **Group 22A**, eg Avatar® (indoxacarb) **Group 28**, eg Altacor® (chlorantraniliprole) **Spray oils**, eg Summer spray oils (paraffinic oil, petroleum oil)	• A minimum number of sprays may be compulsory under legislation. Check. • Follow label instructions for rates, number of applications and interval between applications. Fewer sprays are required if damage was not severe the previous season. Spraying usually commences at petal fall or soon after. • Thoroughly wet every part of foliage and fruit with spray. • **Observe with-holding periods.** • Insegar® is an IGR and prevents eggs from hatching.

Oriental fruit moth, peach tip moth

An example of a tip or shoot boring caterpillar

Scientific name

Introduced moth (*Grapholita molesta,* Lepidoptera). Widespread in southern Australia and coastal Qld. Not known to occur in WA.

Host range

Fruit, eg mainly stone fruits, peach, nectarine, also almond, apricot, plum and cherry and is becoming a more serious pest of nashi, quince, apple and pear. **Ornamental** varieties of these species.

Description & damage

Moths (adults) are mottled brown-grey and **6-7 mm** long when at rest with wings folded. Males are slightly smaller than females. When their wings are outspread they measure about 13 mm across. Moths are inactive during the day and are rarely seen but during late afternoon on warm days they can be seen in flight near the tree tops. Moths are only active in dim light and when the temperature is high enough probably above 18ºC. If these conditions prevail mating followed by egg laying will occur. **Caterpillars** (larvae) when fully grown are nearly **12 mm** long, creamy white or pale pink, with a light brown head. They have a special appendage, the anal comb, a toothed horny plate on the last segment. **Pupae** are cocoons about 15 mm long by 3 mm wide at the center.

Twigs/shoots. The caterpillar usually enters the twig near the tip (and often through the petiole) and tunnels downward for **7-10 cm** causing the twig to wilt, collapse, produce gum and die. An individual larva may attack as many as 3 shoots during a season. When older larvae move from one twig to another, the point of entry into the shoots may be at the axil of a leaf below the tip. Death of the tip of a shoot may cause the buds below to break dormancy and grow resulting in a rosette of shoots. There may be severe damage to twigs.

Fruit. Later generations bore into the fruit as well. Larvae may enter fruit either through the stem of the fruit or where a leaf or small branch touches the fruit (Fig. 63). Fruit can appear perfect on the outside but when cut open numerous feeding burrows can be seen. These tunnels may be filled with brown particles of excreta, similar to codling moth damage to apples.

General.

- **Populations which build up** on growing points in spring invade fruit later in the summer.
- **Damage to growing points** is usually more important in young trees which are being trained.
- **Up to 80% of the crop can be lost** in some untreated **peach** orchards and spread of brown rot is enhanced especially during wet weather.

Diagnostics.

- **Limited** host range.
- **Blackened shoot tips** which may exude blobs of gum are easy to recognize.
- **Fruit** may also be attacked by other caterpillars, eg budworms (*Helicoverpa* spp.), peach and nectarines also by the yellow peach moth and the orange fruitborer, depending on the region. Rarely by codling moth. Expert assistance may be required to differentiate some of these pests. Do not confuse with fruit fly maggots which are smaller (page 68).

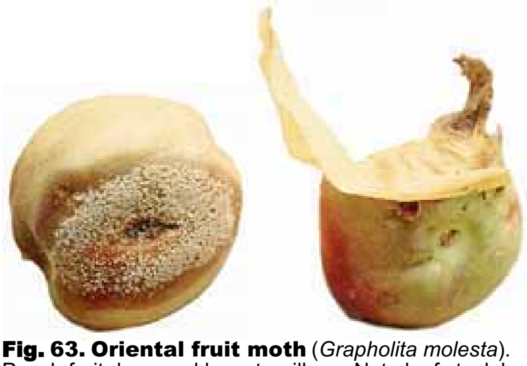


Fig. 63. Oriental fruit moth (*Grapholita molesta*). Peach fruit damaged by caterpillars. Note leaf stuck by webbing to fruit and the small caterpillar on the surface. Brown rot infection may develop around entrance holes. Photo©CIT, Canberra (P.W.Unger).

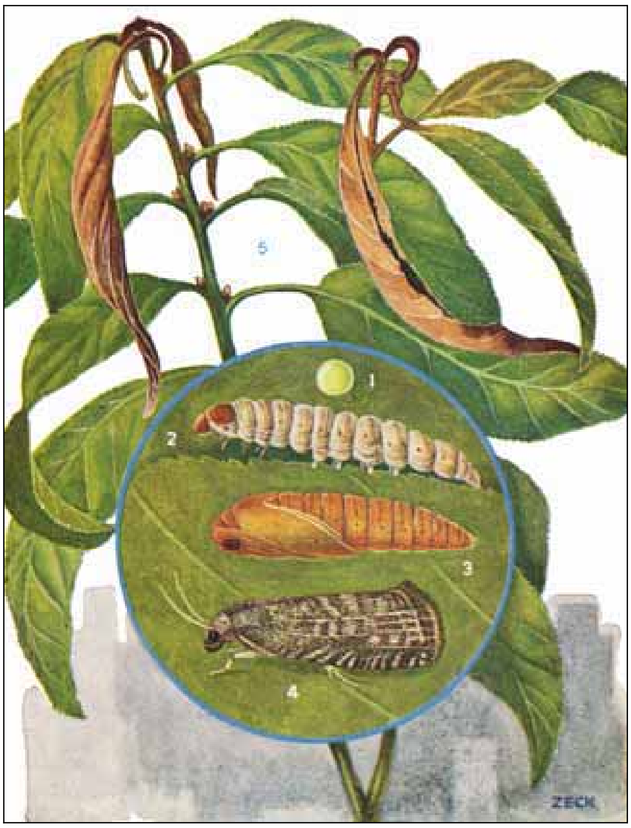


Fig. 64. Oriental fruit moth (*Grapholita molesta*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

1. Eggs (x 10)
2. Caterpillars (x 8)
3. Pupa (x 8)
4. Moth (x 8)
5. Twig dieback caused by the caterpillar feeding within tips

Pest cycle

There is a **complete metamorphosis** (egg, caterpillar, pupa and adult) with several over-lapping generations (probably 5-6) each year. Adult moths lay their eggs on the undersides or on young stems or fruit. Mature larvae spin a cocoon usually high in the tree near where it has been feeding. Life cycle takes about 5 weeks in summer. Moths which emerge late in the season lay eggs but except for those which infest quince most of the larvae which hatch from these eggs die. The last generation of larvae in late summer and autumn spin their silken cocoons under bark near the base of the host tree, in wounds from broken limbs or on litter on the ground. Late in winter or early spring dormant larvae pupate; the pupa, at first yellowish, turns brown then almost black just before the moth emerges any time from August to early November depending on temperature.

'Overwintering'

As larvae in cocoons under bark on the trees, on mummified fruit and litter on the ground, and in crevices in the soil. Very cold winters can kill some carry-over pupae.

Spread

- By moths flying, they are not strong fliers. They may migrate from lightly infested adjacent trees into susceptible fruit orchards.
- Transfer of infested fruit, litter,
- Transfer of infested nursery stock.
- Possibly also in packing boxes.

Conditions favouring

- **Warm, moist conditions**, over-irrigation, over-fertilizing, severe pruning or other factors which favour **lush tree growth** and plenty food for caterpillars. Moth populations buildup quickly. These conditions also favour the brown rot fungus.
- The lower development threshold is 7.5°C.
- Hot, dry and windy weather is unfavorable. Even if a heavy infestation is threatened in spring, hot summer winds can reduce it.
- Twig damage can occur from early spring through to autumn.
- Late-maturing varieties of peaches suffer greater losses than early varieties.
- Populations on other hosts nearby which only suffer slight damage can cause problems for peaches and nashi.

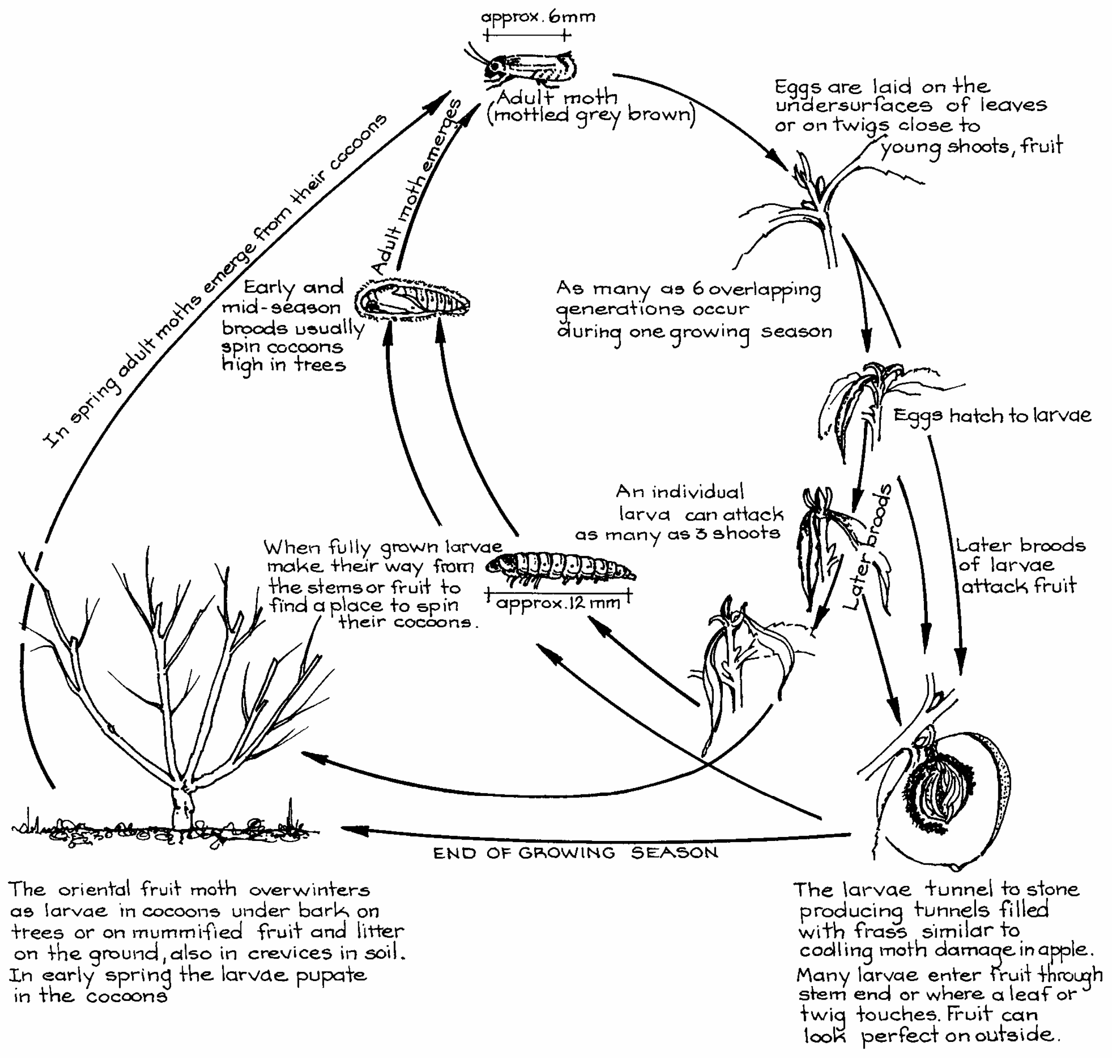


Fig. 65. Pest cycle of the oriental fruit moth (*Grapholita molesta*).

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation.
2. **Crop region.** Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage and record results as recommended.
   - **Orchards without MD** need pheromone traps and/or spray warning services (if available) which indicate when conditions favour infestation. Also check infestation at thinning time, if present review program.
   - **Orchards with MD.** It is recommended that growers use a consultant or suitably trained staff to carry out monitoring as **MD** interferes with trap catches. Efforts are being made to find more effective attractants for monitoring.
   - Monitoring may be required after harvest through to leaf fall.
5. **Threshold.** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic, environmental? Do you need to calculate your own threshold?
6. **Action.** Decisions about some methods of control, eg mating disruption (**MD**), need to be made long before monitoring has indicated a need for an insecticide application. Seek expert advice if unsure.
   - **Orchards without MD** or warning service, should apply **insecticides** when moth activity is first observed (usually within 14 days of petal fall, October onwards) or if 10% of shoots are infested. If a warning service based on **trap catches** is available, intervals between applications could be extended beyond the usual 3 weeks. Observe withholding periods.
   - **Orchards with MD** may require spraying.
7. **Evaluation.** Review **IPM** program to see how well it worked, eg after harvest through to leaf fall.

Control methods

Infestations should be controlled in **both** bearing and young non-bearing trees as the framework of developing trees may be seriously damaged. Also moths may spread to adjoining mature trees.

Cultural methods. Avoid heavy pruning, fertilizing, irrigation which promote lush growth.

Sanitation.
- Damage to individual home garden trees may be reduced by pruning off and destroying infested tips (about 20 cm) starting in spring. This reduces the number of 1st generation moths.
- Destroy all fallen and infested fruit on the tree every few days (page 91, codling moth).
- Remove loose or rough bark under which larvae may pupate from the tree.

Biological control.
- **Natural controls.** Wasps parasitize larvae and pupae and may reduce numbers considerably.
- **For purchase. Mating disruption (MD).**
  – **Pheromone lures** are available for monitoring.
  – **Pheromones**, eg Isomate® OFM Rosso-S, Isomate® C/OFM TT and Disrupt-OFM®, are used **commercially** to control oriental fruit moth. The pheromone is contained in a thin flexible polythene tube with an aluminum wire for stiffness. It looks rather like a garbage bag tie. The large quantities of female pheromone released by the dispensers confuse male moths, preventing them from locating and mating with females. Dispensers are twisted around the laterals of trees in spring, when leaf buds are emerging from dormancy in spring. They must be replaced with new dispensers 3 months later. All trees in an orchard must be treated, for near perfect control it is also necessary to treat trees adjacent to the orchard (See Table 10 below and page 44).
  – **MD** for **OFM** control has been successful over large areas with low populations and where alternative hosts are not present. **MD** can be augmented with pesticides if populations are high. Alternate hosts should be treated with **MD** to prevent migration of mated female moths.

Resistant varieties. Fruit damage is said not to be so common in low-chill cultivars.

Physical & mechanical methods.
Hessian or cardboard bands around trunks can be used in a manner similar to that for codling moth.

Insecticides.
- Determine the need for spray applications by monitoring and refer to predictive models which use temperature and other factors to predict favourable conditions. The aim is to kill moths as they alight on treated surfaces and caterpillars as they crawl on the surface of the plant.
- The **use of pesticides** to control oriental fruit moth may reduce natural enemies of twospotted mites increasing damage by this pest and special attention to its control may be necessary.

Table 10. Oriental fruit moth – Some insecticides and bio-controls.

What to use?	When and how to apply?
MATING DISRUPTION (MD) **Pheromones,** eg Isomate® OFM Rosso –S Pheromone Insect Confusion agent Isomate® OFM Rosso Pheromone Insect Confusion Agent Isomate® C/OFM TT Pheromone Insect Confusion Agent Disrupt-OFM Mating Disruption Agent	Mating disruption of **OFM** has been successful where populations of **OFM** are low over large areas and alternate hosts not present. When traps indicate, apply dispensers at the recommended number per hectare, height and distribution in trees. Suitability depends on size and layout of blocks. May be necessary to supplement **MD** with an effective insecticide.
TRAP CATCHES NOT AVAILABLE **Group 1A**, eg carbaryl (not on food-producing plants in home gardens) **Group 1B**, eg Lebaycid® (fenthion); Malathion® (maldison) **Group 4A**, eg Calypso® (thiacloprid); Sumarai® (clothianidin) **Group 5**, eg Entrust® Naturalyte Insect control (spinosad) **Group 22A**, eg Avator® (indoxacarb) **Group 28**, eg Altacor® (chlorantraniliprole)	• Follow label instructions. • Apply when moth activity is indicated from monitoring and at recommended intervals thereafter. • These sprays may affect predators of twopotted mite and lightbrown apple moth.
TRAP CATCHES FROM PHEROMONE LURES Available for monitoring only	• Intervals between spraying will be longer and will depend on trap catches.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Fruit-tree borer

The most easily controlled 'borer'

Scientific name

A native moth (*Maroga melanostigma*, Order Lepidoptera). Synonym *Crytophasa melanostigma*.

Other borers may also attack shrubs, trees, vines (page 79) including:

Order Lepidoptera
- Family Oecophoridae, eg **fruit-tree borer**
- Family Cossidae (wood moths)
- Family Hepialidae (ghost moths)

Order Coleoptera (page 99)
- Family Cerambycidae (longicorn beetles) (page 111)
- Family Curculionidae (weevils)
- Family Bostrichidae (auger beetles)
- Family Platypodidae (ambrosia beetles, pinhole borers)
- Family Scolytidae (bark beetles)

Order Hymenoptera
- Family Siricidae (wood wasps, eg sirex wasp, page 116)

Host range

Ornamental trees, eg black wattle (*Acacia decurrens*), banksia, flowering *Prunus* spp., elm, plane, willow, *Pistacia* spp., crepe myrtle and jacaranda, eucalypt, grevillea, hakea, NSW Christmas bush (*Ceratopetalum gummiferum*), *Cassinia, Helichrysum* (shrubby species), *Leptospermum,* melaleuca*, Prostanthera.*
Fruit trees, eg stone fruits, especially cherry, peach, nectarine, plum, prune, also apple, pear, raspberry.

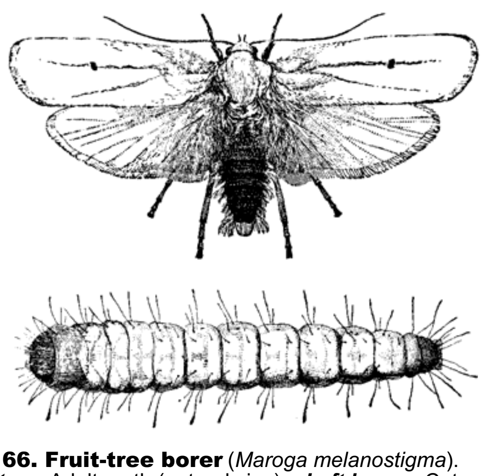
Description & damage

Moths (adults) are satiny-white and **35-60 mm** across their outspread wings. The upper surface of the abdomen is black, with an orange-colored fringe of hairs, and a thick tuft at the tip. Moths are nocturnal and rarely seen. **Caterpillars** (larvae) are fleshy, brownish-red, sparsely hairy and up to **50 mm** long and feed in the phloem-cambium region. During the day the caterpillars hide in the tunnel and come out to feed at night on callus tissue which grows around tunnel entrances. Caterpillars sometimes take leaves into their tunnels for food.

Trunks and branches. Although this is probably the most frequently noticed borer, many other borers cause more serious damage. Tunnels are vertical, short (only 8-10 cm deep) and are usually made in the forks of trees or between main branches. Damaged areas and tunnel entrances are neatly covered with chewed wood, bark, webbing and droppings which protect caterpillars from predators, eg ants. Some trees, eg cherry, ooze gum from damaged areas.
- Attacks weaken branches and may ringbark and kill smaller branches or small trees and allow entry of wood rot fungi.
- Branches may also be completely **ringbarked** or severely weakened in the crotches. Damaged branches, stems or canes may break.

Productivity of commercial crops such as prunes may be affected.

Diagnostics.
- Fruit-tree borer tunnels only 8-10 cm deep.
- Can be mistaken on some hosts with damage caused by other moth borers, eg wood moth damage on wattles, which are also covered with webbing, chewed wood but the larvae and the tunnels they make are much larger in diameter.
- Do not confuse with beetle borers (pages 103, 111).
- It is often necessary to seek diagnostic assistance (page xiv).



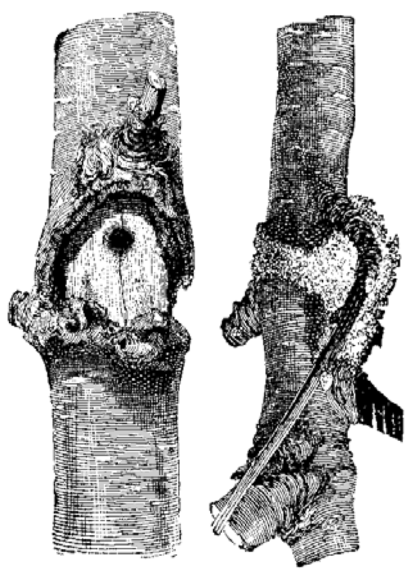


Fig. 66. Fruit-tree borer (*Maroga melanostigma*).
Left top: Adult moth (natural size). ***Left lower:*** Caterpillar (up to 50 mm long). ***Right:*** Branch showing webbed material covering tunnel entrance, when webbed material is removed the damage is apparent (see page 30 for internal damage).
Photo© NSW Dept of Industry and Investment.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with 1 generation every 1-2 years. Eggs are laid on the surface of the bark, usually at branch junctions, and the larvae hatching from the eggs burrow downwards into the tree creating short tunnels. The tunnel is increased in size as the larva grows, until it is 6-10 cm in length by the time the larva is fully grown. When fully grown the larva closes the entrance to the tunnel with a wad of silken web and chewed wood and changes into a pupa. Moths emerge the following summer.

'Overwintering'

Probably as caterpillars or pupae in tunnels in trunks and branches.

Spread

Mainly by moths flying. Infested wood could spread caterpillars and pupae.

Conditions favouring

Trees stressed by poor soil, inadequate irrigation, poor drainage. Trunks damaged by sunburn may be more susceptible.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** if this borer is a problem, which fits your situation.
2. **Crop, region**. Recognize variations for your crop, eg ornamental, commercial, and for your locality.
3. **Identification** of pest may have to be confirmed professionally (page xiv) to avoid mistaken diagnosis as larvae of wood moths or beetles which make longer tunnels and are more difficult to control.
4. **Monitor** pest and/or damage and record results as recommended. **Inspect deciduous trees during dormancy in winter when damage is easily observed**. Frass is easily seen. The giant wood moth (*Xyleutes cinereus*) is monitored in some eucalypt plantations in coastal areas of Qld, and northern NSW.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? Do you need to calculate your own threshold?
6. **Action** is usually taken when infestation is first noticed to avoid serious damage to smaller trees. Prune to remove damaged branches, fertilize and irrigate to promote vigour. Treat remaining borer tunnels as recommended. In extreme cases treat major hosts in your cropping area.
7. **Evaluation**. Check trees regularly for infestation. If the frass is visible again then the borer is still active and further treatments will be needed. Review the control program and monitoring techniques to decide further improvements, especially cultural/sanitation practices.

Control methods

As caterpillars do not tunnel far into the wood, this borer is easy to control on small trees. Other borers are not usually noticed until they have done much damage and larvae have penetrated deep into the wood. Apply control measures when infestation is first noticed. The most convenient time to do it on deciduous trees is usually during winter pruning, when damage is easy to see. If large trees are badly affected contact a qualified arborist to properly assess and treat the damage.

Cultural methods.

Fertilize and irrigate trees appropriately.

- **Provide good cultural care**, eg adequate drainage, irrigation, good fertilizer practices, etc.
- **Judicious pruning** at the correct time may stimulate vigour and protect limbs from sunburn. Make all pruning cuts cleanly so that stubs are not left to dieback and so encourage further borer attack. Trim ragged edges around the damaged area.

Sanitation.

- **If the problem is extensive**, or occurs over more than one season, consider either treating or removing other major hosts in the areas such as plums or thickets of black wattle trees within 50m of commercial plantings to reduce buildup of moth populations.
- **If small twiggy growth** on shrubs or trees has been attacked, prune off. Consider removing severely damaged limbs during pruning.
- **Cut back** severely infested branches well below infested sections and paint the cut surface with fungicide paint if recommended.
- **Do not leave prunings lying around** as moths may emerge to lay eggs on other hosts.

Biological control.

The wasp (*Trichogramma carverae*) lays its eggs in the eggs of the fruit-tree borer and is being studied as a possible bio-control agent. There are several other parasites and predators of the larvae.

Physical methods/Insecticides.

These are mostly suitable if only a few trees are involved as in a home garden situation.

- **Remove** webbing and sawdust-like material to expose damaged wood and caterpillars which can then be **squashed** or if they are in the tunnel either poke a thin wire down the short tunnels to kill the caterpillars, or squirt a **household insecticide** into the tunnels.
- **Only** in severe infestations is it necessary to spray trunks, branches and leaves. Seek advice.
- If considered necessary, smooth damaged **wood**, plug tunnels with putty or similar material.
- **Light trapping** of moths at night is being researched.

Table 11. Fruit-tree moth borer – Some insecticides.

What to use?	When and how to apply?
INSECTICIDES, eg	• Seek advice regarding spray applications.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

ORDER COLEOPTERA

Beetles, weevils

NO. SPECIES IN AUSTRALIA

More than 28,000 named species in Australia. There are more than 6000 species of native weevils in Australia. The Coleoptera is by far the largest order of insects both in Australia and world wide and has more plant feeders than any other order. Many species are predatory and feed on other insects. Rhinoceros, flower and other beetles are kept as pets.

www.ento.csiro.au/education/insects/**coleoptera**.html

SOME DISTINCTIVE FEATURES

Elytra enable them expand into habitats which could damage unprotected wings

ADULT

Body
1. Hard and compact (with exceptions).
2. **Prothorax** often appears separated from the other 2 parts of the thorax.
3. Many beetles are **brilliantly colored** and are of various shapes and sizes.

Wings
1. Usually 2 pairs.
2. **Forewings** hardened into hard wing covers (**elytra**) which are not used in flight.
3. **Hindwings** gauzy and used in flight. They are neatly tucked under wing covers when not in use.

Mouth Chewing mouthparts.

Antennae Usually well developed and conspicuous.

Eyes Compound eyes.

LARVA

Legs
1. No prolegs (abdominal legs).
2. Commonly 3 pairs thoracic legs (long or short) each pair ending in 1-2 claws, eg scarab grubs.
3. Some are entirely legless, eg longicorn beetle larvae.

Head Always distinct, usually dark colored, bearing definite but minute antennae.

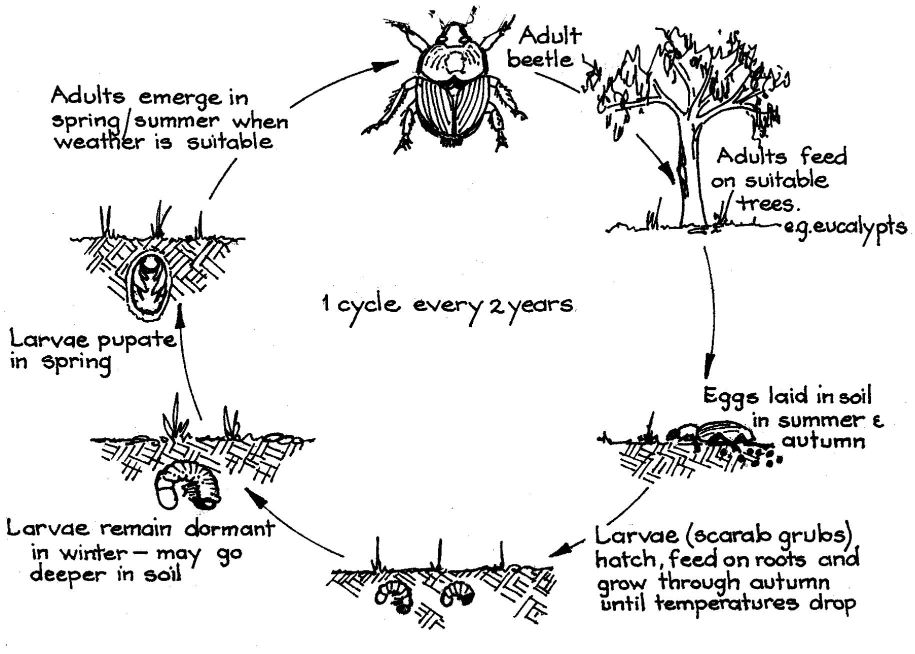
Mouth Chewing mouthparts.

LIFE CYCLE

There is a **complete metamorphosis** (egg, larva (**grub, curl grub, scarab grub, wireworm, mealworm, borer**), pupa and adult. Life cycles vary in duration and location.

Christmas beetle

Many variations



METHOD OF FEEDING

ADULT Biting and chewing mouthparts, usually well developed. Many feed on plant material, nectar or are predators, some do not feed at all.

LARVA Biting and chewing mouthparts, usually well developed.

PLANT DAMAGE

Feeding habits of adults and larvae may be similar or different

DIRECT CHEWING DAMAGE

Both adults and larvae may feed on plant material.

LEAVES **Chewed,** eg leaf beetles (adults and larvae), pumpkin beetle (adults), metallic flea beetles (adults), Christmas beetle (adults), black vine weevil (adults)
Skeletonization, eg leafeating ladybirds (adults and larvae), elm leaf beetles (adult and larvae)
Leafmining, eg lantana leafminer (larvae)

FLOWERS, BUDS **Chewing,** eg orchid beetle (adults)

FRUIT, SEED, GRAIN **Chewing damage,** eg bean weevil (larvae), driedfruit beetles (adults and larvae), rust red flour beetle (adults and larvae)

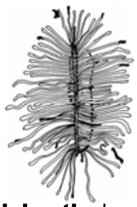
TRUNKS, BARK **Borers,** eg longicorn beetles (larvae), jewel beetles (larvae), auger beetle (larvae)
Bark beetles, eg pine bark beetles (adults and larvae)

ROOTS, CROWNS **Chewing damage**, eg scarab grubs (larvae), black vine weevil (larvae), orchid beetle (larvae), vegetable weevil (larvae)

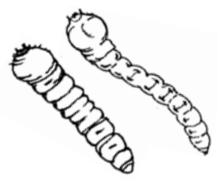
INDIRECT DAMAGE

- **Transmission of diseases**, eg
  - Driedfruit beetles and caterpillars of oriental fruit moth and lightbrown apple moth, help spread brown rot of stone fruit (fungal disease).
  - Squash mosaic virus of melons in Qld is spread by leafeating beetles.
  - Overseas, elm bark beetles spread Dutch elm disease (fungal disease).

LIST OF SOME SPECIES

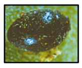
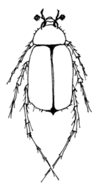


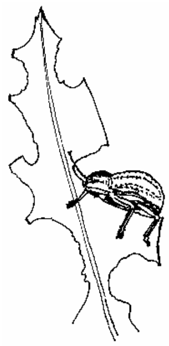
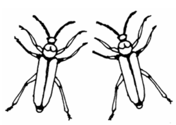
Bark beetle. Larvae damage under bark



Top: Jewel beetle larva
Lower: Longicorn larva

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
BARK BEETLES (several families)		
Cypress bark beetle	*Phloeosinus cupressi*	Cypress, other conifers
Cypress bark weevil	*Aesiotes leucurus*	Cypress, *Pinus* spp.
Elm bark beetle	*Scolytus multistriatus*	Elm
Five spined bark beetle	*Ips grandicollis*	Many *Pinus* spp.
Pine bark weevil	*Aesiotes notabilis*	Various conifers
BORERS (several families)		
Auger beetles	Family Bostrichidae	Eucalypts, tamarisk
Elephant weevil	*Orthorhinus cylindrirostris*	Trees, fruit trees Curculionidae
Jewel beetles	Family Buprestidae	Various trees, especially cypress. Adults are nectar feeders and pollinators of native plants
Kurrajong weevil	*Axionicus insignis*	Kurrajong Curculionidae
Longicorn beetles	Family Cerambycidae	Various trees, shrubs, especially eucalypts
Not known in Australia: Asian longicorn beetle	*Anoplophora glabripennis*	Wide range of mainly deciduous trees. Larvae bore holes in wood of living trees and forest products
Australian standards. Timber natural durability ratings: Powderpost beetles	*Lyctus* spp, (Bostrichidae)	Sapwood of certain hardwoods, not softwood

LIST OF SOME SPECIES *(contd)*	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (not exhaustive)**
	LADYBIRDS (Family Coccinellidae)		
Leafeating ladybirds	Cucurbit ladybird	*Epilachna cucurbitae*	Cucurbits, many other plants
	Twentysixspotted potato ladybird	*E. vigintioctopunctata pardalis*	Potato, tomato, sometimes beans, weeds
Beneficial ladybirds	**Predatory ladybirds**	**Some feed on fungi**	
	Common spotted ladybird	*Harmonia conformis*	Aphids, scales
	Fungus-feeding ladybird (bright yellow)	*Illeius galbula*	Powdery and downy mildews
	Mealybug ladybird	*Cryptolaemus montrouzieri*	Main targets are mealybugs and soft scales, but also other insects
Mite-eating ladybird	Mite-eating ladybirds (tiny, black, 2 mm long)	*Stethorus* spp.	Twospotted mite
	Scale-eating ladybird	*Rhyzobius lophanthae*	Scales
	Spotted amber ladybird	*Hippodamia variegata*	Small insects, eg aphids, thrips
Transverse ladybird	Transverse ladybird	*Coccinella transversalis*	Aphids, scales
	Vedalia ladybird	*Rodolia cardinalis*	Cottonycushion scale
Leaf beetles	**LEAF and FLEA BEETLES (Family Chrysomelidae)**		**>3000 spp in Australia**
	Bean weevil	*Acanthoscelides obtectus*	Beans
	Couch flea beetle	*Chaetocnema australica*	Turf, eg bent, couch
	Elm leaf beetle	*Pyrrhalta luteola*	Elms
	Eucalyptus tortoise beetles	*Chrysophtharta* spp. *Paropsis* spp.	Eucalypts
	Figleaf beetles	*Poneridia* spp.	Cultivated ornamental and fruiting and figs, native Moreton Bay fig
	Metallic flea beetles	*Haltica* spp.	Ornamentals, eg fuchsia, hibiscus, hollyhock, zinnia, weeds, eg mallow
	Orchid beetle	*Stethopachys formosa*	Orchids
	Palm leaf beetle	*Brontispa longissima*	Palms
	Pumpkin beetle	*Aulacophora hilaris*	Cucurbits, related plants
	Redshouldered leaf beetle	*Monolepta australis*	Fruit, ornamentals blossoms, tender foliage, fruit of a wide range of fruit and vegetables
	Swarming leaf beetles	*Rhyparida* spp.	Ornamentals, fruit, native trees, pasture species
	Staghorn fern beetle	*Halticorcus platycerii*	Ferns
	Leafminers		
Biological control agent	Lantana leafminers	*Octotoma scabripennis* *Uroplata girardi*	Lantana. Introduced biological control agents
	SCARAB BEETLES (Family Scarabaeidae)		
Many scarab beetles, eg *Dilochrosis walteri* feed on flowers in southwest WA	African black beetle	*Heteronychus arator*	Grasses, other plants
	Argentine scarab	*Cyclocephala signaticollis*	Grasses, other plants
	Blackheaded pasture cockchafer	*Aphodius tasmaniae*	Grasses, clovers
	Christmas beetles	*Anoplognathus* spp.	**Adults** feed on foliage of eucalypt and other plants. **Larvae** feed on roots of grasses and garden plants
	Flower scarabs	*Protaetia* spp.	Flowers of trees, melaleuca, roses, wattle
	Japanese beetle **Not known in Australia**	*Popillia japonica*	Destructive plant pest. **Adults** feed on foliage of fruit, many different plants, **larvae** attack roots of grasses, field crops, garden and nursery plants.
Nectar scarab. small native beetle up to **6 mm** long	Nectar scarabs	*Phyllotocus* spp.	**Adult scarabs** feed on pollen
	Pruinose scarab	*Sericesthis geminata*	As for Christmas beetles

LIST OF SOME SPECIES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	STORED PRODUCT PESTS (various families)		
	Confused flour beetle	*Trilobium confusum*	**Damaged** stored foodstuffs, seed, peanuts, chocolate, etc
	Rice weevil	*Sitophilus oryzae*	**Undamaged** grain, destructive pest of stored products
	Lesser grain borer	*Rhyzopertha dominica*	The most serious pest of stored grain in Australia
Not known in Australia	Khapra beetle	*Trogoderma granarium*	Grains, seeds, processed products; monitored at storage sites in export terminals & grain processors to maintain Australia's pest-free status
	WEEVILS (Family Curculionidae)		
	Apple root weevils	*Perperus* spp.	Apples, pears, peaches
	Argentine stem weevil	*Listronotus bonariensis*	Grasses and cereals
	Botany Bay weevil	*Chrysolopus spectabilis*	Feed on wattles in east Australia
	Wattle pigs	*Leptopius* spp.	Large and sluggish, bits of soil on its body, spends some time in soil
	Black vine weevil	*Otiorhynchus sulcatus*	Ornamentals, berry crops, nurseries
	Fruit-tree root weevil	*Leptopius squalidus*	Pome & stone fruits
	Fuller's rose weevil	*Asynonychus cervinus*	Roses, ornamentals, fruit trees
	Garden weevil	*Phlyctinus callosus*	Vegetables, succulents, eg cacti
	Strawberry weevil	*Rhinaria perdix*	Strawberry
Catarcus weevil chewing leaves.	Vegetable weevil	*Listroderes difficilis*	Vegetables, weeds, etc
	Vine weevil	*Orthorhinus klugi*	Grape, black wattles
	Whitefringed weevil	*Graphognathus leucoloma*	Shrubs, fruit trees, vegetables
	OTHER FAMILIES		
	Click beetles, wireworms	Family Elateridae	Grass, flowers, grains, vegetables, can flick into the air
	Driedfruit beetles	Family Nitidulidae	Maturing fruit. Spreads brown rot of stone fruit
	Small hive beetle	*Aethina tumida*	Combs in honeybee colonies
Endangered species	Broad-toothed stag beetle	*Lissotes latidens*	Rotting logs on the ground in Tasmania
	BENEFICIAL BEETLES		
Natural controls	Ground beetles	Family Carabidae	Feed on caterpillars, insects, etc. Occasionally may damage plants
	Steelblue ladybird	*Halmus chalybeus*	Aphids, scale, other insects; was introduced to NZ from Australia for control of scales
	Chilocorus predators	*Chilocorus* spp.	Red, oriental & white louse scale
	Plague soldier beetle	*Chauliognathus lugubris* (Family Cantharidae)	Adults & larvae feed on insects. **Adults** weigh down plants when resting but may nibble cherries, etc. **Larvae** in soil mostly predatory, some feed on plant seeds and roots
Soldier beetles About 13 mm long	Rove beetles	Staphylinidae	Adults and larvae feed on ground dwelling insects, eggs and larvae of pest moths in gardens
Biological control agents	Dung beetles	*Family Scarabaeidae* (some native spp. endangered)	Adults roll balls of dung to store food for themselves and their larvae
	Chilocorus predators	*Chilocorus* spp.	Red, oriental, white louse scales
	Lantana leafminers	Various species	*Lanatana camara*
Suppliers www.goodbugs.org.au/.	Predatory ladybirds	Coccinellidae	**See previous page**
	Salvinia weevil	*Cyrtobagous salviniae*	Salvinia
	St John's wort leaf beetles	*Chrysolina* spp.	St John's wort
	Seed-feeding weevils	*Melanterius* spp	Wattles, introduced to South Africa from Australia for wattle control

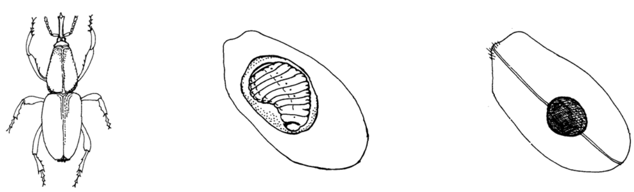
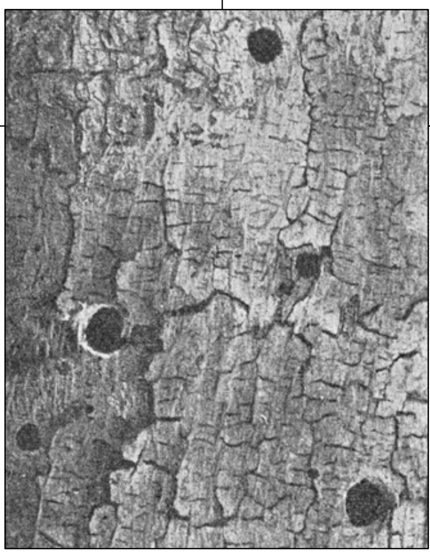


Fig 67. Rice weevil (*Sitophilus oryzae*). ***Left:*** Adult (3 mm long). ***Centre:*** Larvae in seed. ***Right:*** Exit hole of adult

BEETLES AND WEEVILS

Summary - Some exceptions

	SOME DISTINCTIVE FEATURES	PLANT DAMAGE
BEETLES 	**ADULT Flight** Usually can fly **Head** Not long **Body** Not roughened **Antennae** Various (not usually elbowed) **LARVA Legs** Mostly thoracic legs which may be short or long	**DIRECT FEEDING DAMAGE** **LEAVES** Eaten, eg Christmas beetles Leafmining, eg lantana leafminer Skeletonization, eg leafeating ladybirds **FLOWERS BUDS** Chewing damage, eg orchid beetle **FRUIT SEED** Chewing damage, eg driedfruit beetles **STEMS** Bark, eg elm bark beetle **BARK** Borers, eg longicorn beetle **INDIRECT DAMAGE** • Transmit diseases, eg elm bark beetle spreads Dutch elm disease overseas
WEEVILS 	**ADULT Flight** Many unable to fly **Head** Long snout **Body** Usually rounded, often roughened with knobs, spines, scales **Antennae** Often elbowed, clubbed at tips **LARVA Legs** Legless **Body** Stout grub, usually feeds **within** plant tissues (stems, trunks, roots, seeds etc)	**DIRECT FEEDING DAMAGE** **LEAVES** Chewed edges, eg black vine weevils **SEEDS** Chewing, eg rice weevil **STEMS** Bark, eg pine bark weevil **BARK** Borers, eg elephant weevil larvae Surface chewers, eg garden weevil **ROOTS TUBERS** Gouging tubers, eg black vine weevil **INDIRECT DAMAGE**



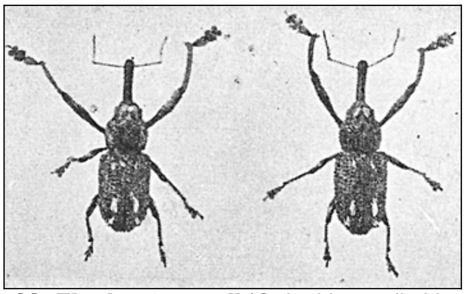


Fig. 68. Elephant weevil (*Orthorhinus cylindrirostris.*).
Left: Exit holes made by emergence of adults after pupating under bark. ***Right:*** Adult elephant weevils, note elbowed antennae. Photos©NSW Dept of Industry and Investment.

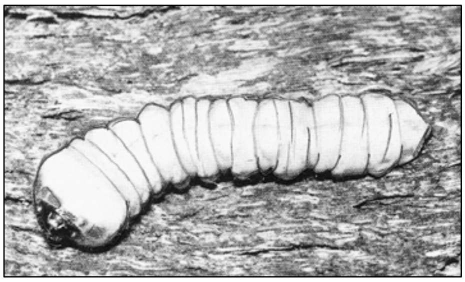


Fig 69. Beetle 'borers' can grow up to 30 mm in length, bark has been removed. ***Upper:*** Larvae of jewel beetles (Buprestidae) are cobra-shaped. ***Lower:*** Larva of a longicorn beetle (Cerambycidae). Adults do little, if any damage, some jewel beetles are important pollinators. Photos©NSW Dept of Industry and Investment.

Fig. 70. Leaf beetles (Chrysomelidae). ***Upper:*** Leaf beetle (adult) 5-15 mm long which feeds on foliage. ***Lower:*** Larvae 10-20 mm long which also feed on foliage. Photos©NSW Dept of Industry and Investment.

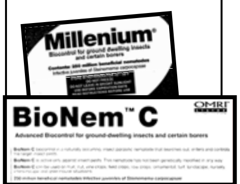
	TRADE NAMES	**NEMATODE SPECIES**	**TARGET BEETLE/WEEVIL**	**SUPPLIERS**
Fungi	BioCane™	*Metarhizium* sp.) 	**Greyback canegrub** (*Dermolepida albohirtum*)	**Becker Underwood** **www.beckerunderwood.com**
Nematodes	Nematode	*Heterorhabditis bacteriophaga*	**Black vine weevil** (*Otiorhynchus sulcatus*)	**EcoGrow** **www.ecogrow.org.au/**
	Nematode	*Heterorhabditis zealandica*	**Argentine stem weevil** (*Listronotus bonariensis*) **African black beetle** **Blackheaded cockchafer** **Redheaded cockchafer** **Argentine scarab** **Bill bug weevil**	**EcoGrow** www.**ecogrow**.org.au/
	Nematode	*Steinernema carpocapsae*	**Banana weevil borer** (*Cosmopolites sordidus*)	**EcoGrow** www.**ecogrow**.org.au/
	Bionem C **Millenium**	*Steinernema carpocapsae* 	**Ground dwelling insects** including billbugs, black vine weevil, strawberry root weevil	**Becker Underwood** www.**beckerunderwood**.com

Fig. 71. Biological control of beetles using fungi and nematodes. Follow storage and application instructions carefully.

Potato leafeating ladbirds

An example of a leafeating beetle

Scientific name

Potato ladybirds (*Epilachna* spp., Coccinellidae).

Host range

Mainly cucurbits, eg
Vegetables, eg all cucurbits especially rockmelon also cucumber, marrow, pumpkin, zucchini, related vine plants; bean, potato, tomato.
Weeds, eg nightshades (*Solanum* spp.), false castor oil and paddymelon.

Description & damage

Both adults and larvae **chew** leaves.

Adult beetles are oval, strongly convex in outline and about **6 mm** long with chewing mouthparts. They are mainly yellow-orange with 26 or 28 black spots, they fly well but do not fly readily and are rather sluggish. **Larvae,** when fully grown are yellow-green, and **6 mm** long and covered with long, black branching spines which give them a 'burry' appearance.

Leaves. Adults feed on leaf **uppersurfaces**, often starting at the margin while the larvae generally feed on leaf **undersurfaces**. Leaves are initially skeletonized but adults may also chew holes right through leaving only the veins. Severely skeletonized leaves wither, plants look scorched. Young crops may be severely injured.

Fruit. Young fruits, eg cucurbits, may have parts of their skin eaten. Injury reduces yield.

Diagnostics.

- **Do not confuse potato ladybirds** with:
  - Pumpkin beetles which have a limited host range and 2 large spots on each wing cover.
  - Common spotted ladybirds (*Harmonia conformis*) which have only 18 spots are beneficial and feed on aphids, scales and other small insects.
  - Other beneficial ladybirds which have fewer spots or various patterns on their wing covers.
- **Do not confuse larvae** with larvae of beneficial ladybirds which are **not** 'burry'.
  List of suppliers www.**goodbugs**.org.au/
- **Damage** by adults and larvae is distinctive, ie skeletonisation.

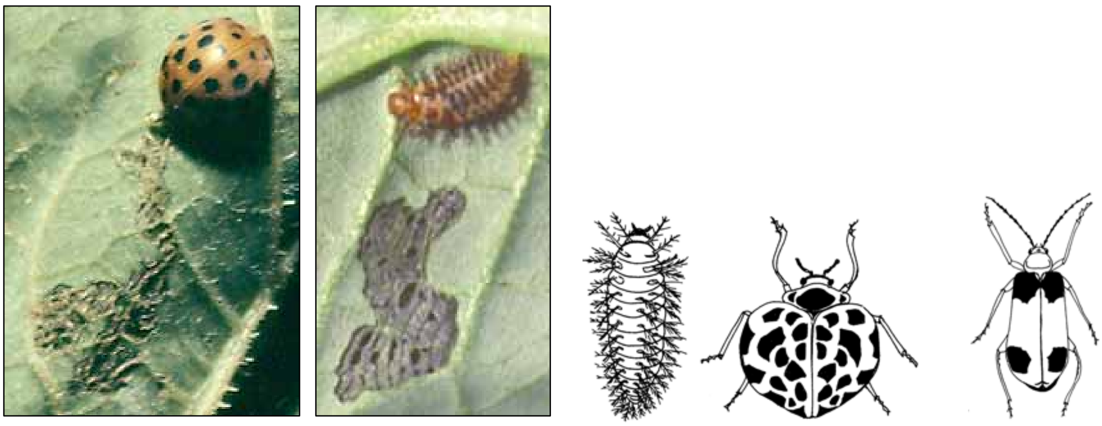
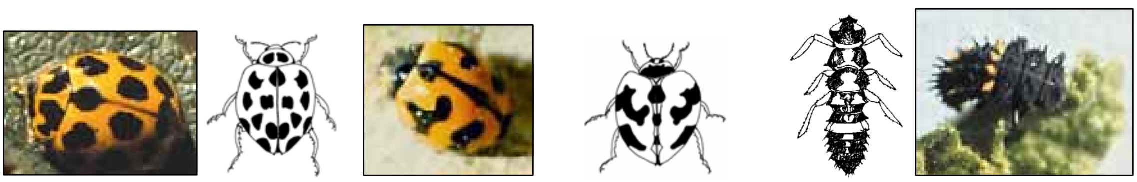


Fig. 72. Leafeating ladybirds (*Epilachna* spp). ***Left:*** Typical skeletonization caused by leafeating ladybirds and their larva. Photo©CIT, Canberra (P.W.Unger). ***Centre:*** Spiny larva and adult. ***Extreme right:*** Pumpkin beetle. All about 6 mm long.



Larvae of beneficial ladybirds

Fig. 73. Predatory ladybirds and their larvae feed on aphids, scales, mites and other insects. ***Left:*** Common spotted ladybird (*Harmonia conformis*). ***Centre:*** Transverse ladybird (*Coccinella transversalis*). ***Right:*** Larva of beneficial ladybirds. All about 5-7 mm long. Photo©CIT, Canberra (P.W.Unger).

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult), with many overlapping generations during spring, summer and autumn. The life cycle takes about 5-6 weeks for completion and all stages may be found on the plant at once. Female beetles deposit eggs in spring in small groups usually on the lower surfaces of leaves, where most of the larval feeding occurs. When fully grown, the larvae congregate in numbers on the foliage of the food plant or nearby litter and pupate. The pupae are attached to the plant or litter at their hind end. The last larval skin remains attached around the end of the pupa.

'Overwintering'

As inactive adults.

Spread

- By adult beetles flying (although they do not fly readily, this is their main method of spread). They may be assisted by wind.
- Movement of infested seedlings.

Conditions favoring

High humidity as in coastal or irrigated areas. October to April. Leafeating ladybirds require higher humidity than pumpkin beetles so are more of a problem in coastal areas than inland. However, in certain irrigated inland areas they can be a problem, eg Murrumbidgee Irrigation Area.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region**. Recognize variations.
3. **Identification** can be difficult so consult a diagnostic service if necessary (page xiv).
4. **Monitor** larvae, adults, pest damage and beneficial insects weekly during the time when damage is expected, eg examine a prescribed number of potato plants in a row at several widely spaced locations throughout the crop. Seek advice if necessary on monitoring and about the need for monitoring in your crop and region. Remember if monitoring, you need to know **when** and **where** to look, and **what** and **how** to monitor.
5. **Threshold**s will vary according to the crop. How much damage can you accept on your crop? An example of a threshold might be:
   - If there is more than an average 25% leaf area lost on 3 out of 30 potato plants examined, then control measures should be started (Brough et al. 1994).
6. **Action**. Take appropriate action when your predetermined threshold is reached.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Sanitation.

- On a few plants in a home garden situation, adults and larvae may be collected or squashed.
- Destroy infested crop debris as soon as possible after harvest to assist control, though adult beetles spread by flying.

Biological control.

- A few parasitoids and predators attack larvae and adults. The 'burry' larvae may deter some known parasites and predators.
- No biological control agents are available for purchase and none have been released by government agencies.

Pest-tested planting material.

- Check incoming seedlings for adults and larvae.

Insecticides.

- Apply foliage sprays or dusts if monitoring indicates a need.

Table 12. Leafeating ladybirds – Some insecticides.

What to use?	When and how to use?
FOLIAGE SPRAYS AND DUSTS **Group 1A,** eg various products (carbaryl is not registered for use on food-producing plants in the home garden) **Group 1B,** eg various products (malathion) **Home garden sprays,** eg several containing bioallethrin + bioresmethrin	• Apply after monitoring or at first sign of infestation, depending on the situation.

Black vine weevil (BVW)

European strawberry weevil (Tas.)

Scientific name

Otiorhynchus sulcatus (Family Curculionidaae). Do not confuse this weevil with the vine weevil (*Orthorhinus klugi*). Other weevils damage plants in a similar manner to **BVW**, eg

Fruit-tree root weevil (*Leptopius squalidus*)
Fuller's rose weevil (*Asynonychus cervinus*)
Garden weevil (*Phlyctinus callosus*)
Whitefringed weevil (*Graphognathus leucoloma*)

Host range

Ornamentals, eg numerous greenhouse and outdoor plants, begonia, cyclamen, geranium, impatiens, orchids, maiden hair fern, woody ornamentals (azalea, conifers, fuchsia, pittosporum, rhododendron, rose), containers, nurseries.
Fruit, eg apple, blackberry, blackcurrant, gooseberry, grape, strawberry.
Vegetables, eg seedlings, and some **Weeds**.

Description & damage

Adult weevils are **10-12 mm** long with an elongated snout. They are shiny black with faint yellow spots on their backs. Adult females are about **9 mm** long, black with rough wing cases, which are relatively rounded with parallel ridges running length-wise with patches of yellowish hair. Antennae are long, slender and elbowed. Adults feed at **night**, hide during the day under mulch, clods of earth or debris on the soil surface, or rest on the plant in dark protected places. If disturbed on the plant during the day they drop to the ground as if dead. **Eggs** are each about 0.7 mm in diameter, roughly spherical and white initially before turning brown. **Larvae** are white, curved, legless, about **10 mm** long when fully grown and have brownish heads. Newly hatched larvae have straight, pinkish white bodies with brown heads. **Pupae** are 8-10 mm long, milky white initially with large spines on the head, legs and abdomen. As they mature they darken until almost black. They are hard to find in the soil.

Leaves. **Adults** feed at **night** chewing large ragged notches from flower and leaf margins. They may eat whole leaves, leaving only the midribs and main veins. Damage may be unsightly but usually not significant on most perennials.

Stems and stalks. **Adults** feed on stems of seedlings and host plants at, or just below, ground level. They may also chew fruit stalks of grapes and sometimes feed on fruit.

Roots, corms. **Larvae** feed on roots eating smaller ones and ring barking larger roots or the main stem just below the surface. Large larvae may bore into crowns or corms. Look for larvae 2-40 cm down in the soil near roots. Severe root damage may cause infested plants to suddenly wilt and die. It is the root damage that is serious.

General. Plants may grow poorly in spring due to larvae feeding on roots. Others may die after planting out, which can be embarrassing for contractors and purchasers. **BWV** can cause substantial losses in container-grown perennials. Slow growing species cannot compensate for the loss of root tissue and suffer most damage. In hot weather plants that appear healthy may deteriorate when subjected to the slightest water stress.

Diagnostics. Detection of either adults (which are active at night) or larvae is difficult, and infestations are sometimes overlooked for years.

- **Adults.** Do not confuse with **other weevil pests**, eg garden weevil (*Philistines callous*) which may be confused with **BVW**. It is smaller (6-7 mm long) and dull gray with a pale 'V' on the upper elongated snout. Adults of both species rest during the day under leaves or plants and so are seldom associated with damage.
- **Larvae.** Do not confuse with scarab grub larvae which have 3 pairs legs on the thorax and are larger.
- **Damage.** Tell-tale notching on leaves by **adults** is distinctive, look for adults during the day under pot rims, etc, or on the plants at night. Root and stem damage by **larvae** may be mistaken for *Phytophthora* root rot. Look for larvae near roots.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and female adult) with 1 generation over 1-2 years. In glasshouses there may be 2 generations per year, all stages may be present at the same time. Female weevils emerge in early spring and feed for about a month, then can lay up to 1000 fertile eggs without mating, during their life (about 1 year) in the soil near the base of plants. Peak emergence is Jan-Feb and again in Aug-Sept. Adults may lay 200-400 eggs in the 1st year and 400+ eggs the next. Eggs hatch in 15-21 days; larvae feed for 3-4 months then pupate a few centimeters below the soil surface. Pupal period lasts 18-20 days.

'Overwintering'

Usually as larvae but all stages can 'overwinter'.

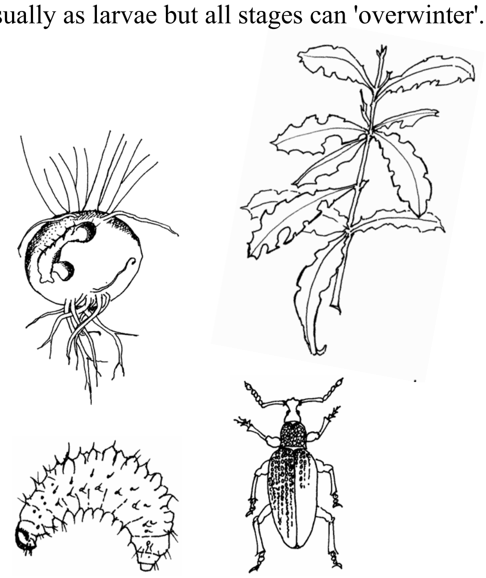


Fig. 74. Black vine weevil (*Otiorhynchus sulcatus*)
Above: Corm damage by larvae, leaf damage by adults.
Below: Larva (9 mm long) and adult (12 mm long)

Spread

- By the adults crawling up to 1,000 metres a day. Adults do not fly.
- By humans, eg various stages (eggs, larvae, pupae, adults) may be carried on potted plants, other plant material and in infested soil.

Conditions favouring

- Precise timing of life cycle varies from year to year depending on temperature and humidity.
- Warmer temperatures during late summer and early autumn might allow more adults to survive.
- Larvae/adults feed at temperatures as low as 2°C.
- Use of polythene sheeting in strawberries.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your crop or situation.
2. **Crop, region**. Recognize variations.
3. **Identification** can be difficult so consult a diagnostic service (page xiv). Adult weevils are seen between Nov. and Jan. in NSW.
4. **Monitor** and record your findings of pest/damage.
   - Monitor **indicator plants** (very susceptible hosts) for signs of infestation and keep records.
   - Check for **adults** weekly from Nov. to Mar. under boards or other traps, placed close to susceptible plants, eg rhododendron. Shake out traps over a white sheet at midday during summer and count/ record number. Also check under rims of pots for adults hiding during the day.
   - Check for **larvae** during winter near the crown or root ball when repotting.
   - Check for **larvae** on roots of susceptible plants randomly from March onwards, especially during hot weather if plants look stressed despite adequate irrigation. For some plants, 3-5 grubs in a litre pot (about 120cm diameter) can sever the root system.
   - Check **crop plants** regularly during spring and summer for tell-tale leaf notching.
5. **Threshold**. May be very low in commercial crops which can sustain considerable economic damage. You may have to calculate your own threshold at which you start control methods.
6. **Action**. In nurseries, sanitation, purchase of weevil-free stock, monitoring and bio-control agents can keep **BVW** under control. Purchase stock for resale when adults are not likely to be active.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Control is difficult especially in field grown crops. Adults tend to live and feed in protected areas of the plant and larvae live in soil.

Sanitation.

- Discard severely infested container plants and treat remainder. Also destroy infested plant material and crop debris.
- Remove media (and larvae) from potted plants and repot in **clean** soil.
- **Do not** re-use potting mix from infested plants or compost unless it is pasteurized.
- Reduce hiding places used by adults during the day by removing litter on the soil surface.

Biological control.

- **Natural enemies** include predatory wasps, flies and beetles, various parasitic flies. Chickens feed on vine weevils in management systems.
- **Nematodes are commercially available**, eg
  Heterorhabditis bacteriophaga
  Steinernema carpocapsae
  Becker Underwood www.beckerunderwood.com/
  Ecogrow Environmental www.ecogrow.com.au

  They can reduce populations of **BVW** larvae by 90-100%. Nematodes seek out natural openings on larvae and move into the blood stream where they release bacteria causing septicaemia. **BVW** larvae die and nematodes multiply in the dead insects. After 2-3 weeks thousands emerge to attack other larvae. **Follow instructions carefully for timing and conditions of application.** Nematodes may be more expensive and usually need to be ordered in advance but may not need to be registered as a pesticide, and there may be no re-entry times. Check.

Resistant varieties.

Some varieties of some species appear to be very susceptible, eg *Pittosporum* 'James Stirling'.

Plant quarantine.

Do **not** introduce infested media, soil or plants to non-infested areas.

Pest-tested planting material.

- Only purchase stock from **BVW**-free properties or from suppliers with a control program.
- Check root areas of incoming stock.
- Use clean potting mix.

Physical & mechanical methods.

- Trap adults in corrugated cardboard around plant bases, shake out every day over a bucket of soapy water.
- Use Tanglefoot® or other adhesive to trap adult weevils as they climb onto benches. Apply to table legs to trap adults active at night.
- If practiced daily, these may prove effective.

Insecticides.

Destroy badly infested container plants before treating the rest.

- **Formulations** applied to the soil need to provide sustained control of larvae.
- **Soil drenching larvae** can be ineffective due to chemicals leaching out of growing media after irrigation, the difficulty in contacting larvae deep among roots and getting uniform coverage of media where it is protected by foliage.
- **Spraying adult weevils** late in the day or at night can be ineffective as the weevils tend to drop to the ground when disturbed. **Adults** may develop **resistance** to insecticides.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 13. Black vine weevil – Some insecticides, biocontrol agents.

What to use?	When and how to use?
SOIL TREATMENTS TO CONTROL LARVAE **Group 1B**, eg SusCon Green®(chlorpyrifos) **Biocontrol agents**, eg Nematodes (*Heterorhabditis bacteriophaga, Steinernema carpocapsae*)	• SusCon Green® is incorporated into potting mix used for container-grown ornamentals. Minimal impact on non-target organisms.

Scarab grubs

Scarab beetles, cockchafers, dung beetles

Scientific name

Scarab grubs belong to the Family Scarabaeidae (scarab beetles, cockchafers and dung beetles), a number of other members of this family also attack growing plants including:

African black beetle (*Heteronychus arator*)
Argentinian scarab (*Cyclocephala signaticollis*)
Black beetle (*Metanastes vulgivagus*)
Blackheaded pasture cockchafer (*Aphodius tasmaniae*)
Blacksoil scarab (*Othnonius batesii*)
Cane grubs (*Lepidiota* spp.)
Christmas beetles (*Anoplognathus* spp.)
Greyback canegrub (*Dermolepia albohirtum*)
Pasture whitegrubs (*Rhopaea* spp.)
Pruinose scarab (*Sericesthis geminata*)
Redheaded pasture cockchafer (*Adoryphorus couloni*)
Wheat root scarab (*Sericesthis batesi*)
Brown cockchafer (*Ataenius imparalis*)
Dusky pasture scarab (*Sericesthis nigrolineata*)
Paspalum whitegrub (*Lepidiota laevis*)
Pasture whitegrubs (*Rhopaea* spp.)
See also page 100.

Host range

Adult beetles. feed on the young foliage of a range of plants depending on the species.

- Adults of some species feed on different plants from the larvae, eg Christmas beetles feed on eucalypt foliage, their larvae feed on grass roots.
- Adults of some species, eg African black beetle, feed on the same plants as the larvae.

Young larvae. feed on organic matter in the soil and when older feed mainly on **roots** of: **Ornamentals**, eg herbaceous perennials, potted plants. **Fruit,** eg peanut, pineapple, strawberry. **Vegetables**, eg potato. **Field crops**, eg maize, sugarcane, winter cereals. **Grasses**, eg pasture, lawns, turf, golf courses. **Weeds**.

Description & damage

Adult beetles are **2-70 mm** long, body is usually stout, chunky, convex and of various colors. Forelegs strongly developed for digging. They may be seen swarming on certain eucalypts during December-January. Many scarab beetles eat leaves but some feed on nectar. Some species fly at night, others during the day. **Larvae or 'curl' grubs** are **20-70 mm** long when fully fed, plump, soft, gray to white in colour with a hard, shiny, dark coloured head with prominent jaws. They have well developed legs on the thorax and are nearly always curled into a C-shape. Larvae have 3 stages or **instars**. Younger instars live closer to the surface; older instars feed at a greater depth.

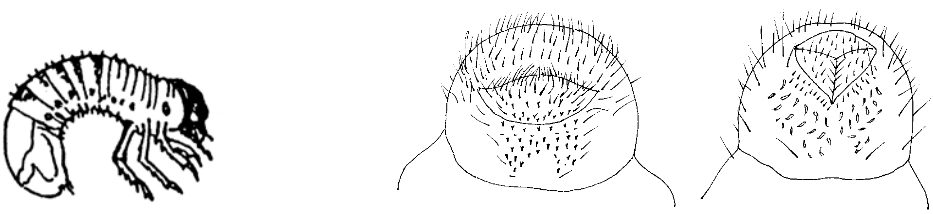
Turf/pasture. Adults burrow into fine grasses, physically disturbing the surface, some feed on the surface. Infestation tends to move outwards from a central point where the eggs were laid.

- **Primary damage** is caused by **larvae** chewing on grass roots which leaves the plant prone to water and heat stress. Damage is usually first noticed in autumn when patches of turf or pasture die and become soft and uneven.
- **Secondary damage** is caused by birds feeding on grubs particularly if the area is wet. Turf can be rolled back like a carpet to reveal the grubs. Stock may pull up pasture. Up to 250 scarab grubs/square metre have been recorded in the ACT. In some species, eg pasture cockchafer late instar larvae cause further damage by harvesting leaves to take into burrows below the surface.
- Severe damage may result in bare areas allowing weed invasion. Damage is very patchy.

Other hosts. Scarab grubs may be a sporadic pest of some crops. The entire root system of **strawberries and pineapple** can be eaten causing plants to be deprived of water and nutrients, wilt and die. **Potato** stems may be severed below ground or round deep holes gouged in tubers. Roots of **potted plants** in nurseries may be eaten right up to the crown causing them to wilt and wobble. Adults of some species chew stems just below ground level leaving a frayed edge.

Diagnostics. Damage by larvae is often misdiagnosed.

- Adult beetles are more easily identified but may not be available when identification is needed.
- Larvae are often identified from the shape of the anus and surrounding hairs.
- Molecular diagnostics often are needed to identify larval insects or adult members of a species complex.
- Do not confuse with damage caused by other agents, eg root rot, etc. Scarabs are minor pests of glasshouses. Damage is more likely to be caused by **BVW**.
- Lucid keys www.**lucidcentral**.com/
  Key to the Flower Chafers of NSW
  Key to the Christmas Beetles of NSW
  Key to the Dung Beetles of Eastern NSW
  Key to Adult Cane Beetles
- If in doubt see advice (page xiv).



Typical larva — Christmas beetle raster — Pruinose scarab raster

Fig. 75. Scarab grub larvae (Scarabaeidae)
Left: Typical scarab grub (larva) up to 20-70 mm long, usually found in the soil.
Right: Rasters of Christmas beetle and pruinose larvae.

Pest cycle

There is a **complete metamorphosis** (egg, larva - curl grub, scarab grub, pupa and adult) with only 1 generation each 1-3 years. In spring female beetles, seek out egg laying sites usually near the soil surface of well watered fine open textured turf. Eggs hatch in Jan-Feb, larvae burrow and feed just below the soil surface on organic matter. Towards **autumn** larvae move deeper into the soil and feed on grass roots. At the start of winter, larvae feed less actively and burrow even deeper into the soil. During late spring they pupate and in summer (Dec.-Jan.) adults emerge, fly off to favored host plants, mate and start egg laying. All scarabs have a similar life cycle, eg **1 year** - black beetle, pasture cockchafer, pruinose scarab, Argentinian scarab and pasture scarab; **2 years** - Christmas beetle. Timing of the life cycle varies between species and is affected by climatic conditions.

'Overwintering'

As larvae deep in the soil in special chambers.

Spread

- Adults can fly long distances.
- Adults of some species may crawl in from nearby areas or be transported in flood water.
- Larvae may be spread in containers and bush litter used as mulch.

Conditions favoring

- Numbers are regulated by weather, natural enemies, eg birds, diseases.
- Beetles favour well watered lawns of fine textured grasses and open textured soil for egg laying.
- Street lights attract beetles which may burrow in soil under the lights in an attempt to lay eggs.
- Severe damage usually occurs during autumn.
- Planting crops, eg pineapple, strawberry, nursery stock, vegetables, in recently-ploughed pasture or grassland containing paspalum, a favoured food. Improved pastures.
- Severe defoliation of trees by adults usually only occurs when moist soil favour emergence of large numbers of adults (drought hardens soil, newly formed beetles die in their chambers).

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation, based on the previous season's records of infestation.
2. **Crop, region**. Turf, pasture, eastern states, etc.
3. **Identification** can be difficult at the grub stage so consult a diagnostic service (see page xiv) to ensure correct control methods for your scarab grub, eg Argentine scarab beetle is the main pest species in the ACT and African Black beetle in Vic.
4. **Monitor** scarab grub numbers by soil plugs in October to indicate need for treatment. In high priority areas also monitor adults at egg laying time with light traps. Also check bird activity. Record findings.
5. **Threshold** will vary with crop, locality and likely economic damage (page 39). How much damage is acceptable? For many crops, thresholds have not been determined.
   - As many as 250 scarab grubs/square meter have been recorded in the ACT. Overseas recommendations suggest that pesticides are only necessary if there are 6 or more scarab grubs in an area 30 cm by 30 cm square by 5-8 cm deep. Since larvae live in soil under the plants, it is always difficult to know how many are present. Generally the first sign of infestation is the symptoms produced on the plant.
   - A population of about 5 mature larvae per **pineapple** plant produces visible wilting and yellowing.
   - 3 or more per **strawberry** plant - grower is not aware of them until plants start to show symptoms.
6. **Action**. Good cultural methods can reduce populations of grubs and reduce damage.
   - Remember by the time damage is apparent it is too late to apply chemicals.
   - With some crops treat preplant as it is impossible to treat after planting.
   - **For some crops** economic injury levels have **not** been established and there may be no satisfactory means of controlling these pests.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required, eg use of more tolerant varieties, and compare the current seasons data with previous ones.

Fig. 76. African black beetle (*Heteronychus arator*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged about x3.5
1.Eggs in soil
2.Larva or grub
3.Pupa
4.Adult female beetle
5.Adult male beetle, note shape of front tarsus or foot and damaged maize stem

Actual size
6.Eggs
7.Larva or grub
8.Pupa
9.Beetle and young maize plants that have been attacked

Control methods

Control of scarab grubs is difficult and often not economic. Good culture is a good start.

Cultural methods. Healthy vigorous turf can support many grubs without apparent damage.

- **Avoid frequent light watering** that may encourage egg laying and shallow-rooted turf which will not tolerate surface drying. Remedy soil compaction, the most common cause of water run-off, which prevents water penetration.
- **Fertilize** when turf is actively growing, eg spring/autumn. Fertilize and/or water pasture if economic. Reduce stocking pressure.
- **Core turf** to aerate lawn, aid water penetration.
- **Lawns containing clovers** are less severely damaged, as grubs prefer to eat grass roots.
- **For crops other than turf**, a period of fallow between ploughing and planting can be beneficial.
- **Thorough preplant** cultivations expose larvae to birds and mechanically injure and kill them.
- **Avoid planting** new ground with susceptible crops, eg maize, after pasture in areas with a known history of scarab grub infestation.
- **Check the top 10-15cm** of soil before planting for scarab grubs and other pests.
- **Cut lawns at recommended height**. Close or irregular cutting reduces turf vigour by removing too great a proportion of the leaf blade, which is the major food-producing part of the plant and exposes the crown to excessive drying out and damage. Bare patches may develop.
  - Mow turf frequently removing only 1/3rd of the height of the existing grass. Find out the correct mowing height for the turf you have.
  - If turf is allowed to grow too tall, only cut a few centimetres of the top and cut again a week later.

Sanitation.

- Remove litter on the soil surface to reduce hiding places for adults during the day.
- Use clean potting mix to prevent larvae/pupae from being introduced.
- Avoid spreading infested soil or potting mix around the property.
- Before planting remove volunteer plants and trash through cultivation to maximize mechanical injury to larvae.
- Destroy any infested plant material and debris.

Biological control.

- **Natural controls.**
  - **Predators**. In wet turf and pasture, currawongs, starlings, other birds, bandicoots and ground beetles feed on **larvae** close to the surface or exposed by cultivation. Birds, robber flies adults and some species of possum will attack **adult** beetles.
  - **Parasitic** wasps and flies lay eggs in larvae. Wasps feed on nectar from flowers.
  - **Diseases** caused by viruses, bacteria, fungi and nematodes infect larvae. If grubs are present and near the surface, watering during the day or early evening may increase activity of these diseases.
  - **Prolonged drought**, wet or extremely high soil temperatures at egg laying kills many eggs.
  - Viral, bacterial and fungal disease organisms are being researched for **adult scarab beetles**.
- **Commercially available** products include:
  - **Nematodes**. *Heterorhabditis zealandica* controls African black beetle, Argentine scarab, Argentine stem weevil, black-headed cockchafer, red-headed cockchafer, bill bug weevil. www.ento.csiro.au/biocontrol/scarabs.html
  - **Biocane™ Granules** (*Metarhizium* sp.) controls greyback canegrub (*Dermolepida albohirtum*).

Tolerant varieties.

- Roots of some grasses, eg tall fescue, regenerate more quickly than some other grasses. Clover is less severely damaged.

Plant quarantine.

- **AQIS**. NZ grass grub (*Costelytra zealandica*) is a serious pest of pasture and crop plants in NZ. It could enter Australia as adult beetles in cargo and goods freighted to Australia from NZ.

Pest-tested planting material.

- Plant clean plant material from properties known **not** to be infested.
- Check root area of incoming stock.

Physical & mechanical method.

- Overseas a nail-studded roller behind mowers injures grubs feeding close to the surface and may encourage secondary infection of grubs.

Insecticides. If chemical insecticides are to successfully control larvae then:

- Soil drenches will be needed.
- Apply during Jan-Feb when grubs are **small**, close to soil surface feeding on organic matter, body fat is minimal and before obvious damage.
- Treatment carried out when turf is damaged, usually late in autumn, leads to poor results, as grubs, feeding deeper in soil, contain larger quantities of fat which may absorb some of the chemical preventing them from being killed.
- Select insecticides non-toxic to birds.
- Target adult beetles by spraying late in the day or at night to control species active at that time.
- Failure to control scarab grubs is usually due to poor timing and/or methods of application.
- Spring applications for residual pesticides, control of scarab grubs may suppress earthworms and some predatory invertebrates but effects short-lived.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 14. Scarab grubs – Some insecticides and biocontrol agents.

What to use?	When and how to use?
SOIL TREATMENTS (LARVAE) **Group 1A**, eg carbaryl (not on food-producing plants in the home garden) **Group 1B**, eg various (chlorpyrifos) **Group 3A**, eg Baythroid® Turf (cyfluthrin); Brigade®, MaxGuard® (bifenthrin); Tempo® (beta-cyfluthrin) **Group 4A**, eg Confidor®, Confidor® Guard Soil Insecticide, Merit® (imidacloprid); Initiator® (imidacloriid + fertilizer); Meridian® (thiamethoxam) **Group 28**, eg Acelepryn® (chlorantraniliprole) **Biocontrol agents**, eg Nematode (*Heterorhabditis zealandica*); Biocane™ Granules (*Metarhizium* sp.) **Others**, eg Eucalyptus oil/Melaleuca oil	• **Preplant treatment** may be necessary for some crops, eg strawberry. • **Turf**. Where scarab grubs are a problem apply in January after young grubs hatch out from December-laid eggs. **Check local dates for application.** – **Before treatment** mow turf and water lightly and to ensure insecticide reaches larvae in soil. – **After treatment** water heavily to carry chemical into root zone and reach larvae 25 mm deep and avoid poisoning ducks. Check how long the treatment is effective for. • **Establishment of young eucalypts plantations**. Initiator® provides extended protection against damage caused by scarab larvae and adults, and other insects. • **Ornamentals in pots.** Seek advice. **Permits may be required.**

Longicorn beetles

Common borers

Scientific name

The native fig longicorn (*Acalolepta vastator*), Family Cerambycidae, Order Coleoptera. This family belongs to one of the **most common groups** of tree-boring insects in Australia. Other insects also damage trees and shrubs by 'boring' into limbs and trunks, and occasionally roots, eg

Order Coleoptera.
Family Cerambycidae (**longicorn beetles**), eg
- Citrus longicorn (*Skeletodes tetrops*)
- Fig longicorn (*Acalolepta vastator*)
- Pittosporum longicorn (*Strongylurus thoracicus*)
- Poinciana longicorn (*Agrianome spinicollis*)

Family Curculionidae (weevils)
Family Bostrychidae (auger beetles)
Family Buprestidae (jewel beetles)
Family Scolytidae (bark beetles)
Family Platypodidae (ambrosia beetles, pinhole borers)

Order Lepidoptera.
Family Oecophoridae, eg fruit-tree borer (page 96)
Family Cossidae (wood moths)
Family Hepialidae (ghost moths)

Order Hymenoptera.
Family Siricidae (wood wasps, eg sirex wasp)

Host range

Most longicorn beetles only attack branches that are already dead, or newly felled trees. Species that attack living trees and shrubs may attack only one type of plant or only a few different types.

Fig longicorn. Native and cultivated fig (*Ficus* spp.), citrus, grapevine, passion vine and wisteria, red cedar (*Toona australis*) and other plants.

Description & damage

Adult beetles are about **30 mm** long and gray. They have very long antennae ('long horned' or 'longicorn' refers to these antennae). Males have antennae about 3 times the length of the body. Fig longicorns have a prominent spine on each side of the thorax. Adults do very little damage, except perhaps chewing a few new shoots or young bark. Adults fly at night, may be attracted to house or shed lights and may be seen resting by day in the junction of main branches on infested trees.

Larvae grow up to **40 mm** long, are legless, creamy-white, club-shaped, glossy with a dark brown head and well developed black jaws. Compare with jewel beetle larvae which are more cobra-shaped (page 103).

Pupae are whitish, about **25 mm** long and slightly flattened, broadest across the middle.

Trunks/limbs/roots. Fig longicorn attacks young healthy citrus trees as well as older trees. It is more prevalent after pruning especially in limes.

- **Internal damage** is caused by **larvae** chewing tunnels in the phloem and cambium under the bark and may affect the sap flow to roots and branches. Tunnels may extend up or down for a metre or more in trunks, limbs and roots. Tunnels are oval and tightly packed with frass (sawdust). Branches may die.
- **External symptoms.**
  - Damage is more noticeable in smooth-barked trees. Considerable damage may be done before cracking bark indicates their presence.
  - Damage is characterized by oval holes and dead patches of bark which crack and eventually fall away leaving the sapwood exposed. Unless controlled, longicorn beetles can cause excessive scarring of trees and often death by ringbarking.
  - Sometimes larvae may be traced by the formation of hard lumps along infested branches (frass and gnawed wood mixed with gum).
  - Trees are commonly attacked near the base of the trunk due to damage from lawnmowers and cars.
  - Branches may snap off. On some hosts exudation of gum is the most obvious symptom.
- **Secondary damage.** Under moist conditions, longicorn damage may predispose trunks and major limbs to secondary fungal rots. Injury by longicorns on mango facilitates entry of *Botryodiplodia theobromae* which can grow beyond damaged tissue. Frequently more advanced stages of longicorn damage are associated with attack by other boring insects, eg auger and bark beetles. However, they are much smaller insects and produce round or ovoid holes in the bark from which fine dry powdery sawdust is extruded.

Diagnostics

- **Longicorn tunnels** are often difficult to recognize. With beetle borers evidence of their presence may be first indicated when droplets of clear or yellowish gum exudes from the bark.
- **Oval exit holes** of the adult are visible on trunks or limbs in advanced infestations.
- It may be necessary to get expert advice from an arborist to confirm identity and get advice on control. If not immediately obvious then 'sounding' will indicate the distribution of damage (Mann, personal correspondence).
- See also fruit-tree borer (page 96), termites (page 178) and wood rot (page 361).
- Lucid key www.lucidcentral.com/ *Wood Boring Beetles of the World Part I: Wood Boring Beetle Families*.

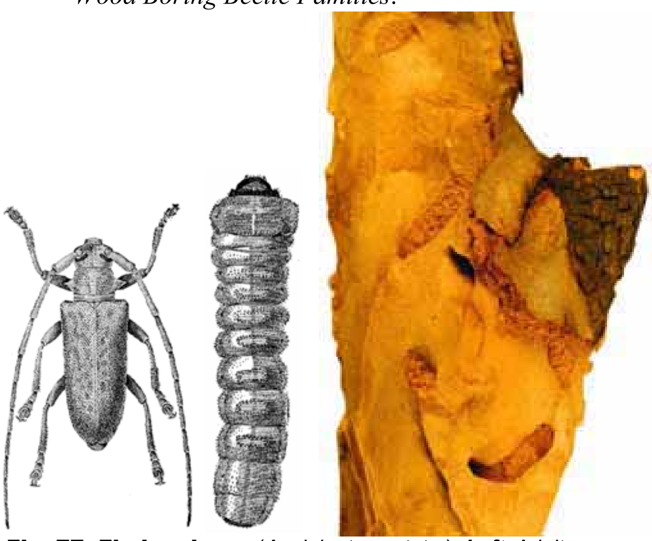


Fig. 77. Fig longicorn (*Acalolepta vastator*). ***Left:*** Adult about 30 mm long causes little damage, may feed on new shoots or young bark. ***Centre:*** Larva about 40 mm long feeds internally just below the bark. Photos© NSW Dept of Industry and Investment. ***Right:*** Larval damage by another species to eucalypt, bark removed, oval tunnels packed with coarse frass. Photo©CIT, Canberra (P.W.Unger).

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with 1 generation each year. Adults emerge from trees in spring and summer, mating occurs shortly afterwards. Egg laying begins and continues throughout most of summer. Females lay their eggs singly into rough bark, cracks of twigs and small branches or in wounds. They gnaw a circular patch about 1 mm in diameter around each egg. After hatching larvae eat their way into the wood and tunnel either upwards into the trunk or downwards into the roots for distances up to 1 metre. The circular patch of bark dries and falls out leaving a round pit which exposes the sapwood. When fully grown, larvae pupate just under the bark at the end of their tunnel. Adult beetles start to emerge from trees during spring through **oval exit holes** in late spring or summer.

'Overwintering'

In trunks, limbs, roots of host plants as larvae.

Spread

By adults flying. Movement of infested wood.

Conditions favoring

- Adult female longicorns prefer to lay their eggs on trees that have been weakened in some way, eg drought, waterlogging, sunburn, often following canopy pruning) or severe pruning, lawnmower or storm damage, old age, insect damage, disease, or fire damage.
- Research suggests that excessive use of fungicides kill fungi which attack larvae and may result in increased borer damage.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region**. Recognize variations depending on the crop, eg citrus, wisteria.
3. **Identification** of borer must be confirmed. Consult a diagnostic service if required (page xiv).
4. **Monitor** pest and/or damage and record results as recommended (page 39). Seek advice but you could monitor all blocks that have a history of borer problems, a rating system for citrus, eg.
   0. No damage
   1. Small patch on the trunk or a limb
   2. Trunk and a limb with 2-3 patches
   3. Most lower limbs and trunk with serious patches
   4. Extensive damage, serious dieback, secondary rot.
5. **Threshold**. For **citrus**, when the average rating is 2 or more. How much damage can you accept?
6. **Action**. Take appropriate action when any threshold is reached.
7. **Evaluation**. Treated trees should be inspected at 2-3 weeks intervals for the next few months after treatment and any missed tunnels or new larval damage treated. Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Control is difficult as damage is not usually noticed until larvae have penetrated deep into the wood.

Cultural methods. Maintain tree vigour, adequate drainage and irrigation, fertilizer practice. The best treatment for all tree problems is to ensure that the trees are as healthy as possible and therefore have the resources to establish their own internal protective walls. Judicious pruning at the correct time may stimulate vigour. All large pruning cuts should be made cleanly so that stubs are not left to die back and encourage further borer attack. Surfaces may be painted as soon as possible with an insecticide. Seek advice.

Sanitation. Control of larvae already in the wood is difficult. Regular pruning and burning of infested small branches may prevent loss of large sections of trees and minimize build-up of longicorns within the planting. If the main trunk is damaged affected tissues may be scraped away.

Biological control.

- **Natural controls.** Predatory beetles feed on larvae. Parasitic wasps attack larvae, papery cocoons and pupae are often seen in tunnels.
- **No biological control agents** seem to be available for purchase or been released as yet.

Physical and mechanical methods.
In small plantings, short tunnels may be probed with wire to kill larvae. Dissecting larvae from channels is discouraged due to mechanical damage caused by knives.

Insecticides.

- **Small accessible infestations** involving only 1-2 small trees. Clean away loose bark until the perimeter around the wound is healthy bark, destroy any larvae found, then paint on or squirt in a household insecticide which will be absorbed without damaging the tree.
- **Well established** trunk boring insects **cannot be controlled** by spraying, tree injection or by just placing insecticide in oval exit holes on the bark.
- **Large infestations** may be treated by a **licensed operator**. Place nozzle over one of the tunnel holes and squirt insecticide under pressure into the tunnel. Penetration along the length will be obvious when the chemical seeps from the other holes along tunnels. Follow-up treatments may be necessary for several months. A fungicide may be included if secondary fungi are a problem (?)
- **Seek advice for individual situations**, eg citrus longicorn damage to citrus.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table15. Fig longicorn – Some insecticides.

What to use?	When and how to use?
INSECTICIDES for Fig longicorn **Group 1B**, eg Gusathion® (azinphos-methyl); Supracide® (methidathion) **DANGEROUS POISON** **Group 2B**, eg Regent®, Legion®, various (fipronil) **Group 3A**, eg Talstar®, Venom®, various (bifenthrin)	**Insecticide should only be applied to large trees and extensive infestations by licensed operators**. **Note:** Stem injection of insecticides to control foliage-feeding insects does not control borers which mostly feed in dead tissue where there is no active conducting tissue.

Bean weevil

Not really a weevil

Scientific name

Acanthoscelides obtectus, Family Chrysomelidae, Order Coleoptera. Note that although this insect is called a weevil it is **not** a true weevil.

Host range

Beans and cowpeas in the field and in storage.

Description & damage

Weevils (adults) are small, stout, oval beetles approximately **3 mm** in length. They have white, gray, brown or black patches on the upper surface. The legs and antennae are reddish. **Larvae.** The 1st stage larvae have legs, and move through the pods and bore into seeds. Later stage larvae are white and legless and grow to a length of **3 mm**.

Seed. Damage is caused by the larvae feeding and developing inside the seed both **in the field** and **after harvest** in storage. After pupation of larvae inside the seed, emerging adults leave round exit holes. Infested seed is rendered unfit for human consumption and seed germination may be seriously affected. Infested seed that has **not** been treated may be found to be riddled when needed for planting.

Diagnostics.
- Circular holes on seed.
- In **lightly** infested seeds all stages are difficult to find. A hand lens is needed to see adults feeding.
- Can be difficult to identify one species of weevil from another. Seek expert advice (page xiv).


Fig. 78. Bean weevil (*Acanthoscelides obtectus*). ***Left:*** Adult about 3 mm long. Photo© NSW Dept of Industry and Investment. ***Right:*** Cavities produced in bean seed by larvae covered by thin circular caps of skin. Photo©CIT, Canberra (P.W.Unger).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa, adult), with up to 6 generations each year. Adult females may lay several hundred small white eggs on bean pods or on split seed on the plant. After hatching, larvae enter and feed in the seeds, damage in the field is not usually noticeable. Larvae complete their development inside the seed **after** the seed is harvested. When fully grown, the larva excavates a chamber near the surface of the bean and pupates. A visible circular cap of skin covers the chamber and is broken when the adult beetle emerges leaving a circular hole. Beetles that emerge in storage from field-infested seed, lay eggs on other bean seeds in storage and on bean pods or exposed seeds on plants in the field.

'Overwintering'

All stages in stored seed.

Spread

- By adult beetles flying, adults can invade bean crops from where seed is stored.
- By the movement of infested seed.

Conditions favoring

- Warm, dry conditions for field infestations.
- In storage they may breed throughout the year.

Management (IPM)

Are you a commercial grower or home gardener?
1. **Obtain/pepare a plan** that fits your situation.
2. **Crop, region.** Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage and record results (page 39).
5. **Threshold.** How much damage can you accept?
6. **Action.** Take appropriate action when any threshold is reached improving sanitation methods, etc.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Cultural methods. To minimize infestation of seed in field, harvest as soon as seed is mature. When beans are harvested for seed they should be bagged as soon as dry and then treated if necessary.

Sanitation. Destroy residues of old infested crops, seed residues and trash in boxes and sheds.

Biological control. No biological control agents are available for purchase and none have been released by government agencies. Little appears to be known about natural controls.

Pest-tested planting material. Check seed with a hand lens prior to planting.

Insecticides. See Table 16 below.

Table 16. Bean weevil – Some insecticides.

What to use?	When and how to use?
DUSTS & SPECIAL PACKAGING Dusts do **not** kill larvae or pupae inside the seed but they do kill the adults **after** they emerge preventing further infestation.	Use only for seed known to be **clean or lightly infested**. After treatment, store in beetle-proof sacks or muslin bags to keep seed free from infestation for a long time.
FUMIGANTS **Group 24A** (pages 60, 267)	

ORDER HYMENOPTERA

Ants, bees, sawflies, wasps

NO. SPECIES IN AUSTRALIA

More than 4,000 species of ants in Australia. World-wide decline in bees and other pollinators, eg beetles, butterflies, flies, bats and birds, is threatening yields of major field crops and biodiversity of wild plants. 25% of Britain's 250 native bee species are classified as rare or threatened.

www.ento.csiro.au/education/insects/**hymenoptera**.html

What wasp is that - An interactive identification guide to the Australasian families of Hymenoptera www.cbit.uq.edu.au/software/**whatwasp**/

Pesticides – A Guide to their effects on honey bees (Rhodes 2006) (available online).

The toxicity of commonly used chemicals to beneficial species www.**goodbugs**.org.au/

SOME DISTINCTIVE FEATURES

1. Has the largest group of **beneficial insects**, eg predators, parasites and pollinators, of any insect order.
2. Some show highly **socialized behaviour**, eg ants, bees.
3. Resistance to pesticides has only occasionally occurred.

ADULT **Body**

1. A marked constriction between the 1st and 2nd segments of the abdomen to form a **'waist'**. Exceptions are sawflies and wood wasps.
2. No scales on body, if hairs then wings are clear.
3. Females often have a long ovipositor for sawing, piercing or stinging.

Wings

1. Usually 2 pairs membraneous (lace-like) wings. A few species, eg ants, have largely dispensed with wings except for some brief prenuptial flights.
2. Forewings larger than forewings and are held together by hooks (hamuli).
3. Wings held flat over body when at rest.

LARVA **Legs**

Some have legs and others are legless, eg

1. Caterpillar-like thoracic legs and 6-8 pairs prolegs, eg cypress pine sawfly larvae.
2. Thoracic legs only, eg steelblue sawfly larvae (spitfires).
3. Maggot-like (legless), eg parasitic wasp larva.

Mouth Chewing mouthparts.

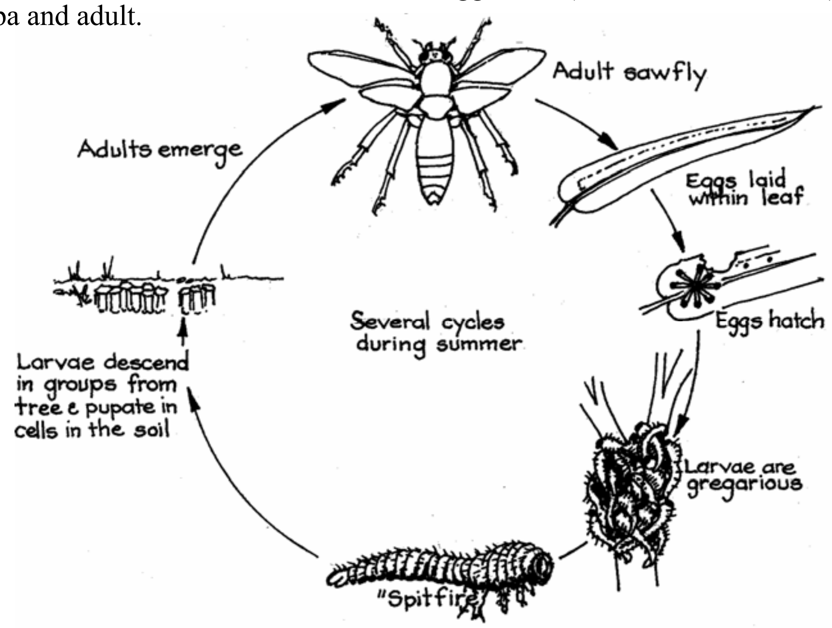
LIFE CYCLE

There is a **complete metamorphosis** - egg, larva (**grub, 'slug', spitfire**) pupa and adult.

Steelblue sawfly (spitfires)

Adults are about 25 mm long

Life cycle may vary markedly, eg ants, bees, wasps



METHOD OF FEEDING

ADULT **Chewing**, but mouthparts are sometimes modified for chewing and lapping.

LARVA **Chewing**.

PLANT DAMAGE

DIRECT CHEWING DAMAGE

Larvae cause most plant damage. Occasionally **adult** ants will eat leaves.

LEAVES	**Chewing damage**, eg steelblue sawfly, callistemon sawfly, cypress pine sawfly **Skeletonization**, eg pear and cherry slug, elm leaf beetle **Leaf mining**, eg leafblister sawfly **Galls**, eg many wasp galls found on native plants, eg eucalypts, wattles
STEMS	**Galls**, eg citrus gall wasp
TRUNKS	**Borers**, eg sirex wasp

INDIRECT DAMAGE

- Wasps may spoil ripe fruit.
- Commercial damage is caused when pollinated flowers start to wither.
- Ants may transfer young scale and other insects to new feeding sites.
- The entrance to some ant nests is surrounded by a mound of soil disfiguring turf, paths, etc.
- Adult leafcutting bees use their legs to cut away portions of leaves to line their nests.

OTHER EFFECTS

- Ants, bees and wasps may aggressively sting humans, eg European wasp.
- Bees introduced to increase pollination of certain crops may displace native bees

LIST OF SOME SPECIES

	COMMON NAME	SCIENTIFIC NAME	PEST STATUS/HOST RANGE/ (not exhaustive)
	ANTS (Family Formicidae)		www.ento.csiro.au/science/**ants**/
	Argentine ant	*Linepithema humile*	World's worst ant pest.
	Bigheaded African ant	*Pheidole magacephala*	Major threat to NT rainforests including Kakadu National Park, displace native ant population
	Crazy ants	*Anoplolepsis gracilipes* (Christmas Island, NT, Qld)	Environmental pest, can be a minor agriculture pest. Decimate red crabs on Christmas Island
	Funnel ants	*Aphaenogaster* spp.	Create a mound around the entrance to the nest
	Seedharvesting ants	*Pheidole* spp.	Harvest seed.
Fire ants are notifiable pests in some states/territories	Fire ant, 'red imported fire ant'	*Solenopsis invicta*	Harvest seed. Agricultural and horticultural pest. Stings humans and pets repeatedly. National Fire Ant Eradication program in place
	Tropical fire ant	*Solenopsis geminata*	Harvest seeds. May feed on plants, emerging seedlings, insects and animal matter, honeydew
	BEES (Pollinators, several families)		**www.aussiebee.com.au/ab11.html**
Honey bees	Honey bee (European honey bee)	*Apis mellifera*	Nectar, introduced pollinator.
Not known in Australia	Africanized honey bee (AHB)	African honey bee (*Apis mellifera scutellata*) **x** European honey bee (*A. mellifera* ssp.)	Extremely aggressive in defense of their colony and are easily provoked into stinging in response to vibration.
Not established in Australia	Asian honey bee	*Apis cerana*	Is the natural host of varroa mites which deplete honey bee colonies, often intercepted in quarantine
Not known in Australia	Giant honeybee	*Apis dorsata*	May carry mites which are parasitic on honeybees, often intercepted by quarantine
There are about 1500 species of native bees	Native honey bees	*Trigona* spp.	Nectar. Also called stingless bees, sugarbag bees
	Yellow-faced bumblebee	*Bombus vosnesenskii*	Recent arrival, may impact native flora and fauna. Could compete with native bees for pollen and nectar
Not known in mainland Australia	Large earth bumble bee (in Tasmania)	*Bombus terrestris*	Good pollinator but may displace some native bees. Can sting
Leafcutting bees	Leafcutting bees	*Megachile* spp.	Feed on nectar, damage rose, lilac

LIST OF SOME SPECIES	**COMMON NAME**	**SCIENTIFIC NAME**	**PEST STATUS/HOST RANGE (not exhaustive)**
(contd)	**WASPS (several families)**		www.cbit.uq.edu.au/software/**whatwasp**/
	Gall wasps (not all galls are caused by wasps)		
	Citrus gall wasp	*Bruchophagus fellis*	Citrus, esp. lemon, grapefruit. Preferred host is common rough lemon. Native host is fingerlime (*Microcitrus australisica*)
Citrus gall wasp damage by larvae	Seed chalcids	Eurytomidae	Various types of seeds
	Capri fig wasp	*Blastophaga psenes*	Figs, pollinated Capri fig develop a special flavour and quality
	Lucerne seed wasp	*Bruchophagus roddi*	Lucerne
	Parsnip seed wasp	*Systole* sp.	Parsnip
	Wattle apple-gall wasp	*Trichilogaster acaciaelongifoliae*	Wattles
Predatory wasps	**Predatory wasps (Vespidae)**		
	English wasp	*Vespula vulgaris*	Sting humans, attack damaged fruit, prey on insects
Locate nests by watching workers flying to & from the nest	European wasp	*V. germanica*	Sting humans, attack damaged fruit, rob bee-hives, kill bees. Prey on insects, eg flies and caterpillars
	Paper wasps	*Polistes* spp., *Ropalidia* spp.	They sting humans, adults feed on nectar and prey on caterpillars to feed their larvae
	Parasitic wasps (several families)		
Biological control agents	Aphid parasites	Various species of wasps eg *Aphidius colemani*	Aphids. Wasp larvae live inside aphids. The adult wasp, escapes by chewing a circular hole in the back of the mummified aphid
 	Braconid wasps	Family Braconidae	Parasites of various aphids, caterpillars, weevils etc
Parasitized aphid; Aphid	Chalcid wasps	Family Chalcididae	Insect larvae and pupae
	Flower wasps	Family Tiphiidae	Both sexes feed mainly on nectar, larvae parasitic on scarab larvae.
Baker, G and Hardy, J. 2005 ***Survey Black Scale parasitoids in South Australian Olives***. Sardi, SA.. (avail online)	Hatchet wasps	Family Evaniidae	Eggs, larvae of insects
	Ichneumon wasps	Family Ichneumonidae	Eggs, larvae of insects
	Greenhouse whitefly parasite	*Encarsia formosa*	Greenhouse whitefly, and to some extent silverfleaf whitefly
	Red scale parasites	*Aphytis* spp. *Encarsia perniciosi*	Red scale (on citrus)
	Black scale parasite	*Metaphycus helvolus*	Soft brown scale
Parasitic wasp laying an egg in a scale insect	Cabbage aphid parasite	*Diaeretiella rapae*	Cabbage aphid
	Cabbage white butterfly parasite	*Cotesia glomerata*	Cabbage white butterfly
	Sirex parasite	*Sirex noctilio*	Sirex on *Pinus radiata*
	Trichogramma wasp	*Trichogramma* spp.	Moths and butterflies eggs, caterpillars.
	Woolly aphid parasite	*Aphelinus mali*	Woolly aphid
	WOOD WASPS (Family Siricidae)		
	Sirex wasp	*Sirex noctilio*	*Pinus radiata,* other *Pinus* spp.
	Tremex wasp	*Tremex fuscicornis*	Poplars and willows
	SAWFLIES (several families)		
	Bramble sawfly	*Philomastix macleaii*	Blackberry, other brambles
	Ringed sawfly	*Pterygophorus cinctus*	Paperbark (*Melaleuca* spp.)
Melaleuca sawfly (*Lophyrotoma zonalis*) is being used in USA as a biological control agent against melaleuca	Melaleuca sawfly, paperbark sawfly	*Lophyrotoma zonalis* (other species may attack *Callistemon*, etc)	Paperbark (*Melaleuca* spp.)
	Cypress pine sawfly	*Zenarge turneri*	Native *Callitris*, exotic cypress
	Raspberry sawfly	*Prophorus morio*	Raspberry, blackberry, loganberry
	Leafblister sawfly	*Phylacteophaga* spp.	Eucalypts
	Steelblue sawfly	*Perga* spp. ('spitfires')	Eucalypts
	Pear and cherry slug	*Caliroa cerasi*	Cherry, pear, plum, also peach, almonds, quinces, hawthorn, Rosaceous plants preferred
Potential bio-control agent(?)	Willow sawfly	*Nematus oligospilus*	Crack, weeping, golden and pencil willows
Not known in Australia	Willow shoot sawfly	*Janus abbreviatus*	Poplar, willow
Endangered (?)	Flightless sawfly	*Clarissa tasbates*	In Tasmania

ANTS, BEES, WASPS AND SAWFLIES

Summary - Some exceptions

	SOME DISTINCTIVE FEATURES	PLANT DAMAGE
ANTS 	1. ‘Waist’ 2. Swelling on ‘waist’ 3. Social insects (males, queens, sterile workers and soldiers) 4. Compare with ‘white ants’ (termites) which belong to the **Order Isoptera**	**DIRECT FEEDING DAMAGE** **LEAVES** Chewed edges, eg adult ants **INDIRECT DAMAGE** • Are attracted to **honeydew** • **Spread** scale insects • **Repel parasitic insects** which might control scales, aphids, leafhoppers, lerp insects, etc • **Nest in turf**, bowling greens, etc • **May sting** humans and animals
BEES 	1. ‘Waist’ 2. Hairs on body 3. Many have long tongue for supping nectar 4. Bees feed their larvae on nectar 5. Broader bodies than wasps 6. Some bees are social insects (males or drones, queens, sterile workers) 7. Use pollen and nectar as food for larvae	**DIRECT FEEDING DAMAGE** • Possible transfer of pollen containing genetically modified material **INDIRECT DAMAGE** • **Adult leafcutting bees** cut pieces of leaves to build nests • **Pollination** of flowers hastens withering reducing their commercial value • Not all species sting. Honeybees vary in their aggressiveness. **BENEFICIAL** • Their main value is as **pollinators**
WASPS 	1. ‘Waist’ 2. No hairs on body 3. Most are parasitic on other insects, some prey on other insects 4. Some wasps are social insects (females, males, workers)	**DIRECT FEEDING DAMAGE** **LEAVES** Galls, eg on eucalypts **FRUIT** General pest **STEMS** Galls, eg citrus gall wasp, sirex wasp (plus a fungus) **INDIRECT DAMAGE** • May sting aggressively **BENEFICIAL** • **Biological control agents**, eg parasitic wasps, predatory wasps • Pollinators
SAWFLIES 	1. No ‘waist’ 2. Stout saw-like ovipositor which the female uses to cut plant tissue to insert her eggs 3. Larvae are often caterpillar-like (thoracic legs + 6-8 pairs prolegs), some only have true legs on the thorax.	**DIRECT FEEDING DAMAGE** **LEAVES** Chewing damage, eg steelblue sawfly Leafmining, eg leafblister sawfly Skeletonization, eg pear and cherry slug **INDIRECT DAMAGE** • Unsightly and sometimes unpleasant communal behaviour

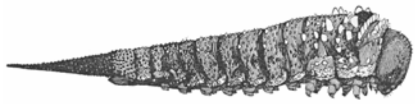


Fig. 79. Teatree sawfly larvae (*Pterygophorus* sp.). Photo©NSW Dept of Industry and Investment.

Fig. 80. Sawfly larvae feeding on *Callistemon*. Photo©CIT, Canberra (P.W.Unger).

Fig. 81. *Callistemon* leaves **skeletonized** by sawfly larvae. Photo©CIT, Canberra (P.W.Unger).

Fig. 82. Leafcutting bees (*Megachile* spp.) indiscriminately damage a number of species but have no great economic effect.

Fig. 83. Cypress pine sawfly larva (*Zenarge turneri*). Photo©CIT, Canberra (P.W.Unger).

Fig. 84. Gall on flower stem of Geraldton wax caused by a small wasp. Photo©WA Agric (Wood & Grimm 1988).

Fig. 85. Parasitic wasp. Tiny wasp laying an egg in a scale insect.

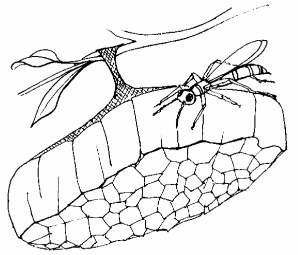


Fig. 86. Predatory wasp. Native paper wasps are common and are aggressive stingers.

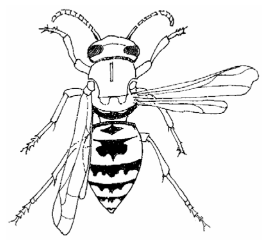


Fig. 87. Predatory wasp. European wasp (*Vespula germanica*). Sting is painful, especially if a mature nest is disturbed which can lead to hundreds of stings. Few predators in Australia to keep it under control.

Fig. 88. Suppliers of parasitic wasps.

PARASITIC WASPS (some examples only)	**PEST (not exhaustive)**	**SUPPLIERS**
Parasitic wasp (*Aphytis* spp.)	**Red scale** (*Aonidiella auranti*)	Australasian Biological Control (ABC) www.**goodbugs**.org.au/ This website lists commercial suppliers of bio control agents and provides advice on developing an **IPM** program suitable for your crop and situation. Some also provide **IPM** monitoring services. Lucid key *What Wasp is That?* www.**cbit**.uq.edu.au/software/**whatwasp**/ www.**lucidcentral**.com/ Parasitic wasps can be killed by insecticides
Greenhouse whitefly parasite (*Encarsia formosa*)	**Greenhouse whitefly** (*Trialeurodes vaporariorum*) **Other whiteflies**	
Parasitic wasps (*Trichogramma* spp.)	**Moth eggs and caterpillars** of *Helicoverpa* spp., codling moth and lightbrown apple moth	
Parasitic wasps (*Aphidius* spp.)	**Aphids,** eg green peach aphid and cotton or melon aphid	

Ants

Scientific name

Family Formicidae, Order Hymenoptera. There are more than 5,000 species of ants in Australia, but only a few ever damage turf and other plant materials or are troublesome to humans, eg

Argentine ant (*Linepithema humile*)
Brown house ant (*Doleromyrma darwiniana*)
Bull ants, bulldog ants (*Myrmecia* spp)
Coastal brown ants (*Pheidole* spp.) .
Funnel ant (*Aphaenogaster pythia*)
Meat ants (*Iridomyrmex* spp.)
Fire ant (*Solenopsis invicta*)
Tropical fire ant (*Solenopsis geminata*)
See also page 115.

Ants Down Under http://**anic**.ento.csiro.au/**ants**/
Australian Ants Online
www.**csiro**.au/resources/**AustralianAntsOnline**.html

Host range

Ants are important predators and scavengers; they contribute to nutrient recycling in soil and soil structure by constructing nests and burrows. They rival earthworms in their ability to move soil.

- Ants are attracted to the **honeydew** excreted by some sap sucking insects, eg aphids, scale.
- Edges of leaves and flowers may be eaten.
- Some species grow their own fungus for food.

Description & damage

Ants are social insects and live in colonies. The **queen** lays all the eggs, is winged at birth but loses them after mating. There may be more than 1 queen in a nest. **Workers** are wingless sterile females who build the nest and tend the queen, larvae and pupae and forage for food. **Soldiers** defend the colony and often have large heads and mandibles. **Males** have wings and mate with the new queens.

Plant damage. Ants may occasionally chew leaf edges causing minor injury. They can also be a nuisance when attempts are made to establish plants through direct seeding. They may nest in indoor potted plants.

- **Nests may damage lawns**, golf greens, pastures. Funnel ants (*Aphaenogaster* spp.) throw up mounds of earth around entrances to their nests creating an artificial drought by removing soil from around roots.

Fig. 89. Ants (Family Formicidae).

- **Seedharvesting ants** (*Pheidole* spp.) remove and destroy seeds.
- **Honeydew** produced by soft scales, aphids, leafhoppers, lerp insects, mealybugs and whiteflies, attracts ants which repel predators and parasites of these pests. Ants may spread young scales to new hosts. If ant populations are very high, numbers of soft scales increase dramatically, trees may dieback.
- **Ants may nest in and around houses** paths, paved areas, pots and invade houses, compost heaps, mulched garden beds and uncultivated land, lawns, school yards, parks. Ants can also block micro-sprinklers in orchards. A few species will occasionally attack electrical wiring and extensive damage has occurred.
- **Some ants infest timber** damaged by fungi, termites or borers in retaining walls, fences and buildings. None of the ant species present in Australia damages timber in **good** condition.
- **Environmental threat**, eg
  - **Stings** of some species need medical attention. Ants may irritate pickers in orchards.
  - **Threaten outdoor activities**, eg barbecues.
  - **Fire ants** (*Solenopsis invicta*) are a public nuisance and pest of agriculture and horticulture. If the nest is disturbed they will aggressively and repeatedly sting humans and pets. Fire ants are predators of root weevil larvae in citrus orchards.
  - **Bigheaded African ants** (*Pheidole magacephala*) are a major threat to Kakadu National Park.
  - **Crazy ants** (*Anoplolepsis gracilipes)* swarm all over, poison and eat slow moving red land crabs or young birds in nests on Christmas Island. Mainly an environmental pest but can be a minor agricultural pest in Christmas Island, NT and Qld.
  - **Ant communities** in any area may provide an indication of the level of **disturbance** of an area.
  - Overseas some species are known to carry diseases and can pose a threat in hospitals and veterinary clinics. Uncommon in Australia where in general ants are mainly a nuisance pest.

Diagnostics.

- Ants are easily recognized due to their 'wasp waists' and elbowed antennae.
- Distinguishing one ant species from another may requires the help of an ant specialist or you can access online keys (see above).

Fig. 90. Argentine ant (*Linepithema humile*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

All enlarged x16
1. Eggs
2. Fully-fed legless larva
3. Pupa of male showing developing wing buds
4. Worker ants about 3 mm long
5. Queen after wings have broken off

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult). At certain times of the year males and females of most species make nuptial flights from the nests. The mated female, or **queen**, then sheds her wings and seeks a place in which to found a new colony. **Nests** of most species are made in the ground, under logs or stones under bark of trees or in old stumps, landscape timbers or in termite mounds. Some live in **cavities in trees**, others more rarely in nests amongst the **foliage** of trees. Black or brown ants invade buildings. A colony of ants may have **more than one nest**, and workers may be seen passing restlessly to and fro along regular runways for long distances through grass, along walls or other surfaces from one nest to another. These nests may be connected by tunnels below ground. The **queen** excavates a chamber or cell within which she remains, laying eggs. Eggs hatch into legless larvae which are fed by the queen, with secretions from her salivary glands, until they enter the pupal stage. **Pupae** change into **worker ants** that construct tunnels, forage for food, tend the queen, care for eggs, feed larvae (usually reared in groups) or move them from place to place in the nest. **Soldiers** (sub-castes of workers) defend the colony.

'Overwintering'

As all stages in nests.

Spread

- By ants **crawling** and mated queens **flying**.
- By **transportation** of ants, larvae and eggs in soil, grass sod, mulch, potting mix, on timber, containers, vehicles, machinery, infested nursery stock, hay, straw, landscaping materials. Humans.

Conditions favouring

Each species has optimum temperature conditions. Many are attracted to their food source.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. Obtain leaflets on ant control for you local area.
2. **Crop, region**. Recognize variations. Are the ants in containers, adjacent to glasshouses, barbecue areas?
3. **Identification** of ant species can often only be accomplished by a trained taxonomist (page xiv).
4. **Monitor** pest and/or damage and record results as recommended. Examine trees, etc, during the warmer parts of the year and the warmer parts of the day, although some ant species are active at night.
5. **Threshold**. Have any thresholds been established? If so, what are they, eg economic, aesthetic, environmental? Do you need to calculate your own threshold? Will depend on the ant species, eg
   - For **fire ants** eradication is being attempted so there is a nil threshold.
   - **Fruit trees**. Thresholds vary but examples include when ants are present on 50% or more of shoots examined for scales or other pests. On rare fruit when noticed or when 5 out of 50 trees are infested.
6. **Action**. Take appropriate action when any threshold is reached. Distribution of baits, tree banding, control honeydew-producing insects, eg scales.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Controlling ants reduces aphid, mealybug and scales.

Cultural methods. Maintain crop vigour.

Sanitation. Clean up plant debris, other litter or food scraps. Store food in air tight containers. In orchards, skirt trees regularly, keep weeds under control so that ants cannot climb up trunks.

Biological control. Many vertebrates prey on ants; wasps, flies and nematodes parasitize them. However, there is currently no effective bio-control agent available for controlling ants in Australia.

Plant quarantine.
- **AQIS**. Many species are not yet in Australia.
- **State/Regional Quarantine**, eg the National Fire Ants Eradication program. There are legal requirement to report suspected fire ant outbreaks in some parts of Australia, areas are quarantined and eradication procedures implemented.

Physical & mechanical methods.
- **Drown ants in pots** by placing pots in water.
- **Sticky materials** used to bands trees prevent ants reaching the tops of trees to feed on honeydew, mate, or deposit eggs; some are chemical-impregnated barriers. Labour intensive but some barriers can provide up to 3 years protection.
- Cultivating around nests discourages ants.

Insecticides.
- Some insecticides used for commercial ant control are **highly toxic**.
- If practical **locate** and **treat the nest**.
- **No** chemicals are registered for use on crops.
- **Spread baits** that worker ants can take back to the nest during foraging to feed the queen.
- **Small colonies in home gardens**. Many dusts, etc are available from garden centers for ant control. Apply according to label directions.
- **Soil around the base of tree** may be treated but, depending on the persistence of the insecticide, ground sprays may only last a short time as subterranean colonies generally survive and rapidly return to pre-treatment levels.

Table 17. Ants – Some insecticides and other controls.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

What to use?	When and how to apply?
IN HORTICULTURE SITUATIONS	
Group 1A, eg carbaryl; Ficam® (bendiocarb); Baygon® (propoxur) **Group 1B**, eg Lebaycid® (fenthion); various (chlorpyrifos) **Group 2C**, eg Choice® (fipronil) **Group 3A**, eg pyrethrins; Baythroid® (cyfluthrin); Cislin® (deltamethrin); various (permethrin); Permaguard® (diatmocous earth/pyrethrin); Temp® Residual insecticide (beta-cyfluthrin) **Group 20A**, eg **Permit required for this bait** - Amdro® (hyramethylnon/soybean oil/ground corm); Maxforce® (hydramethylnon) **Spray oils, etc**, eg various oil sprays; eucalyptus oil, Beat-a-Bug® (garlic/ chilli/pyrethrin/piperonyl butoxide); Hovex® antkiller (boron decahydrate).	• **Permits may be needed in some states**. • Some insecticides are taken back to the nest before ants sense that anything is wrong. Generally slow acting. Colonies may die within weeks. • Various Nest Kill Ant Baits (boron, fipronil) are available for use indoors. • Ants may move nest sites when disturbed or with change in food supply, this can make their control difficult. • Controlling soft scales and other honeydew producers will control ants on trees and shrubs.
Sticky materials, eg Tac-Gel® (polybutene); Trappit® Tanglefoot® (natural gum resins/vegetable oil/wax)	Used to band trees to trap ants attracted to honeydew produced by some sap sucking insects, eg aphids.

Citrus gall wasp

An example of a gall wasp

Scientific name

A native wasp (*Bruchophagus fellis,* Eurytomidae, Order Hymenoptera) infests citrus in Queensland, NSW, Victoria and South Australia. Another gall wasp (*Eurytoma* sp.) has recently been found to also attack some citrus.

Host range

Citrus. Citrus gall wasp is native to coastal NSW and Qld where it develops in the native finger lime (*Microcitrus australiasica*). All citrus can be attacked, but there are differences in susceptibility.

Description & damage

Damage is caused by the **larvae**.

Adult wasps are black, about **3 mm** long, they are smaller than the length of a match. **Larvae,** when fully grown are white, about **3 mm** long, legless, tapering towards each end of the body.

Stems. Injury is caused by the female wasps depositing eggs within the stem and subsequent feeding and development of wasp larvae which causes extensive galling. The galls may be up to **25 cm** long and **3 cm** thick containing hundreds of larvae. Old galls are covered with the small emergence holes of the adult. **Twigs.** In spring heavily flecked young twigs indicate that citrus gall wasps are laying large numbers of eggs in the current spring growth. Twigs may die and be replaced by weaker growth.

Leaf midribs, petioles & fruit stems. Although stems are most frequently attacked, these parts may also be infested.

General. Damage is very serious in nursery stock as the main stem may be attacked. Heavy galling weakens older trees and may reduce fruiting. Fungal diseases, eg melanose, may invade dead tissues and cause further damage.

Diagnostics.

- Galls are quite distinctive (Fig. 91 below).
- Do not confuse **male citrus gall wasps** (black on top and brown underneath) with **parasitic** native female *Magastigmus* wasps which are honey coloured, and about the same size.
- Lucid key *What Wasp is That?* www.**cbit**.uq.edu.au/software/**whatwasp**/

Pest cycle

There is a **complete metamorphosis** (egg, larva (4 stages), pupa and adult) with 1 generation each year. Adult wasps emerge from tiny exit holes on galls in spring, mate and females immediately lay eggs, after which they live only about a week. Young twigs only a few weeks old are selected for egg laying usually on the same tree. Each female deposits more than 100 eggs between bark and wood. Larvae hatch from eggs and feed within plant tissues during summer, autumn and winter to early spring when they pupate in the galls.

Fig. 91. Citrus gall wasp (*Bruchophagus fellis*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

1. Eggs (x 24)
2. Larvae
3. Pupa
4. Adult wasp
5. Emergence holes of adults (all enlarged x 12)
6. Galled lemon twig showing exit holes of adult wasps
7. Gall cut open to show cells in which wasp develops
8. Adult wasps laying eggs (all actual size)

'Overwintering'

As larvae in galls on the host plant.

Spread

- Adults are poor fliers, but are assisted by wind.
- By the movement of infested cuttings and plants.

Conditions favouring

Mild winters, proximity to existing infestations in coastal districts of NSW and Qld. They are not a problem in cold tableland climates.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Plan** for your situation after obtaining advice from your local department of agriculture.
2. **Crop, region**. Not a wide distribution.
3. **Identification** of pest, not difficult, must be confirmed. Consult a diagnostic service (page xiv).
4. **Monitor** and record damage and/or parasitism (page 39), eg
   - **Monitor stems for citrus gall wasp** once during winter by examining 3-5 branches (30 cm long) from 20 randomly selected trees in a 1-5 ha block.
   - **Monitor for parasitism** in crop by collecting say 2-3 galls from each of 10 trees in a block in late August, keeping them in plastic container with a fine mesh lid. Gall wasps will emerge first about 10 days later, *Megastigmus* (if present) will emerge for 2-4 weeks. The number of trees from which samples should be taken depends on the block size and history of infestation.
   - Yellow sticky traps attract wasps and other insects.
5. **Threshold** is determined in some areas by legislation. Outside these legal obligations how much serious damage, weakened trees can you tolerate economically or aesthetically?
6. **Action/Control**. Carry out measures prescribed by legislation. Otherwise biological control starts when **no** parasites have emerged by mid-October. Either release *Megastigmus* when 33% or more branches are infested with 1 or more fresh galls and forego spraying **or** apply a recommended pesticide between the last week in November and the first week in December, if there is a serious infestation.
7. **Evaluation**. Review your current program, assess success of techniques and recommend improvements if necessary. Evaluate sanitation procedures and consider planting less susceptible varieties/crops.

Control methods

Legislation. There is a legal responsibility in some areas of Australia where citrus gall wasp is a 'proclaimed pest', to carry out prescribed controls.

Sanitation.

- **Home gardeners.** Because adults emerge from galls in spring, all galls must be removed by the end of August at the latest and burnt, **before** wasps emerge to lay eggs in new shoots.
- **Commercial growers.**
  – All galls from all the trees in one locality should be removed at one time. Wasps are not strong fliers and prefer to develop in the trees on which they themselves developed.
  – Cut off plants at ground level. Heavily galled trees will benefit from a heavy pruning during winter.
  – Burn all the removed growth in a manner which kills all citrus gall wasps present in the growth.
  – Destroy all **regrowth** not older than 2 years from the plants within 21 days of appearance.
  – Regular **inspections** of nurseries known to be infested have prevented the wasp from becoming a pest of commercial orchards.
  – Do not allow shoots to develop on rough lemon, or Troyer Citrange rootstock in the orchard to become heavily infested with citrus gall wasp.

Biological control.

- **Natural controls.** Citrus gall wasps may be killed by **heat** or **ants** (*Pheidole* spp.) as they emerge. **Native wasps** (*Megastigmus* spp.) parasitize gall wasp larvae and may be trapped in galls, unable to emerge.
- **Wasps for purchase**. Wasps (*Megastigmus* spp.) lay eggs in over 90% of gall wasp eggs in young twigs resulting in smaller and fewer galls. List of suppliers www.**goodbugs**.org.au/

Resistant varieties.

- Avoid planting large areas of susceptible varieties where citrus gall wasp is a pest.
- Citrus gall wasp is **more** common in grapefruit (most susceptible), orange and lemon. Mandarins are **least** susceptible.

Plant quarantine.

- **Commonwealth.** Gall wasp (*B. muli*) occurs in Papua New Guinea. If introduced into Australia it could become a pest of limes.
- **Regional quarantine.** The wasp is a problem in Qld and northern NSW citrus areas and is believed to have been introduced to Sunraysia from **infected budwood**. Areas may be Declared Quarantine Areas and any owner or occupier of land on which infested trees are growing may be required to treat specified citrus trees in a prescribed manner. Check local requirements.

Pest-tested planting material.

- Only purchase and plant gall wasp-free budwood and nursery stock.

Physical & mechanical methods.

- **Yellow sticky traps.** Insectrap® is a non-toxic, sticky, yellow, cylindrical trap that attracts and kills adult citrus gall wasps for 3-4 months, reducing populations; it may attract bees and other insects. The trap is weatherproof and waterproof. The attractant within the trap is food-based.

Insecticides.

- **For home gardeners** there is no practical chemical control.
- **In commercial orchards**, spray susceptible grapefruit and mandarins with an appropriate registered chemical when citrus gall wasp eggs have hatched and before woody tissue has started to form around the larvae, usually early December. Timing of pesticide application is critical.

Table 18. Citrus gall wasp – Some insecticides.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

What to use?	When & how to apply?
Group 1B, eg Supracide®, Suprathion® (methidathion) **DANGEROUS POISON**	**Commercial growers only. Only to be applied by licensed operators.** Toxic to parasitic wasps (*Megastigmus*) in **IPM** programs.

Pear and cherry slug

Not really a slug but a sawfly

Scientific name

A sawfly (*Caliroa cerasi*), Order Hymenoptera.

Host range

Fruit trees, especially cherry, but also plum, pear, occasionally peach, nectarine and almonds, quince, medlar.
Ornamentals, eg ornamental varieties of stone fruits, hawthorn, cotoneaster, sometimes *Photinia* spp., *Hardenbergia*.

Description & damage

Plant damage is caused by the larvae or 'slug'.

Adults are **7 mm** long, glossy, black sawflies. The female has a saw-like ovipositor at the end of her abdomen, which she uses to cut slits in leaves in which to lay her eggs. **Larvae or 'slugs'** are about **13 mm** long when fully grown, the body is rather enlarged in front and tapered to the rear. While feeding, the larvae are covered with an olive-green slime, but at each moult, and when fully grown, they shed this slime and so revert to an orange or an orange-yellow colour.

Leaves only are attacked. Larvae feed mostly on the upper surface of leaves, eating everything except the veins and lower epidermis, creating a 'window pane' effect. Severely skeletonized leaves turn brown, shrivel and fall; trees appear to be scorched by fire and unsightly.

General. Severe infestations year after year can severely weaken trees and reduce cropping. Home gardeners can be bitterly disappointed with their choice of tree.

Diagnostics. Larvae and damage are easy to recognize because of its:

- Limited host range and is the only pest which skeletonizes leaves of these hosts.
- Larvae are often thought to be moth caterpillars but they are slimy and **have no legs**.

Pest cycle

There is a **complete metamorphosis** (egg, larva or slug, pupa and adult) with 2 or more generations per year, but there could be up to 5-6 overlapping generations in some areas, eg ACT. The female has a saw-like ovipositor for slitting the leaf tissue to deposit the eggs under the epidermis. Larvae feed for several weeks then either fall or crawl to the ground where they pupate and spend a short pupal or resting stage. Adults emerge and the cycle starts again. The 2nd and later generations are usually more numerous and destructive than the 1st generation. Larvae can be seen feeding through spring, summer and autumn.

'Overwintering'

Pear and cherry slug 'overwinters' as larvae in small earthen cells in the soil. In spring (late October or November) the adults emerge.

Spread

- As adults flying.
- Movement of infested nursery stock with leaves.
- As there is no pear and cherry slug on deciduous trees in winter, **bare-rooted nursery stock** is most unlikely to introduce this pest.

Conditions favouring

Cool, moist weather during spring, summer and autumn. Adults can only emerge from soil when the weather is moist. The 'slugs' shrivel up on leaf surfaces during hot, dry weather while during very wet weather they may feed on the undersurfaces of leaves.

Fig. 92. Pear and cherry slug (*Caliroa cerasi*). ***Left:*** Adult sawfly (about 7 mm long). Photo©NSW Dept of Industry and Investment. ***Right:*** Larva or slug (about 13 mm long) skeletonizing a cherry leaf. Photo©CIT, Canberra (P.W.Unger).

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** which suits your situation for susceptible hosts and where pear and cherry slug is a perennial pest.
2. **Crop, region**. Mainly a problem in cool moist areas and affects ornamental and fruiting species.
3. **Identification** of pest is important because insecticides such as Dipel® (*Bacillus thuringiensis*) are only effective against some leafeating caterpillars and **not** sawfly larvae. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** susceptible varieties during spring, summer and autumn for larvae and damage and record results (page 39). Seek advice about the need for monitoring in your crop and region. Inspect trees weekly during the time when damage is expected, eg examine foliage of at least 20 trees per hectare for damage, but the number will depend on the variety.
5. **Thresholds** depend the economic value or aesthetic damage to trees, ie whether it is a fruiting or ornamental variety. Many species only have minor damage but some are severely affected. Depending on the variety, control measure might be required if more than 10-20% foliage are infested with larvae and are being skeletonized.
6. **Action/Control**. Take appropriate action when any threshold is reached.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required. For new plantings consider resistant varieties.

Control methods

Cultural methods. Avoid overhead irrigation so that the leaves are not wetted unnecessarily.

Biological control. No biological control agents are available for purchase. Parasites introduced in 1928 and 1931 failed to establish. There appear to be no parasites which attack the pear and cherry slug specifically. The predatory shield bug (*Oechalia schellembergii*) had been observed feeding on larvae. Predatory wasps and birds probably prey on them as well.

Resistant varieties. Cultivars vary in susceptibility. Check before you recommend or purchase.

Physical & mechanical methods. These are suitable for home gardeners who only have 1-2 small, newly planted trees.

- **Drying agents**, eg lime, ash or vacuum cleaner dust, may be dusted on to leaves to dehydrate larvae on a small tree.
- Larvae may be **squashed** by hand.
- Because the insect **pupates in the soil** under the tree, home gardeners can possibly:
  - Spread fly netting on the soil or grass under the tree to trap any emerging sawfly.
  - If there is bare soil under the tree, cultivate to disturb the pupa, this will kill many of them but is not sound environmentally.
  - Hose off.
- **Assess the effectiveness** and ease of use of the above treatments. Remember adults fly and may invade trees from surrounding areas.

Insecticides.

- Insecticides may be applied when larvae are first seen on the leaves.
- Note some insecticides will damage some plant varieties. Check the label.
- Not necessarily a major pest in commercial orchards as spray program against other pests prevents this pest from building up to cause damage

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 19. Pear and cherry slug – Some insecticides.

What to use?	When and how to apply?
FOLIAGE SPRAYS AND DUSTS **Group 1A**, eg carbaryl (not on food-producing plants in the home garden) **Group 1B**, eg Benthion®, Gusathion® (azinphos-methyl)® **DANGEROUS POISON** **Group 3A**, eg pyrethrins **Group 5**, eg Entrust® Naturalyte, Success™ Naturalyte™, Success™ 2 Naturalyte™ (spinosad) – **not toxic to some predators** **Others**, eg Beat-a-Bug® Insect Spray Concentrate (chilli/garlic/pyrethrin/piperonyl butoxide); Garden Spray® (sulphur/mancozeb/carbaryl); various garden sprays and aerosols, eg pyrethrin	• Apply when threshold is reached or as soon as slugs are observed especially during spring and autumn. If the 1st generation is controlled in spring and early summer, later generations may not be such a problem. • If the insecticide selected is only effective for a short time a 2nd application may be necessary. Only apply later sprays if infestation warrants it. • Observe **withholding periods** on fruiting varieties, further sprays can be applied **after** harvest.
PEARS AND PLUMS **Pears**	• If sprayed regularly for **codling moth** pears are unlikely to be attacked. Non-bearing trees may have to be sprayed.
Plums	• If sprayed to control **oriental fruit moth** and **aphids** plums are unlikely be attacked by the pear and cherry slug.

Steelblue sawflies

‘Spitfires’

Scientific name

Perga spp.(Order Hymenoptera). This is the largest and commonest of the eucalyptus-feeding sawflies.

Host range

Various species of eucalypt, eg *E. camaldulensis, E. globulus, E. occidentalis, E. melliodora, E. viminalis.*

Description & damage

Only the **larvae** damage plants.

Adults are called ‘sawflies’ because of the characteristic saw-like egg-laying ovipositor of the female used for cutting plant tissues and inserting their eggs. Adults are about **25 mm** long and are of a general steelblue colour with yellow markings on the head and thorax. They have yellow antennae and legs. The wings have well marked veins and are deep yellow. In the male the upper surface of the abdomen is covered with silvery down.

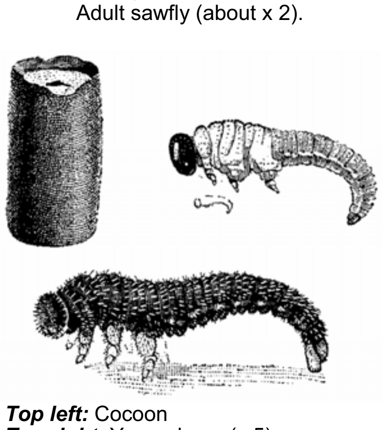
Larvae (‘spitfires’). Young larvae are yellowish with black heads. Fully-fed larvae are about **70 mm** long, black and covered with short white hairs. They have **no** prolegs on the abdomen. They have been called ‘spitfires’ because when disturbed, they bend back their bodies and exude from their mouths, a viscid yellowish substance which has a strong eucalyptus odour. At the same time they raise the tips of their abdomens and tap up and down. Large colonies survive better than smaller colonies and if individuals are separated from the colony they soon die. It has been suggested that some individuals in the colony lead the feeding and movement and the survival of other members is dependent on the activities of these leaders. The yellow exudate has a **high concentration of eucalyptus oil** and can cause severe pain if it gets in the **eyes**, the eyeball becomes bloodshot and is often called ‘Christmas eye’. Medical attention is required to ease the irritation.

Leaves. Juvenile and adult foliage attacked. The larvae feed on the foliage and can seriously defoliate young trees. During the day they rest clustered together in a tightly packed mass on the tree upon which they are feeding. At night they wander individually over the foliage to feed and later return to their resting place. On older trees the damage is not usually long lasting. On small trees larvae from a single batch of eggs can defoliate the whole tree.

Diagnostics

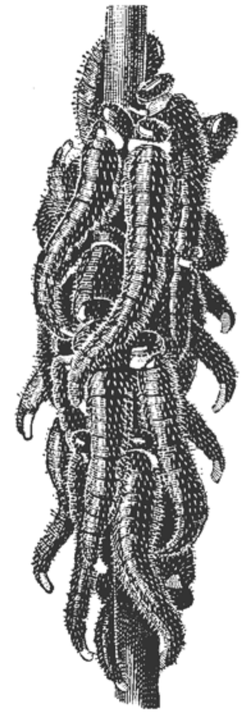
- **Adult sawflies** which do not have a waist like ants and wasps are not often seen.
- **Larvae** are common, gregarious, conspicuous and resemble large hairy caterpillars but do not have any prolegs on the abdomen.
- **Chewing damage** to eucalypt leaves can also be caused by leafeating beetles and their larvae and many caterpillars.

Adult sawfly (about x 2).



Top left: Cocoon
Top right: Young larva (x 5)
Lower: Fully-fed larva (spitfire)

Top: Young larvae. ***Lower:*** The cuticle of the leaf has been removed to show the eggs laid in the leaf tissue.



Fully-fed larva (spitfires), about natural size.

Fig. 93. Steelblue sawfly (*Perga* spp.). Photos©NSW Dept of Industry and Investment.

Pest cycle

There is a **complete metamorphosis** (egg, larva or 'spitfire', pupa and adult) with several generations each year. Adult females emerge from pupal chambers in the soil in late summer. They lay eggs in slits on leaves, larvae feed on foliage during autumn, winter and spring, when they descend from the tree in a slow moving mass (as many as 250) and may wander about on the ground for several days before burrowing into soft ground to a depth of 5-10 cm, usually about the base of the tree. They spin large cocoons in rows against each other, usually with their heads all facing one way. Cocoons are dark brown, thin-walled, cylindrical about 25 mm long and 12 mm across. Timing of the cycle varies according to species, subspecies and geographic location.

'Overwintering'

As larvae in cocoons in the soil. Sometimes odd small colonies are observed even in winter.

Spread

As adults flying and as larvae crawling.

Conditions favouring

- Weather has most impact on sawfly numbers. Long term weather cycles determine numbers.
- Warm weather. In mild winters the pest cycle continues though at a slower rate. In some winters colonies appear particularly damaging.
- Hot and dry weather in early spring kills many mature larvae when they are about to enter soil which is too hard for them to dig into, to pupate.
- Larvae can survive heavy frost in winter.
- Attack declines once trees achieve canopy closure.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation.
2. **Crop, region.** Recognize variations.
3. **Identification** of pest is easy, though the exact species can be more difficult to determine. Consult a diagnostic service if necessary (page xiv). Damage is often not noticed until it is severe, late in the season and larvae are preparing to enter the ground to 'overwinter'.
4. **Monitor** pest and/or damage to trees and record results as recommended (page 39). If sawfly damage is anticipated, young trees can be inspected for clusters of young larvae in autumn before any major feeding has occurred. Techniques for assessing impacts in forest areas are available.
5. **Threshold**. How much damage can you accept to young trees? Have any thresholds been established? If so, what are they, eg economic, aesthetic?
6. **Action**. Take appropriate action when any threshold is reached. Larvae can be eliminated either by physical removal or by applying a chemical insecticide (see Table 20 below).
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required, eg replacing susceptible species/provenances.

Control methods

Biological control. Exudate produced by the 'spitfires' might deter predators and parasites.

- **Natural controls.**
  - **Parasitic flies and wasps** parasitize larvae on leaves and pupae in the soil and seem to stabilize sawfly populations from year to year.
  - **Vertebrate predators** have only a limited impact on sawfly abundance as numbers of larvae tend to remain surprisingly constant throughout winter. Currawongs, cockatoos, gang-gangs and other birds feed on larvae but most find them distasteful. Gang-gangs pull off and discard the head and oil sac before eating the rest.

Resistant varieties.

- **Susceptible species** in some areas include Blakely's red gum (*E. blakelyi*), river red gum (*E. camaldulensis*), yellow box (*E. melliodora*), snow gum (*E. pauciflora*), manna gum (*E. viminalis*), swamp gum (*E. ovata*), wandoo (*E. wandoo),* others.
- **Non-hosts** include ironbark (*E. sideroxylon*), scribbly gum (*E. rossi*), grey box (*E. microcarpa*).
- **Variation.** Within a susceptible eucalypt host species there is little evidence that **individual** trees vary in their susceptibility.
- **Terpenoid oils.** Larvae feed on a wide variety of eucalypts with different amounts of terpenoid oils in the leaves. The ability of the larvae to utilize and store leaf oils for their own defense suggests they may be relatively immune to the effects of terpenoid oil defences in host plants.

Physical & mechanical control.
If only a few trees are affected and clumps of 'spitfires' are within reach, they may be knocked from the tree with a long stick or hosed off with a strong jet of water and destroyed. Branches bearing clumps may be cut off.

Insecticides. If it is not practical to remove and destroy clumps by hands, clumps on small trees less than 3 m high can be spot sprayed. Apply directly to the cluster of larvae using a good wetting agent.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 20. Steelblue sawfly – Some insecticides.

What to use?	When and how to apply?
SMALL TREES, LESS THAN 3 METRES **Group 1B**, eg Malathion® (maldison); Rogor® (dimethoate) **Group 3A**, eg Tempo® Residual Insecticide (beta-cyfluthrin) **Group 4A**, eg Initiator® Systemic Plant Insecticide and Fertiliser (imidacloprid/fertilizer) - **steelblue sawfly larvae are not specifically listed on the label**	Spray when first noticed, the use of a wetting agent is considered essential when spraying eucalypts. **Initiator**® improves the establishment of **young** eucalypts trees, enhancing growth and protection against damage caused by various insect pests, including some defoliating insects.
VERY LARGE VALUABLE TREES	Seek specialist advice. If tree injection is being considered, larvae must be feeding and the tree actively growing (sap moving) when tree injection is carried out.

Leafblister sawflies

Scientific name

Phylacteophaga spp. (Order Hymenoptera). The larvae of several moths and a beetle may also mine in various species of eucalypts.

Beetle (*Syrbis alycore*) Blackbutt leafminer (*Acrocercops lacinella*) (a moth) Jarrah leafminer (*Perthida glyphora*) (a moth)	

Host range

More than 30 species of eucalypts and occasionally brush box. Host species include *Eucalyptus botryoides, E. grandis, E. saligna.*

Description & damage

Adults are only **5 mm** long and live for less than a week and do not feed. **Larvae** are also small, only about **5-6 mm** in length, and are only seen if the cuticle over the blistered leaf area is removed. Blisters also contain excreta produced by the larvae. **Pupae.** Oval-shaped cocoons may be seen within the blistered area. An oval **hole** cut from the center of the cocoon indicates that an adult sawfly has emerged.

Leaves. Damage is caused by **larvae** mining between the upper and lower leaf surfaces giving the leaf a blistered appearance. At times almost every leaf on **young trees** (< 5 m in height) may be affected and the tree may have a scorched appearance. Affected leaves fall, and trees < 5 m in height may be completely defoliated. Larvae feed on juvenile leaves and young adult leaves near the ground, suggesting that leaf nutrition is more important than leaf chemistry and may limit populations once adult leaves start to form.

Leafmining damage. Heaviest damage usually occurs to juvenile foliage within **6 m** of the ground. Older trees, therefore, are not so seriously affected. Attack ceases on trees which have adult foliage.

Diagnostics. Damage may be confused with:

- **Other leaf mining insects** of eucalypts, mostly moth larvae, but none construct a swollen pupal chamber like that of the leaf blister sawfly. The jarrah leafminer (*Perthida glyphopa*) is a major pest of jarrah in WA.
- **Fungal leaf spots**, eg *Mycosphaerella*, which causes a leaf spot on juvenile foliage of blue gums and allied species. This fungus is prevalent in warm, moist environments and causes pale, irregular lesions across both leaf surfaces which may eventually crack and blister.
- **Check for larvae** or cocoons in the blisters by holding leaves up to light. Check for exit holes.

Pest cycle

There is a **complete metamorphosis** (egg, larva, pupa and adult) with 4-8 generations each year. The female sawfly cuts a slit in the leaf usually near the mid-vein into which the egg is laid. The leaf surface swells around the egg, forming a small ‘egg gall’. The small larvae feed between the leaf surfaces until the leaf appears blistered. Larvae pupate in the leaf by constructing their **cocoons within the raised blister** area and a small winged sawfly later emerges from the cocoon though a small hole in the leaf surface. Life cycle takes about 6 weeks in summer to several months in winter. Up to 150 eggs may be laid in a single leaf by several females.

‘Overwintering’

As larvae in leaves in north central Victoria. Also possibly in some areas as pupae in infested leaves.

Spread

- Adults flying.
- Movement of infested nursery or tube stock.

Conditions favouring

- Activity ceases in cold weather but may continue at a reduced rate during mild winters.
- Large outbreaks can occur in young plantations.
- Trees stressed by abnormal weather conditions, eg drought, water logging; also soil deficiencies, competition from weeds, browsing wallabies, rabbits, livestock.

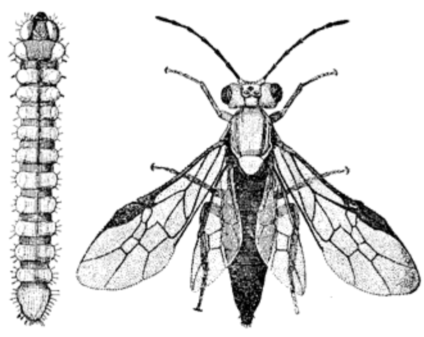


Fig. 94. Leafblister sawfly (*Phylacteophaga* spp.). ***Left:*** Leaves showing leafmining damage by larvae. Larvae and excreta can be seen when leaves are held up to light. ***Right:*** Larva and female adult sawfly (both 5-6 mm long)
Photo© NSW Dept of Industry and Investment.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation.
2. **Crop, region**. Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage and record results as recommended (page 39). Check the foliage regularly for signs of early infestation, especially around May-June and Sept-Oct. Look for egg galls and small blisters which indicate that leaf mining is in the early stages. These may be difficult to detect at first but will become more obvious with experience. Techniques for assessing impacts in forest areas are available.
5. **Threshold**. Do you need a threshold? Have any thresholds been established? If so, what are they, eg economic, aesthetic?
6. **Action**. Take the recommended action when any threshold is reached at the appropriate time before significant damage occurs. Chemical control is most useful when larvae are actively feeding but before they have caused significant damage. Often by the time damage is noticed it is too late to spray.
7. **Evaluation**. Review **IPM** program to see how well it worked. Recommend improvements if required. Continue regular surveillance and assessment of insect activity is essential for effective pest control. Assess as objectively as possible whether insecticide application will produce a benefit and is warranted.

Control methods

Cultural methods. Healthy vigorously growing eucalypts can usually outgrow damage caused by insects, so severe insect attack can be a sign that trees are under stress. Proposed sites for trees must be suitable for the species to be planted, eg water availability, seasonal rainfall, soil texture and structure and depth, site topography and prior land use. Avoid waterlogged hollows, drought conditions or excessively exposed sites. Drought is the major cause of seedling stress so seedlings must be planted when adequate moisture is available. Optimum tree spacing with consideration of growth rates, tree form and proposed silvicultural regime.

Sanitation. Light infestations can be controlled by cutting off infested portions from small trees and destroying them. Remove dead or dying trees.

Biological control.

- **Natural controls.** Little birds such as pardalotes remove larvae from blisters for food. Parasitic wasps attack and kill larvae and pupae in infested leaves.
- **Commercial applications**. Some of the parasitic wasps now being used to control *P. froggatti* in NZ, where it was accidentally introduced are being investigated.

Resistant varieties. Young trees of some eucalypt species are attacked in some seasons and in some regions of Australia.

- **Very susceptible species.** Flooded gum (*E. grandis*), Sydney blue gum (*E. saligna*), southern mahogany (*E. botryiodes*), swamp mahogany (*E. robusta*).
- **Moderately susceptible.** Blakely's (*E. blakelyi*), river red gum (*E. camaldulensis*), blue gum (*E. globules*), sugar gum (*E. cladocalyx*), snow gum (*E. pauciflora*), manna gum (*E. viminalis*), swamp gum (*E. ovata*), red box (*E. polyanthermos*), others.
- **Poor hosts.** Grey box (*E. microcarpa*), Silverton gum (*E. camaldulensis* var. *sub-cinerea*), spotted gum (*E. maculata*).
- **Provenances.** Because of differences in their chemical and physical make-up, not all provenances of river red gum are equally susceptible to attack. In other species, such as flooded gum, there is as yet little evidence that provenances or individual trees of the same species vary in their susceptibility to attack.
- In areas susceptible to leaf blister sawfly attack consider selecting appropriate species or provenances with some resistance to the pest, eg Silverton race of river red gum rather than the susceptible Lake Albacutya and allied provenances.

Insecticides.

- Blisters protect larvae from contact insecticides.
- **Correct timing** of insecticide application is essential.
- **Systemic insecticides** can give some control but only consider spraying if blisters are small and larvae are **actively feeding**. If pupae (raised oval lumps) can be seen in most blisters, then spraying will be ineffective as larvae are no longer feeding.
- **Chemicals have a limited role** in forest tree management due to the localized and sporadic nature of most insect damage. However, they may be needed in plantations of susceptible trees such as flooded gum in the 1st two years after establishment when trees are 1-3 meters high.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

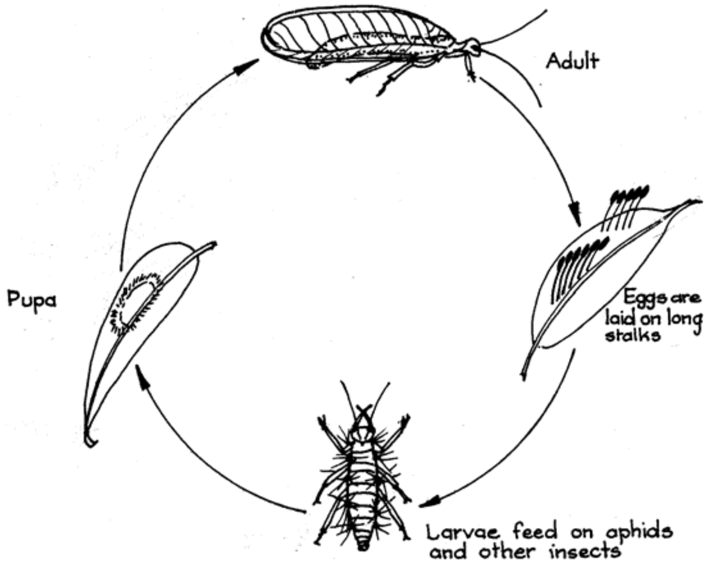
ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 21. Some insecticides for leafminers generally.

What to use?	When and how to apply?
FOLIAGE SPRAYS Many products are registered for **leaf miners generally**, eg **Group 1B**, eg Rogor® (dimethoate) **Group 5**, eg Entrust® Naturalyte™, Success™ Naturalyte™ (spinosad), see also page 74 **Spray oils**, eg Pest oil®, Summer oil, White oil, DC-Tron Plus, various (**petroleum oil**); BioPest®, SK ENSPRAY® (**paraffinic oil**); Eco-oil® (**botanical oil**) **Remember, check the plant and the leafminer the product is registered for use on**	• As larvae are feeding within the leaf, **systemic** sprays are more effective than contact non-systemic ones. • Apply at the first indication of damage during spring. • The use of a wetting agent is considered essential for effective results when spraying eucalypts. • If there are many blister and exit holes it is **too late** to control for this season. • **Initiator® Systemic Plant Insecticide and Fertiliser** (imidacloprid) improves the establishment of **young** eucalypts trees providing, enhancing growth and protection against damage caused by various insect pests, including some defoliating insects (**note leafblister sawfly is not listed on the label**).

ORDER NEUROPTERA

Lacewings, antlions, aphidlions

NO. SPECIES IN AUSTRALIA	More than 600 species. Important predators. Common throughout most of Australia, common on native vegetation such as flowering eucalypts and in suburban garden and homes, some are attracted to lights at night and will release a strong smell when disturbed. www.ento.csiro.au/education/insects/**neuroptera**.html www.brisbaneinsects.com/brisbane_**lacewings**/index.html
SOME DISTINCTIVE FEATURES	**ADULT** **Body** Small to medium-sized, elongate, fragile, up to 50mm long. **Wings** Two pairs nearly equal lace-like wings with a network of veins. Wings held tent-like over body when at rest. Wing spans ranging from 5-150mm. **Head** 1. Prominent head. 2. Large compound eyes, ocelli absent. 3. Antennae long and thread-like or clubbed. **Abdomen** No cerci. **LARVA** 1. Active predators, some larva are called antlions, aphidlions. 2. Modified chewing mouthparts for clasping prey. 3. Three pairs of thoracic legs.
LIFE CYCLE **Lacewing** Many variations in life cycle	There is a **complete metamorphosis** - egg, larva, pupa and adult. Some species have several generations each year and some in colder areas take up to 2 years. 
BIOLOGICAL CONTROL AGENTS	The native **green lacewing** (*Mallada insigna*) and **brown lacewing** (*Micromus Tasmania*) can be purchased in Australia as general predators of small insects. They may not be economically viable. List of suppliers www.**goodbugs**.org.au/
METHOD OF FEEDING	**ADULT** **Chewing** mouthparts. Adults may feed on soft sap sucking insects, eg aphids and scales, honeydew, pollen and nectar. May be attracted to crops by offering yeast, sugar and water. Overseas, adult clusters can be conserved during winter in chambers at temperatures which ensure their survival until spring. **LARVA** **Modified chewing mouthparts for sucking.** Most are active predators of other insects, eg ants, aphids, mites, thrips, whitefly, in the USA also azalea lace bug (*Stephanotis pyrioides*). Some larvae, eg antlions, in sandy areas often trap their prey in pits, small insects fall into the pit where they are grabbed and eaten by the antlion which is waiting just below the surface. Many larvae adorn themselves with the dried bodies of their victims. Strips of lacewing eggs can be attached to a pest-infested plant, eggs hatch and larvae clean up the pests.

ORDER THYSANOPTERA

Thrips

NO. SPECIES IN AUSTRALIA

There are more than 5500 species worldwide, but fewer than 100 species are important pests of economic plants. More than 75 species are associated with horticultural and agricultural crops in Australia.

www.ento.csiro.au/education/insects/**thysanoptera**.html

Lucid Keys www.**lucidcentral**.com/

Pest Thrips of the World, ThripsID,

AQIS Identification Guide (ThripsID) - Thysanoptera

SOME DISTINCTIVE FEATURES

ADULT

Body Most species are tiny, up to **1.5 mm** in length, some longer. Elongated body rather than spherical.

Wings **Two pairs of narrow strap-like**, approximately equal length wings with fringes of hairs around edges which assist flight, the wing membranes being too small to sustain flight. Some species are wingless.

Mouth Slightly asymmetrical cone with stylets.

Legs Minus claws. It is easy to observe this but you need a microscope.

NYMPH Usually paler in colour than the adults, often transparent.

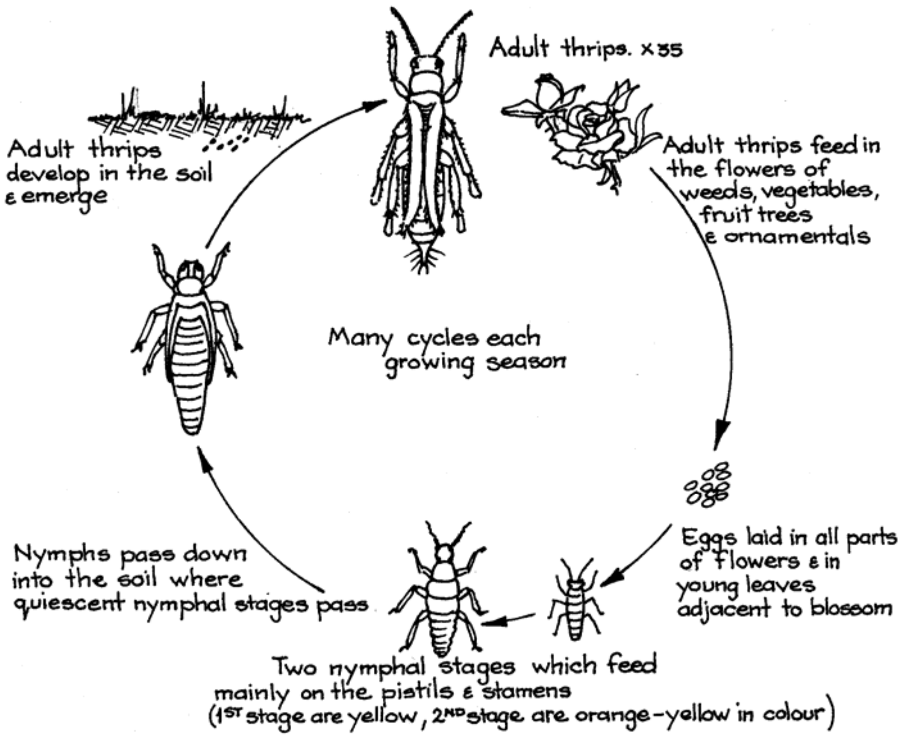
LIFE CYCLE

There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. The larger nymphal stages may be non-feeding, resting pupa-like stages (pre-pupal and pupal). **Parthenogenesis** is common (fertilization is not necessary), the female insect produces live young without the necessity of mating).

Plague thrips

Natural size about 1 mm long

Some variations, eg gladiolus thrips, greenhouse thrips



METHOD OF FEEDING

ADULT NYMPH All stages feed by **rasping** plant tissue and **sucking** sap from individual cells on the surface of the plant. Many species feed on fungi, others feed on pollen and a few species prey on small insects and mites.

PLANT DAMAGE

Because damage caused by thrips may be confused with damage caused by mites, or other insects (whiteflies, leafhoppers, or on some hosts, lace bugs), correct identification of **thrips** is essential

DIRECT RASPING & SUCKING DAMAGE

Damage is caused by **both nymphs and adults feeding**. Often the injury does not become apparent until the insects responsible have departed. Damage affects appearance of plants and also their ability to photosynthesize.

LEAVES **Silvering**, eg greenhouse thrips, gladiolus thrips, onion thrips
Galls, eg various species on wattle, eucalypt
Leaf rolling, eg callistemon leafrolling thrips

FLOWERS **Brown areas, flecking, withering**, eg gladiolus thrips, plague thrips, western flower thrips
Distortion, eg gladiolus thrips, plague thrips, bean blossom thrips

BUDS **Distortion and twisting**, eg plague thrips

FRUIT **Prevent fruit or seed set**, eg plague thrips
Silvered or scarred, eg banana rust thrips

CORMS **Rotting**, eg gladiolus thrips

INDIRECT DAMAGE

- **Transmission of virus diseases**, eg Western flower thrips transmit tomato spotted wilt virus and impatiens necrotic spot virus.
- Drops of excreta **disfigure leaves, flowers**, etc.
- Consumers complain about thrips on plants.
- Yield loss and death of young plants.
- Cause quarantine problems in flowers for export.
- Settle on white sheets and pale coloured garments hung out to dry.
- Land on bare skin, causing itching and prickling, trying to get moisture from skin.

LIST OF SOME SPECIES

Many crops/plants may be affected by several species of thrips, eg strawberry is a host for WFT, plague thrips, onion thrips

Silvering of viburnum leaves by **greenhouse thrips**, dots of excreta.

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Banana flower thrips	*Thrips hawaiiensis*	Banana, various flowers
Banana rust thrips	*Chaetanaphothrips signipennis*	Banana, cunjevoi (*Alocasia macrorhiza*) and some natives
Banana silvering thrips	*Hercinothrips bicinctus*	Banana, choko, passion fruit, weeds
Bean blossom thrips	*Megalurothrips usitatis*	Dwarf French beans, climbing beans, cow pea, weedy vine (*Clitoria ternata*)
Black plague thrips	*Haplothrips froggatti*	Grasses
Citrus rust thrips, orchid thrips	*Chaetanaphothrips orchidii*	Citrus, orchids, glasshouse plants
Cocksfoot thrips	*Chirothrips manicatus*	Grasses
Cuban laurel thrips (a leafrolling thrips)	*Gynaikothrips ficorum*	*Ficus microcarpa* var. *hillii*
Dandelion thrips	*Ceratothrips frici*	Dandelion flowers
Eucalypt thrips	*Thrips australis*	**Flowers** of eucalypts, Myrtaceae (thought to feed on nectar)
	Australothrips bicolor	**Leaves** of eucalypts, other plants
Gall thrips	Phaeothripidae	Syzygium, casuarina, wattles (*Acacia aneurus, A. pendula*)
Gladiolus thrips	*Thrips simplex*	Gladiolus, iris, arum lily, torch lily, 'red-hot' poker, tiger flower, carnations
Goldtipped tubular thrips	*Haplothrips gowdeyi*	Commonly found in flowers
Gorse thrips	*Odontothripiella australis*	Polyphagous, lupins, etc
Grain thrips	*Limothrips cerealium*	Cereals, especially wheat
Greenhouse thrips **Resurgence** in some parts of the world	*Heliothrips haemorrhoidalis*	**Foliage** of azalea, persimmon, citrus, guava, house plants etc

LIST OF SOME SPECIES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	Leafrolling thrips	*Teuchothrips* spp.	*Callistemon*, *Melaleuca*, *Bursaria, Myoporum, Pittosporum*
	Lily thrips (Victoria)	*Liriothrips vaneeckei*	Lily bulbs (**between the scales**)
	Maize thrips	*Frankliniella williamsii*	Maize
	Melon thrips	*Thrips palmi* (**vector** for some viruses, eg tomato spotted wilt)	Ornamentals, vegetables, weeds, cucurbits, grasses, Solanaceae
	Onion thrips, cotton seedling thrips	*Thrips tabaci* (**vector** for some viruses, eg tomato spotted wilt virus, iris yellow spot virus)	Wide host range, mainly **foliage** of vegetables, eg onion, bean, pea, tomato, weeds, grasses, ornamentals, eg carnation, rose
	Plague thrips	*Thrips imaginis*	Mainly feeds on the **blossoms** of ornamentals, eg roses, fruit trees, vegetables, weeds
	Redbanded thrips	*Selenothrips rubrocinctus*	Cashew, mango, guava, avocado, mangosteen
	Strawberry thrips	*Scirtothrips dorsalis*	Strawberry, citrus fruit
	South African citrus thrips (Qld)	*Scirtothrips aurantii*	Ornamental and fruit crops, especially citrus
	Tomato thrips	*Frankliniella schultzei* (**vector** for some viruses, eg tomato spotted wilt)	**Flowers** of tobacco, cotton, grain legumes, lettuce, tomato, others
Major pest	Western flower thrips (WFT)	*F. occidentalis* (**vector** for some viruses, eg tomato spotted wilt)	Many ornamentals, fruit, vegetables, field crops
Not known in Australia	Banded greenhouse thrips	*Echinothrips americanus*	Ornamentals, woody ornamentals; often intercepted in quarantine
	PREDATORY THRIPS		
Obligate predatory thrips	Predatory thrips (only on insects, mites)	*Aleurodothrips fasciapennis* *Podothrips* sp.	Scales on mango and citrus. Scales on grasses and bamboo
	Sixspotted thrips	*Scolothrips sexmaculatus*	Spider mites on leaves
Facultative predatory thrips	Predatory thrips	*Desmothrips* *Aelothrips* *Andrewarthaia*	Feed on larvae of other thrips in flowers of grasses and native plants. Also feed on plant tissue
	FUNGAL-FEEDING THRIPS		
	Giant thrips	*Idolothrips spectrum* up to **7 mm** long and one of the largest thrips in the world	Fungal spores on dead eucalypt leaves
	About 50% of thrips feed only on fungal hyphae or their liquid breakdown products, some ingest whole fungal spores. Fungal-feeding species live in leaf litter, dead twigs and branches, flowers and pollen grains.		

Fig. 95. Onion thrips injury to onion leaves. Photo©CIT, Canberra (P.W.Unger).

Fig. 96. Leafrolling thrips (*Teuchothrips* sp.) damage to new leaves of bottlebrush (*Callistemon* sp.). Photo©CIT, Canberra (P.W.Unger). See also page 33.

Gladiolus thrips

Scientific name

Thrips simplex (Thysanoptera). A key pest in Qld, SA, a minor pest in NSW and NT. An entire crop can be ruined if control is inadequate.

Host range

Ornamentals: Unlike many other species of thrips, gladiolus thrips is restricted in its host range. A major pest of gladiolus, minor pest of carnations, iris, calla or arum lily, torch lily or 'red-hot poker' (*Kniphofia* sp.), montbretias (*Tritonia* spp.), and tiger flower (*Tigridia pavonia*).

Description & damage

Leaves, flowers and corms may be damaged by nymphs and adults rasping the surface of plant tissues and sucking up the sap which exudes.

Adult females, are about 2 mm long, dark brown with 2 pairs of delicately fringed wings. Males are slightly smaller than females. **Nymphs** are similar to adults but are pale yellow and wingless. **Pre-pupae** and **pupae** are yellowish.

Damage.

- **Leaves.** Young nymphs feed inside leaf sheaths and buds. Adults mostly feed in the open on leaves which become **bleached** and **silvery**. Extensive leaf damage may cause new corms to be stunted.
- **Flowers.** Thrips move into flower spikes as they develop. Flower spikes may be stunted, flowers may fail to open or be distorted or the petals marked with small pale flecks. Injury is often wrongly attributed to drought or disease. Slight injury especially on dark blooms appears as whitish or flecked areas, even a few flecks reduces their market value. Damage is very noticeable on dark-colored flowers.
- **Corms.** Thrips also feed and breed on corms in the ground and in storage. Surface of corms becomes sticky, then hard and scabby. Young root buds may also be injured. When damaged corms are planted, thrips feed on young roots and growth from the corm may be seriously affected.

Diagnostics. Damage to leaves and flowers may be confused with damage caused by mites, drought, etc.

- It can be difficult to distinguish one species from another. Seek specialist advice if necessary.
- Home gardeners need to identify the problem only as thrips.
- Commercial growers need to identify the **species** of thrips, eg gladiolus thrips, western flower thrips **(WFT)** (page 138).
- **Various keys** are available, eg Lucidcentral: Search for a *Thrips ID key* www.lucidcentral.com/

Pest cycle

There is a **gradual metamorphosis** (egg, nymph (2 stages), pre-pupa, pupa and adult) with many generations during the warmer months of the year. The life cycle from egg to adult varies from about **10 days** in warm weather to a **month** or more under cool conditions. The tiny eggs are deposited in plant tissue. Nymphs and pre-pupae are found within leaf sheaths and flower buds, but the adults feed mainly in the open on the leaves. The pupal stage may be passed either on plants or in the soil beneath plants.

'Overwintering'

In coastal areas all stages of the life cycle have been observed during winter. If plants are left for a long time in the field after flowering, thrips will migrate to, and 'overwinter' in, the corms as the leaves die down and continue feeding.

Spread

- Adult thrips do not fly readily, migration through a gladiolus crop is slow, but is assisted by wind.
- By the movement of infested corms.

Conditions favouring

Hot dry conditions. Cool, wet weather affects them adversely and heavy rain at times destroys large numbers. Gladiolus thrips can cause serious damage to late flowering plants and stored gladiolus corms.

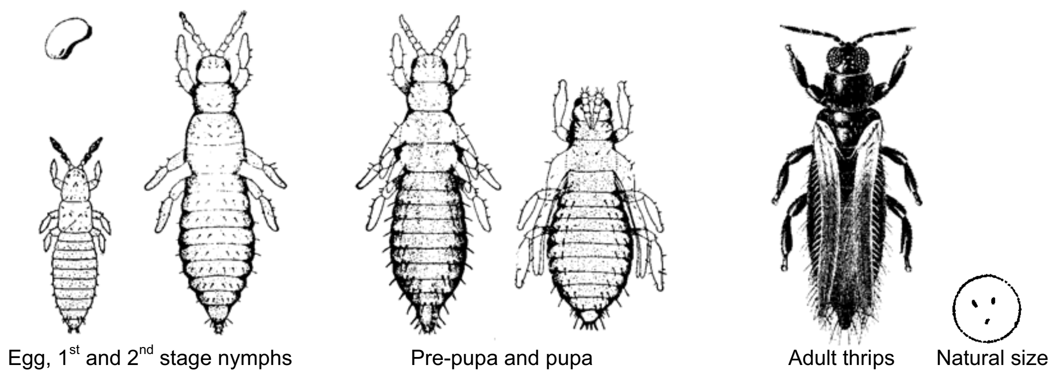


Fig. 97. Gladiolus thrips (*Taeniothrips simplex*). Photo© NSW Dept of Industry and Investment.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. Obtain leaflets on gladiolus thrips control for your local area. See **IPM** program for **WFT** as an example (see page 139).
2. **Crop, region.** Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv). Commercial growers must confirm that the problem is thrips and that the thrips present is gladiolus thrips.
4. **Monitor** pest and/or damage and record results as recommended (page 39). Use blue sticky traps to monitor thrips and any beneficials in the crop or introduced to the crop before deciding treatment (page 139). Indicator plants can be used to detect new arrivals.
5. **Threshold.** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic?
6. **Action/Control.** Take appropriate action when any threshold is reached. Remember thrips need to be managed rather than controlled.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required. Continued monitoring is usually necessary.

Control methods

Cultural methods.

- For new plantings select land as far away as possible from old plantings and volunteer plants.
- Avoid continuous cropping if practical. Commercial growers whose properties are isolated from areas in which gladioli or other host plants are growing, may make a break in planting, so that for a period of several months there is no foliage on which thrips can develop.
- Adult thrips do not fly readily. Where there is a dominant prevailing wind, early-blooming varieties can be planted in beds furthest down-wind. Later-blooming crops can then be planted upwind from older infested crops.
- Gladiolus thrips is favoured by hot dry weather, frequent use of overhead sprinklers or hosing of plants will retard development of thrips but may damage flowers. Ensure satisfactory drainage.

Sanitation.

- Remove and dispose of **crop residues**.
- Dispose of **all** trash (old plants, flowers, leaves, growing media, etc) and old unsaleable plants which could harbour thrips, daily.
- Pull up and destroy **volunteer** gladioli and other host pants growing around production areas before planting the main crop.
- Place old blooms infested with thrips in a black plastic bag, seal immediately and leave in sun to solarise (heat up) for at least 3 days to kill thrips.
- Keep greenhouses and surrounding facilities clean, neat and orderly.
- **Fallow** greenhouses between crops (page 139).
- Do **not** move from infested to 'clean' areas.
- Avoid wearing pale coloured clothing such as white, yellow or blue which attract thrips.


Fig. 98. Gladiolus thrips (*Thrips simplex*). ***Left:*** Injury to gladiolus flowers and foliage. Photo©CIT, Canberra (P.W.Unger). ***Right upper:*** Corm showing injured area and killed rootlets around basal plate. ***Right lower:*** Uninjured corm. Photos© NSW Dept of Industry and Investment.

Biological control.
- **Natural controls**. There are many naturally occurring predators, eg mites and bugs, parasitic wasps and fungal pathogens. The beetle (*Dalotia (Atheta) coriaria*) is one such predator that will feed on thrips.
- **Bio-control agents** for thrips generally can be purchased, eg a soil mite (*Hypoaspis* sp.) feeds on thrips pupae near the soil surface, also predatory mites (*Neoseiulus cucumeris, Typhlodromus montdorensis*). Their effectiveness on gladiolus thrips is untested.
  List of suppliers www.**goodbugs**.org.au

Resistant varieties. Varieties vary in their susceptibility to injury.
- Deep reds and purples are **most severely affected**, there are exceptions to this rule.
- In general, light coloured varieties are least liable to show damage.

Plant quarantine. Quarantine new plants and check for thrips before introducing them into the property. Examine incoming plants to eliminate introduction. Inspect corms.

Pest-tested planting material.
Only purchase corms from reputable suppliers who will guarantee corms are thrips-free. Only save corms from thrips-free crops.

Physical & mechanical methods.
To prevent infestation of protected crops use fine thrips-proof mesh screens. Vents must also be screened.

Insecticides.
- Corn, soil and foliage treatments are available (Table 22 below).
- Sprays aim to kill nymphs and adults as they do not kill eggs inserted in plant tissue and pupae (mostly in the soil) are protected from sprays.
- **Systemic foliage insecticides** are usually more effective as there is difficulty in contacting thrips with non-systemic insecticides. Spray gladioli for thrips at the 4-leaf stage and again when the flower pikes appear through the leaves.
- **Resistance strategy**.
  - Follow **CropLife Australia Resistance Management Strategies**. If spraying is necessary rotate insecticides with different resistance groups to delay development of resistance. See also **WFT** (page 140).
  - Several sprays may be necessary for thorough control. Time between sprays will depend on the temperature (time of year). This allows eggs and pupae that were not exposed to chemicals at the time of the 1st spray to develop into active life stages which can be killed by a 2nd spray.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 22. Gladiolus thrips – Some insecticides and physical treatments.

What to use?	When and how to apply?
FOLIAGE TREATMENTS **Group 3A**, eg Bifen®, Scotts Procide®, Surefire Fivestar®, Talstar®, various (bifenthrin) Many other insecticides are registered for thrips generally.	• Where gladiolus thrips is a recurring problem, treatment may need to commence when susceptible varieties are about 15-20 cm high and may need to continue at regular intervals until flowering. • The label may indicate need for a wetting agent. • Most insecticides are **toxic to bees**.
CORM TREATMENTS 1. Storage at 10°C 2. Hot water treatments (HWT) 3. Pesticide dusts **Group M2 (fungicide)**, eg Dusting Sulphur® (sulphur)	• Before storing dust corms with an insecticide dust. • **HWT** corms before planting. Obtain expert advice on how to do this so that thrips are controlled but corms not injured. • Home gardeners can dust corms before storage by placing them in a bag with a little sulphur dust and shaking.

Plague thrips

A **native thrips**, which is a key pest in NSW, Vic, SA and WA, minor pest in NT.

Scientific name

Thrips imaginis (Order Thysanoptera).

Host range

Wide range of plants.
Ornamentals, eg carnation, dahlia, marigold, roses. **Native flowers**, eg *Acacia victoriae, Atriplex suberecta, Eucalyptus tetragona*. **Fruit,** eg apple, citrus, stone fruits, grape, raspberry, strawberry. **Vegetables**, eg cucurbits. **Pasture,** eg grasses. **Field crops**, eg lucerne. **Weeds,** eg capeweed. Thrips can invade white washing on clotheslines.

Description & damage

Damage is caused by nymphs and adults rasping the plant surface and sucking sap and by the egg-laying of female thrips. Plague thrips is mainly a blossom feeder, but may attack young foliage. Other species of thrips also feed in blossoms, eg at least 2 species are found in rose flowers.

Adult females are narrow-bodied, light brown or gray and about **1-2 mm** long. Males are smaller and yellow. Both sexes have 2 pairs of narrow delicate wings, fringed with long hairs, which lie along the back when not in use. **1st stage** nymphs are yellow with red eyes, **2nd stage** nymphs change to orange-red. 2mm long. Nymphs are similar in shape, pale to orange-yellow, wingless and smaller.

Damage.

- **Flowers. Nymphs** usually feed on stamens and pistils but can also feed on the petals, **adults** mainly feed on petals. If flowers are heavily infested adults can be easily seen with the naked eye. Thrips feeding causes **anthers, petals and pistil** to brown, shrivel and fall prematurely. Where thrips enter unopened blossoms, normal opening may be adversely affected. Petals of infested **roses** brown, dark drops of faeces disfigure light-coloured blooms.
- **Leaves. Egg laying** in young rose tissue may cause the tissue around the eggs to die and fall out, leaving small irregularly-shaped 'shotholes'. Damage is barely detectable when leaves mature. Young leaves of some hosts, eg **citrus, stone fruit** may become spotted yellow and scarred with tiny blisters due to egg laying.
- **Fruit.** Apples, pears, peaches and plums may be heavily infested; injured blossoms turn brown and fall prematurely. In **apples**, egg laying and feeding by thrips causes blossoms to wither and **reduces fruit set**. Note reduced fruit setting in apples may also be caused by late frosts, unusual heat waves during blossoming, a dry spell before flowering and an absence of bees as well as thrips injury or a combination of any of these.

Diagnostics. Thrips can be detected by shaking flowers upside down over a sheet of white paper or handkerchief. Alternatively they can be made to run around the side of flowers by gently breathing warm air into the flower.

- It can be difficult to distinguish one species from another. Home gardeners need to identify the problem only as thrips.
- As other thrips species also feed in flowers, eg **WFT** (*Frankliniella occidentalis*), onion thrips (*F. schultzii*), commercial growers need to identify the **species** of thrips, eg plague thrips, western flower thrips **(WFT)** (page 138).
- Lucid key *Thrips ID key* www.**lucidcentral**.com/

Pest cycle

There is a **gradual metamorphosis** (egg, larval stages (2), pre-pupal, pupal and adult stage) with at least **12 generations** each year. The adult female inserts minute, transparent eggs **in the tissue** of all parts of the flower, eg petals, sepals, blossom stems, stamens, pistils, calyx cups, and in the young leaves adjacent to the blossoms. As many as **150 eggs** have been found in a single blossom stalk. The tiny nymphs that emerge cluster mainly inside blooms where they mostly feed on the **pistils**, **stamens and petals**, but may also feed on the **young leaves**. When fully grown they crawl down the plant, enter the **soil** to a depth of about **5 cm**, change to pre-pupae and then pupae. The emerging females are yellow but they begin to turn brown in 2-3 days. The **life cycle** from egg to adult, varies from about **10-30 days** depending on temperature.

Fig. 99. Plague thrips (*Thrips imaginis*).
Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x35
1. Egg
2. 1st stage nymph
3. 2nd stage nymph
4. Pre-pupa
5. Pupa
6. Adult winged thrips

Actual size
7. Thrips on petals

‘Overwintering’

In coastal areas plague thrips are present in varying numbers throughout the year but it is only in spring and early summer that they cause plant damage.

Spread

- Adult thrips fly readily within a crop.
- They may be carried long distances by wind and migrate to crops in large numbers from a wide range of weeds, grasses, other flowering plants.

Conditions favoring

- Commonly found in huge numbers in and/or near blossoms in spring. Crops at greatest risk during flowering and podding.
- Serious **spring** outbreaks follow mild winters, which allow survival of the hibernating thrips, preceded by autumns with above average rainfall. If these conditions are followed by a dry sunny spring with abundant flowers on capeweed and other hosts, thrips build up on these hosts then, when their flowers dry off, migrate to crops, causing severe outbreaks of thrips in spring and early summer.
- A spring with alternating warm and cold periods bring thrips generations into line. During warm days millions of the tiny thrips appear suddenly, and often disappear next day in a cold change.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation. Obtain leaflets on plague thrips control for you local area. See western flower thrips **(WFT)** (page 139).
2. **Crop, region.** Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** thrips on flowers during flowering on crops and weed hosts as for **WFT** (page 139). Otherwise **open buds** and examine flowers for presence of thrips, control if more than 4-6 per flower. Flowers could be stored in 70% alcohol to dislodge thrips and prevent escape; they can be identified and counted later.
5. **Threshold.** How much damage can you accept? What is your threshold? Economic, aesthetic?
   - With **fruit** it is usual to commence applications when there are 4-8 thrips per flower or if the thrips look numerous on capeweed. As an example, in **apple**, 6-8 thrips per blossom during pink to full bloom following a warm dry spell, may indicate potential for reduced fruit set.
   - **On ornamentals like roses**, it is usually necessary to commence applications as soon as thrips start to appear in buds or as soon as petal colour is visible.
6. **Action/Control.** Take appropriate action when any threshold is reached. Plague thrips can cause total loss of some fruit crops, eg raspberry, if not controlled. However, damage on some plants, eg grapevines, citrus, plum, pears, is not always economic and therefore control may not be necessary.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required.

Control methods

Control of plague thrips in blossoms is difficult because eggs are inserted within the plant tissues and nymphs and adults feed and shelter within opening buds out of reach of insecticides.

Cultural methods. Heavy rain or overhead irrigation can reduce infestations spectacularly but may damage flowers. If the soil surface is compacted adult thrips cannot emerge from pupae in soil. Vigorously growing crops can usually compensate for flower abortion.

Sanitation. In the home garden, remove and destroy infested spent blooms of roses by placing in a plastic bag with the neck secured and leaving in sun for a few days. Remove weeds especially flowering ones, eg Paterson’s curse, wild mustard.

Biological control.

- **Natural controls** include fungal diseases (*Metarhizium* spp., *Entomophora* spp. *Beauveria* spp., *Paecolomyces* sp.). Although there are some predators, eg lacewing larvae, mites, thrips, and some parasites, eg wasps, their effect can be insignificant compared with that of the weather. Conserve pirate bugs, lacewing larvae and ladybirds which prey on thrips.
- **Biocontrol agents** which can be purchased.
  - A soil mite (*Hypoaspis miles*) feeds on thrips pupae near the soil surface.
  - Predatory mites *Neoseiulus cucumeris* and *Typhlodromus montdorensis* feed on thrips larvae. List of suppliers www.goodbugs.org.au

Physical & mechanical methods. In greenhouses thrips-screens on vents and doors prevent their entry (page 140).

Insecticides. When treating thrips in flowers, aim to not only kill thrips present but also to prevent re-infestation (page 140).

Table 23. Plague thrips – some insecticides.

What to use?	When and how to apply?
TOXICITY OF INSECTICIDES TO BEES Most insecticides are toxic to some degree to bees. Follow label instructions regarding application. Information on the toxicity of insecticides to honey bees is available from local State/ Territory Depts., eg ***Pesticides – A Guide to their Effects on Honey Bees*. NSW DPI Primefact 148 (2006)**.	• Avoid spraying in full bloom, danger to bees. • If unavoidable carefully consider the toxicity and formulation of the pesticide to be used. • Any spraying should be done **late in the evening** when bees have returned to hives.
BLOSSOM TREATMENTS **Group 2C**, eg Regent® (fipronil) **Group 3A**, eg pyrethrin, Baythroid® (cyfluthrin), Mavrik® (tau-fluvalinate); Talstar® (bifenthrin), Sumi-Alfa® Flex (esfenvalerate); Titan®, various (cypermethrin) **Group 4A**, eg Crown®, Procide® (acetamiprid) **Others**, eg Beat-a-Bug® (chilli/garlic/pyrethrin/piperonyl butoxide) CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE	• **For effective control** it is necessary for the insecticide to have a residual activity of 2-4 weeks. The more quickly the insecticide breaks down, the more **frequently** it must be applied. • Follow label directions but usually 2 applications are necessary - about 2 weeks apart. The 2nd spray will kill nymphs which have hatched from eggs which were unaffected by the 1st spray and adults which have emerged from pupae in the soil since the 1st spray.

Western flower thrips (WFT)

Scientific name

WFT (*Frankliniella occidentalis*, Order Thysanoptera) **is one of the world's most important horticultural pests** due to:

- Its **resistance** to many insecticides.
- Efficiently **spreading** tomato spotted wilt virus **(TSWV)** and impatiens necrotic spot virus **(INSV)**.
- **Feeding** in unopened growth or flower buds.
- Its **tiny** size, **rapid** life cycle (13 days at 30°C), and **high** reproductive capacity (an adult female can live for 30-45 days and lay 150-300 eggs).

Host range

WFT has been recorded on more than 250 plant species including weeds and greenhouse crops. **Ornamentals,** eg chrysanthemum, gerbera, gypsophila and roses; cut flowers, native plants. **Fruit,** eg strawberry, stone fruits, soft fruits. **Vegetables,** eg capsicum, cucumber, lettuce, potato, tomato, various herbs. **Field crops,** eg peanut. **Weeds,** eg capeweed, flowering white clover, redflowered mallow, sow thistle, wild mustard, Paterson's curse.

Description & damage

Adults and nymphs damage plants by rasping or scraping surface cells and sucking cell sap.

Adults are **1-2 mm** long and just visible to the naked eye. They have 2 pairs of feathery long narrow wings with a fringe of long fine hairs along the margin. Wings are held parallel along the back when at rest. **Nymphs** are wingless, white, straw yellow or brown in color.

Damage.

- **Flowers, new buds and young leaves**
  - **Damage is not always obvious** after feeding but becomes more obvious as affected flowers, leaves or fruit grow. Crops show **silvering, flecking or deformation** of flowers, growing tips, young foliage, stems and fruit. **WFT** does not generally infest foliage, but when it does, drops of excreta may disfigure leaves.
  - **Most weeds** are symptomless.
- **Strawberry.** Thrips feed between prominent seeds in green fruit causing surface bronzing, reducing shelf life and marketability.
- **Pollen removal.** Thrips are attracted to most plants in flower that produce copious quantities of pollen, eg Asteraceae, legumes. Flowers of African violets become covered with pollen.

Transmission of virus diseases, eg tomato spotted wilt virus **(TSWV)**, impatiens yellow spot virus (**INSV**) and other viruses are the main cause of crops losses. Symptoms of **TSWV** include stunting, distortion and color variation in the leaves (page 286). Test kits are available for testing for **TSWV.**

General. The presence of **TSWV** does **not** mean that **WFT** is in your crops, other thrips, eg onion thrips (*Thrips tabaci*), tomato thrips (*F. schultzei*) also spread **TSWV.** If thrips numbers are high their feeding can damage crops regardless of whether they have **TSWV** or not. Damage to native plants is confined to pollen removal. Thrips are attracted to white washing and pale coloured clothes.

Diagnostics.

- **Several species of thrips** can infest flowers. **WFT** is the most serious. Diagnosis is difficult because to the naked eye most thrips found in flowers look alike. Other thrips commonly caught in traps in greenhouses are onion thrips (*Thrips tabaci*) and tomato thrips (*F. schultzei*).
- **Thrips can be identified** as thrips using a hand lens, but it is **very difficult** to tell one species from another. A qualified taxonomist is required to identify them accurately. Thrips can be caught on a yellow or blue sticky trap or be shaken out of flowers onto white paper or a sticky trap. Place in cling wrap and send it to your nearest diagnostic service (page xiv).
- **Keys.** There are many keys available, even ones for identifying thrips on particular crops, eg cotton, strawberries. There are also several Lucid Keys, eg *ID Thrips, AQIS Identification Guide – Thysanoptera* www.**lucidcentral**.com/
- **Commercial growers**. If thrips are a recurring problem on crops, growers should learn how to distinguish one species from another using a high power microscope. **WFT** has a pair of long hairs at each corner of the thorax.
- **DNA** finger-printing indicates that there are at least 2 different **WFT** populations in Australia.
- **Home gardeners**. Because damage by thrips may be mistaken for damage caused by mites or other insects, eg leafhoppers, white flies or on some hosts, lace bugs, the main thing is for them to identify the problem as thrips and not as something else.

Pest cycle

There is a **gradual metamorphosis** (egg, larval stages, pre-pupal, pupal and adult stage) with many generations each year. The **WFT** life cycle is mostly continuous and all stages can be found throughout the year. Female thrips live for 4-5 weeks and insert 150-300 eggs into flower parts and are protected from sprays. Nymphs have a pupal stage in the soil from which adults emerge. At 10-20°C the length of the life cycle is 25-35 days. At 20-30°C the life cycle is 15-25 days.

'Overwintering'

On infested crops, stock plants, cuttings, weed hosts, crop and weed debris. Especially critical in spring and early summer when a major source of **WFT** is likely to be greenhouse crops.

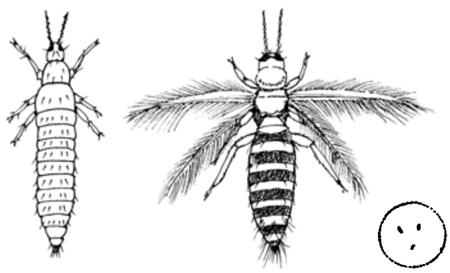


Fig. 100. WFT (*Frankliniella occidentalis*). ***Left:*** Nymph. ***Centre:*** Adult (1-2 mm long). ***Right*** Natural size.

Spread

- By thrips flying assisted by wind. Larvae pick up the virus during feeding, after which it is replicated and circulated in the thrips' body. It can be successfully transmitted after only 30 minutes by (predominantly) adult **WFT** during feeding to healthy plants for the rest of their adult life (30-45 days).
- Movement of infested plants, vegetative propagation material, cut flowers, cuttings, seedlings, runners, weeds.
- Thrips may continually invade flowers from surrounding areas.

Conditions favouring

- Warm and moist springs and summers, optimum temperature is 20-30°C
- Thrips numbers outside are lowest in winter.
- Failure to allow a fallow break between successive **WFT-susceptible crops**.

Management (IPM)

WFT is difficult to control once established. For commercial growers:

1. **Obtain advice** from your State Dept. **WFT** Coordinator (state website), on monitoring and thresholds for different crops, eg **Qld DPIF. 2008.** ***Thrips and Tospovirus: A Management Guide***; **NSW DPI. 2007.** ***Western FlowerThrips & Tomato Spotted Wilt Virus.*** There is a **National Strategy for the Management of WFT.**
2. **Crop, region**. National Strategies for Managing **WFT** vary depending on the crop, eg field crops, cucumbers, strawberry, ornamentals, greenhouses, type of viruses spread, etc.
3. **Identification** is critical for effective control so consult a diagnostic service (page xiv) if necessary. Early detection and regular monitoring of **WFT** with sticky traps, etc, is essential for effective control before populations reach damaging levels (page 39).
4. **Monitor** for **WFT** in crops, greenhouses and sheds using blue sticky traps, the following is only a guide:
   - **Record** population trends on a chart. Continue monitoring after any treatments.
   - **Know when to start** monitoring, when to inspect flowers and put out traps, etc.
   - **Crop inspection**. Walk through and inspect the crop regularly, count thrips in new buds and flowers, or dislodge them by tapping flowers over a white tray. A x10 hand lens is needed to identify them.
   - **Sticky blue traps** attract thrips and some leafminers (not beneficial insects), yellow cards attract many other insects as well, eg thrips, whitefly, aphids, fungus gnats, shoreflies. **Hang** traps just above or within the crop, near green house doors, flowers and young growth, and packing sheds. Adjust position of traps so they are in the best place to catch thrips. **Inspect** traps fortnightly or as recommended, replace every 2 weeks or more frequently if they get dirty or crowded with insects.
   - **Indicator plants**, eg petunia (Calypso, Super Blue Magic, Summer Madness) or fava beans, can be placed in a greenhouse to detect for early **TSWV** and **INWV** symptoms.
5. **Thresholds** are different depending on crop type and quarantine regulations, designation of **WFT-free** zones, etc. These are **established** thresholds and may need to be complied with. Swiss work shows that if sprays are only applied to chrysanthemum crops when the pest level reached **20 WFT**/trap/week, damage did not exceed 5%.
6. **Action/control** depends on **delaying** development of resistant **WFT** and whether an insecticide permit is needed before spraying with an appropriate chemical. Continued and vigorous non-chemical control including sanitation must be conducted at all times. Release bio-control agents if appropriate. Thrips programs need to be all year round.
7. **Evaluation**. Review **IPM** program. How successful was it? Are improvements necessary? Continue to monitor, record and assess your methods.

Control methods

Cultural methods

- If practical propagate or plant crops when thrips numbers are low.
- If possible roses and nursery stock should have no leaves at the time of planting.
- Grow and train crops so that good spray coverage is easy to achieve.
- New susceptible crops should be planted as far away as possible from a source of infestation.
- **Avoid continuous cropping.** Start thrips control at the end of the previous crop or season.
  - **Consider a plant-free fallow period** before starting the next crop. Eliminate weeds/host plants.
  - **Heat empty greenhouse** until temperature of **soil** is about 30°C for about 3 weeks, longer at lower temperatures. This will allow thrips in the soil to emerge as adults and starve in the absence of food plants. Check for living adult thrips on traps. When there are no thrips and any uprooted plants are completely dry, plants can be removed from the greenhouse. It may take between 2-4 weeks to dry uprooted plants and kill all thrips.
  - **Some growers** may apply a smoke or aerosol after the second week to ensure all thrips are killed.

Sanitation

- **Aim** to identify and eradicate **non-crop hosts** of **WFT** including weed hosts which not only serve as hosts for thrips but for viruses (**INSV**, **TSWV**), eg hanging baskets, etc.
- **Avoid carryover** from one crop to the next by removing prunings, unwanted blooms, remains of previous crops and weeds.
- **Dispose** of plant residues, eg plough in or burn old crop debris, cover dump and waste sites and place waste in black plastic bags, seal immediately and leave in the sun to solarize (heat up).
- **Move** from clean to infested greenhouses, **never** from infested to clean areas unless clothes are changed. Avoid wearing pale white, yellow or blue clothing attractive to thrips.
- **Clean** equipment after use in infested areas.
- **Roguing.** Remove any plants with thrips or symptoms of **TSWV** or **INSW** immediately.
- **Remove plants that attract thrips** in garden beds around production areas. Ideally have 10 metres bare ground such as asphalt around greenhouses or closely mown grass. Do not plant flowers or allow weeds to grow in this area, this applies to hydroponic growers as well.

Biological control

- **Natural controls** include predatory mites, bugs, parasitic wasps, eg (*Ceranisus menes*) and fungi, eg (*Beauveria bassiana*, *Verticillium lecanii*).
- **Commercially available**, eg
  - **Predators.** List of suppliers www.**goodbugs**.org.au
    - ❑ **Predatory mites**, eg *Amblyseius montdorensis* and *Neoseiulus cucumeris* suppress low populations of **WFT** and other thrips in protected areas, eg greenhouses. Mainly attack 1st stage nymphs, so large numbers and frequent introductions are needed for successful control. Provide adequate ventilation and choose insecticides carefully. If thrips are absent mites feed on pollen.
    - ❑ **Soil-dwelling mite** (*Hypoaspis miles*) is a general predator feeding on thrips pupae near the soil surface, fungus gnat eggs, larvae and pupae, nematodes, etc.
    - ❑ **Pirate bugs** (*Orius* spp.) feed on larvae and adult thrips, also excess pollen in the absence of thrips. May be difficult to establish.
    - ❑ **Lacewings.** *Mallada signata* feeds on thrips, aphids, mealybugs, whiteflies. *Chrysoperia* sp. preys on **WFT** adults, larvae can be purchased.

Resistant varieties.

- Plant **WFT**-tolerant cultivars if practical. This does not necessarily reduce spread of **TSWV** (page 286).

Plant quarantine.

- **AQIS.** Consignments **to** some countries are fumigated and/or destroyed if thrips are found. All plants and cuttings **imported** into Australia are subject to mandatory treatments to kill thrips and other insects. Flowers, vegetables and fruit are subject to inspections and if infested, are treated. Some products may be destroyed.
- **State/Regional quarantine.** Status of **WFT** within Australia is under constant review.
  - **Protocols** for entry to various states may involve inspection, treatment, or sourced from a property free of this pest (area freedom).
  - Check with **transporters** to ensure plants do not become contaminated after they leave the property.
  - **Non-hosts** are plants not known to be hosts of **WFT** and include banana leaf, bulbs without leaves, conifers, ferns, roses (dormant and without leaf), trees (deciduous and without leaf). Non-hosts pose a very low risk of transporting **WFT** so that certification of **WFT-**free plants may not be needed. A declaration must accompany plants indicating that 'only non-hosts' plants are being transported.
- **Local quarantine.** Do not bring plants onto your property or return them from market unnecessarily.
  - Quarantine new plants and check for thrips, if present treat before placing with rest of stock.
  - Separate growing and retail areas.

Pest-tested planting material.

- Only buy certified **WFT** and **TSWV**-free seedlings and cuttings from reliable or accredited suppliers. Greatest risk is from **cuttings**.
- Ensure **stock plants** for cuttings are thrips-free.

Physical & mechanical methods.

- **Insect microscreens** (100-200 mesh) over greenhouse vents and doors prevent thrips invasions from outside (anti-thrips net).
- **Greenhouse plastics. WFT** prefer to enter tunnels that transmit higher levels of **UV** light. So **UV**-absorbing greenhouses plastic films could be used to influence flight behaviour.

Insecticides.

Except for **WFT**, thrips are easily controlled with current insecticides. Most states have a **Western flower thrips (WFT) Insecticide Resistance Management Plan**. Access a copy.

- **Permits** may be required.
- **Intervals between sprays.** Insecticides kill nymphs and adults, **not** eggs (which are inside the leaf) and pupae (which are mostly in the soil). Several sprays may be prescribed to cover the time taken for eggs to hatch into larvae and for pupae to develop into adults.
- **Resistance management**
  - **WFT** is notorious for its resistance to insecticides.
  - Only a few insecticides give any practical control of **WFT** which quickly becomes resistant to organophosphates, carbamate and synthetic pyrethroid insecticides.
  - Follow **Croplife Australia Resistance Management Strategies** for **WFT** on labels. Rotate insecticides as recommended to delay development of resistance.
  - Use application techniques, eg sprayer, aerosol, fogger, that give a good spray coverage of tiny droplets to contact thrips hiding in buds, etc.
  - Hydroponic growers incorporate insecticide into fertigation water. Weed removal is still essential otherwise **WFT** may again become a problem.
  - Consult various references (Stephens 2000).
- **Once harvesting has commenced** it is not possible to follow insecticide usage plans.
- **Insecticides may be toxic** to bees (page 114).
- **Pest stimulation** (increased egg laying) after exposure to residues of Mavrik® (tau-fluvalinate), Kelthane® (dicofol) and malathion occurs with citrus thrips. Whether this occurs with **WFT** is unknown, do not apply pesticides preventatively.
- **Herbicides**. Identify and eradicate **non-crop hosts** of **WFT**, including weeds.
- Effectiveness of insecticides may be improved by increasing greenhouse temperatures from 21-23°C to 26-28°C. Once in the air thrips have a greater chance of being exposed to insecticide and mortality rates increase by about 25%.

Table 24. Some insecticides for Western Flower Thrips and other thrips spp.

What to use?	When and how to apply?
FOLIAGE **Group 5**, eg Entrust Naturalyte, Success™ Naturalyte (spinosad) **Each state has management strategies for WFT, check current recommendations in your state for your crop**, eg **WFT** Insecticide Resistance Management Plans **PERMITS MAY BE REQUIRED**	• Remember **WFT** can be difficult to target with insecticides as they lurk in inaccessible places. • **For effective control** it is necessary for the insecticide to have a residual activity of 2-4 weeks. • Only larval and adult stages susceptible to insecticides. • **Follow Croplife Australia Resistance Management Strategies**
SEED TREATMENTS **Group 4A**, eg Picus® Seed Treatment (imadicloprid) protects cotton seedlings from injury due to onion thrips (*Thrips tabaci*) and other thrips	• Seed treatments protect certain crops from injury from thrips and certain other sucking insects and subsequent spread of virus diseases.
FERTIGATION, FUMIGATION	• Insecticide in fertigation water, eg hydroponic lettuce. • Some growers fumigate soil and greenhouse between crops (page 61, Table 6.)
TREATMENTS UNDER INVESTIGATION **Group UN**, eg soil drenches of Azamax® (azadirachtin) and a foliar spray program of Neem® (azadirachtin) **Spray oils**	

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

ORDER HEMIPTERA

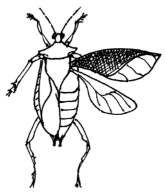
Bugs; hoppers; aphids, lerps, mealybugs, scales, whiteflies

NO. SPECIES IN AUSTRALIA

More than 6,000 species. A very diverse Order. Aphids and whiteflies are commonly found on sticky traps together with other small flying insects such as thrips, fungus gnats, shore flies, leafminers (flies) and a range of beneficial insects. Identification of these insects can be difficult, but necessary.

www.ento.csiro.au/education/insects/**hemiptera.html**

SOME DISTINCTIVE FEATURES



True bug, forewing with thickened portion

Although some people call all insects bugs this is not correct. True bugs belong to the Order Hemiptera

ADULT

Wings — **Usually 2 pairs** (sometimes wingless).

1. **Heteroptera** (**different** wing). The **true bugs**, eg crusader bug, green vegetable bug. Forewings usually have a thickened front portion and a clear gauzy rear section, often folded flat over body.
2. **Hoppers** (**same** wing), eg cicadas, leaf hoppers, plant hoppers. Forewings of same texture all over (either entirely thickened or entirely clear), often held tent-like over abdomen.
3. **Aphids, lerps, mealybugs, scales, whiteflies.** Soft bodies and usually **no wings**, although some may have forewings only, adult whiteflies have 2 pairs. They often cover themselves with wax or froth which prevents their soft bodies from drying out.

Antennae — Often conspicuous in Heteroptera, but inconspicuous in the other 2 groups (there are some exceptions, eg aphids).

Mouth — Mouthparts common to all Hemiptera, include a **sucking beak** arising from the underside of the head.

NYMPH — **Commonly resemble adults** although color and markings may be very different. Young stages may be quite unlike the adult, eg

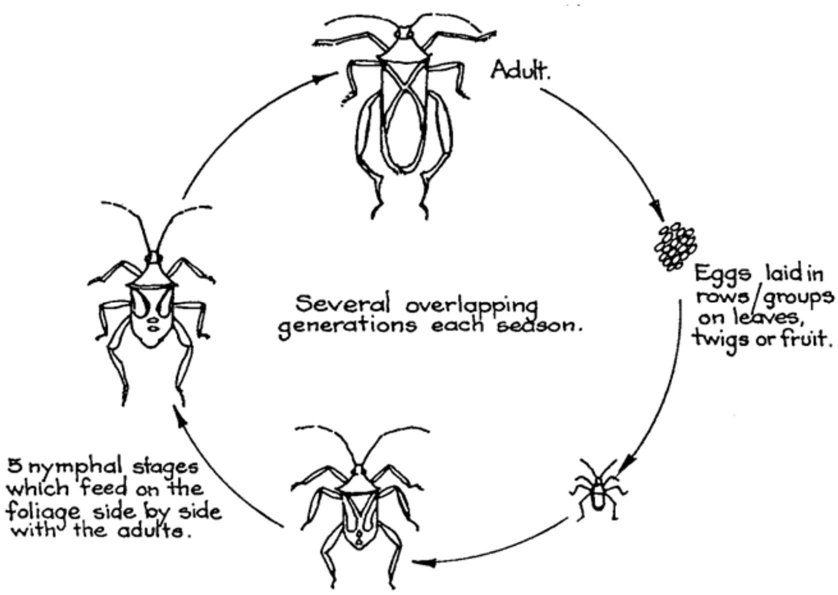
- **Cicada** nymphs are specialized for **burrowing**.
- **Green vegetable bug nymphs** are **brightly colored** with red, green, yellow, orange and black markings.

LIFE CYCLE

There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. No one member of the order is truly representative. There are many variations in winged/wingless populations, females may lay eggs, or give birth to live young. **Parthenogenesis** is common (page 23).

Crusader bug

20-30 mm long



Many variations, eg aphids, lerps, mealybugs, scales

METHOD OF FEEDING

ADULT NYMPH — Most Hemipterous **adults and nymphs are plant feeders** and feed by **piercing plant tissues** and **sucking sap**. The 'beak' is used to guide the mouthparts to food. Some are predators and feed on other insects, eg caterpillars, some feed on fungi.

PLANT DAMAGE

DIRECT SUCKING DAMAGE

Damage is caused by both the nymphs and adults sucking plant sap.

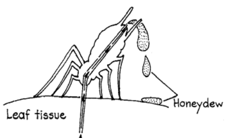
LEAVES
- **Chlorotic mottling**, eg azalea lace bug, leafhoppers, greenhouse whitefly
- **Death of tissue**, eg black peach aphid, green peach aphid
- **Distortion, curling**, eg cabbage aphid, cherry aphid, green peach aphid, grape phylloxera aphid
- **Galls**, eg purse gall aphid
- **Premature leaf fall**, eg lerp insects

FLOWERS
- **Distortion**, eg aphids

FRUIT BUDS
- **Distortion**, eg apple dimpling bug
- **Mottling**, eg green vegetable bug
- **Premature fruit fall**, eg bronze orange bug

SHOOTS STEMS
- **Death**, eg black peach aphid, crusader bug
- **Distortion**, eg green peach aphid, black citrus aphid
- **Galls**, eg woolly aphid
- **Wilting**, eg crusader bug, longtailed mealybug

ROOTS
- **Distortion, galls**, eg grape phylloxera aphid, woolly aphid



Honeydew

INDIRECT DAMAGE

- **Presence of insects**, nymph skins and excreta may reduce value of the crop and affect trade, eg scale on fruit.
- **Transmission of many virus and virus-like diseases** especially by aphids, some leafhoppers and whiteflies.
- **Tainting of fruit**, eg green vegetable bug, shield bugs generally.
- **Honeydew/Sooty mould**. Many Hemiptera, eg aphids, leafhoppers, lerp, mealy-bugs, soft scales and whitefly consume large quantities of watery plant sap.
  - Many sugars present in plant sap are not required by insects and are excreted as honeydew.
  - Wherever honeydew falls sooty mould may grow.
  - Some Hemiptera, eg psyllids allow their honeydew to harden into protective 'lerps' while others use it to attract ants which protect them against predators.
  - Relationship can be specific, eg a single ant species may attend a single Hemipterous species or it may be broad.
  - Reduces the value of affected plants and fruit. Plants can look unsightly.

LIST OF SOME SPECIES

TRUE BUGS

Acacia-spotting bug sucking damage to leaves

Green vegetable bug

A large number of true bugs feed on seeds and fruit; some are predators and some feed on fungi

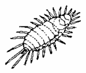
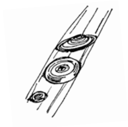
COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
BUGS (several families)		
MIRID BUGS	**Family Miridae**	
Acacia spotting bug	*Rayieria tumidiceps*	Acacia
Apple dimpling bug	*Campylomma livida*	Apple, also peaches, potato, etc, May prey on some insects
STINK BUGS	**Family Pentatomidae**	
Bronze orange bug	*Musgraveia sulciventris*	Citrus (Family Tessaratomidae, very closely related to the Pentatomidae)
Spined citrus bug	*Biprorulus bibax*	Citrus, esp. lemons, mandarins
Green vegetable bug	*Nezara viridula*	Wide range of plants, especially fruit parts and pods
Horehound bug	*Agonoscelis rutila*	Horehound, ornamentals, occasional fruit trees
JEWEL BUGS	**Family Scutellidae**	
Cotton harlequin bug	*Tectocoris diophthalmus*	Cotton, related weeds, kurrajongs, bottle trees
CHINCH BUGS	**Family Lygaeidae**	
Rutherglen bug	*Nysius vinitor*	Fruit, vegetables, weeds
SQUASH BUGS	**Family Coreidae**	
Crusader bug	*Mictis profana*	Ornamentals, eg rose, eucalypt, wattle, fruit, eg citrus, grape
Fruitspotting bug	*Amblypelta nitida*	Developing fruits
STAINER BUGS	**Family Pyrrhocoridae**	
Harlequin bug	*Dindymus versicolor*	Ornamentals, fruit, vegetables
Pale cotton stainer	*Dysdercus sidae*	Cotton, native/cultivated plants weeds
MISCELLANEOUS BUGS		
Azalea lace bug	*Stephanitis pyrioides*	Azalea, rhododendron
Spittle bugs	Aphrophoridae, Cercopidae	Ornamentals, eg wattles, eucalypts; herbs, eg mint

CICADAS

Do not confuse cicadas with grasshoppers or beetles that have **chewing** mouthparts

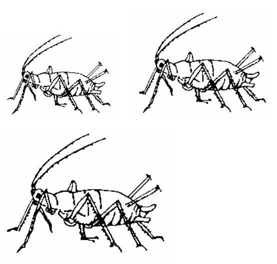
COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
CICADAS (Family Cicadidae)		**More than 250 species in Australia**
Greengrocer	*Cyclochila australasiae*	Nymphs of cicadas live in the soil for up to 17 years feeding on tree roots. Large numbers are noisy
Double drummer.	*Thopha saccata*	

LIST OF SOME SPECIES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
LEAFHOPPERS *(contd)*	**LEAFHOPPERS (Family Cicadellidae)**		
	Apple leafhopper, canary fly (Tas)	*Edwardsiana australia*	Apples, crab apples, prunes
	Common brown leafhopper	*Orosius argentatus*	Vegetables, ornamentals, field crops, weeds. Spreads tomato big bud/greening phytoplasma
	Elm leafhopper	*Ribautiana ulmi*	Elm, *Alnus subcordata* sp.
	Glassy winged sharpshooter (GWSS)	*Homalodisca coagulata*	**Overseas**, a serious pest of horticultural crops. Spreads Pierce's disease of grapes.
	Vegetable leafhopper, tomato leafhopper (Qld)	*Austroasca viridigrisea*	Broadleaved plants, vegetables, ornamentals, weeds
FROGHOPPERS	**FROGHOPPERS, PLANTHOPPERSA, TREEHOPPERS (several families)**		
	Froghoppers	Family Cercopidae	Native plants
	Green treehopper	*Sextius virescens*	Wattles
	Gumtree hoppers	*Eurymela* spp.	Eucalypts, wattles
	Passionvine hopper	*Scolypopa australis*	Ornamentals, fruit, eg passion vine, vegetables, eg beans
	Turf planthopper	*Toya dryope*	Turf
APHIDS	**APHIDS (Aphididae, other families)**		**Spread virus diseases**
More than 70 introduced species of aphids, most native species are not a problem	Black citrus aphid	*Toxoptera citricidus*	Mainly citrus, sometimes other Rutaceae
	Black peach aphid	*Brachycaudus persicae*	Peach, other stone fruit
	Blue-green aphid	*Acyrthosiphon kondii*	Lucerne, other legumes
	Cabbage aphid	*Brevicoryne brassicae*	Brassicaceae, vegetables, ornamentals and weeds
	Cherry aphid	*Myzus cerasi*	Cherry
	Cotton aphid	*Aphis gossypii*	Wide range, including cotton, vegetables, pawpaw, citrus
Recent introduction	Currant-lettuce aphid WA state quarantine	(*Phenacoccus parvis*) in Tas, Vic, NSW not in WA & Qld (2005)	Wide host range, eg lettuce, gooseberry, red currant, weeds
	Cypress pine aphid	*Cinara tujafilina*	Cypress pine (*Callitris cupressi*)
	Grape phylloxera	*Daktulosphaira vitifolii*	Grapes
	Green peach aphid	*Myzus persicae*	Peach, nectarine; ornamentals vegetables, fruit, weeds
	Lily aphid	*Aulacorthium circumflexum*	Lily, greenhouse plants
	Oleander aphid	*Aphis nerii*	Oleander, wild cotton
	Poplar gall aphid	*Pemphigus bursarius*	Poplar
	Potato aphid, tomato aphid (Qld)	*Macrosiphum euphorbiae*	Wide range, especially tomato, potato, rose, gladiolus, weeds
	Turnip aphid	*Lipaphis erysimi*	Brassicas, eg, vegetables, stock, weeds
	Bean root aphid	*Smynthurodes betae*	Cotton seedlings, French bean
	Rose aphid	*Macrosiphum rosae*	Roses
	Rose-grain aphid	*Metopolophium dirhodum*	Cereals
	Woolly aphid	*Eriosoma lanigerum*	Apples, crab apples, rarely pears, occasionally hawthorn, cotoneaster, firethorn
A parasitic wasp (*Aphidius sonchi*) was introduced to control sowthislte aphid	Sowthistle aphid	*Hyperomyzus lacturae*	Sowthistle, thought to carry the virus necrotic yellows of lettuce
LERPS	**LERPS, PSYLLIDS (Family Psyllidae)**		
Not known in Australia	Asian citrus psylla	*Diaphorina citri*	*Citrus* spp., other Rutaceae
	Bellbird psyllid	*Glycaspis baileyi*	Eucalypts
	Boronia psyllid	*Ctenarytaina thysanura*	Boronia
	Brown basket lerp	*Cardiaspina fiscella*	Eucalypt
	Morton Bay fig pysllid	*Mycopsylla fici*	Morton Bay fig
	Hibiscus woolly psyllid	*Heterpsylla cubana*	Hibiscus
	Kurrajong star psyllid	*Protyora sterculiae*	Kurrajong
Lerps on eucalypts	Kurrajong twig psyllid	*Aconopsylla sterculiae*	Kurrajong

LIST OF SOME SPECIES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
MEALYBUGS	**MEALYBUGS (Family Pseudococcidae)**		
	Longtailed mealybug	*Pseudococcus longispinus*	Wide host range. Major pest of glasshouses, indoor plants.
	Citrophilous mealybug	*P. calceolariae*	Citrus, grapevine, other hosts
	Hibiscus mealybug	*Maconellicoccus hirsutus*	Hibiscus
	Root mealybug	*Rhizoecus falcifer*	Many plant species
	Wattle mealybug	*Melanococcus albizziae*	Wattle
	Woolly giant mealybug	*Monophlebulus pilosior*	Native mealybug. Does not cause much plant damage
SCALES	**SCALES (several families)**		
Armoured Scales	**ARMOURED SCALES**	**Family Diaspididae**	
Very small <3mm	Red scale	*Aonidiella aurantii*	Citrus, other fruit, eg fig, olive, pear, grape, ornamentals, weeds
	Rose scale	*Aulacaspis rosae*	Rose, raspberry, loganberry, blackberry
	Fig wax scale (recently introduced)	*Ceroplastes rusci*	Fig, broad range of host plants
	San Jose scale	*Quadraspidiotus perniciosus*	Pome and stone fruits, ornamental trees and hedge plants such as hawthorn, tree lucerne
	White palm scale	*Phenacaspis eugeniae*	Palms, magnolia, NSW Christmas bush, lilly-pilly, waratah
Soft scales	**SOFT SCALES**	**Family Coccidae**	
	Black scale, brown olive scale	*Saissetia oleae*	Wide host range eg ornamental trees and shrubs, occasionally succulent hosts such as geranium
	White wax scale	*Ceroplastes destructor*	Citrus, native and introduced trees and shrubs, eg lilly pilly, gardenia, pittosporum
	Pink wax scale	*C. rubens*	Ornamentals, citrus
	Soft brown scale	*Coccus hesperidum*	**Fruit**, eg citrus (grapefruit is preferred), fig, **ornamentals**, eg camellia, daphne, oleander, palms
	OTHER SCALES		
	Cottony cushion scale	*Icerya purchasi*	**Ornamentals**, eg wattle, laburnum, pigface, **fruit**, eg citrus, fig,
	Gumtree scale	*Eriococcus coriaceus*	Eucalypts
	Pink ground pearl	*Eumargarodes laingi*	Roots of sugarcane, grasses, turf
	White ground pearl	*Promargarodes australis*	Roots of sugarcane
WHITEFLIES	**WHITEFLIES (Family Aleyrodidae)**		
	Ash whitefly	*Siphoninus phillyreae*	Oleaceae, eg olive, ash, Rosaceae, eg apple, pear, plum, pomegranate
	Australian citrus whitefly	*Orchamoplatus citri*	Citrus
	Azalea whitefly	*Pealius azaleae*	Azalea
Not known in Australia	Woolly whitefly	*Aleurothrixus floccosus*	Citrus, eugenia
Not known in Australia	Bayberry whitefly	*Parabemisia myricae*	*Citrus* spp., gardenia; also other ornamentals, fruits
Not known in Australia	Giant whitefly	*Aleurodicus dugesii*	Many ornamentals, vegetables
	Greenhouse whitefly	*Trialeurodes vaporariorum*	Broadleaved plants, ornamentals, vegetables, weeds, glasshouses
	Cotton whitefly, tobacco whitefly	*Bemesia tabaci*	Wide range of plant, ornamental, fruit, vegetables, weeds
	Silverleaf whitefly **SLWF** = poinsettia whitefly	*Bemesia tabaci*- type B	Vegetables, field crops, ornamentals, weeds
	Coconut whitefly	*Aleurodicus destructor*	Coconut
	Spiralling whitefly	*A. dispersus*	Ornamentals, fruit, vegetables
BENEFICIALS	**BENEFICIAL HEMIPTERA**		
	Assassin bugs	Family Reduviidae More than 300 spp.	Range of insects, painful sting, many general predators
	Predatory shield bug	*Oechalia schellembergii*	Larvae of the grapevine moth
Biological control agents	Cochineal scales	*Dactylopius* spp.	Introduced to Australia to control prickly pear (*Opuntia* spp.)
	Lantana lace bugs	*Leptobyrsa decora* *Teleinemia scrupulosa*	Lantana (*Lantana camara*)

BUGS; HOPPERS; APHIDS, LERPS, MEALYBUGS, SCALES, WHITEFLIES

Summary - Some exceptions

	SOME DISTINCTIVE FEATURES	PLANT DAMAGE
BUGS 	1. **Thickened** region on **forewing**. 2. Wings held **flat** over body, tips usually overlap. 3. Antennae often **long** and conspicuous, jointed. 4. **Sucking beak** arises from front part of the head. 5. Some produce an **offensive odour** if disturbed, eg stink or shield bugs.	**DIRECT SUCKING DAMAGE** **LEAVES** Chlorotic mottling, eg lace bugs Wilting, eg bronze orange bug, harlequin bug Spots, eg acacia spotting bug **FRUIT FLOWERS** Distortion, eg apple dimpling bug, green mired bug Marking, eg green vegetable bug **SHOOTS** Wilting, eg crusader bug, Rutherglen bug **INDIRECT DAMAGE** • Disfigurement with **frass**, azalea lace bug. **BENEFICIAL EFFECTS** • Some bugs are **beneficial**, eg assassin bugs.
HOPPERS 	1. Forewings **same** through out, same texture. 2. Wings usually held **roof-wise** over body. 3. Antennae mostly **short** but may be long. 4. **Sucking beak** arises from hind part of head.	**DIRECT SUCKING DAMAGE** **LEAVES** Mottling, eg apple leafhopper Wilting, eg passionvine hopper **INDIRECT DAMAGE** • Secrete **honeydew**. • Some **transmit** virus & virus-like diseases, common brown leafhopper transmits tomato big bud phytoplasma.
APHIDS 	1. **Soft, globular body** (enlarged central portion of abdomen), up to 8 mm long. Variable in colour. 2. **Cornicles** often present towards end of abdomen. 3. **Wingless or winged** with wings usually held vertically above body. 4. Wings same texture. 5. **Unusual life cycle:** • Often complex and variable • Eggs or live young • Parthenogenesis or sexual reproduction	**DIRECT SUCKING DAMAGE** **LEAVES** Death, eg green peach aphid Distortion, eg cabbage aphid Galls, eg grape phylloxera **FLOWERS BUDS** Distortion, eg rose aphid, black peach aphid **FRUIT** Distortion, eg green peach aphid Fruit fall, eg woolly aphid **STEMS TRUNK** Death of shoots (dieback), eg black peach aphid Shoot distortion, eg black citrus aphid **ROOTS** Unhealthy plants, eg black peach aphid **INDIRECT DAMAGE** • Produce **honeydew**, eg most aphids. • **Transmit** many virus & virus-like diseases, eg cucumber mosaic virus. • **Stunted growth generally.**

Summary - Some exceptions *(contd)*

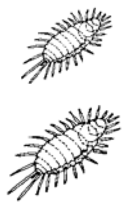
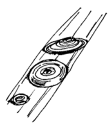
	SOME DISTINCTIVE FEATURES	PLANT DAMAGE
LERPS 	1. **Adults are similar in appearance to aphids with wings**, usually **free living** and can jump (hence the nick name of **jumping plant lice**). 2. Wings held **roof-like** over body. 3. Vary in size, up to **10 mm**. 4. Nymphs of some species shelter beneath a **lerp** covering which is **easily removed**.	**DIRECT SUCKING DAMAGE** LEAVES Dead areas, eg many species which attack eucalypts Defoliation, eg as above Mottling, eg as above **INDIRECT DAMAGE** • Secrete **honeydew**. • Lerp **coverings**
MEALYBUGS 	1. Oval to elongated body **up to 20 mm** long. 2. Soft-bodied and quite mobile (move very slowly). 3. Frill of **white filaments** around margin of body. 4. Secrete a **white waxy meal**. 5. Closely related to scale insects.	**DIRECT SUCKING DAMAGE** LEAVES Wilting and death eg longtailed mealybug especially on greenhouse and indoor plants ROOTS Death, eg root mealybugs GENERAL Death of plant, eg many species of mealybug **INDIRECT DAMAGE** • Disfigurement from presence and **honeydew** and **waxy deposits**
SCALES  	1. **Female wingless and stationary** and degenerate, male is winged. 2. Female is **larger** than the male. 3. Female is protected by secretions: 4. **Armoured scales**: • Usually very small, may look like dust • Soft flattened body under a separate hard scaly covering. • Little if any honeydew 5. **Soft scales**: • Larger than armoured scales. • Soft body with, initially no covering. However, the upper surface of adults is usually tough or protected with a waxy or mealy secretion. • Produce honeydew in varying amounts which attracts ants and on which sooty mould grows.	**DIRECT SUCKING DAMAGE** LEAVES Yellowing, eg black scale Leaf fall, eg red scale (citrus) FRUIT Disfigurement, eg red scale STEMS TRUNK Dieback, eg San Jose scale, gumtree scale GENERAL Stunting, eg white louse scale Dieback, especially armoured scales **INDIRECT DAMAGE** • Soft scales produce **honeydew**, eg soft brown scale. • Unsightly, eg white wax scale. • Loss of overseas markets, eg San Jose scale. Citrus fruit with scale on local markets reduces value
WHITEFLIES 	1. Adult male and female insects **winged**. 2. Up to **3 mm** wingspan. 3. Body and wings covered with **white powdery material**. 4. Two pairs wings of almost equal size, held flat over body. 5. Nymphs oval and flattened, **not mobile**. Parasitized nymphs turn **black**.	**DIRECT SUCKING DAMAGE** LEAVES Mottling, eg greenhouse whitefly **(GHWF)** GENERAL Death of seedlings, eg **GHWF** Reduced vigour, eg silverleaf whitefly **(SLWF)** **INDIRECT DAMAGE** • **Honeydew** and associated **sooty mould** • Overseas they are known to **transmit** some virus and virus-like diseases.

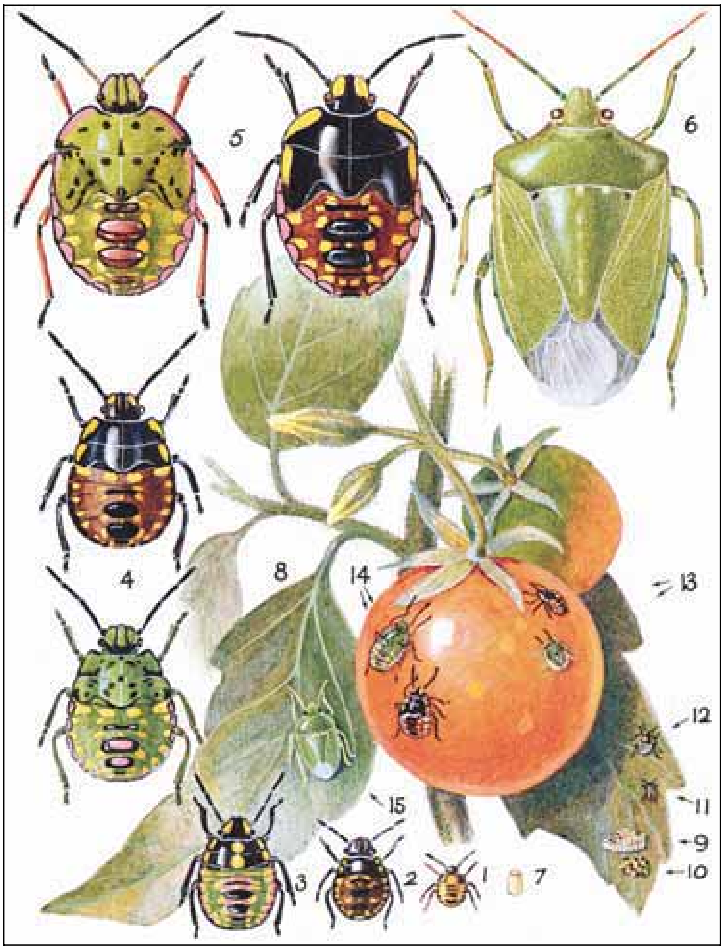
Fig. 101. Miscellaneous true bugs (Heteroptera).

Green vegetable bug (*Nezara viridula*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x4:
1. 1^{st}-stage nymph
2. 2^{nd}-stage nymph
3. 3^{rd}-stage nymph
4. 4^{th}-stage nymph (2 colour forms)
5. 5^{th}-stage nymph (2 colour forms)
6. Adult
7. Egg

All actual size:

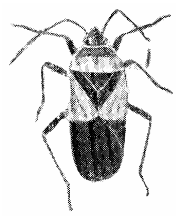
8. Tomato leaf
9. Eggs laid in cluster
10. 1^{st} stage nymphs (group)
11. 2^{nd} stage nymph
12. 3^{rd} stage nymph
13. 4^{th} stage nymph
14. 5^{th} stage nymph
15. Adult



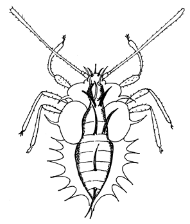
Spined citrus bug (*Biprorulus bibax*), green, 20 mm long.

Bronze orange bug (*Musgraveia sulciventris*), 25 mm long.

Rutherglen bug (*Nysius vinitor*), grey, 5 mm long.
Photo© NSW Dept of Industry and Investment.

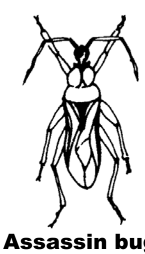


Harlequin bug (*Dindymus versicolor*), red/black, 12 mm long.
Photo© NSW Dept of Industry and Investment.



Lace bugs (Tingidae). Only a few species damage plants, eg azalea, macadamia and olive lace bugs, they are host specific. ***Left:*** Adult lace bug, 3 mm long. ***Right:*** Spiny nymph, 3 mm long.

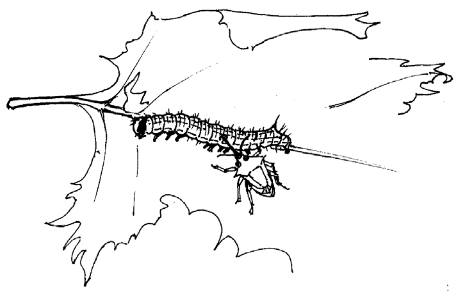
BENEFICIAL BUGS



Assassin bugs (Reduviidae), dark, 20 mm long.

Vine moth bug (*Oechalia schellembergii*), brown, 12 mm long.

Some predatory bugs seek out prey, others wait in ambush.



Vine moth bug, predatory shield bug (*Oechalia schellembergii*) sucks the contents from a **grapevine moth caterpillar** feeding on a grapevine leaf.

Crusader bug

An example of a shield bug

This native bug has a wide distribution over Australia, but does not occur in Tasmania. It has potential as a biological control agent for the giant sensitive tree (*Mimosa pigra*) (Elliott et al 1998).

Scientific name

Mictis profana (Coreidae, Order Hemiptera).

Host range

Wide range of native and introduced plants. **Ornamentals**, eg cassia, eucalypt, hibiscus, rose, wattle, wisteria. **Fruit**, eg citrus, grape.

Description & damage

Plant damage is caused by the nymphs and adults sucking sap from the young shoots.

Adult bugs are **20-30 mm** long and dark brown to black in colour. When wings are folded there is a well-defined yellow, **St Andrew's Cross** on its back, it is from this that the bug takes its popular name. The undersurface of the body and the long legs and antennae are brown, but in some individuals the tips of the antennae are orange. When disturbed adults fly readily and exude an unpleasant smelling liquid. **Nymphs** resemble the adults without the conspicuous yellow cross. The 1st stage nymphs are brown with a reddish abdomen and look like large ants. Later stage nymphs are brown and have two small orange spots in the middle of the upper surfaces of their abdomens. The developing wings (or 'wingbuds') are also marked with orange in the last 2 nymphal stages.

Shoots. Nymphs and adults suck sap from the young growth including flowering shoots causing them to wilt, turn brown and die.

General. May be an important pest of young trees, eg *Acacia* spp. in the NT, *A. ampliceps* and *A. auriculiformis* in plantations in Qld when almost all trees and 95% of shoot tips can be attacked causing dieback, loss of apical dominance and 'bushing' of trees.

DIAGNOSTICS

- Adults are identified by their creamy **'cross'**.
- Nymphs move rapidly over the plant and superficially look like rather large ants.
- Unpleasant smell.
- **Wilted or dead tips** of new growth which may curl over. Crusader bugs causing the damage may have long since departed to seek a new food source.

Pest cycle

There is a **gradual metamorphosis** (egg, nymph (5 stages), and adult) with 3-4 overlapping generations each season. In spring, 'overwintering' females lay eggs in rows or groups on leaves, twigs or fruit and sometimes debris on the soil. Eggs are relatively large, elongated and brown, with a rounded lid on top which is pushed off by the young bug when emerging. Nymphs feed on the foliage of host plants side by side with adults. Adults can live for more than 4 weeks. A complete life cycle takes about 8 weeks in summer.

'Overwintering'

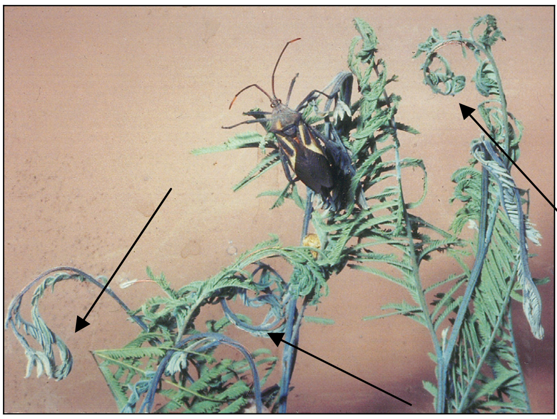
As adults in sheltered places emerging to attack new growth in spring.

Spread

- Adults can fly freely in warm weather.
- Movement of infested plants (minor).

Conditions favoring

Late summer and autumn especially in cooler regions. They are a sporadic pest, occurring one season and not the next.



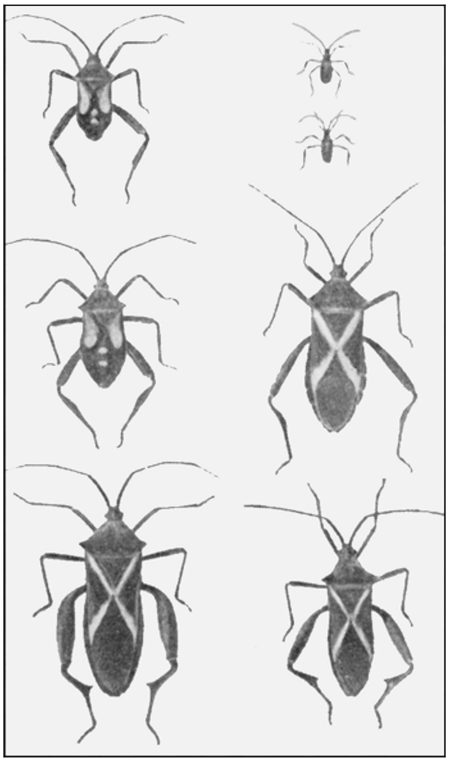
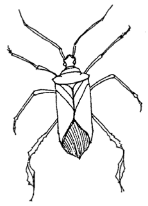


Fig. 102. Crusader bug (*Mictis profana*). ***Left:*** Nymph sucking sap from tips of new wattle shoots which wither. and die. ***Right:*** Nymphs and adults actual size (20-30 mm long). Photo©CIT, Canberra (P.W.Unger). Photo©NSW Dept of Industry and Investment.

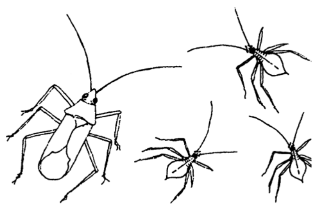
Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region**. Know the variations, eg not in Tasmania.
3. **Identification** if necessary consult a diagnostic service (page xiv) but the adult is distinctive.
4. **Monitor** the pest and/or damage visually during spring and summer. Remember you need to know **when, where, what and how to monitor** (page 39).
   - **Citrus trees** are usually monitored once or twice from October to April, depending on development of infestations. Check 5 randomly selected young shoots on each tree (Smith et al 1997).
5. **Threshold**. How much damage can you accept? On many plants the damage may not be significant.
   - **On citrus** if 25% or more shoots are infested on young trees then action is needed.
6. **Action**. Action is rarely required on older trees. If required, bugs on young trees may be collected and destroyed or in severe infestations spot sprayed with a selective insecticide.
7. **Evaluation.** Review your program and recommend improvements where needed. It may be necessary to continue monitoring trees after treatment. Keep records so you can compare each year's results.



Passionvine bug (*Fabrictilis gonagra*) is about 18 mm long, black with a red band behind its head and red spots on the underside of its body.



Fruitspotting bugs (*Amblypelta* spp.) are difficult to see. ***Left:*** Yellow-green adult bug about 15 mm long. ***Right:*** Nymphs.

Fig. 103. Other squash bugs (Coreidae).

Control methods

Often damage is of no economic importance and so no control measures are required. A few bugs on a large shrub can be ignored.

Sanitation. If only a few small shrubs, plants or nursery stock are affected bugs can be collected by hand. Wear gloves to avoid getting their offensive fluid on hands. Alternatively, bugs may be shaken into a wide mouthed container or onto a sheet. Destroy bugs by stamping on or by some other means. Damaged shoots may be pruned off.

Biological control. Many predators feed on crusader bugs including other insects, eg assassin bug (*Pristhesancus plagipennis*), praying mantises, and birds. Wasps that parasitize eggs are the main natural enemies of crusader bug.

Resistant varieties. Some varieties of host plants are all susceptible, eg all citrus varieties are susceptible.

Insecticides. Spot spray nymphal stages on plants if infestation is severe. Do not spray trees greater than 3 meters high (Table 25 below).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 25. Crusader bug – Some insecticides.

What to use?	When & how to apply?
FOLIAGE SPRAYS **No products are registered specifically for crusader bugs**. Some sprays are registered for 'bugs' generally, eg **Group 1B**, eg Rogor® (dimethoate) Various home garden sprays, eg Bug Gun (permethrin)	• Application of insecticides is not usually necessary in a home garden situation. Non-chemical measures should be sufficient. • Follow resistance management strategies on labels. • Spot spray nymphs when first noticed. • On citrus, the addition of a wetting agent such as white oil to the spray will make it more effective.

Cabbage aphid

Scientific name

Brevicoryne brassicae (Order Hemiptera).
Common and serious pest of Brassicas wherever they are grown throughout the world. Several other aphids will also attack Brassicaceae, including the green peach aphid (*Myzus persicae*), turnip aphid (*Lipaphis erysimi*).

Host range

Brassicas, including:
Vegetables, eg broccoli, brussell sprouts, cabbage, cauliflower.
Ornamentals, eg stock, wallflower.
Field crops, eg rape, turnip.
Weeds, eg Indian mustard, shepherd's purse, wild radish, turnip weed.

Description & damage

Adult aphids are globular and about **2.5 mm** long when mature, slaty grey and covered with a mealy material. Globules of honeydew may be seen among aphid colonies. Winged and wingless forms occur together on the same plant.

- **Leaves, flower heads.** Nymphs and adults damage plants by piercing plant tissues and sucking plant juices. Infestation usually starts on leaf **upper surfaces**, a single winged female surrounded by wingless young; leaves curl in and protect the colony. Aphids prefer to feed on the tender growing parts of the plant, eg **youngest leaves** and **flowering parts** deep within heads of cabbage and Brussel sprouts. **Large colonies** cause much curling of the leaves and twisting of tender shoots making the aphids hard to control. Plants stop growing and leaves become yellowish, they may suddenly wilt and die.
- **Transplanted seedlings.** Cabbage aphids do not usually infest seedlings but build up after thinning or transplanting. Large colonies can stunt or kill small plants.
- **White caste skins** (left behind after aphids have moulted), honeydew, ants, sooty mould.
- **Aphids** are most abundant on **lower leaves** of established plants.
- **General**. Spread through a crop is rapid.
- **Transplanted seedlings.** Cabbage aphids do not usually infest seedlings but build up after thinning or transplanting. Large colonies can stunt or kill small plants.

Transmission of virus diseases.
Cabbage aphid is a vector of the cauliflower mosaic virus and possibly other virus diseases as well in a non-persistent/semi-persistent manner. The virus is lost during moulting and is not transmitted directly to progeny.

Diagnostics
Because of their mealy-gray appearance and habit of clustering together on leaf undersurfaces to form colonies, cabbage aphids are easy to recognize.

Fig.104. Cabbage aphid (*Brevicoryne brassicae*). Curling and distortion of cabbage leaves caused by cabbage aphids. Photo©CIT, Canberra (P.W.Unger).

Pest cycle

There is a **gradual metamorphosis** (live nymphs, adult) with many generations each season. The aphids first appear on the leaves in small colonies, which may include adults and a variable number of young. Such colonies reproduce rapidly, no eggs are laid, **active young are born alive**. In warmer areas a generation matures in 2 weeks. However, as the number of aphids in an area increases, the food decreases and their individual growth become much slower.

'Overwintering'

In warmer areas, young are born alive throughout the year while in cooler areas wingless forms overwinter. In **colder countries**, this species has an egg-laying form and the eggs 'overwinter'.

Spread

- By **winged forms** flying. Winged forms are produced when the colony is crowded, spread through a crop is rapid.
- By **seedlings**.

Conditions favoring

Warm, dry conditions during late summer and autumn. In coastal areas they may be important pests in spring. Aphids multiply in colonies at an incredibly rapid rate depending on temperature, eg each female can produce 3 young/day at 16°C and up to 6/day at 24°C. Aphids do **not** thrive in very hot and dry or very cold conditions.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Access a plan** in advance that fits your situation.
2. **Crop, region**. Know variations.
3. **Identification**. If necessary consult a diagnostic service (page xiv) as several species of aphids can attack cabbages.
4. **Monitor** pest and/or damage and record results. Early aphid infestations are of greater significance in terms of potential damage. Different methods can be used, eg
   - **Monitor number of stunted plants**. Inspect crop weekly when aphids are expected. Examine 10 plants at each of 6 widely spaced locations along a zigzag route through the crop.
   - **Monitor number of natural enemies of aphids**, eg hoverflies, daily weather conditions.
   - **Satellite mapping**. In the UK, aphid populations can be assessed on Brussell sprouts using satellite mapping and **Geographic Information Systems (GIS)** software. Research also indicates that growers may only need to monitor the **edges** of fields rather than the whole field.
   - **An Aphid Alert** service is available in the USA for insects that affect soybeans. It provides a warning when aphids are near threshold level, indicating that it is time for growers to scout their fields and consider an insecticide application to protect their crops www.**aphidalert**.com
5. **The threshold** is usually an economic threshold. How much damage can you accept? One suggestion is to take action if more than 10 out of 30 cabbage plants plants are infested. In some crops control measures are recommended (**if** all the plants inspected have aphids at a predetermined threshold levels).
6. **Action** at the determined threshold can be bio-controls, which do not prevent economic damage and/or insecticides (see Table 26 below). Where transverse ladybirds are found in nurseries try to avoid spraying.
7. **Evaluation.** Review your program, recommend improvements if necessary.

Control methods

Cultural methods.

- Avoid year-round growing of Brassicas.
- Site plants away from sources of infestation.
- Sow late to avoid aphid flights,
- Organic gardeners may use repellant plants such as garlic to assist with aphid control.
- Planting dill near cabbage encourages predatory hover fly (Syrphidae) larvae.
- In the USA, opaque mulches of aluminum and other reflective materials reduce aphid numbers on vegetable plants by up to 96% and prevent weed growth. The aluminum reflects the blue of the sky and disorientates aphids. In Australia, plants tend to become scorched.
- Intercropping disrupts the visual and chemical cues that aphids use to locate host plants, ie the contrast between crop and surrounding soil is reduced. Intercropping Brussel sprouts with French dwarf beans or weeds may help reduce aphid infestations.

Sanitation.

Prompt disposal of harvested crops and control of Brassica weeds assist control.

Biological control.

- **Natural controls** do not prevent economic damage.
  - **Predators**, eg common spotted ladybird (*Harmonia conformis*), birds, young mantids, mites, lacewings, spiders, earwigs, hoverfly larvae. Some **ladybirds** can consume up to 100 aphids per day and will feed on twospotted mites if aphids are absent. **Tasmanian lacewing** (*Micromus tasmaniae*) larvae consume up to 10 aphids per day.
  - **Parasitic wasps**, eg the cabbage aphid parasite (*Diaeretiella rapae*) leaves many swollen empty aphids on plants, each with a small hole through which the adult wasp has emerged (page 152).
  - **Various diseases** are being researched for possible use as biological control agents, eg the fungi, *Metarhizium anisoplia* and *Entomophora*.
  - **Heavy rain** can destroy large numbers of aphids.
- **Commercial biocontrol agents**.
  - **Predators**, eg lacewings, ladybirds.
  - **Parasitic wasps**, eg *Trichogramma* spp.

  List of suppliers www.**goodbugs**.org.au

Resistant varieties.

Use resistant or tolerant cultivars if practical; red cabbage is reputed to have some resistance.

Plant quarantine.

Not really applicable.

Pest-tested planting material.

Ensure transplants are aphid-free before planting. Screen seedling houses to exclude aphids prior to transplanting.

Physical & mechanical methods.

Aphids can be hosed off plants using a strong jet of water but tend to return quickly.

Insecticides. Table 26 below.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 26. Cabbage aphid – Some insecticides.

What to use?	When & how to apply?
FOLIAGE SPRAYS AND DUSTS **Group 1A**, eg Aphidex®, Pirimor®, Ospray® (pirimicarb) - **systemic aphicide** **Group 1B**, eg Eraser®, Lancer®, Orthene® (acephate) **Group 3A**, eg Ambush®, Pounce® (permethrin) **Group 4A**, eg Confidor®, various (imadicloprid) **Group 9B**, eg Chess® (pymetrozine) - not toxic to predators **Group 21B**, eg Derris® Dust (rotenone) **Spray oils**, eg Bioclear® (paraffinic oil); Eco-oil® (vegetable oil) **House and garden sprays and dusts** for aphids generally, eg soap sprays, pyrethrin, Derris® Dust (rotenone)	• When observed. • Insecticidal soap may be phytotoxic under some conditions especially to Brussel sprouts and cabbages. • Observe label withholding periods for edible crops.
SEED TREATMENTS	**Group 4A**, eg Picus® Seed Treatment (imadicloprid) protects seedlings of certain crops (cotton, canola and cereals) from early aphid injury caused by **other aphid species** and in some instances, spread of virus diseases.

Green peach aphid

Scientific name

Myzus persicae (Order Hemiptera) is a common and major pest of many plants.

Host range

Primary food plants. Peaches and nectarines, also apricot and plums, rarely almonds.

Secondary food plants. Wide range of plants including **ornamentals**, eg Iceland poppy, rose; **fruit**, eg plum, strawberry; **vegetables**, eg cabbages, peas, potatoes; **weeds**, eg capeweed, dock, sowthistle. Many ornamentals, vegetables, fruit and weeds may host **several aphid** species.

Description & damage

Aphids have sucking beaks and feed by puncturing plant tissues and extracting sap.

Adults are globular, mostly green with dark green markings but may be pale yellow or pale pink and about **2.5 mm** long. On the abdomen there is 1 pair of **cornicles** with distinct dark tips. Aphids live in colonies formed from the young of a single female, single or small numbers of aphids are sometimes found on shoots. **Nymphs** are like adults except smaller and wingless, colour varies from green to pale yellow and pale pink. **White papery nymph skins** are shed as they moult and grow and are found on leaves and buds.

Leaves. The green peach aphid sucks sap from young leaves causing them to wrinkle. It produces copious amounts of **honeydew**, which attracts **ants** and on which **sooty mould** grows reducing photosynthesis, making plants shiny, unsightly and unsaleable. Honeydew is sticky and may drip on onto underlying leaves and plants, floors, seats, etc. Ants protect and care for the aphids, move them around and keep away predators and parasites. In return ants feed off the honeydew.

Transmission of virus diseases.

- Over 100 virus diseases of **secondary hosts** may be transmitted from plant to plant by the green peach aphid during feeding, eg cucumber mosaic virus (the most common plant virus in the world), turnip mosaic virus, potato leaf roll virus, pea mosaic virus, bean yellow mosaic.
- Green peach aphid does **not** transmit virus diseases of stone fruits.
- Ornamental plants affected by virus diseases transmitted by green peach aphid include carnation, chrysanthemum, gladiolus, tulip, lilium, hyacinth, iris, narcissus, daphne, lilac.

DAMAGE TO STONE FRUITS.

Flowers/Fruit. Aphids feeding on swelling buds often cause premature opening of flowers. A single petal emerging from a bud indicates its presence. Later generations feed on flower parts before the petals unfold fully. Opening buds and flowers are distorted and fall readily, reducing fruit setting. Young fruit may be attacked and fall.

Leaves/shoots. Aphids feed on spring growth and inject toxic saliva into the developing plant tissue producing shoot, leaf and flower **distortion**. Aphids infest young leaves and laterals of fruit trees, causing the leaves to curl, shrivel and fall (page 153, Fig. 106; page 31, Fig. 16). Trees may become unproductive and may take several years to recover from repeated severe attacks.

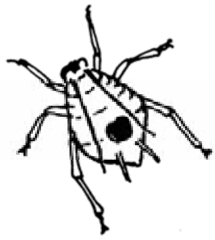
DAMAGE TO ORNAMENTALS.

Green peach aphid attacks new growth in spring causing shoot, leaf and flower distortion, wilting and retarded growth in a range of ornamentals. Small numbers affect plant appearance and distorted leaves cannot be fixed. Large numbers of live young may occur in hot spots in a crop.

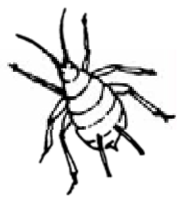
Diagnostics.

- **On stone fruits** green peach aphids are easy to recognize from other aphids. Cherry aphids and black peach aphids are black.
- **If aphids have moved to secondary hosts**, look for **white nymph** skins on leaves and buds of these plants, drops of honeydew, ants, sooty mould, shriveled leaves. Check leaf undersurfaces.
- **On stone fruits** do not confuse green peach aphid damage to leaves with the fungal disease peach leaf curl (pages 152, 358). It is possible to have both problems together in spring.
- **Comparison of symptoms:**

	Green peach aphid injury	**Peach leaf curl symptoms**
Leaves	Leaves wrinkled (no blisters or thickening), aphids, nymph skins, honeydew, infested leaves die and fall	Blistered, may be thickened, affected areas blacken and die, affected leaves fall
Other features	Infested leaves die and fall trees become unproductive	Fruit may be infected, reduced fruit crop, reduced tree vigour.



Parasitized aphid



Unparasitized aphid

Fig. 105. Green peach aphid (*Myzus persicae*). Note distinctive cornicles at rear of aphids. ***Left:*** Parasitised aphid with exit hole through which the adult wasp has emerged. ***Right:*** Unparasitised aphid.

Pest cycle

There is a **gradual metamorphosis** (egg, nymphs, adult) with many generations each year. **In spring** aphids multiply rapidly on peach and nectarine trees, producing wingless young-bearing females and cause serious damage. **In early summer**, as the peach foliage hardens off, the winged forms migrate to their secondary food plants (ornamentals, vegetables and weeds), where they spend the summer. **In late autumn**, some females and males migrate back to the peaches and nectarines. Eggs are laid about the bases of the buds from May to mid-July. Eggs may also be laid on cherry trees but fail to survive. Eggs hatch in late July to mid-August, but the aphids remain in the buds until bud burst when they multiply rapidly as the trees come into leaf. **In warm districts** (eg coastal areas) the autumn migration to the peach and nectarine trees does **not** occur and so eggs are rarely seen.

'Overwintering'

In mild climates there is **no egg stage**. Aphids breed throughout the year on secondary host plants occasionally producing winged forms which fly to other secondary hosts. Where winters are cold, eggs 'overwinter' about the bases of buds on peach and nectarine trees. Sheltered conditions may allow aphids to survive throughout the year.

Spread

- As winged forms flying assisted by wind.
- Movement of infested plants, young nursery trees may carry over-wintering eggs. Seedlings and container plants may carry wingless forms.

Conditions favoring

- Aphids generally do not like hot dry weather.
- Aphids are **seasonal pests** and may occur in large numbers for a relatively short time usually during spring and autumn.
- Abundant growth of herbaceous weeds in the previous summer and autumn,
- Late leaf-fall from the peach trees.
- **Cool wet weather in spring** favours severe damage in spring due to the slow hardening of early peach growth and delayed appearance of natural enemies.
- Researchers in the UK have found that **GPAs** that had become more resistant to pesticides were less able to withstand the British winter. They also became less sensitive to their environment and didn't notice warnings from alarm pheromones secreted by other aphids and became victims to ladybirds and other predators.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Access a plan** in advance that fits your situation.
2. **Crop, region**. Recognize variations as weather can affect severity of damage and appearance of natural enemies. **GPA** is a serious pest.
3. **Identification** must be confirmed. Consult a diagnostic service if necessary (pages 152, xiv).
4. **Monitor** at least weekly for aphids and beneficials when they are expected, seek advice (page 39). **Know when and where** to look, **what and how** to monitor.
   - **Stone fruits.** 'Overwintering' eggs on peach and nectarine trees in cool climates; can be monitored by inspecting bark of all trees while they are being pruned. Mark all trees infested with the tiny black 'overwintering' eggs (Brough et al 1994.
   - **Ornamentals and vegetables crops.** Monitor populations on commercial crops. Control measures can be implemented before damage is obvious.
     – Yellow sticky traps can be used to monitor winged adults; other insects are also attracted so accurate identification of the trapped insects is important.
     – Examine say 10 plants at say 5 locations in the crop for aphids, caste skins, honeydew and black sooty mould, predators and parasitized aphids (mummies). Also look for ants.
5. **Thresholds** will vary depending on the crop. Economic damage to ornamentals and vegetables can be considerable. There may be a nil threshold on peach trees, ie all infested trees should be treated. There may be a complaint threshold for honeydew.
6. **Action/control.** Unless aphids are present in high numbers on some crops, eg potatoes, they may not cause major damage. Biological control agents are commercially available. Spray all marked infested peach trees with winter oil either while trees are dormant or at budswell. Brough (1994) suggested checking results at **flowering** by inspecting 5 flower clusters from each infested tree. If aphid colonies are found spray with a recommended insecticide when all petals have fallen. Control ants if present.
7. **Evaluate** the program, are improvements needed?

Fig. 106. Green peach aphid (*Myzus persicae*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

All enlarged about x14
1. 1st stage nymph
2. Adult wingless viviparous female
3. Pre-adult nymph of winged viviparous female
4. Adult winged viviparous female
5. Overwintering egg when first laid
6. Eggs several days old

Actual size
7. Peach shoot showing curling and distortion of leaves
8. Peach twig; arrows indicate where eggs are generally laid

Control methods

For peach and nectarine trees

Ants attracted by honeydew and sooty mould will disappear once aphids are under control.

Cultural methods.

- Avoid overfertilising plants, especially with nitrogen as aphids prefer lush growth.
- Control ants as they spread and protect aphids from natural enemies.
- Some plants repel aphids eg chives, garlic, lavender, mint, pyrethrum, rosemary, tansy, wormwood.

Sanitation. Remove weeds which can be alternate hosts in and around nurseries and greenhouses to reduce breeding sites. Remove severely infested herbaceous plants.

Biological control.

- **Natural control.** Encourage natural enemies which attack aphid colonies in spring, however, they do not usually prevent economic damage.
  - **Predators**, eg hoverfly larvae (Syrphidae), small birds, eg silver eyes. **Ladybird beetles** and their larvae reportedly eat as many as 2,4000 aphids during their lives. **Green lacewing** larvae (Chrysopidae) consume up to 100 aphids/day.
  - **Parasitic wasps,** eg *Diaeretiella* sp., lay their eggs in aphid bodies which swell up. When the adult wasp emerges there is an obvious exit hole, 'mummies' may be brown/black (page 152).
  - **Fungal and other diseases.** Various fungi attack aphids in warm humid weather, eg *Aschersonia, Beauveria, Entomophora*, *Metarhizium, Verticillium.*
  - **GPA** populations are reduced by heavy rain and/or early leaf fall in autumn.
  - If weather prevents returning winged males from reaching peach trees females will lay infertile eggs.
- **Commercially available**
  - Predatory green lacewings (*Mallada signata*).
  - Parasitic wasps (on aphids), eg *Aphidius colemani*.
  - List of suppliers www.goodbugs.org.au

Resistant varieties.
Not practical for tree hosts but may be useful for secondary hosts, eg lettuce. Lucerne aphids are now controlled by a combination of parasites, predators and tolerant or resistant varieties.

Pest-tested planting material.

- Use aphid-free planting material as aphids reproduce rapidly and establish quickly on crops.
- Keep parent stock plants free of aphids (and other vectors) to prevent infection with virus diseases and to reduce spread of aphids on propagation material.

Physical & mechanical methods.

- Some growers install screens (correct mesh size) on greenhouse vents to prevent entry of aphids and other small insects such as thrips.
- Squash aphids with fingers by simply wiping down the sides of affected shoots with your finger. Wear gloves to avoid stains.
- Hosing with water may temporarily remove aphids from some plants. Aphids tend to return.

Insecticides.
Many naturally occurring or commercial biocontrols are susceptible to insecticides.

- **GPA** has developed **resistance** to more than 60 insecticides including several organo-phosphates, carbamates and synthetic pyrethroids. Follow **Croplife Australia's resistance management strategies** and label directions.
- Insecticides **combined with** the activity of aphid predators in spring are an important component of the resistance management strategy for green peach aphid.
- **Aphicides** will reduce impacts on non-target organisms.
- **Newer systemic insecticides** may be applied as spot sprays or root drenches and used with biocontrol agents.
- **Spot treatment** is the preferred application method, **not** blanket spraying. Sprays other than oils will kill large number of predators.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 27. Green peach aphid - Some insecticides for use on stone fruit

What to use?	When & how to apply?
DORMANT SPRAYS **Spray oils**, eg Winter oil (petroleum oil); Bioclear®, Biopest® (paraffinic oil) – dormant or delayed dormant	• Apply to dormant peaches and nectarines no later than early budswell to kill 'overwintering' eggs. • Limited use as aphids move in from adjacent plants.
SEMI-DORMANT SPRAYS	• Semi-dormant sprays to control young aphids when hatching is complete. • These sprays can often be combined with other pesticide sprays which may be necessary at this time.
FOLIAGE SPRAYS **Group 1A**, eg Pirimor® (pirimicarb) – **systemic aphicide** **Group 1B**, eg Malathion® (maldison) **Group 4A**, eg Confidor®, various (imidacloprid); Calypso® (thiacloprid); Samurai®, various (clothianidin) **Group 9B**, eg Chess® (pymetrozine) - **not toxic to some predators** **Spray oils, soaps**, eg Eco-oil® (botanical oils); insecticide soaps **Home garden sprays**, eg there are many sprays for aphids generally on roses and other ornamental plants.	• Trees must have produced some foliage for these sprays to be effective. • Apply when observed. • Some sprays are toxic to early peaches. Only spray if monitoring indicates a need (infestation is severe) and the early budswell oil spray was missed. • **Follow resistance management strategies**.

Woolly aphid

Scientific name

Eriosoma lanigerum (Order Hemiptera). Woolly aphid is a serious pest of apple trees. Other aphids also attack apples.

Apple-grass aphid (*Rhopalosiphum insertum*) Pear root aphid (*E. pyricola*) Spiraea aphid, apple aphid (*Aphis spiraecola*) Overseas also *Aphis pomi, Dysaphis plantaginea*

Host range

Fruit, eg apple, rarely pears. **Ornamentals**, eg crab apple, occasionally cotoneaster, hawthorn (*Pyracantha* spp.), liquidamber.

Description & damage

Adults are nearly all females and wingless, however, winged females may be produced in autumn. Aphids are globular in shape, purplish-brown and usually covered with long, white woolly threads which they secrete from pores on the body. These threads form a loose tangled mass over the active colonies and act as protection. The aphids also produce a white powder which covers their bodies. **Nymphs** are smaller than adults, pale and initially not so globular. **Honeydew** (sticky sugary secretion) is produced. **Sooty mould** grows on it and the white woolly threads stick to it.

Above ground limbs & lateral growth. Woolly aphids feed on the laterals and trunks of apple trees by piercing and sucking plant sap. However, they can only attack wood where the bark is still thin, eg lateral growth, or where the bark has been broken as a result of injury or at existing feeding sites. The feeding sites become gnarled and lumpy and trees may be weakened. Lateral growth may become cracked and distorted and most or all the buds are destroyed. Heavily infested trees become ‘staggy’ in appearance, with the quantity of productive wood greatly reduced. The woolly threads secreted by the aphids disfigure the laterals.

Fruit. Black sooty mould grows on honeydew and the white woolly threads stick to it. Heavy infestations:

- Disfigure fruit.
- Annoy pickers.
- Cause fruit to fall prematurely.
- Interfere with the coloring of red varieties.
- Downgrade commercial fruit.

Roots. Heavy infestations, mostly on roots near the surface, produce characteristic lumpy swellings and can severely stunt growth, particularly in young trees. But once trees are established, root infestations do not usually affect their vigour.

General. The major cause of damage occurs when large aphid populations build up on laterals. The copious amounts of honeydew encourages sooty mould which interferes with the tree's growth by preventing photosynthesis.

Diagnostics.

- White woolly threads, black aphids, sticky honeydew.
- Black sooty mould growing on the honeydew.
- Limited host range.
- Do not confuse with **mealybugs**.
- Do not confuse with **powdery mildew**, etc.
- Gnarled and lumpy lateral growth.

Fig. 107. Woolly aphid *(Eriosoma lanigerum).* ***Top left:*** Swellings on lateral growth caused by aphids feeding. ***Lower left:*** Galls on apple root. Photo©NSW Dept of Industry and Investment. ***Right:*** Twigs with aphids under woolly threads. Photo©CIT, Canberra (P.W.Unger).

Pest cycle

There is a **gradual metamorphosis** (eggs that rarely hatch, live nymphs and adults) with many generations each year. Survival of the population during winter depends mostly on young aphids in cracks and crevices of old wood. Most aphids are wingless females that reproduce asexually (without being fertilized) and give birth to between 2-20 live female nymphs a day. These take from 8-20 days to mature. Once aphids settle at a feeding site they remain there until autumn. A few sexual forms appear on apple but they do not feed and their eggs rarely hatch. Some migration from trees to susceptible rootstocks takes place in early winter with a return to aboveground parts in spring. On roots and aerial parts reproduction continues through winter though at a reduced rate.

'Overwintering'

- Mainly as young aphids in cracks and crevices on the **above ground parts** of apple trees and on exposed roots or those less than 10mm below the soil surface.
- As young aphids on the roots of susceptible rootstock but these aphids do not appear to be important for 'overwintering'.
- Woolly aphid infestations survive better in the field during winter on Granny Smith and Jonathan than on Delicious or Rome Beauty.

Spread

- Occasionally young winged adults, produced during summer, establish colonies on neighboring trees.
- Movement of infested propagating stock, nursery stock and plant material.
- By wind, birds, insects or people.

Conditions favoring

- **Spring and autumn**, eg 6-18°C temperature.
- Low humidity and temperatures above 27°C are unfavourable to it, but low temperatures have little effect apart from slowing down their rate of development.
- Cool and moist conditions, eg **shaded situations**, the interiors of dense, strongly growing trees or trees shaded by windbreaks.
- Lack of predators, parasites and diseases which attack woolly aphids (Asante 1999).
- As aphids become more resistant to pesticides they become less sensitive to their environment.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Access a plan** that fits your situation. State *Orchard Plant Protection Guides* available.
2. **Crop, region**. Recognize variations.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv) to avoid confusing waxiness, sooty mould and honeydew with other pests.
4. **Monitor** pest and/or damage and record results weekly (page 39). **Seek advice** for your situation.
   - **Early detection** before the 'waxy wool' is produced in quantity is important as it protects the aphids from insecticide sprays.
   - It is easier to count colonies to estimate population numbers than to tally individual aphids.
   - Brough et al (1994) suggested inspecting 5 laterals from each of 20 trees per hectare during spring and autumn.
5. **Threshold**. How much damage can you accept? Thresholds have been determined for some commercial growers, eg if one (1) or more laterals are found to be infested.
6. **Action.** Take appropriate action when any threshold is reached, preferably that which does not harm natural parasites and predators. A resurgence of aphids may occur prior to harvest.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required, eg use of resistant rootstock for new plantings so that woolly aphids will no longer multiply on and damage roots.

Control methods

Control is difficult because susceptible rootstock have a more-or-less permanent infestation on the roots, which may re-infest aerial parts.

Biological control. The introduced wasp parasitoid (*Aphelinus mali*) and native species of ladybird beetles will attack woolly aphid but their populations may not increase rapidly enough to prevent woolly aphid populations reaching damaging levels.

- **Introduced *Aphelinus***. Woolly aphid has been under biological control since 1923 when the **parasitic wasp** (*Aphelinus mali*) was released. The wasp lays eggs in the body of the aphid and the larva feeds on the body of the aphid killing it. Parasitized aphids lose their woolly covering and become **black**. A **small exit hole** which can be seen with the naked eye, is made in the back of the dead aphid by the wasp when it emerges. The wasp **'overwinters'** as a pupa in the body of a dead parasitized aphid and the adult wasps emerge in September at the same time as the colonies of woolly aphid become active. It is possible that dormant sprays do not affect the protected stage of the parasite but many of the more modern insecticides used during the growing season are harmful, the wasp is therefore scarce in **commercial orchards** but gives useful control in non-bearing orchards where fewer pesticides are used. *A. mali* can complete 8-9 overlapping generations each year. **Conserving** *Aphelinus mali*:
  - Occasional infestations on **hawthorn** and other hosts are valuable for maintaining *Aphelinus* populations. Hawthorn and other hosts near apples should not be sprayed.
  - **Twigs** with parasitized aphids may be collected before winter and stored in a shed away from birds and placed in infested trees in spring.

- **Natural controls.** Natural enemies of woolly aphid have been well documented by Asante (1997). However, they often do not increase quickly enough to prevent woolly aphid populations reaching the threshold level detailed on page 156.
  - **Predators** in Australia include ladybirds, eg common spotted ladybird (*Harmonia conformis*), transverse ladybird (*Coccinella transversalis*), mealybug ladybird (*Cryptolaemus montrouzieri*), also lacewing and syrphid fly larvae and earwigs.
  - **Parasites**, eg 5 species of wasps and 2 species of mites assist in reducing woolly aphid populations.
  - **Fungal diseases**, eg *Verticillium lecanii* is reputed to infect woolly aphid.

Resistant varieties.

- **Malling-Merton series rootstocks** with some resistance to woolly aphid have been readily available for many years, and trees are grafted onto these stocks. The use of resistant rootstocks means that woolly aphid can no longer multiply on or damage roots and act as a source of re-infestation and that woolly aphid has only to be controlled on aerial parts of trees. Note that **even** on resistant rootstock a few aphids may still be found on roots.
- **Rootstock can be chosen** which have some resistance not only to woolly aphid, but also to *Phytophthora* collar rot and fireblight (NSW Agfact Apple Rootstock Identification).
- **Northern Spy:**
  - Is resistant to wooly aphid.
  - Is moderately susceptible to *Phytophthora.*
  - Is moderately resistant to fireblight.
  - Causes minimal suckering.
  - Is tolerant to different soil types.
  - Other roots stock may be more susceptible to *Phytophthora*, fireblight, etc.

Pest-tested planting material. Examine purchased nursery stock to check for the need for treatment prior to planting.

Insecticides. **Apples**

- **A dormant spray of winter oil** may kill some 'overwintering' aphids in cracks on trunks and limbs (not very effective) but not *Aphelinus*.
- **Growing season sprays** should be applied when infestations are first noticed usually in spring and autumn when trees are growing vigorously. Remember,
  - Sprays may be toxic to *Aphelinus*.
  - A resurgence of aphids may occur prior to harvest.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 28. Woolly aphid – Some insecticides.

What to use?	When & how to apply?
ROOT OR NURSERY STOCK DIPS **Group 1B**, eg Rogor® (dimethoate), permit may be required	Use for nursery trees with gross infection prior to planting. Severely infested roots or whole plants of nursery stock may be dipped in insecticide and drained prior to planting.
DORMANT SPRAYS - deciduous trees **Spray oils**, none registered for woolly aphid	• Indicates their lack of effectiveness, but does not kill *Aphelinus*.
GROWING SEASON SPRAYS **Group 1A**, eg Aphidex®, Pirimor®, various (pirimicarb) - **systemic aphicide** **Group 1B**, eg Rogor® (dimethoate) - **systemic** Folimat®, Sentinel® (omethoate) – **systemic** Malathion® (maldison) - **non-systemic** Lorsban®, various (chlorpyrifos) - **non-systemic** **Group 4A**, eg Confidor®, Kohinor®, Surefire®, (imidacloprid); Samurai® (clothianidin) - **systemic**	• Apply when infestations are **first** noticed and any threshold is reached, usually in spring and autumn. • Systemic pesticides give best control and should be applied when trees are growing vigorously. If trees are not growing vigorously use contact insecticides.
SOIL TREATMENTS **Group 4A**, eg Confidor®, Confidor® Soil Guard Insecticide (imidacloprid) - **systemic** - to conserve *Aphelinus mali* use at the reduced rate as recommended on the label. Commercial growers only.	• For trees up to 7 years of age. • During late summer/autumn, mark affected trees for treatment the following season, ie green tip to petal fall. • If aerial colonies are present, maximum effectiveness may not be achieved until the following season. Do not treat any more than once in any 2 year period.

Lerp insects, psyllids

Scientific name

Psyllids (Family Psyllidae, Order Hemiptera). Many species in Australia are of little economic significance but some may kill hosts.

Brown basket lerp (*Cardiaspina fiscella*)
Redgum sugar lerp (WA, NT, Qld) (*Glycaspis blakei*)
Bluegum psyllid (*Ctenarytaina eucalypti*)
Eucalypt shoot psyllid (*Blastopsylla occidentalis*)
Spottedgum psyllid (*Eucalyptolyma maideni*)
See also page 143

Host range

Lerp insects attack native trees, especially eucalypts. **Psyllids** attack a wide range of native plants, eg callistemon, eucalypts, hibiscus, grevillea, Christmas bush, boronia, leucaena. Many psyllids are host specific or restricted to one group of closely related eucalypts, eg bluegum psyllid (*Ctenarytaina eucalypti*) infests blue gum (*E. globulus*), shining gum and some species with blue-grey foliage. Some eucalypt species may be infested with many species of psyllids, eg Sydney bluegum (*E. saligna*) may host 16 species.

Description & damage

Adult lerps and psyllids are small free living, sap sucking insects (rather like aphids), with 2 pairs of wings held roof-like over their head. They are not strong fliers, but they can jump, hence their nick-name 'jumping plant lice'. Adult psyllids are up to **10 mm** long.

Nymphs of **lerp insects** secrete a shell-like covering called a lerp beneath which they shelter and feed. The lerp has a characteristic **shape and colour** for each species; it is about **1-5 mm** across. Nymphs may be seen either through the covering or when it is removed. Unlike scales they remain fully mobile through all stages. Some argue that the lerp offers protection against predators and parasites while others say that it protects it against dehydration. The first sign of attack is the presence of lerp coverings on leaves. Nymphs of **psyllids** are free-living and do not form a lerp covering, but secrete **white waxy threads**. They feed on leaves and terminal shoots, causing distortion and dis-colouration. Sometimes their feeding causes exudation of sticky white sap which hides the insect.

Fig. 108. Lerp insects.
Left: Discoloured areas caused by lerp insects sucking plant sap. ***Right:*** Leaves with lerp coverings. Photos©NSW Dept of Industry and Investment.

Leaves. If attack is severe, masses of whitish lerps give trees a **silvery appearance**. Discarded lerp coverings fall from the tree. **Purplish patches** develop on **leaves** due to the sucking of nymphs and adults. The toxic saliva of some lerp insects causes leaf tissue to break down and brown. Trees look as if scorched by fire. If attack is severe, infested leaves may **fall** prematurely. Lerp insects produce **honeydew** which attracts ants and on which **sooty mould** grows, making trees and evergreen plants underneath appear black.

- **Cut foliage** of bluegum is downgraded by bluegum psyllid (*Ctenarytaina eucalypti*); seedlings are injured in commercial nurseries.
- **Saplings** of Dunn's white gum (*E. dunnii*) in plantations may be killed.
- **Single trees** are unlikely to die from attack.
- **Psyllids** tend to concentrate on the older less vigorous lower foliage of a tree.

General. Populations ebb and flow. Local outbreaks can slow tree growth and make trees more susceptible to attack by other insects, especially borers and termites. Lerps of some species were used by aborigines as food. Vigorously growing eucalypts can usually recover from one infestation when psyllid populations decline, but if infestations are sustained over consecutive seasons, trees may die.

Diagnostics.

- Silvery appearance of tree due to lerp coverings.
- The differing shapes and patterns of lerps are used to identify the species attacking a tree (Fig. 108 below).
- Do not confuse lerp covering with scale insects.
- Do not confuse damaged left by lerps (after lerp coverings have gone) with damage caused by other sapsucking insects, fungal leaf spots or environmental conditions.
- Psyllids secret waxy threads and may hide in blobs of plant sap, do not confuse with mealybugs.

Pest cycle

There is a **gradual metamorphosis** (egg, 5 nymphal stages and adult) with several generations each season. Adult **brown lace lerps** deposits their eggs on leaves. Eggs hatch into tiny flattened pink crawlers which wander over the leaf searching for stomata near a vein to insert its stylets and start feeding on plant sap. Once settled nymphs quickly secrete a lerp (made of starch derived from the plant sap), which is glued onto one side of the leaf. As nymphs grow the lerps are enlarged from one edge. After the winged adult has emerged and flown off, empty lerps remain on the leaf for some time. The life cycle may be completed in 1-2 months.

'Overwintering'

The main lerp stage appears to be from autumn through winter to spring. Adults appear in summer.

Spread

By adults flying within adjacent plantings but they cannot fly far. Re-infestation is slow.

Conditions favoring

- **Heavy infestations** do not usually occur until autumn, when summer leaf growth has replaced foliage defoliated by the previous infestation.
- **Outbreaks do not occur every year**. Not known why some species have population explosions.
- **High populations** collapse eventually either due to changes in **weather** or depletion of **suitable foliage** due to feeding damage and premature leaf fall. Once populations start to decline effect of **natural enemies** increases.
- **Stress** due to wind, frost, root damage, compacted soil, drought, waterlogging may make foliage more attractive to psyllids. Outbreaks may occur after a succession of unusually dry and/or wet conditions.
- **Prolonged** high temperatures are unfavourable.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Plan** in advance that fits your situation.
2. **Crop, region.** Recognize variations, eg urban tree plantings, plantation forests.
3. **Identification** of pest must be confirmed. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage early, especially new foliage, to prevent stress and/or death of susceptible young trees, record results. Check bird populations which prey on lerps to avoid unnecessary treatments.
5. **Threshold.** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic, environmental?
6. **Action.** Take appropriate action when a threshold is reached, eg improve tree vigour.
7. **Evaluation.** Review the program and assess its success, recommend improvements if required, eg replacing susceptible varieties in young plantings. Continue to monitor trees after treatment.

Control methods

Control is difficult. Practically there is not much you can do about large populations on tall trees. Small trees continually attacked may be better replaced with less susceptible species.

Cultural methods. Improve general vigour of trees. It is thought that the more nutritious the sap (quality and quantity of nitrogen compounds in the sap), the faster psyllid populations grow.

Biological control. No biological control agents are available for purchase or have been released in Australia. Natural controls exert some control if lerp densities are low. Ants attracted to honeydew deter insect predators/parasites.

- **Predators** feed on lerp insects but do not exert sufficient influence to keep attacks in check.
  - **Larvae** of syrphid flies and ladybirds, also lacewings and spiders.
  - **Birds**. Canopy-feeding birds such as pardalotes feed on the nymphs whereas bell miners feed on the lerp itself. Flying adults are captured by swallows and martens. Aggressive colony-forming **bell miners,** the honeyeater (*Manorinus melanophrys*), in the canopy of unhealthy Sydney blue gum (*Eucalyptus saligna*) has been well reported. Bell miners are thought to reduce the effectiveness of natural enemies by feeding directly on or interfering with their reproduction thus causing more damage. But it may be that when lerp and other insects are numerous on blue gums they damage trees severely, irrespective of the presence of bell miners.
- **Parasites**. Minute wasps parasitize nymphs under the lerp. The wasp larva develops within the nymph and eventually pupates into a distinct dark black pupa under the lerp. Holes in lerp coverings (exit holes) indicate **parasitism.** Bluegum psyllid in California is controlled by a parasitoid *Psyllaephagus pilosus* from Australia.

Resistant/Tolerant varieties. In lerp-prone areas of Australia resistant or tolerant species and provenances of eucalypts is the only viable long term strategy. Trees produced vegetatively or selections of seedlings from resistant parent trees may be used for planting, rather than seedlings from parents of unknown resistance. Establishment of seed orchards of resistant stock as a source of improved seed is a long term option.

- **Susceptible species** vary according to the region and include Swamp mahogany (*E. robusta*), Flooded gum (*E. grandis*), Mahogany gums (*E. botryoides, E. robusta*), River red gum (*E. camaldulensis*), Forest red gum (*E. terecornis*), Yellow box (*E. melliodora*), and Blakely's red gum (*E. blakelyi*).

Insecticides.

- **Young eucalypts during establishment** may be protected by insecticide/fertilizer in tablet formulation applied at planting.
- **Small trees < 3 m high.** As the protective lerp covering makes contact sprays ineffective, **systemic** insecticides may be applied at the first sign of infestation. **Wetting agents** improve effectiveness. Foliage applications may disrupt natural controls temporarily; also there is often rapid re-infestation during outbreaks.
- **Timing.** Only treat severe infestations. When damage is noticeable it is usually too late to take effective action. Apply insecticide when new foliage has developed and lerps seem to be increasing. One application per season may give effective control for 6-8 weeks or longer if isolated trees are treated (re-infestation is slow, adults do not fly far). **Insecticides** are **not** a long term solution.
- **Stem injection** is effective for large trees.

Table 29. Lerp insects – Some insecticides.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

What to use?	When and how to apply?
SMALL TREES (less than 3 metres)	
Foliage sprays, eg **Group 1B**, eg Rogor® (dimethoate) **Group 4A**, eg Confidor® (imidacloprid); Crown® (acetamiprid) **Soil treatments** eg **Group 4A**, eg Initiator® (imidacloprid/fertilizer)	• Foliage sprays, at first sign of infestation. Add a wetting agent. • **Initiator**® is for use in the establishment of young eucalypt plantations by providing enhanced growth and extended protection against damage by caused by various insect pests including psyllids.
LARGE TREES	
Foliage sprays, eg **Group 1B**, eg Rogor® (dimethoate) **Stem injection**, eg **Group 1B**, eg Rogor® (dimethoate)	• **Foliage sprays**. **Only councils and arborists have suitable equipment to spray large trees**. • **Stem injection**. A systemic insecticide is injected into the sap stream near the base of the tree and is carried to the upper crown which is then taken up by feeding psyllids. **Permits** may be required for stem injection.

Longtailed mealybug

Scientific name

Pseudococcus longispinus (Pseudococcidae, Order Hemiptera). This is a common and key pest in NSW, Victoria and WA. It is a minor pest in the NT. Other mealybugs include:

Citrus mealybug (*Planococcus citri*)
Citrophilous mealybug (*Pseudococcus calceolariae*)
Root mealybug (*Rhizoecus* spp.)
Hibiscus mealybug (*Maconellicoccus hirsutus*)
Grass-crown mealybug (*Antonina graminis*)
Tuber mealybug (*Pseudococcus affinis*), the **most important** root-feeding mealybug in Australia
See also page 144.

Closely related to scales but mealybugs remain mobile throughout their lives. Mealybugs are a major cause of plant damage in greenhouses.

Host range

Very wide host range. A **serious pest** of both indoor and outdoor plants in warm, humid climates, rarely attacks annuals but is an important pest of perennial plants. They attack roots, stems and leaves. Woody trees, shrubs and ferns are the most important plants infested.
Ornamentals, eg trees and shrubs, herbaceous plants, ferns, orchids, bulbs, African violets, cacti, indoor plants, ornamental grasses, eg *Papyrus*, a major greenhouse pest.
Fruit, eg citrus, custard apple, grapes.
Pastures, field crops, clovers.

Description & damage

Adult females are **3-5 mm** long, slow moving, oval, wingless, flattened with well developed legs. Their bodies are covered with wax glands which secrete a white **mealy wax** (hence the name mealybug), which forms short hair-like filaments at the sides of the body. The hind end bears a pair of wax filaments which are usually longer than the body and may be broken off. They have well developed legs and antennae and when disturbed or seeking fresh feeding sites, crawl slowly but freely. The length of the side filaments are about ½ the length of the body. **Adult males** are tiny, delicate winged insects with long waxy tail filaments, but are rarely seen. **Nymphs.** 1st stage nymphs (crawlers) are minute, pink and mobile. Later stage nymphs resemble adult females. Males resemble females, but later form cottony cocoons about **3 mm** long within which they develop. A colony can be almost completely enveloped in a woolly mass.

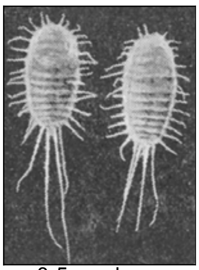
Above-ground damage. Mealybugs feed on stems and leaves by sucking sap and congregate in sheltered parts, eg sheaths, leaf bases, leaf under-surfaces, around buds, stems, lower parts of fronds, crowns, flowers, where 2 pieces of fruit touch. Infestations are often not noticed until numerous and unsightly.

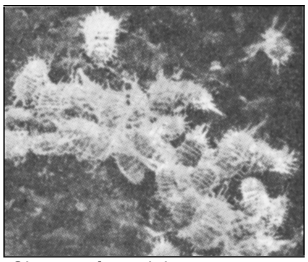
- **Sap feeding** distorts and yellows foliage.
- **Unchecked infestations** on soft-leaved plants, eg African violet, cause them to wilt and die.
- **Economic damage** on many plants is caused by the large quantities of **honeydew** produced; **sooty mould** develops on it, disfiguring leaves, stems and fruit. Large infestations make plants unsaleable.
- **Ants** are attracted to honeydew. **Coastal brown ants** (*Pheidole megacephala*) tend mealybugs for honeydew and move them around and fend off natural enemies.
- **Overseas** mealybugs have been recorded as transmitting virus diseases, eg citrus mealybugs possibly vector banana streak virus (**BSV**).

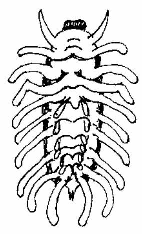
Below-ground damage. Other species may also feed on roots and this may not be noticed until the plant is repotted, wilts or dies.

Diagnostics.

- **Check roots** of wilted plants for mealybugs. Indoor plants often have large numbers of some species before their presence is noticed.
- **Do not confuse:**
  - Mealybug colonies with fungal growth.
  - Mealybugs with the **larvae** of mealybug ladybirds which feed on mealybugs. Ladybird larvae are about 3 times as long as mealybugs. They have long marginal filaments, are also covered with white mealy material, but they are **more active** and have **biting** mouthparts (Fig. 109 below).
- **Identification of species** depends on:
  - Length of anal filaments.
  - Colour of body fluid exuded from dorsal glands.
  - Presence of wax-free areas along the back.
  - Expert help is usually needed.
- **Longtailed mealybug** has tail filaments longer than its body. When squashed, body fluid is pale yellow and there is no wax-free area along the back. Eggs laid beneath the body hatch almost immediately. Do not confuse with:
  - **Citrophilous mealybug** with tail filaments about ⅓rd its body length, 4 dark longitudinal dorsal stripes. Body fluid dark red, eggs laid in cottony sac.
  - **Citrus mealybug** with tail filaments not more than ⅓rd body length, median dorsal stripe. Body fluid yellow-orange, eggs laid in cottony mass.



Longtailed mealybugs, 3-5 mm long.


Cluster of mealybugs.


Mealybug ladybird larvae 8-15 mm long.

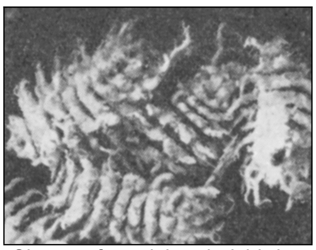

Cluster of mealybug ladybird larvae.

Fig. 109. Longtailed mealybug (*Pseudococcus longispinus*). Photos© NSW Dept of Industry and Investment.

Pest cycle

There is a **gradual metamorphosis** (eggs, nymphs (3-4 stages) and adults) with several overlapping generations per year in NSW and Vic and SA. Longtailed mealybugs produce about 200 young in 2-3 weeks. Eggs hatch as they are being laid. Eggs of other species, eg citrophilous and tuber mealybugs, are laid in a loose cottony mass, light yellow crawlers hatch 3-9 days later. Life cycle takes about 6 weeks in summer and about 12 weeks in winter.

'Overwintering'

- **Outdoors**, as eggs during cold weather.
- In **greenhouses** and warm climates the cycle is continuous.
- On **citrus** most longtailed mealybugs 'overwinter' as juveniles which reach adulthood by Aug-Sept.
- Mealybugs can 'overwinter' on **weeds** growing in paths, etc which can lead to rapid re-infestation.

Spread

- Mealybugs move around only short distances very slowly to find better feeding sites.
- Movement of infested plants into glasshouses, purchasing infested plants, taken to displays, etc.
- By wind and visiting insects.
- By ants, birds and on worker's clothing. Ants tunnel through soil and potting mix to move young root mealybugs from plant to plant (including weeds) quickly spreading these pests throughout a nursery.

Conditions favoring

- Warm, humid conditions, as in greenhouses, bathrooms.
- Sprays used to control other pests kill off ladybird and lacewing predators which usually suppress mealybug populations.
- Weakened plants, eg those grown in very dry situations or those held in pots for too long.
- Thickly-foliaged mature trees. Shade.
- Dusty trees.
- Ants attracted to honeydew discourage the predatory mealybug ladybirds (*Cryptolaemus*).
- Plants with a high nitrogen content.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation.
2. **Crop, region**. Obtain a program for longtailed mealybugs on your crop in your region.
3. **Identification** can be difficult. Consult a diagnostic service to avoid confusion with other species of mealybugs (page xiv).

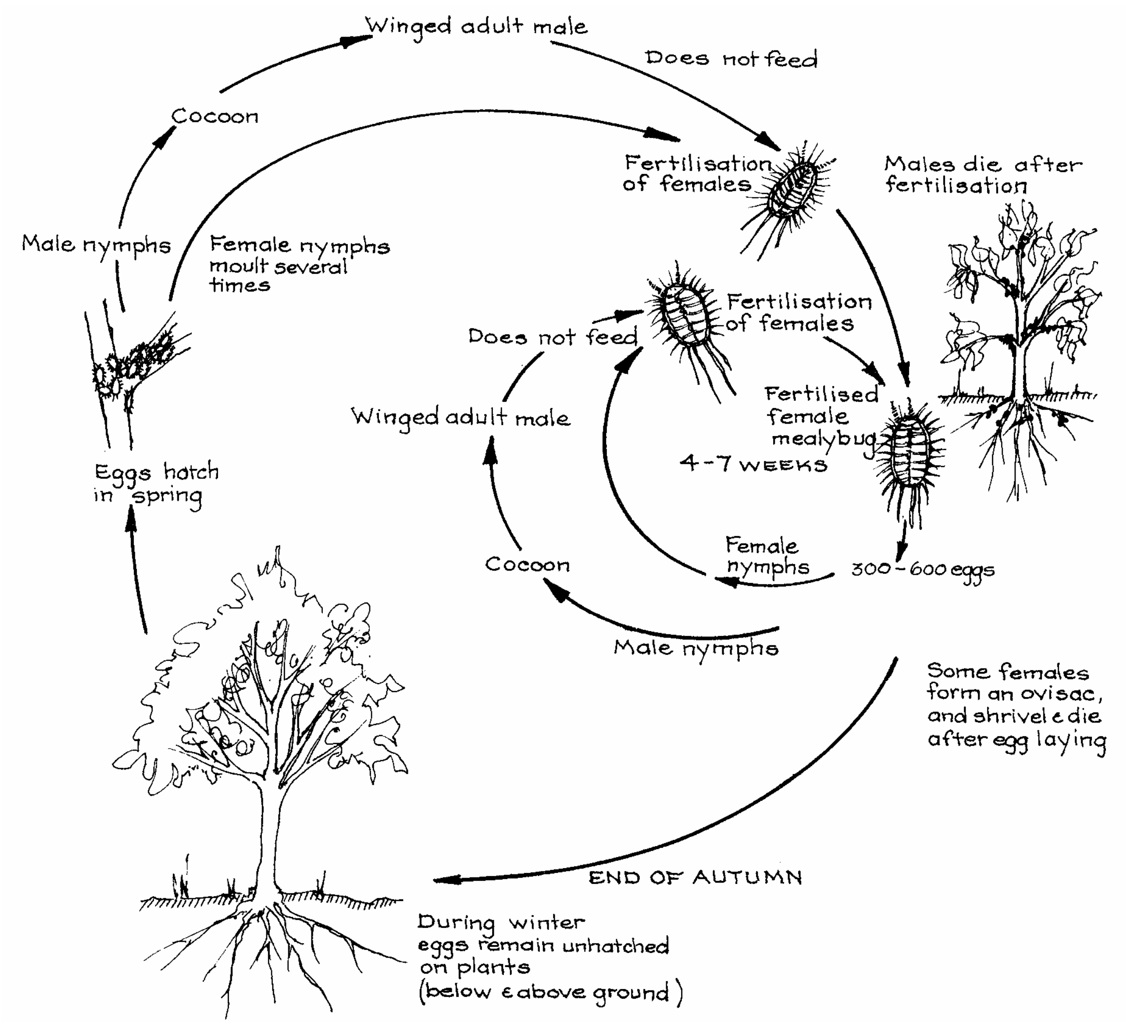


Fig. 110. Pest cycle of the longtailed mealybug (*Pseudococcus longispinus*).

4. **Monitor** for mealybugs when they are known to be active and record findings. Check roots of wilting plants, for the presence of mealybugs, sooty mould, honeydew, ants. Also monitor for biological control agents. If using an **IPM** program it will tell you **when and where** to look, **what and how** to monitor, eg adults, crawlers, main parasites and predators. Desire Sticky traps are available for citrophilous mealybug: http://insense.com.au/products.htm
5. **Thresholds** vary according to the crop and method of proposed control. Some pest scouts prefer to use a lower action level early in the season depending on the variety, populations of mealybugs and predators, and degree of parasitism. How much damage can you accept?
6. **Action**. Take appropriate action if threshold is reached.
7. **Evaluation.** Review your program and recommend improvements. Monitor trees and bins **after** treatment, compare results with the previous season.

Control methods

Cultural methods.

- **Adequate irrigation** helps reduce effects of infestation by replacing sap lost to sucking insects. Maintain plant vigour.
- **Cover crops** decrease temperatures, increase humidity in summer favouring natural controls.

Sanitation.

- **Discard** severely infested small plants of little value in greenhouses and houses.
- **Prune** off badly affected sections of plants.
- **Minor infestations** on house plants may be picked off and killed or removed by dabbing with a small brush or cotton bud dipped in methylated spirits. This is tedious and time-consuming, will not eradicate them and may break stems and foliage of soft-foliaged plants. Plants may be washed with or dipped upside down in warm soapy water and then rinsed in clear tepid water. Large plants may be sponged.
- **Sooty mould** in the navels of mature oranges is not easy to remove by washing before packing.
- **Throughly disinfest** recycled pots to avoid transferring eggs or nymphs from crop to crop.
- If root mealybugs, thoroughly disinfest nearby gravel including beneath plastic and weed mats.

Biological control.

- **Natural controls** are not always effective. Parasites and predators are discouraged by dust and ants (attracted by honeydew) and some pesticides.
  - **Predators** include lacewing larvae (*Chrysopa* sp., *Oligochrysa lutea*), mealybug ladybird.
  - **Parasites** include various wasp parasites, eg *Anagyrus*, *Leptomastix.*
  - **Root mealybugs** are underground and not so accessible to natural controls.
- **Commercially available**
  - **Main parasite** is the small wasp (*Leptomastix dactylopii*) which may be reared or purchased. Two parasites (*Coccophagus gumeyi* and *Tetracnemoides brevicornis*) have been released to suppress citrophilous mealybug.
  - **Main predator** is the mealybug ladybird (*Cryptolaemus montrouzieri*) which is black and red, 3.5 mm long, lays its yellow eggs singly in mealybug egg sacs or near clusters of mealybugs. Other ladybirds include *Rhyzobius ruficollis* and *Scymnus* spp. Larvae of the cecid fly (*Diadiplosis koebelei*) and lacewings (*Mallada* spp.) also feed on mealybugs.
  - List of suppliers www.goodbugs.org.au

Resistant/Tolerant varieties. Some plants are very susceptible, eg African violet, citrus, ferns.

Plant quarantine. Nurseries growing very susceptible species should quarantine and examine new stock brought in from external sources. Keeping mealybugs out of nurseries is preferable to controlling them once they are established.

Pest-tested planting material. Only propagate from and purchase mealybug-free stock. Examine all stock plants.

Insecticides. Mealybugs are difficult to control with insecticides because they feed in protected places, are covered with water-repellent wax and lay large numbers of eggs which develop quickly under ideal conditions **(see also page 170)**.

- Glasshouses may require regular treatments.
- Apply insecticides to crawlers - the arrival of ants indicate crawlers are about! Use a hand lens to identify them so you can initiate control measures.
- Control ants if present outdoors in spring.
- **Systemic** insecticides are generally more effective than contact ones.
- Apply high volume sprays to fully wet canopy, application must be thorough.
- If mealybugs are on **roots of plants in pots**, wet soil in pot thoroughly the night before treatment to lesson chance of root damage. Place pot in basin and allow insecticide solution to soak in. Use enough liquid to wet the complete root zone.

Table 30. Longtailed mealybug – Some insecticides.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

What to use?	When & how to apply?
HOUSE PLANTS Only use sprays labeled for **indoor** use.	• Take plants outside for treatment unless label advises otherwise. • Oils may injure many indoor plants, especially maiden hair ferns.
GLASSHOUSES **Seek advice**	• Regular treatments may be required. Outdoors avoid spraying mealybug-prone plants for other pests and diseases (this will kill any natural controls). Control ants. Consider spot spraying.
OUTDOORS Insecticides registered for mealybugs generally: **Group 1A**, eg Bugmaster® (carbaryl) **Group 1B**, eg Rogor® (dimethoate); maldison; Folimat® (omethoate) **Group 3A**, eg pyrethrins, Baythroid® (cyfluthrin); Procide®, various (bifenthrin) **Group 4A**, eg Confidor®, various (imidacloprid); Maxguard® (acetamiprid); Sumarai® (clothianidin) **Group 16**, eg Applaud® (buprofezine) **Spray oils**, eg certain petroleum, paraffinic and botanical oils **Soap sprays**, eg BugGuard®, Natrasoap® (potassium salts of fatty acids)	• **Only** after monitoring and if natural enemies cannot cope with infestation. • **Contact sprays** are only effective if mealybugs are actively moving over the plant. Adult mealybugs that have developed their waxy covering are difficult to kill with contact pesticides. Contact sprays are devastating to all beneficials. Contact sprays can be effective against crawlers. • **Systemic sprays** give good control of adult mealybugs that are feeding. Once they have stopped feeding it is too late to control them. Some systemic sprays are not so harmful to some beneficials. • **Spray oils** are only effective against young stages of mealybugs but are less harmful to beneficials than many insecticides. Loosens sooty mould. Oil sprays smother nymphs.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Fig. 111. Some soft scales (Family Coccidae)

(some other honeydew-producing scales are included)

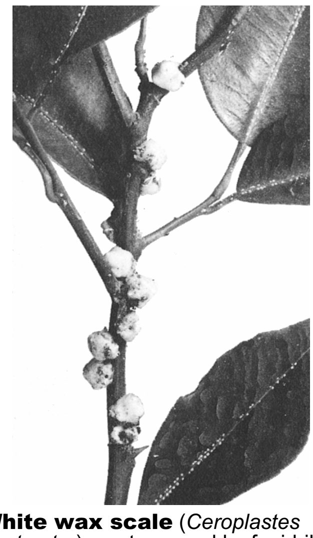
Wattle tick scale (*Cryptes baccatus*). Drops of honeydew. Photo©CIT, Canberra (P.W.Unger).

Gumtree scale (*Eriococcus coriaceus*). Small male scales and larger female scales. Photo©NSW Dept of Industry and Investment.

Black scale (*Saissetia oleae*) on stems. Photo©CIT, Canberra (P.W.Unger).

Frosted scale (*Eulecanium pruinosum*). Photo©NSW Dept of Industry and Investment.

Soft brown scale (*Coccus hesperidum*) on stems and leaf midribs. Photo©NSW Dept of Industry and Investment.



White wax scale (*Ceroplastes destructor*) on stems and leaf midribs. Photo©NSW Dept of Industry and Investment.

Cottonycushion scale (*Icerya purchasi*). Fluted egg sac. Photo©NSW Dept of Industry and Investment.

Black scale

An example of a soft scale (Family Coccidae)

Scientific name

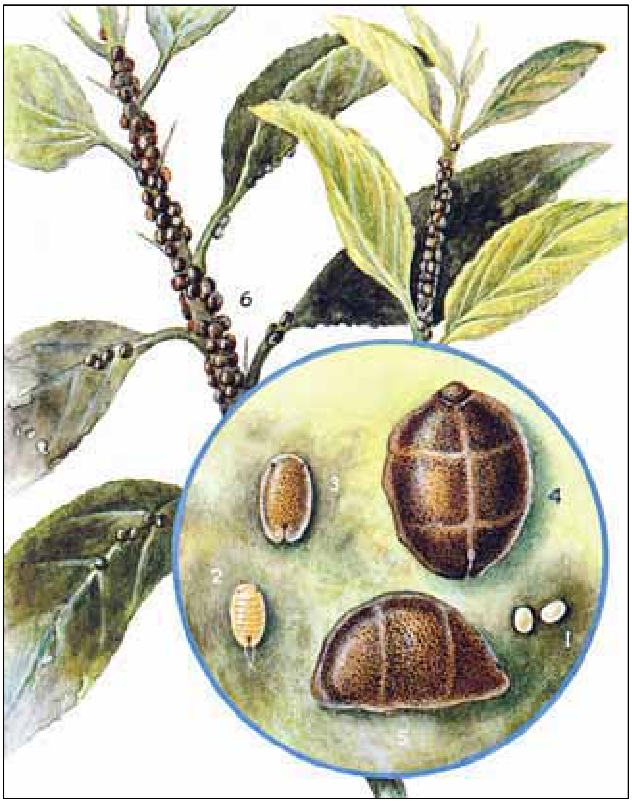
Saissetia oleae (Order Hemiptera), sometimes called brown olive scale. Widespread, common. Key pest in Qld, NSW, Vic, NT and WA. See page 144 for other soft scales.

Host range

Wide range of plants. Mostly woody plants, but occasionally found on succulent hosts, eg vines, geraniums, watermelon.
Ornamentals, eg gardenia, holly, house plants. hibiscus, oleander, poplar, tamarisk.
Fruit crops, eg especially citrus, also apricot, passionvine, olive, vines, apple, pear, plum.

Description & damage

Adult female scales are stationary and tend to cluster in small colonies on various parts of the plant. They are dark brown, bun-shaped, and about 3 mm long and 2 mm wide (Fig. 112). The surface is smooth but ridges on their back form a raised **'H' pattern**, particularly on young adult scales. Young adult females, before egg laying, are dark mottled grey, softer and less humped than later and are often called the **'rubber' stage**. Male scales are narrower, flat, tiny, winged and rarely seen.
Nymphs are initially light brown or pink and about 0.5 mm long. Newly hatched **'crawlers'** move around for 12-24 hours in search of food then settle permanently along veins of young leaves. Older stages look like adult females but are paler.



Honeydew, sooty mould and ants... Plant damage caused by nymphs and adults sucking plant sap is often not great. It is the production of copious amounts of honeydew by the young scales with the resultant growth of sooty mould which causes the greatest problem. **Ants** are attracted to honeydew especially when eggs hatch into crawlers. Ants feed on the honeydew protecting the scales from natural enemies and help spread the crawlers from plant to plant.

Leaves, twigs and stems. Although all stages are found on branches, twigs, stems, stalks, leaf midribs and young fruit, twigs and stems are preferred. Soft scales feeding on young tissue can produce distorted foliage and yellowing of foliage. Heavy infestation can cause twigs and branches to die back. Leaves drop if infestation is heavy.

Fruit. Citrus fruit are greenish where scales were attached, and if covered with scales or sooty mould, are **difficult to clean** before packing, especially if skin is rough, eg mandarins.

General. Extensive sooty mould can reduce photosynthesis and tree vigour. Soft scales can be major economic pests, eg grapevine scale, (*Parthenolecanium persicae*) on grapevines, but not all scales are economic pests (Buchan 2008).

Diagnostics.

- **Soft scale are so named** because most species have bodies that are exposed and 'soft' but in many cases, mature females are not the least bit soft, upon maturing their skin becomes hardened serving as a shell for eggs shell for the eggs and young.
- **Adult females** are generally large, obvious and are easy to recognize on stems. They are dome-shaped and about the size of a match head. The tiny eggs laid **under the female** look like piles of very find sand. Black scale may be confused in the juvenile stages with citricola, hemispherical and soft brown scales. After the 2nd moult black scale can be recognized by the characteristic 'H' pattern on its back.
- **Scale covers** or ovisacs may remain on twigs long after scales have died. Squash the scale between the fingers to see if it is alive, if alive your fingers will be wet from the juice squeezed out, if dead you fingers will be dry and dusty.
- Increased **ant activity**, eg aggressive meat ants (*Iridomyrmex* spp.) protect scales and other honeydew producing insects.
- Soft scale produce large amounts of **honeydew** one sure sign is the presence of honeydew so if you see that or **sooty mould** look for a culprit.
- Lucid Keys www.lucidcentral.com/ and search for: *Scale Insects: Identification Tools for Species of Quarantine Significance*

Fig. 112. Black scale (*Saissetia oleae*).
Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged x24
1. Eggs
2. 1st stage female or "crawler"

Enlarged x12
3. 2nd stage female
4. Adult female (top view)
5. Adult female (side view

Actual size
6. Scales and sooty on citrus shoots, leaves

Pest cycle

There is a **gradual metamorphosis** (egg, nymphs and adults) with 2 overlapping generations per year in southern Australia and 3-4 in northern Australia (page 55). In southern areas the main hatchings are usually in spring and autumn. The life cycle takes 4-8 months in southern districts but less in warmer areas, eg Qld. Each female may lay up to **2,000 eggs** which appear like little heaps of sand beneath the parent scale. The young nymphs, after hatching remain beneath the parent scale for 1-2 days, and then crawl actively **(crawlers)** about before settling usually **along the veins on leaves** or on **young shoots**. After eggs have hatched, the body of the female scale seems to shrink and eventually falls off. After 4-6 weeks the young scale moults and migrates to the **stem** of the plant, where it remains for the rest of its life. After another 4-6 weeks moulting again occurs and the insect reaches the 'rubber' or early adult stage, when the **'H'** formation on its back becomes obvious. The period from settling to the start of the next hatch of eggs is 3-4 months. The autumn hatched eggs may mature on the **leaves**. Other species of soft scales have only one generation of crawlers each year, while others have several.

'Overwintering'

On the host plant in cooler areas as adults.

Spread

- Because of their small size and habit of feeding in concealed areas, scales are commonly spread on infested plants (cuttings, nursery stock, etc).
- By nymphs crawling from plant to plant if plants touch. Crawlers also move from plant to plant by wind dispersal and on clothing and equipment.
- By ants and other insects, by birds.

Conditions favoring

- Temperate climates with moderate temperatures and high humidities.
- High temperatures (44°C and above) and dry conditions kill nearly all eggs and crawlers beneath parent scales. Settled crawlers are not so susceptible.
- Dense unpruned portions of trees.
- Vigorous citrus trees are more likely to suffer infestation. Not usually a problem of olive trees in good health but in some regions it seems to attack trees of all health levels.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region.** Recognize variations, eg is black scale really a problem. Host?
3. **Identification** must be confirmed. If in doubt consult a diagnostic service (page xiv) as it is essential to be able to distinguish:
   - The **crawler** and **adult stage**.
   - **When** they are likely to occur, are there 2, 4 or 6 generations each year?
   - **Where each stage will occur during the year**, spring crawlers will settle on stems and twigs while autumn crawlers may settle on leaves.
4. **Monitor** scales, crawlers and their predators and parasites, honeydew, sooty mould and ants on fruit, trunks, branches or leaves using a x 10 hand lens at regular intervals. Ant presence increases when crawlers are around. Record your findings:
   - **Stock plants** can be a source of scales. Check mature scales for eggs underneath and check if any adult scales are still alive.
   - **Check and monitor for signs of beneficials**, eg predators and parasites, holes in scale covering.
   - **Ants, sooty mould and honeydew** on leaves, stems and fruit especially if conditions are humid.
   - **On citrus and other evergreen trees**, depending on your situation, check for **crawlers** and **natural enemies** once in Nov-Dec and again in Feb-March (Brough et al 1994). Check for presence or absence of **adult female scales** on 5 randomly selected green twigs (with 5-10 leaves) per tree. If trees are tall, take 10% of samples from the tops of trees.
5. **Thresholds** vary according to the crop, eg
   - **Citrus**. The threshold may be 10% or more of green twigs infested with one or more scales, while for mandarins the threshold may be 5%.
   - **Otherwise** seek advice or determine your own threshold depending on how much damage you can tolerate economically or aesthetically.
6. **Action**. Take appropriate action when any threshold is reached, eg sanitation, parasites and predators, insecticides and controlling ants, if active, at tree base.
7. **Evaluation.** Review **your** program to see how well it worked, recommend improvements if required. Monitor trees for scale **after** treatment.

Control methods

Difficult to control because mature scales are resistant to pesticides and correct timing is necessary to target crawlers.

Cultural methods.

- Maintain trees in good health but do not encourage excessive vigour.
- Provide wind shelter to limit spread of crawlers.
- Pruning to provide open airy trees discourages black scale infestation. Heavily infested plants should be fertilized to restore vigour.
- Harvest fruit at the correct time.

Sanitation.

- Discard heavily infested house or stock plants.
- Prune out or hand pick isolated infestations on a few plants or wash with soap using a soft brush to remove scales and sooty mould. Some scales are easier to remove than others.

Biological control.

Many natural enemies when not undermined by the indiscriminate use of sprays. Most common biocontrols are parasitic wasps and ladybeetles.

- **Natural controls**. Weather, parasites, predators and diseases in some plantings can exert some control. However, **ants** in large numbers can deter parasitic wasps. Very hot weather can kill many crawlers.
  - **Parasites**. Several wasps parasitize adult black scales. Some species of wasp will target a specific species of scale but some attack a range of scales.
    - ❑ **Introduced wasps** (*Aphytis spp.*, (common) *Aspidiotiphagus* sp., *Comperiella bifasciata*, *Encarsia perniciosi*, *Metaphycus* sp., *Scutellista* sp.
    - ❑ **Native wasps** (*Rhopalencyrtoidea dubia, Aenasoidea varia*).
    - ❑ **Wasps deposit eggs** on or under scales, and larvae feed on the scale. Parasitized scales are dark and there is an obvious **exit hole**.
    - ❑ **Wasp parasites** together with **proper pruning** may provide sufficient control in some areas. In other regions biological control may be ineffective.
    - ❑ **Baker, G and Hardy, J. 2005** ***Survey Black Scale Parasitoids in South Australian Olives*****. Sardi, SA**.
  - **Predators**
    - ❑ **Ladybirds** and larvae scatter scale eggs and kill adults, eg mealybug ladybird (*Cryptolaemus montrouzieri*), ladybirds (*Orcus australasiae, O. chalybeus*), *Diomus* spp. and steelblue ladybird (*Halmus chalybeus*). Also gumtree scale ladybird (*Rhyzobius ventralis*), black ladybird (*R. forestieri*), and scale-eating ladybird (*R. lophanthae*).

- **Lacewings** (Order Neuroptera), various species feed on black scales.
- **Scale-eating caterpillar** (*Catablemma dubia*) use remnant scale coverings to 'ornament' their grey parchment-like cocoons.
- **Wasps. Larvae** of some parasitic wasps prey on eggs of black and other soft scales. **Adult** wasps also kill scales by sucking their juice.

– **Fungal diseases**. Several species, eg *Nectria* spp., a red-headed fungus (*Fusarium coccophilum*) and a felt fungus (*Septobasidium* sp.) may attack scales in warm moist autumns and cover scale-infested branches with a white fungal growth.

- **Commercially available**.
  - **Some predators** may be purchased, eg mealybug ladybird.
  - **Parasitic wasps** (*Metaphycus* spp.) for the control of black scale and soft brown scale on citrus, olives and ornamentals are being researched.
  - List of suppliers www.goodbugs.org.au/

Resistant varieties.
Black scale has a wide host range but not all varieties of a particular species are susceptible, eg although all citrus varieties are **susceptible** to red scale, lemons are preferred.

Plant quarantine.
- **Avoid introducing** infested stock, buds, grafts, or cuttings into the property or into the greenhouse. Inspect new arrivals.
- **Lucid Keys** www.lucidcentral.com/ and search for: *Scale Insects: Identification Tools for Species of Quarantine Significance*

Pest-tested planting material.
Only plant scale-free nursery stock.

Physical & mechanical methods.
Ants attracted to honeydew produced by soft scales can be controlled by applying thick sticky bands, insecticide sprays or baits around the base of trunks, to trap or kill the ants. Skirt pruning and good weed control prevents ants accessing trees.

Insecticides.
- **Avoid indiscriminate use** of persistent broad spectrum insecticides which kill natural enemies.
- **Timing.** Spray when **crawlers** can be seen on leaves and twigs and no liquid exudes when old scales are squashed. Later stages have a protective waxy layer which makes them resistant to insecticides and spray oils.
- **Spray oils** control scales by suffocating the insect. Plants must be thoroughly sprayed. Oil will **not** kill eggs that are under the adult scales.
  - **Evergreen trees**, eg citrus, may be sprayed with petroleum oil in summer.
  - **Deciduous trees** (< 3 m high) may be sprayed with petroleum oil when trees are **bare in winter**.
  - **Oil sprays** also loosen sooty mould.
  - **Caution when using oils**.
    - If oil is absorbed into the plant, injury will result. Oils vary in their ability to cause plant injury, the lower the viscosity of the oil the less likely it is to injure plants.
    - Do not spray on days when shade temp is likely to exceed 35°C and/or soil is dry.
    - Ensure that the oil-water mixture in the spray is well agitated to prevent separation.
    - Oils are available in varying degrees of refinement.
    - If applied at the right time and with good coverage oil sprays will kill scale without injuring beneficial insects or the host.
- **Contact chemicals** are only effective against **crawlers**. Adult scales with their waxy coverings are difficult to kill with contact pesticides. Contact sprays are devastating to all beneficials.
- **Systemic chemicals** should give good control of adult scales that are actively feeding. Once the scale has stopped feeding it is too late to control it. Systemics are absorbed by the plants so beneficials are less exposed to them.
- **Ants** repel parasites and predators of black scale and spread scale around the property. Increased ant activity serves as a good guide to presence of crawlers of black and other soft scales.

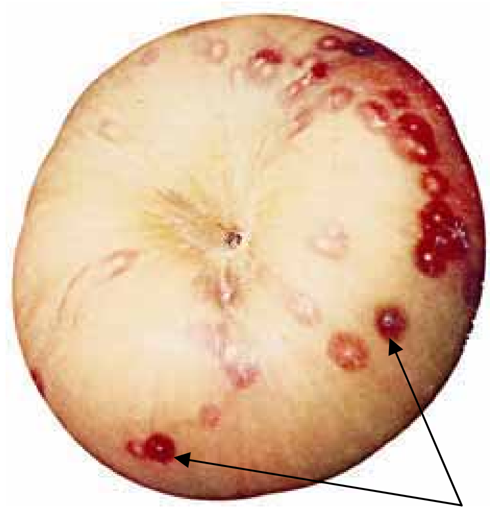
CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 31. Soft scales – Some insecticides.

What to use?	When & how to apply?
DECIDUOUS SHRUBS AND TREES, eg ash **Spray oils**, eg Pest Oil® (**petroleum oil**), Bioclear®, EcoPest® Oil, SK-Enspray99® (**paraffinic oil**)	• Dormant oil applications are the preferred spray for scales on deciduous plants. One spray is usually enough. They have few or no harmful effects on parasites and predators but require substantial amount of oil for control and there are no crawlers at that time. Oil sprays smother the scales, but do not kill the eggs under the adult scale. Apply after pruning where appropriate.
EVERGREEN PLANTS, eg oleander, citrus **Foliage sprays** **Group 1B**, eg various products **Group 3A**, eg pyrethrin **Group 4A**, eg Confidor® (imidacloprid) **Group 7C**, eg Admiral® IGR (pyriproxyfen) **Sprays oils**, eg D-C-Tron Plus, Pest oil®, Summer oil, White oil (**petroleum oil**); Bioclear l®, BioPest l®, EcoPest l® Oil, various (**paraffinic oil**); Eco-Oil® (**botanical oil**) **Soap sprays** were the original control for scales on the citrus tree growing at the back door of old homesteads **Soil-applied insecticides** **Group 4A**, eg Iniator® (imidacloprid/fertilizer) – protects **young** eucalypts from insect pests including **gumtree scale**. Confidor® Guard soil insecticide (imidacloprid) is registered for **pink wax scale** on **citrus**	• Do not neglect small infestations. Apply sprays at the **crawler stage**, later stages are resistant to insecticides. • Two sprays during each crawler stage are necessary because pesticides do not kill the eggs, the 2nd spray, therefore, kills crawlers developing from the eggs still unhatched at the time of the 1st spray. A 2nd crawler stage may be present sometime in autumn. • The main crawler stage is usually about mid-December to mid-January but timing will depend on observation of the stages present and increased ant activity. • Ensure appropriate spray volumes are applied to thoroughly drench trees. • Apply after badly infested areas have been pruned out, some scales can be washed off.
STEM INJECTION – LARGE TREES Various systemic chemicals are available to kill scale and other sap sucking insects, but they are difficult to control.	• Seek professional advice. **Permits** may be required for stem injection use.

Fig. 113. Some armoured scales (Family Diaspididae)



San Jose scale (*Quadraspidiotus perniciosus*) on apple. Pinkish discolouration around each tiny scale. Photo©CIT, Canberra (P.W.Unger).

San Jose scale (*Quadraspidiotus perniciosus*) on trunk of a flowering cherry tree. Scales are tiny and look like specks of dust. Photo©CIT, Canberra (P.W.Unger)

Red scale (*Aonidiella aurantii*) on citrus fruit. Photo©CIT, Canberra (P.W.Unger).

Armoured scale on Russian olive (*Eleagnus* sp.). Photo©CIT, Canberra (P.W.Unger).

Armoured scales on citrus twigs. ***Left:*** Red scale (*Aonidiella aurantii*). ***Right:*** White louse scale (*Unaspis citri*). Photo©NSW Dept of Industry and Investment.

Rose scale (*Aulacaspis rosae*) on rose canes. ***Left:*** Small rectangular male scales. ***Right:*** Round female scales. Photo©CIT, Canberra (P.W.Unger).

San Jose scale

An example of an armoured scale (Family Diaspididae)

A major pest of deciduous fruit trees throughout the world. Minor pest in SE Qld, Vic and WA.

Scientific name

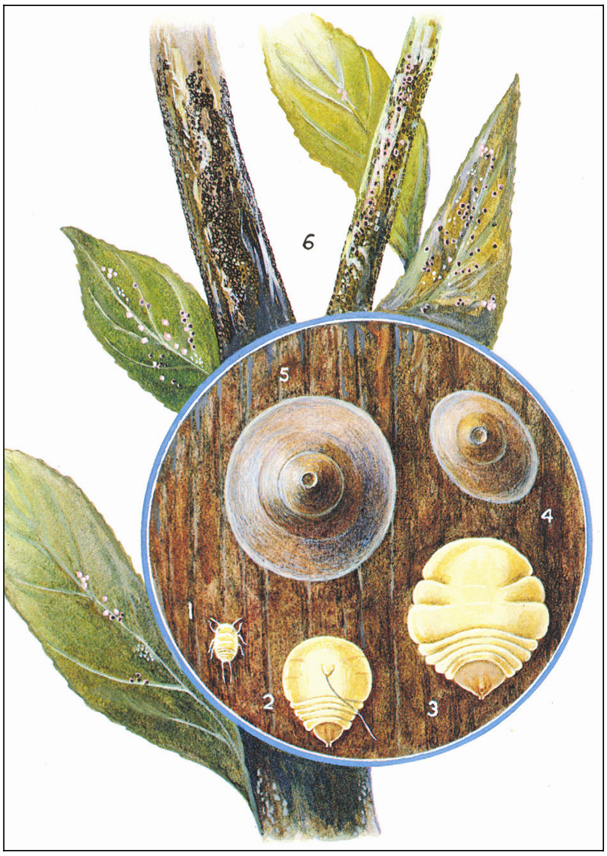
Quadraspidiotus perniciosus (Order Hemiptera), an armoured scale, sometimes called a hard scale).

Host range

Wide range of deciduous fruits and trees and shrubs, other plants, including:
Fruit, eg especially pome fruit, eg apple, pear, quince, and stone fruit, eg almond, apricot, cherry, peach, plum. Not usually citrus.
Ornamentals, eg the flowering species of pome and stone fruits, also many introduced trees and shrubs, eg hawthorn, willow.
Other crops, eg hedges of tree lucerne may become seriously infested.

Description & damage

Adult females are yellow, about the size of a pin head, soft bodied and concealed by a roughly circular **2 mm** diameter grey-brown scale covering. The **male** scale covering is smaller and oval in shape with a raised dot near the larger end of the scale. The adult male emerges from the scale covering as a minute, winged insect. Scales can overlap. **Nymphs** (crawlers) are active, 6-legged and yellow. These settle near the adult, insert their long tube-like mouthparts into the sap, lose their legs and begin secreting their scale covering.



Twigs, limbs and trunks. This scale is found principally on the trunk, branches and twigs of deciduous trees. Small circular gray scales can be seen on the base of young shoots, originating from main branches. Nymphs and adults damage plants by sucking sap mainly through the bark and injecting a substance toxic to the plant.

- **Poor growth**, dead or rough, cracked twigs
- **Infested plants** may suffer water stress.
- **Young trees** can be quickly killed by heavy populations of scales on the trunk and limbs.
- **Limbs and twigs** heavily infested with scale may die during the growing season, especially in autumn. The following spring, shoots develop below dead branches; the framework of young trees may be seriously affected.
- **Little or no honeydew** is produced.
- **Bark** is rough, pink or ashy due to the masses of tiny difficult-to-see scale coverings. The purplish colour is similar to the colour of the bark. Pink or red spots about **1 mm** in diameter surrounded by a white halo develop around each gray scale.
- **Gum droplets** occur on branches of stone fruit.

Fruit, especially apples and pears, develop characteristic pink or red spots about **1 mm** in diameter surrounded by a white halo. One tiny scale is in the center of each reddish spot. Other scale insects may produce the same reaction. Cherry fruit are infested mostly at the calyx end.

Leaves may also be infested, usually with male scales. Look for look for yellowish areas on leaves where scale have settled, leaves which fall and twigs and stems dying.

General. Small populations cause debilitation and aesthetic value. Once established it usually increases very rapidly and may seriously injure or kill the tree over a period of several years

Examine closely the photographs on the previous page to appreciate how **tiny** the scales are, they are easily overlooked on twigs and branches

Fig. 114. San Jose scale
(*Quadraspidiotus perniciosus*).
Photo© NSW Dept of Industry and Investment (E.H.Zeck).

All enlarged x35
1. Ist-stage nymph (or crawler)
2. 2nd-stage nymph
3. Adult female
4. Scale covering of male
5. Scale covering of female

Actual size
6. Scale on twigs and leaves

Diagnostics. Look at twigs for encrusted scales. Although the scale is visible throughout the year, it is most readily detected in winter on deciduous hosts when trees are bare of foliage and on fruits during harvest.

- **Low populations of scale are hard to detect and can become major infestations before they are noticed**.
- Honeydew is not produced.
- Dying branches in autumn.
- Limbs and trunk covered with 'dust' (scales). Hand lens is needed to confirm identification. May be necessary to consult a diagnostic service.
- Determine whether scales are **dead or alive**. Lift the hard grey scale cover with a pin or finger nail and examine the insect body underneath. Dead scale insects will be dry and shrivelled while live scales will be soft and fluid-filled.

Pest cycle

There is a **gradual metamorphosis** (egg, nymphs and adult) with several generations each year. In spring, the 2nd stage nymphs ('black caps') begin to grow and are usually fully grown by the time the trees come into bloom. The females when mature produce active 6-legged young (crawlers) which make their way from under the parent scale, move about for a while, then settle down near the adult to feed by inserting their long tube-like mouth into the sap; they lose their legs and begin secreting their protective scale covering. They remain fixed in this one place for life. Male nymphs develop a pair of wings and emerge. The period from birth until young are again produced is about 6 weeks, as 1 female can produce as many as 400 live young, the increase in numbers of scale insects in one season is obviously tremendous! Large populations can build up in one season, covering all the bark on the tree.

'Overwintering'

In colder districts, as 2nd stage nymphs, often called 'black caps'. In warmer areas, all stages may be found.

Spread

- Movement of infested nursery stock is the **main** method of spread.
- Nymphs may be blown by wind.
- Nymphs may also be accidentally carried by birds, insects and humans, and on boxes, bags, fruit and other materials.

Conditions favoring

Relatively warm, dry climates but will tolerate humid or cold conditions.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. Follow any control measures prescribed by legislation. San Jose scale often develops to damaging proportions before growers become aware of its presence.
2. **Crop, region**. Recognize variations.
3. **Identification**. If in doubt consult a diagnostic service (page xiv). Scales are obvious on fruit and leaves. Scales on limbs are easily seen with a hand lens during winter.
4. **Monitor** scales and damage, **tag** infested trees.
   - Know when crawlers should be around.
   - Use a hand lens to see crawlers. Check for holes in armoured scales which indicate parasites active; check during monitoring if the scales are still alive.
   - **Examine bark of trees** during winter pruning, dormancy, fruiting and after harvest, for cracked, rough, scaly bark, dead twigs. Check prunings to make sure that scale has not developed in tree tops. **Suspect** trees should be checked thoroughly for **live** scales. Check trees downwind of infested trees.
   - **Monitor trees for crawlers** using double-sided sticky tape in spring if inadequate control is achieved with dormant sprays.
   - **Traps** are available to monitor male scale flights in spring. Desire sticky and InSense Lure traps available for San Jose, red scale and citrus red scale: http://insense.com.au/products.htm
   - **Monitor scale populations on fruit** during harvest and grading. **Tag infested trees** and record which blocks are infested.
   - **Keep records** of all infested trees (page 39).
5. **Threshold** may be **nil tolerance** for export grade fruit and if any scales are found control is prescribed by law. How much damage can you accept?
6. **Action/control** for some markets is compulsory by law. Trees can be thoroughly sprayed with an appropriate registered chemical. The aim should be to eradicate San Jose scale from every tree in the orchard. In practice this is rarely achieved. All infestations should be controlled **immediately**. Winter oil is the preferred treatment on deciduous hosts. Due to potential damage from the pest on apples annual dormant sprays are recommended in some areas. Occasionally inadequate control is achieved with dormant sprays.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required. Approximately 6-12 weeks after the initial oil spray during dormancy on deciduous hosts, examine scales by removing scale covers and confirming that they are dead. If any live scales are found consider a spray with other insecticides. Repeat this procedure until no live scales are found. Record results.

Control methods

This scale is difficult to control. It is a **'proclaimed pest'** in some areas and its control is **required by law**. Scale should be eradicated from every tree in an orchard.

Sanitation.

- Remove dead or dying infested branches.
- Reduce movement of staff through infested areas; crawlers may be carried on clothes and equipment.

Biological control.

- **Natural controls** are present but appear to have little or no economic effect. Most common biocontrols are parasitic wasps and ladybeetles.
  - **Diseases**, eg red-headed fungi (*Fusarium* spp.).
  - **Predators,** eg native ladybird (*Rhizobius lindi*), lacewing larvae, moth caterpillar (*Batrachedra* sp.), predatory green and brown lacewings, predatory beetles and mites, scale-eating caterpillars.
  - **Parasitic wasps (on scales).** Avoid long-lasting sprays which might have residual effects.

Wasp depositing an egg in a scale insect

- **Commercially available.** Green lacewing (*Mallada* sp.) larvae feed on crawlers. A wasp (*Aphytis melinus*) can be purchased for red scale control. List of suppliers www.**goodbugs**.org.au

Plant quarantine.

- **AQIS**. Presence of San Jose scale on fruit will result in its rejection as export grade fruit to European countries.
- **Lucid keys** - www.**lucidcentral**.com/ *Scale insects: Identification Tools for Species in Quarantine*.
- **State/Regional quarantine**. San Jose scale does not occur in SA.
- **Local quarantine**. Avoid introducing infested plant material (stock, buds, grafts or cuttings) into a property.

Pest-tested planting material.

- Maintain scale-free stock plants.
- Do not propagate from infested plants. Careful inspection of propagation wood is essential, if in doubt, discard it! It can be difficult to disinfest propagation wood from this pest.
- Carefully examine young trees when received from the nursery and, if infested, dipped in a suitable oil emulsion (excluding the roots) and then drain, tops downwards in the shade before planting out in the orchard. This can delay appearance of scale in an orchard for years.

Insecticides. Because scales can be found under rough bark, behind buds and within cracks of the bark, it is essential to spray thoroughly right to the base of the trunk.

- **If any scales are found**, spray thoroughly with a registered chemical at bud movement.
- **Winter oil** is the preferred treatment. Oil sprays smother scale insects but eggs are **not** killed.
- **Spray oils** can also be applied at the susceptible crawler stage. To determine when crawlers are hatching set traps of double-sided sticky tape. Tightly encircle infested twigs or branches with the tape, examine it with a hand lens to identify crawlers. Crawlers will appear as yellow or orange specks. Check tapes weekly.
- **Do not apply spray oils** during fog or rain or during hot weather (above 34°C). Some plants are prone to damage from spray oils.
- **Avoid indiscriminate** use of broad spectrum sprays that kill natural enemies and have long lasting residual effects.
- **Treat isolated infestations** by spot spraying, pruning or hand-picking to remove scales.

- **Resistance.** Reliance on just one chemical will hasten the development of insecticide resistance in scale populations. Follow **Croplife Australia Resistance Management Strategies**.
- **Try to control the crawlers** which have not yet produced their protective waxy covering. Control of scale is difficult because of the **'timing window'** that allows the grower only limited periods in which to apply control measures. Armoured scales resist their actions well.
- **Eradication, pruning and discarding** seem to be the best methods of controlling armoured scale.

> **Contact sprays** are only effective on scale crawlers and mealybugs that are actively moving over the plant. Adult scales and mealybugs that have developed their waxy covering are difficult to kill with contact pesticides. **Systemics** give good control of adult scales and mealybugs that are feeding. Once the pest has stopped feeding it is too late to control it.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 32. Armoured scales – Some insecticides.

What to use?	When & how to apply?
DECIDUOUS TREES	
Light infestation **Group M2** (fungicide), eg Lime Sulphur (polysulphides) **Spray oils**, eg Winter Oils, Dormant Oils (**petroleum oils**); White oil, Pest Oil (**petroleum oil**); Bioclear®, EcoPest® Oil (**paraffinic oil**)	• Apply 1 spray in mid-winter. If infestation is light on deciduous ornamentals usually one application of the winter spray is usually sufficient. • Apply spray oil before budbreak. • High volume sprays have traditionally been used to thoroughly wet the trunk and branches (the whole tree above ground level). • Do not use 2 full strength oil sprays in 1 season.
Well established infestations and especially on mature and rough-barked trees, one example: **1st spray** Winter oil (**petroleum oil**) during dormancy. **2nd spray** The insecticide selected will depend on the need to control other pests, eg mites, caterpillars. **3rd spray** Only if winter sprays have been missed; the insecticide selected will also depend on the need to control other pests, eg mites, caterpillars.	Only apply after **monitoring** has indicated that the infestation **is** well established. • Apply 1 spray in mid-winter. • During the **growing season**, on fruiting varieties, sprays are best applied **after** harvest is complete.
EVERGREEN TREES **Group 1B**, eg various products **Group 7B**, eg Insegar® (fenoxycarb) - **suppression only**. **Group 4A**, eg Confidor® Guard soil insecticide (imidacloprid) is registered for **red scale** on **citrus**	• Seek advice on what and when to apply as some are more toxic to mite predators than others, also some may cause fruit damage. • If infested trees have cracked bark it is very difficult to locate the scales or contact them with sprays.

Greenhouse whitefly (GHWF)

Scientific name

There are about 20 species of whiteflies in Australia including the greenhouse whitefly (*Trialeurodes vaporariorum*, Aleyrodidae, Order Hemiptera), also:

Ash whitefly **(AWF)** (*Siphoninus phillyreae*)
Eastern Australian native whitefly (*Bemisia tabaci* Aus) (**EANW**)
Tobacco whitefly **(TWF)** (*Bemesia tabaci*)
Silverleaf whitefly **(SLWF)** (*Bemesia tabaci* B-Biotype). Recently *Bemesia tabaci* Q-Biotype) has been found in Australia which cannot be differentiated visually from the Q-Biotype.
Spiralling whitefly **(SPWF)** (*Aleurodicus dispersus*)

AWF and **SPWF** are serious pests of plants in Australia.
www.ipm.ucdavis.edu/PMG/**PESTNOTES**/pn7401.html

Host range

GHWF and **SLWF** have a broad and overlapping host range of over 600 plant species. It is not unusual to find both insects on the same property or even on the same crop.

- **GHWF** is a serious, persistent pest of broadleaved plants in greenhouses and outdoors, eg **ornamentals,** eg boronia, fuchsia, hibiscus; **fruit,** eg citrus; **vegetables,** eg beans, cucurbits, potatoes, tomatoes; **weeds,** eg sow thistle.
- **SLWF** - many species, field crops, eg beans, carrots.
- **AWF** - trees and shrubs, pome and stone fruit, citrus.
- **SPWF** - fruits, vegetables, ornamentals, weeds.

Description & damage

Adults are small, delicate, moth-like, **1-2 mm** long with 2 pairs of white powdery wings which are folded when at rest (Fig.116). Wings held flat and roof-like over body. Adults are gregarious, do not fly readily and usually remain on the under-surfaces of young leaves uppermost on the host plant. Males usually live for about 1 month and females for 1-3 months. Adults fold their wings in a triangle. **Eggs** are inserted vertically into the leaf undersurface often in circles and are small, bullet shaped and yellowish when laid and grayish purple when mature. **Nymphs** are whitish to greenish yellow, flattened and oval (scale-like) with fine waxy marginal filaments (Fig. 115). Nymphs are **0.3-0.75 mm** long depending on nymphal stage. **Pupae** have a few long hairs and a fringe of very short hairs around upper edge.

Leaves. Nymphs and adults suck sap from new shoots and leaf undersurfaces of **soft-foliaged** plants. If an infested plant is disturbed, adults may rise in the air, flutter about the plant but resettle quickly. Leaves develop a sandy mottle. Nymphs and adults secrete **honeydew** on which sooty mould grows disfiguring plants and preventing photosynthesis. Parasitized nymphs are **black** and commonly found on infested plants.

Heavily infested seedlings may die.

Fruit. Sooty mould may make fruit so dingy that it has to be washed before marketing or eating.

General. Plants may wilt, turn yellow and display reduced growth rates if infestations are severe. The yield of established plants can be reduced if infestations continue unchecked throughout the growing season. Severe infestations can cause plants to lose vigour and wilt. Small numbers of whiteflies in a home garden may not be a cause of concern, doing little damage.

Transmit virus diseases. GHWF spreads lettuce infectious yellow virus which infects petunia, zinnia and other hosts. **SLWF** spreads tomato leaf curl virus in ornamentals and vegetables.

Diagnostics

- Do not confuse **damage** caused by **thrips** to leaves with that caused by other insects and twospotted mite (Table 33 below).
- **Adult whiteflies as a group**, are easy to distinguish from other insects, but it can be difficult to distinguish one species from another.
- **Nymphs** are often mistaken for **scale insects** and are more difficult to identify but are distinctive for each species (Fig 115).
- **Identification** of one species from another is based on size, shape of wings, pupae hairs, pattern of egg laying, etc (Goodwin et al 2000).
- **GHWF** - examine late instar or redeye pupal stage with a hand lens (x10) or a microscope.
- Some whiteflies only attack certain type of plants, eg **AWF** mainly attacks trees and shrubs.
- **SLWF** flies greater distances than **GHWF**.
- Know which whiteflies are present in your crop so you can select appropriate biocontrols/insecticides.
- If unsure, consult a diagnostic service.
- **Lucid keys** - www.**lucidcentral**.com/ *Platanthera Interactive Key to North America, north of Mexico (Pupal Key to Genera of White Flies),* also *Whitefly Fauna of the Word*, *Key to Cotton Insects*

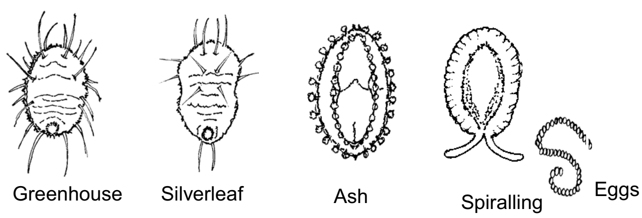


Fig. 115. Stationary later stage nymphs (pupae) of different species of whiteflies (about 0.8 mm long). The pupal stage which looks like small scale under leaves is often the more distinctive if not send to a diagnostic service.

Table 33. Leaf symptoms caused by some sucking insects and mites.

	Greenhouse whitefly	Various leafhoppers	Lace bugs	Greenhouse thrips	Twospotted mite
Upper leaf surface	Sandy speckling,	Speckled feeding patterns	Sandy speckling	Silvering	Sandy speckling
Lower leaf surface	Whiteflies, Stationary nymphs, honeydew, sooty mould	Clean, insects have flown away	Lace bugs, spiny nymphs, black spots of excreta	Thrips visible, black spots of excreta	Mites visible, webbing, excreta

Pest cycle

There is a **gradual metamorphosis** (egg, 4 nymph stages and adult) with many generations each year. One generation from egg to adult takes 3-8 weeks, depending on the temperature and the host plant. Each female lays several hundred eggs in circles or arcs on smooth-leafed plants, or scattered about if leaves are hairy. Each egg has a short stalk which is embedded in leaf tissue, supporting the egg in an upright position; a cluster of eggs looks rather like a group of minute pegs. After hatching, the 1st stage nymph crawls about on the underside of the leaf for up to 3 days before settling down to feed. **Later nymphal stages** complete their development at this site chosen by the 1st stage nymph. These oval shaped immature forms look like **scale** insects. The adult emerges after the 4th nymphal stage.

'Overwintering'

- Outdoors in cooler climates as unhatched eggs on leaf undersides and as adults in sheltered places.
- In warm climates and in greenhouses the cycle is continuous.

Spread

- As adults flying assisted by wind.
- Movement of infested plants carrying eggs, nymphs and/or adults.

Conditions favoring

- Mild moist conditions. Optimum temperature is about 30°C when life cycle takes about 18 days.
- Outdoors, sporadic pest in protected humid sites in late spring, summer and autumn.
- High nitrogen levels.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Plan** well in advance, consulting professionals if necessary, eg. National Spiralling Whitefly Consultative Committee.
2. **Crop, region**. Recognize that variations in climate and species will affect your plan. The Cotton CRC website has a Cotton Pest Management Guide.
3. **Identification**. Consult a diagnostic service (page xiv) if necessary, to ensure correct identification of the whitefly in your crop.
4. **Monitor** to detect early infestation of whiteflies and their parasites before applying an insecticide (page 39). Group susceptible plants to maintain regular monitoring and treatments. **GHWF** nymphs become black and **SLWF** nymphs become brown about 2 weeks after successful parasitism. Monitor weekly mainly during autumn and spring as **GHWF** is most active during that time (this may vary depending on the crop).
   - **Plant inspections** for **nymphs**. Crops very susceptible to whiteflies are useful for pest scouting, eg poinsettia, gerbera, rose, hibiscus. (Bodman and Hargreaves 2000). Examine 5 compound leaves (5 simple leaves = 1 compound leaf) on 20 plants widely spaced through the crop.
   - **Yellow sticky traps** trap **adults** (1 per 100 m^2). Monitor **GHWF** weekly. Desire sticky and InSense Lure traps are used to monitor adult whitefly: http://**insense**.com.au/products.htm
   - **Sooty mould and honeydew** also be monitored. Whitefly on leaf undersurface can be hard to see but look for honeydew dripping down on leaves below.
5. **Thresholds** vary with area, host, etc, and have been determined for some commercial crops, but seek up-to-date advice about the need to monitor, eg
   - **Specialist propagators** may have a **nil tolerance** for whitefly. Treatment is applied as soon as whiteflies (particularly **SLWF**) are detected.
   - **Roses.** Treatment may be required if more than 10% plants are infested.
6. **Action/control.** Small populations in a home garden can often be ignored. Commercially suppression using *Encarsia* sp. is preferred. When any threshold is reached commercial growers should apply control in the **early stages** of infestation. If *Encarsia* is used, an insecticide program prior to shipment may be required. Insecticides can be useful to:
   - Reduce whitefly numbers to a level at which *Encarsia* can be successful. Control whiteflies in hot spots.
   - If temperature is not suitable for *Encarsia*.
   - Continue to monitor plants after treatment.
   - Destroying nests of ants feeding on aphid honeydew will allow parasites and predators do their job.
   - Avoid broad spectrum insecticides.

8. **Evaluation.** Review **IPM** program to see how well it worked and implement improvements if required.

Control methods

GHWF and other whiteflies may be common in some areas but are easy to control compared with **SLWF** which has a wider host range, higher reproductive rate, develops resistance rapidly to insecticides and is adapted to high temperatures. Where populations are a mix of **SLWF** and **GHWF**, consider treating as if all are **SLWF**.

Cultural methods.

- Reducing humidity can help to control whitefly in glasshouse and outdoor situations.
- Some plants, when used as companion plants are reputed to repel whiteflies, eg nasturtium.

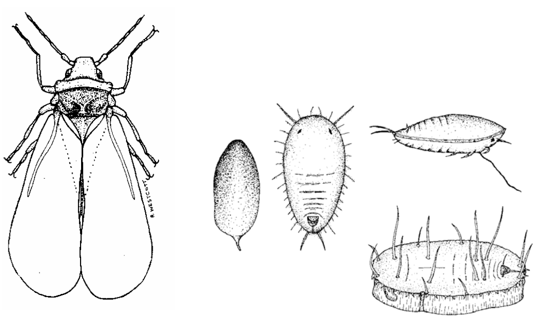


Fig. 116. Greenhouse whitefly (*Trialeurodes vaporariorum*). ***Left:*** Adults on undersurface of leaf. ***Centre:*** Adult about 1 mm long. ***Right clockwise:*** **Egg** on stalk (about 0.24 mm long); **Top and side views of 1st stage nymph** (when fully fed about 0.3 mm long); **4th stage nymph** (about 0.75 mm long) with wax rods on the upper surface which are not always obvious, may be mistaken for scale. Photo© NSW Dept of Industry and Investment.

Sanitation.
- Avoid carry-over to new crops, remove and destroy crop debris and infested plant material. Remove older affected leaves.
- If practical completely clean the production area at the end of the crop. Remove all plant material, including weeds, for a week or more.
- Control broadleaf weeds around crops and greenhouses as **SWF** has a very wide host range.

Biological control.
- **Natural controls** include many predators, parasites and diseases. Some overseas examples.
  - **Ash whitefly.** A small parasitic wasp, *Encarsia inaron*, provides good control in the USA and NZ.
  - **Computer programs**, eg Biocontrol-Poinsettia, helps growers overseas calculate how many wasps they should release and how often.
  - **The fungal diseases** BotaniGard®, Naturalis®-L (*Beauveria bassiana*) and *Verticillium lecanii* can be used while populations are still low.
- **Commercial biocontrol agents.**
  - **Predatory lacewing** (*Mallada signata*).
  - **Greenhouse whitefly wasp parasite** (*Encarsia formosa*), a tiny introduced parasitic wasp, 0.5 mm long, lays one egg inside the body of the 4th stage whitefly nymph. When hatched the wasp larva feeds inside the whitefly nymph which turns **black** within a few days (unparasitized nymphs are white; when the wasp, ***Eretmocerus***, lay its eggs under young scale, the host darkens then **yellows**). Wasp larva pupate and after 3-4 weeks, the adult wasp emerges by cutting a round hole through the upper surface of the nymph. Infestations are often kept in check and plants should be examined for parasitized nymphs since chemical treatment may not be necessary.
    - ❑ In greenhouses, *Encarsia* is often **killed by sprays** used to control other pests, eg aphids, and does not work well in hairy or sticky leafed crops.
    - ❑ The 1st, 2nd and 3rd stage nymphs may also be parasitized but are unsuitable hosts and nymphs of the whitefly and larvae of the wasp die.
    - ❑ In greenhouses, temperatures **> 22°C** must be maintained if *Encarsia* is to be successful in reducing whitefly populations. At temperatures **< 22°C** whitefly development is considerably faster than that of *Encarsia*.
    - ❑ *Encarsia* can take 10 days after an initial release to exert its full effect. About **80%** of nymphs must be parasitized before new releases can be stopped.
    - ❑ *Encarsia* is more successful in controlling **GHWF** than **SLWF**.
    - ❑ **Lucid keys** - www.**lucidcentral**.com/ *What Wasp is That*?
    - ❑ List of suppliers www.**goodbugs**.org.au

Resistant varieties. Use if possible, cultivars with **hairy leaves** and **toxic sap** which are considered to slow whitefly development.

Plant quarantine.
- **GHWF** is spread throughout Australia. Inspect plant material before introducing it into growing areas.
- **SPWF.** Quarantine areas have been declared in some regions for **SPWF** which **prohibit and regulate** movement of **SPWF**-infested and uninfested plants, plant materials and fruit, out of Quarantine areas without an inspector's approval.

> **Interstate Certification Assurance (ICA)** Operational Procedures, ***Property Freedom for Spiraling Whitefly*** (ICA-36), covers certification of property for live plants and parts of plants including plant parts intended for propagation, leafy vegetables and cut flowers and foliage. ***Inspection and Treatment of Plants for Spiraling whitefly*** (ICA-35) is in preparation.

Pest-tested planting material.
Inspect new plant material before introducing it to the main growing area/greenhouse. Use hand lens.

Physical a mechanical methods.
- **Yellow** plastic sheets or fluorescent painted boards, covered with clear sticky grease attract whiteflies which stick to the surface when they land. Clean boards regularly and re-coat with the sticky material. Useful for small areas outdoors, in glasshouses and if pesticides cannot be used. To avoid catching parasites keep traps above plants.
- **Small outbreaks** can be dispersed by hosing.
- **Greenhouse screens** with a pore size 400 µm (micrometers) or less, prevent adult whiteflies moving in from infested areas. Screens are expensive and these will not screen out **WFT**.
- **UV** blocking plastic being researched. Different types of **UV** reflective mulches.
- **Destroying nests of ants** feeding on honeydew will assist parasites and predators to do their job.

Insecticides.
- **Spray application** must be thorough, as infestations are mostly on leaf undersurfaces.
- **Apply to young nymphs and adults**. Systemic sprays may be needed for persistent infestations.
- **Restrictions** on some crops, permits may be required.
- Follow **CropLife Australia Resistance Management Strategies** as **SLWF** can rapidly develop resistance.
- Avoid broad spectrum insecticides.

Table 34. Whiteflies generally - Some insecticides.

What to use?	When & how to apply?
FOLIAGE TREATMENTS **Group 1B**, eg Rogor®, various (dimethoate), Folimat® (omethoate), Lancer®, Orthene® (acephate) **Group 3A**, eg Baythroid® (cyfluthrin), Jury®, Talstar®, Procide®, various (bifenthrin), Tempo® Residual (beta-cyfluthrin) **Group 4A**, eg Confidor® (imidacloprid), Crown® (acetamiprid), Actara® (thiamethoxam) **Group 7C**, eg Admiral® Insect Growth Regulator (pyriproxifen) **SLWF** & **GHWF** on **cotton & some vegetables** **Group 12A**, eg Pegasus® (diafenthiuron) suppresses **SLWF** in cotton with minimal disruption to natural enemies. **Group UN**, eg Neemtech® (azadarachtin) **Spray oils (immature stationary whitefly)**, eg Pestoil®, White oil (**petroleum oil**), Bioclear®, Biopest®, Ecopest® oil (**paraffin oil**), Eco-Oil® (**botanical oil**) **Soap sprays**, eg Natrasoap® (potassium salts of fatty acids **Various Garden sprays**, eg Beat–a-Bug® (chilli/garlic/ pyrethrin/piperonyl butoxide), also pyrethrin, bioallethrin, bioresmethrin	• Follow **CropLife Australia Resistance Management Strategies**. When observed, thoroughly apply to undersurfaces of leaves. Repeat applications may be needed as insecticides may not kill eggs. Seek advice about when is best to spray the crop. • Spray oils and soap sprays suppress development of eggs, metamorphosis and adult formation. They are most effective against immature whitefly. • **Permits** may be required for many situations, eg in glasshouses. • Few insecticides for **glasshouse** whitefly control are predator- and parasite-safe. Admiral® and Pegasus® cause minimal disruption of the parasites and predators of **SLWF**. Overseas the growth regulator Novaluron® (novularon) has little effect on *Encarsia* and other introduced beneficials, also suppresses leafminers, **WFT** and some moth pests. **CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE**
SOIL TREATMENTS **Group 4A**, eg Confidor Guard Soil Insecticide (imidacloprid) for **SLWF** on certain vegetables. **Permit required**	**ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE**

ORDER ISOPTERA

Termites, 'white ants'

NO. SPECIES IN AUSTRALIA

More than 300 species. Their resemblance to ants is superficial; they are more closely related to cockroaches. Comparatively few species damage standing trees economically or are considered to be major pests of buildings. Termites cause over $80 million damage each year in Australia.

www.ento.csiro.au/education/insects/**isoptera**.html
www.**termite**.com.au/**termites**/
Pest control company *Fact Sheets*

SOME DISTINCTIVE FEATURES

Termites are **social insects** that work and live together in colonies. Within each colony are several types (castes), eg workers, soldiers and reproductives. Their body is **not constricted** between thorax and abdomen as in 'true ants'.

ADULT

Workers
1. Wingless, sterile and blind.
2. Small, soft body, **whitish in colour** with large rounded, often brown head with powerful jaws.
3. Build and repair the nest, construct galleries, tend the king, queen and young, find food for themselves and other castes.

Soldiers
1. Wingless, sterile and blind.
2. Similar to workers but with heavily armoured dark coloured head and larger jaws, head may be pointed.
3. Protect the nest from invaders (defence)

Reproductives
1. **Kings, queens** and other reproductive forms.
2. Adults have, for a short period only, 2 pairs of nearly equal membranous wings which break off after flight.

LIFE CYCLE

Termites
About 14 mm long

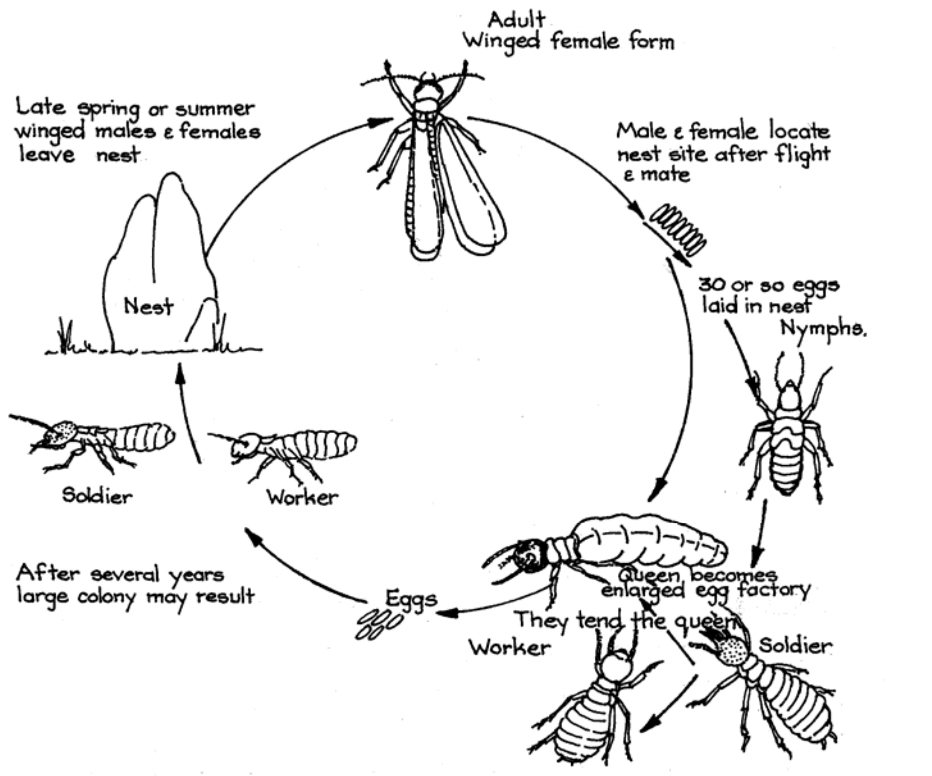
Nests may contain as many as 3-4 million individuals depending on the species

Tunnels. Most termites remain within a closed system of tunnels devoid of light, protected to some extent from natural enemies, temperature and humidity extremes The only exceptions are during swarming flights, repair or construction of a nest. Exceptions include grass-eating species.

Nest. Most species either build a small mound at the base of a tree trunk or live in a nest remote from the feeding sites foraging tunnels which can be up to 200 metres away from the nest to the feeding sites.

Large earthen mounds can be up to 7 meters high.

There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. Only the **king and queen reproduce** (only the queen lays eggs).



METHOD OF FEEDING

ADULT
NYMPH

Both have **chewing** mouthparts. Termites eat all types of **plants** and **plant materials**, eg grass, wood. Cellulose is the basic food o all termites which they digest with the aid of micro-organisms in their gut. They mostly **live in the dark** and build protective tunnels to travel between the nest and food source.

PLANT DAMAGE

Few species feed on living plants

DIRECT CHEWING DAMAGE

Only the worker castes damage plants and plant material, and may comprise 80% to 90% of a termite colony. They eat out large galleries or runways through which the workers forage for food and travel to and from the nest. Cellulose found in plants is the basic food requirement of all termites. They may damage materials they cannot digest, eg plastics, tuber, metal or mortar encountered during their search for food.

TREES Young and old trees and shrubs.

WOOD Buildings, fence posts, telegraph poles, piers, **wood chips** and **bark** used as landscape mulches.

STRAW Some species of **grasses** only.

CROPS **Tubers**, eg potatoes.
Stalks, eg sugarcane.

Termite tunnels in potato (cross section)

INDIRECT DAMAGE

Weakening of structures (collapse of trees, timber) and infrastructure damage, eg cables, plastic sheathing and conduits.

LIST OF SOME SPECIES

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
SUBTERRANEAN TERMITES		

Most pest species are subterranean.

Require a constant source of moisture. They obtain their moisture from the soil and are generally ground-dwelling.
Tunnels are underground, usually in the top 20 cm of the soil, originating from the nest, to reach a source of food, which may be up to 50 meter from a central colony; or as shelter tubes up vertical objects.
They build their nests in soil, in trees and other sheltered situations. Nests are mostly around ground level. Many nests are started in or near dead tree stumps.

OBLIGATE MOUND COLONIES

Central colony is always a raised mound. **Subterranean tunnels** radiate from the central colony to food sources.

Most small termite species in the NT do little damage to native plants, ornamentals or fruit trees and rarely need to be controlled (Andersen, et al. 2000)

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Subterranean termite	*Coptotermes lacteus* Qld, NSW, Vic *C. brunneus* WA	Dead wood in ground (poles, fallen trees), not a pest of buildings or living trees. Fruit trees. Nest up to **2 m** high
Spinifex termite	*Nasutitermes triodiae*	Grass, not timber in service, nest up to **7 m** high
Magnetic termite, compass termite	*Amitermes meridionalis*	Grass, mound is up to **4 m** high, Orientated N-S so the E and W sides face the morning and afternoon sun respectively. The thin wedge faces N at midday thus striving to keep the nest at the preferred 30°C. As the morning or afternoon sun heats up a side of the mound the termites move to the other cooler side

NON-MOUND COLONIES

Nests underground inside living or dead trees, stumps, poles, wood in the ground. Some species build mounds in some areas. **Subterranean tunnels** radiate from the nest to food sources.

The most destructive termite species in Australia

The world's worst termite. Not known in Australia

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Subterranean termite	*Coptotermes acinaciformis* Occurs throughout Australia, this species builds nests in mounds in the northern (Qld) & SW areas of its range.	All timber structures, forest, fruit and ornamental trees**.** Eats out a central pipe within trees especially eucalypts. Packed with **'mudguts'** or claylike faecal material. Adjacent trees become infested via galleries
Formosan subterranean termite	*C. formosanus*	A destructive species damaging houses, buildings, live trees, crops
Giant northern termite Workers > 12 mm	*Mastotermes darwiniensis* Most damaging species in the NT	Houses, posts, young trees, sugar-cane, etc. Threat to tree planting, may ringbark trees. Largest soldiers in Australia. Very destructive where it occurs

ARBOREAL COLONIES

Nests in trees at various heights or on top of posts. Ground contact is necessary and galleries run down inside and outside the stem. **Underground tunnels** radiate from the base of the tree or post to food sources.

Many other genera and species

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Niggerhead termites	*Nasutitermes walkeri*	Decayed timber in fences in contact with soil. Rarely attacks timber on or in houses

LIST OF SOME SPECIES *(contd)*	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (not exhaustive)**
	DAMPWOOD TERMITES		
	Nests are small; there may be separate and independent colonies in stumps, rotting logs or rot pockets in dead or living trees and timber that has a high moisture content. Often no contact with soil. **Rambling tunnels** in damp wood.		
Many other genera/species	Dampwood termite	*Porotermes adamsoni*	Living trees, mainly eucalypts, other trees, poles, occasionally houses. Rarely infests small diameter trees
	Ringant termite	*Neotermes insularis* Largest termite species in Australia up to **15 mm** long.	Colonies in branches and stubs of wood of living trees, especially eucalypts. Serious pest of forests of the east coast of Australia
	DRYWOOD TERMITES		
	Nests are small and independent groups in dead branch stubs, stumps, poles on ground. Attack either dead wood in trees or dry wood in service in houses. **Moisture.** They require only the moisture of the atmosphere and of the dry timber in which they occur. They obtain water from the wood in which they live and have no contact with the soil, or any other source of moisture. **Rambling galleries** in dry wood, They occur in warm tropical areas and in dry areas of subtropical Australia.		
	Drywood termites	*Cryptotermes* spp.	Furniture, structural timber, dead wood in trees and poles
Not established in Australia	West Indian drywood termite	*Cryptotermes brevis*	Buildings, furniture. The world's most destructive termite species

BENEFICIAL ACTIVITIES OF TERMITES

RECYCLING OF NUTRIENTS

- Termites play a prominent part in the recycling of plant nutrients through the disintegration and decomposition of dead wood, plant debris, fungi and animal droppings. Most termite species eat grass and other surface vegetation and have an important role in maintaining soil fertility and aeration. Many convert dead trees and other plant material to organic matter and minerals. They may search for food in the open on humid nights.
- Termite galleries improve soil structure, water entry and storage in soil.

HABITATS FOR WILDLIFE

- **The excavation of termites** alters the structure of trees and provides habitat spaces for bats, birds, reptiles, etc.
- **Lace monitors** (tree goannas) lay eggs in termite mounds in eastern Australia which are perfect incubators. After the eggs are laid, the termites quickly repair the damage imprisoning and protecting the monitor eggs inside the mound for 9 months. Adult monitors return at precisely the right time to dig an escape tunnel for the hatchlings. Termites pay a heavy price as the effort to re-build their nests year after year is extraordinary and in some occasions the termite colony may die.

FOOD CHAIN

- Termites are an important component of the food chain of many animals, eg birds, lizards, echidnas, spiders and predatory insects.

DIDJERIDOO

- When termites hollow out the center of a log many channels and irregularities are formed. It is this that alters the resonance of the didgeridoo creating the unique sound that is distinctive of Aborigine Australian culture.

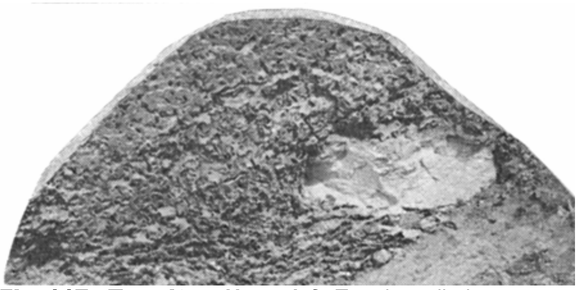


Fig. 117. Termites. ***Upper left:*** Termite galleries on a timber pole; galleries tend to follow cracks in the wood. ***Lower:*** Small termite mound (*Nasutitermes exitiosis*). Portion removed to show internal structure. Photo©NSW Dept of Industry and Investment.

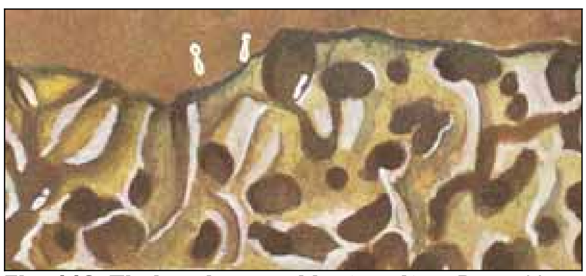


Fig. 118. Timber damaged by termites. Paper thin walls between runways creating a honeycomb. Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Termites

'White ants'

Not all termite species found in timber are a threat to houses. Only a few of the species found in **trees** may infest buildings. Of the few hundred Australian species only about **six** are considered to be **major pests** of buildings. Seek **species identification** and treatment advice if buildings are close by to avoid unnecessary treatments. **Check pest species which occur in your area**.

Scientific name

Termite pests of living trees include:

Subterranean termites, eg *Coptotermes* spp. Dampwood termites, eg *Porotermes* spp. Drywood termites, eg *Cryptotermes* spp. See also page 175

In Australia, subterranean termites are the most destructive species, working from a central nest or colony situated in the ground or in trees from which subterranean tunnels radiate to food sources.

Host range

Timber, eg building timbers, fence posts, rail sleepers, telegraph posts, wood chips and bark. **Trees, shrubs, fruit trees, vines**, eg large and small trees and shrubs, cashew, citrus, grape. **Crops**, eg potatoes, sugarcane. **Some species** feed on grass, spinifex, and fungi in the nest or on moist wood from which they get proteins, etc.

Description & damage

Adults (males and females) are winged insects about **14 mm** long (including wings). They leave the nest, establish new colonies and become **'king' and 'queen'** of the new nest. **Workers** are small, wingless, sterile white-bodied ('white ants'), blind, with well-developed jaws for gnawing wood. About 80-90% of the colony in our common pest species are workers. **Soldiers**, depending on the species, are blind, sterile and have longer jaws than workers. They protect the colony from invaders, and may constitute as little as 2% of the colony. Termites have a thin skin and desiccate readily.

Trees. Damage is caused by workers seeking food for the colony traveling to and from the nest along runways in a continuous stream. Large trees are usually attacked through the centre of the trunk, often with little external evidence of termite activity. They do not normally affect the living part of the tree but cause structural weakness in old slow-growing trees. Termites work inside the trunk, **along the grain**, eating out large runways. In one tree, there may be several runways which are gradually widened and extended until only **thin** layers of wood remain between them (Fig. 118).

Firewood. Seek advice about local termite species. Many termites found in firewood are feeding workers from large colonies, unable to survive on their own, in small pieces of wood or to invade structural timbers. Some species found may not attack buildings. **Large** blocks of firewood or intact logs could possibly harbour a small nest. It is unwise to stack large timber next to houses or fences. Some species that can damage sound timber will dry out and die in chopped wood.

Mulches and compost. Wood chips, bark and neglected compost heaps can provide food and shelter for some termite species. Finer mulches, eg leaf litter, lucerne hay, break down too quickly to provide enough food and shelter.

Potato stems and tubers become tunneled, 'honey-combed' and spongy, skin is intact (page 175). Crops are mainly reached by underground runways.

Diagnostics. Trees and other plants.

- **All tree assessments** should be carried out by a professional arborist.
- **Do not confuse** termite damage to trees with that caused by borers or wood rot (page 178, Table 35). Termite galleries are constructed from soil. Wood-boring moths often cover their activities at the junction of branches with frass (silk and droppings).
- **Damage is difficult** to detect in the early stages. Unless runways are discovered during monitoring, inspections or pruning, damage is not often noticed until trees collapse, or crops harvested. Occasionally runways can be traced back to the nest.
  - **Expert ID needed.** It is usually easy to know whether the pest is a termite or not but **difficult to distinguish** one species of termite from another. Collect several soldiers, put in methylated spirit in a jar and take to a termite expert. Collect soldier caste termites with as little disturbance as possible. Termite diagnostics is offered by arborists and pest control companies.
  - **Bait monitors** alert tree growers to the **presence** of termites and can be placed at various distances from trees where termite activity is suspected.
  - **Wood chips.** Water area well the evening before gently scraping back the wood chips. During hot and dry weather termites move deeper under-ground to keep cool and damp.
  - **Inspection tools**. Experience is necessary and when used in conjunction with other technology helps identify where termites might be.
    - ❑ **Tappers** (Termite Inspection Tools) or hammers. As old living trees with **fungal decay** (page 361) appear to be most susceptible to termite damage (some exceptions in tropics), the analysis of termite damage is the same as for fungal decay hollows (Mann, 2009).
    - ❑ **Drilling of trees** to assess presence of termites can be destructive to trees.
    - ❑ **Temperature probes** can locate termite colonies in trees. The temperature of areas with termite activity is generally several degrees higher than 'normal' tree temperature and can be detected. **Non-invasive Thermacam Technology** can be used by arborists to locate termites in trees. All material has a unique thermal signature and when moisture, heat or pests are introduced, thermal images change.
    - ❑ **Moisture meters** are **non-destructive**. Termites need moisture to survive.
    - ❑ **Termatrac technology** (rather similar to radar), can detect termites inside timber, plaster board etc.
    - ❑ **Borescopes** give a clear picture using mirrors and a small light at the end of a flexible probe. They are expensive and usually only used to check for termites in inaccessible places in buildings.

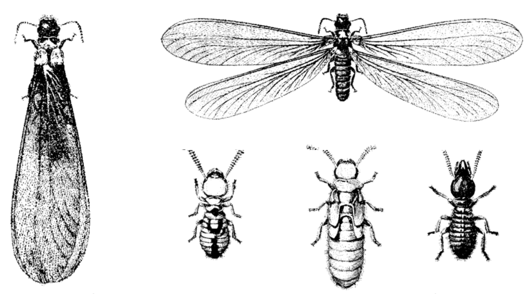


Fig. 119. Subterranean termite (*Coptotermes acinaciformis*). ***Left:*** Male winged form. ***Upper:*** Female winged form. ***Lower left to right:*** Worker (forages for food), nymph with wing buds; soldier (defends the nest). Photo© NSW Dept of Industry and Investment.

Pest cycle

There is a **gradual metamorphosis** (egg, nymphs, workers, soldiers, kings and queens). Once a year (or more often, during warm humid weather) winged males and females leave the nest in thousands. After a short, fluttering flight they alight on the ground, cast off their wings, pair and start to form new nests in a gallery or chamber in the ground adjacent to timber or an old stump. A few survive to found new colonies of which they become 'king' and 'queen'. Eggs are laid and new generations of worker and soldier termites are produced. The queen may live and continue to lay eggs for many years. The destructive potential of the colony is not fully developed for many years; a colony from a single pair reaches about 100 strong in 3-5 years.

'Overwintering'

As all stages in colonies. Reproductives in termite colonies can survive for many years. Soldiers and workers for only short periods of time.

Spread

- Workers of some types may travel up to **50 meters** through galleries searching for food but cannot establish new colonies.
- By **winged** adult males and females flying. In summer during hot humid weather flights may occur inside buildings late in the day or to lighted windows at night.
- **Movement of timber or wood** carrying eggs, a queen or nymphs.

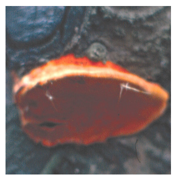
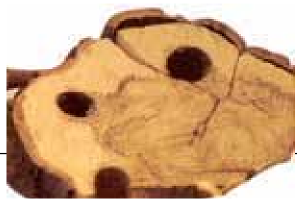
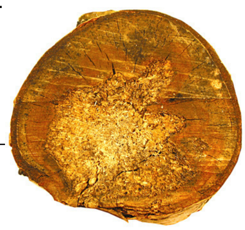
Conditions favoring

- The main pest species are subterranean termites which **must** have contact with the ground or access to a continual source of **moisture**.
- Warm soil with an abundant supply of food in the form of wood or other cellulose material.
- Trees with fire scars.
- Termites are generally more abundant in the tropical and semi-tropical regions of Australia.
- Old living trees often with **fungal decay** appear to be most susceptible to termite damage (except a *Coptotermes* sp. that is only found in the tropics).
- Potatoes or fruit trees planted in **freshly** or **incompletely cleared land** or adjacent to bushland may be attacked. Infestations start from a dead tree stump or log in the potato field, orchard or on adjoining land. Outside rows are more likely to be attacked than inner rows.
- The adoption of zero till and stubble retention practices has resulted in the re-appearance of subterranean termites in some cropping lands.
- **Wooden stakes** of susceptible timbers or sapwoods used for supporting plants can attract termites.
- Mulches of chips of wood, bark and nut shells are also attractive.

Management (IPM

1. **Obtain/plan.** In most situations termite control should be carried out by **licensed pest control operator**.
2. **Crop, region.** Pest species vary according to region. Obtain leaflets on local species. It may be necessary to treat areas **before** planting fruit or other trees.
3. **Identification.** Consult an arborist, licensed pest controller or a diagnostic service (page xiv).
4. **Monitor** pest and/or damage and record results as recommended by a trained pest control specialist.
   – **Regular inspections by trained personnel** of trees, fences, where termites have been a problem.
   – **Early warning systems. Bait stations** (usually containing an attractive wood) are placed in areas where termites may be foraging. The termites aggregate at the station and continue to feed. Use mountain ash (*E. regnans*) as bait for termites less resin in it. Some termite monitoring and baiting systems are designed to be spread throughout the colony by the worker termites.
   – **Monitor mulch** by vigorously raking it back and forth at least twice a year, especially during sultry summer months when queens are likely to be starting new colonies.
5. **Threshold** is usually a nil tolerance if it is a species that devastates trees, plantations, buildings. How much damage can you accept?
6. **Action.** Professionals will undertake any treatments required and may recommend treatments that you can carry out, eg removal of unwanted timber, etc.
7. **Evaluation** of the program may require an annual inspection by trained personnel. Keep records of treatments, inspections and results. Put improvements in place if necessary.

Table 35. Comparison of termite, borer and wood rot damage.

Tree trunk	TERMITE DAMAGE	BORER DAMAGE	WOOD ROT
External damage	• Flight cuts, through which winged termites leave parent colony. • Often no obvious damage, timber hollowed out from within. • In some cases distinctive gallery running on trunk or structure.  Photo© NSW Dept of Industry and Investment	• Flight holes of various sizes depending on species of borer. • Fine timber dust. • Shape, size of holes and host indicate which borers • See also page 111. 	• If decay is advanced, fruiting bodies of various colours, eg red pink, white or brown and of various shapes and sizes, may have developed • See also page 361. 
Internal damage	• Fluted areas, termite damage, it is easy to distinguish from borer damage, and wood rot (fungal decay). • 'Mud guts'. • If active, termites seen. • Timber hollow and light in density.  Photo© NSW Dept of Industry and Investment (E.H.Zeck).	• Individual tunnels may be oval or round, may or may not be filled with frass. • Galleries below bark. • Presence of either sluggish larvae or in some cases, adults below bark. 	• Heartwood stained with coloured or white threads, may be soft, lighter in density. • When dried out wood is friable, very light in weight with no structural strength. • No hollow fluted areas (termites) or holes (borers). 

Control methods

Control in trees. No system provides **total control** against termites, but risk of termite attack can be minimized. For **most horticulturists**, termite control is a **specialist task** and trained pest control specialists should be consulted to identify, locate and deal with the infestation. **Incorrect** or rough attempts to control termites may cause the termites to withdraw from the treated area, to another location, spreading the problem. Standards are available for termite prevention and control in buildings and structures.

Cultural methods.

- **During maintenance** avoid mechanical injury to trunks and limbs of trees.
- The best treatment for all tree problems is to ensure that the trees are as healthy as possible.

Sanitation.

- **Prior to planting** clear old stumps, roots and timber that might attract termites from within 100 meter radius. Burn or completely remove tree stumps. Clearing and cultivating land for dryland cropping can eliminate termites from these soils.
- **After planting**. Keep ground under trees free of weeds and logs.
- **After attack.** Check current legislation regarding tree removal. Obtain professional advice from an arborist (tree surgeon) to assess hazard and damage, and under-take treatments, eg apply insecticide to trunk. Find nest or colony, if possible, and destroy it.

Biological control.

- **Natural predators.** Winged reproductives are eaten by lizards, snakes, frogs, birds, ants, dragonflies and other insects. Echidnas use the long, sharp claws on their feet to dig open termite and ant nests and subterranean galleries to feed on workers and soldiers. Ants, some beetles and other insects feed on young termites, eggs and termite wastes in termite nests.
- **Commercially available agents**, may be able to treat established infestations in the future:
  - **Green muscardine fungus** (*Metarhizium* sp.).
  - A **nematode** (*Steinernema carpocapsae*).

Resistant/tolerant varieties. CSIRO releases timber durability ratings, termite hazard potential maps and decay potential for the whole of Australia to ensure that correct timber is used. Some timbers have some resistance to some termite species, eg Jarrah (*Eucalyptus marginata*) is resistant to *Coptotermes acinaciformis* but susceptible to *Nasutitermes exitiosus*. **Resistant timbers will not protect buildings**.

Plant quarantine. Serious termites overseas:

- **Formosan termite** (*Coptotermes formosanus)*
- **West Indian drywood termite** (*Cryptotermes brevis*) was first detected in Qld in 1964 but is not established throughout the country. Infestations in buildings are fumigated.

Physical & mechanical methods.

- Destroy nests on the ground by breaking open and burning (if local regulations permit).
- Turn over compost regularly.

Insecticides.

- **Most insecticides** used for termite control may only be applied by Licensed Pest Control Operators. Safety precautions prevent personal exposure to insecticide.
- **Because of toxicity problems**, fewer and fewer insecticides are available for termite control.
- **Before or during planting**. In areas of high termite activity, nests should be found and destroyed, planting holes and soil may need treatment.
- **After attack**.
  - **Small trees and shrubs**. When the tree itself cannot be treated, insecticide may be pressure injected to **soil** around the base of the affected tree.
  - **Large trees**. Boring holes about 15mm in diameter, sloping slightly downwards into the tree at several levels above the ground. This will give you some idea of the extent of the damage and decide whether the tree should be treated or removed.
  - **Locate nest** by probing the trunk, crown or between the roots. Ideally, holes are drilled into the hollow center of the trunk above the nest and insecticide run or forced into galleries. If the nest cannot be located, it may be necessary to drill into the galleries and flood them with insecticide. Nests high in trees made by arboreal termites may be removed and insecticide run into the galleries.
  - **Suppressing or eliminating a colony.** A bait toxicant in timber or cellulose matrix can be placed in a bait station or the colony indirectly by dusting aggregated termites. Bait stations may be below and above ground. The Sentricon Termite Colony Elimination System acts as a **monitoring device to detect** foraging termites. The bait can be replaced with a bait toxicant when termites are found. Following cessation of termite activity, the bait matrix is replaced with wood and monitoring resumed.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 36. Termites in trees, stumps – Some insecticides.

What to use?	When & how to apply?
NESTS IN TREES **Group 1B**, eg Chlorpyrifos®, Deter®, Dursban® (chlorpyrifos); Maldison® (malathion) **Group 2B**, eg Termidor® (fipronil) **Group 3A**, eg Ambush® (permethrin); Generex®, EnviroGuard®, various (bifenthrin); Prevail®, Stedfast® (alpha-cypermethrin) **Group 4A**, eg Imidacloprid® Termiticide, Premise® Foam (imidacloprid, **Group 15**, eg Intrigue® (triflumuron)	Application by **Licensed Pest Control Operators.** Make an effort to locate the nest.
BAITS STATIONS **Group 15**, eg Recruit®, Sentricon® (hexaflumuron); Nemesis®, Requiem® (chlorfluazuron) termite bait; Flurox® Termite Bait (flufenoxuron)	Application by **Licensed Pest Control Operators.** Licensed pest control operators will provide advice on the location of bait stations and prepare a diagram of buildings, grounds and trees etc., inspect fences etc.

ORDER ORTHOPTERA

Crickets, grasshoppers, katydids, locusts

NO. SPECIES IN AUSTRALIA

In excess of 2,500 species. The general appearance of these insects makes this order difficult to confuse with other orders. Resistance to pesticides has only occasionally occurred.

www.ento.csiro.au/education/insects/**orthoptera**.html

The Australian Plague Locust Commission (APLC) may be accessed at:
www.daff.gov.au/animal-plant-health/**locusts**

SOME DISTINCTIVE FEATURES

ADULT

Body Generally fairly large, no distinct constriction between head and thorax. Many are well camouflaged.

Wings
1. Two pairs in adult. Some species with short wings or without wings.
2. Forewing thickened, forming a cover over the hindwing.
3. Hindwing gauzy and plaited or fan-like.
4. Some males produce **sounds** by rubbing specialized parts of the forewings, abdomen and/or legs together to produce a characteristic song, eg **crickets** rubbing their forewings together.

Legs **Hindlegs** enlarged and developed for jumping.

Thorax **Pronotum** (upper surface of 1st segment of the thorax) is prominent, often saddle-shaped..

NYMPH Similar to adult, but smaller and wingless.

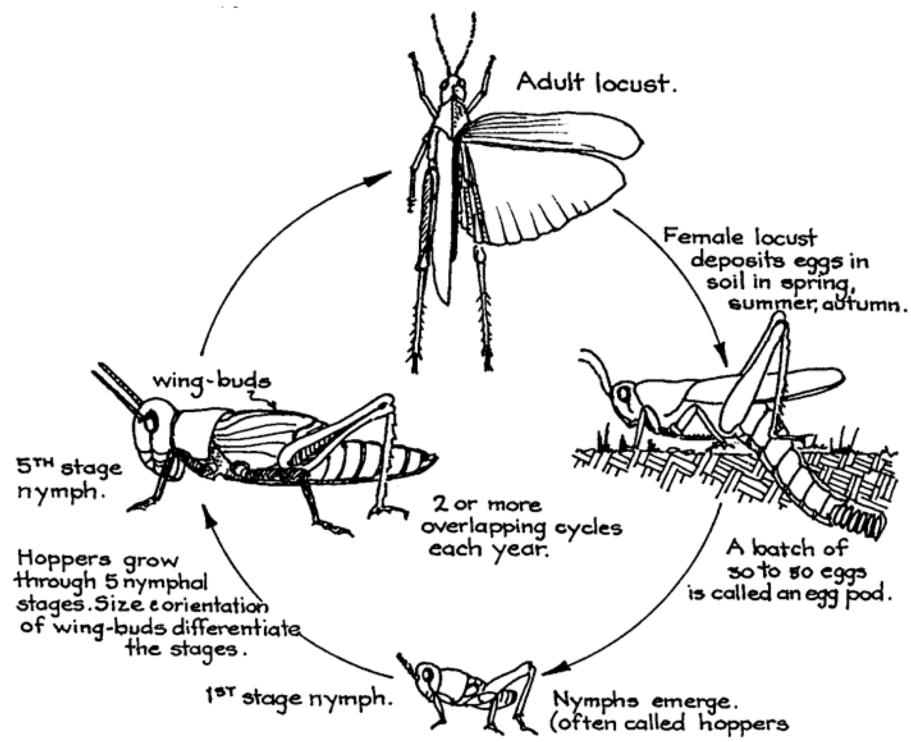
LIFE CYCLE

There is a **gradual metamorphosis** - egg, nymph (**usually 5 stages**) and adult. It is difficult to produce a generalized life cycle for such a diverse order. For example, **locusts** and **crickets** lay eggs in the **soil** but tree grasshoppers or long horned crickets and grasshoppers lay them on leaves.

Australian plague locust

Adults are 20-45 mm long

There are many variations, eg spur-throated locust has 1 generation each year



METHOD OF FEEDING

ADULT
NYMPH All stages have chewing mouthparts and mostly feed on plants, a few species prey on other insects. Many feed at night and rest on plants during the day.

PLANT DAMAGE

DIRECT CHEWING DAMAGE

Damage is caused by **both adults and nymphs feeding**. Since ancient times locusts have been known for devouring crops when large swarms occur. However, some tree 'crickets' are omnivorous and may do little harm.

LEAVES STEMS	**Eaten**, eg Australian plague locust
FRUIT SEED	**Eaten**, eg citrus treehopper (fruit), field crickets (seed)
ROOTS	**Eaten**, eg mole crickets, sandgropers

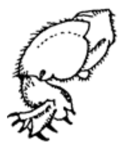
INDIRECT DAMAGE

- **Tunneling in soil**, eg mole crickets.
- Some tree crickets **bite** if handled.

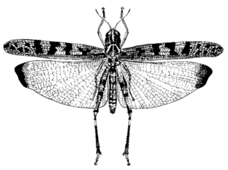
LOCUSTS OR GRASSHOPPERS

Locusts form into bands as hoppers (flightless young) and swarms (adults). Grasshoppers do neither. Some gregarious grasshoppers are called locusts,
www.ento.**csiro**.au/**education**/insects/**orthoptera**.html

LIST OF SOME SPECIES

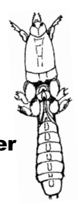


Mole cricket front legs modified for digging



Australian plague locust

Not known in Australia



Sand groper

Threatened species

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
CRICKETS (several families)		Most are vegetarians, some predators
Arboreal cricket	*Hemiphonus* sp.	River red gum, wattle
Black field cricket	*Teleogryllus commodus*	Grasses, clovers, vegetables, nursery stock. Widespread
Mole crickets	Family Gryllotalpidae Their loud persistent, monotonous call can be heard after dark coming from holes in lawns especially after afternoon rain	Roots of turf, tubers, other garden species. Common
KATYDIDS & LONGHORNED GRASSHOPPERS (Family Tettigoniidae)		
Citrus katydid	*Caedicia* spp.	Citrus fruits, blackberries, etc
Inland katydid	*C. simplex*	Fruit, eg peaches, citrus. Common in gardens
LOCUSTS & GRASSHOPPERS (Family Acrididae)		
Australian plague locust **(APL)**	*Chortoicetes terminifera*	Almost any plant material, but prefer grasses
Spur-throated locust	*Nomadacris guttulosa*	Grass, eucalypts, other trees. May roost in trees
Migratory locust	*Locusta migratoria*	Range of species, palms
Eastern plague locust	*Oedaleus australis*	Almost any plant material
Yellow-winged locust	*Gastrimargus musicus*	Almost any plant material
Desert locust	*Schistocerca gregaria*	Plagues threaten agricultural production in Africa, the Middle East, Asia (done so for centuries)
Giant grasshopper, hedge grasshopper	*Valanga irregularis*	Trees, shrubs in northern Australia, eg palms, agricultural and horticultural crops, young eucalypts. Up to **75 mm** long.
Small plague grasshopper	*Austroicetes cruciata*	Almost any plant material
Wingless grasshopper	*Phaulacridium vittatum*	Wide range of plants
SANDGROPERS (Family Cylindrachetidae)		
Sandgropers	*Cylindracheta* spp.	Live underground in sandy soils, feeding and shredding under-ground stems and roots.
BENEFICIAL & ENDANGERED ORTHOPTERA		
Tree crickets King crickets	Gryllacridae Stenopelmatidae	Caterpillars, insect eggs. May feed on leaves
Predatory grasshopper	Tettigoniidae	Other insects, may eat plants
Cooloola Monster (primitive cricket-like)	*Cooloola propator*	Believed to feed on other soil-dwelling insects

Australian plague locust

Outbreaks of the Australian Plague Locust **(APL)** are common throughout south eastern Australia. Plagues also occur in WA. The **APL** can easily cause costly disruption to agricultural production and urban horticulture in rural towns. It is not so much a problem in coastal cities and towns.

Scientific name

Chortoicetes terminifera (Order Orthoptera). Native to Australia.

Host range

APL prefers grasses such as pasture and related winter and summer cereal crops, but will eat any green plant material if grass is not available, eg sorghum, lucerne, vegetables and orchard trees.

Description & damage

Adults are **20-45 mm** long**.** Forewings with mottled markings, hindwings with **black tips** (otherwise clear); shank of hindlegs scarlet. Males are usually smaller than females. The general color is brown, but green forms are common in dispersed populations. **Hoppers** (nymphs) resemble adults but lack fully grown wings. Bands of hoppers can be so dense that they can be seen from the air as an advancing front eating out vegetation as they progress.

Damage. Hopper and adults chew pieces out of leaves and stems often all that remains is the midrib and stems. **Pasture** and **young crops** can be invaded by hoppers and completely defoliated. **Orchards, vegetables, other crops** may be damaged in closely settled districts. **Home gardens** in urban areas usually only suffer minor damage.

General. **APLs** migrate in huge swarms denuding large areas of vegetation. A single swarm may contain millions of locusts. **APLC** have calculated that a 1 km swarm of **APL** could eat between 0.8 and 10 tonnes of vegetation per day depending on swarm density. Losses may amount to several millions of dollars during a plague unless organized control action is taken.

Diagnostics. **Adult APLs** are relatively easy to identify from the black tips on their hindwings and red shanks of their hindlegs (Fig.120 below). **Hoppers** are more difficult to identify. Good descriptions are available:

- State/Territory Department Fact Sheets.
- Australian Plague Locust Commission **(APLC)** www.daff.gov.au/animal-plant-health/**locusts**
- Zborowski. 1998. *Field Guide to the Locusts and Related Grasshoppers in Australia.* APLC, GPO Box 858, Canberra, ACT 2601.
- If still in doubt send specimens to your local diagnostic service (page xiv).

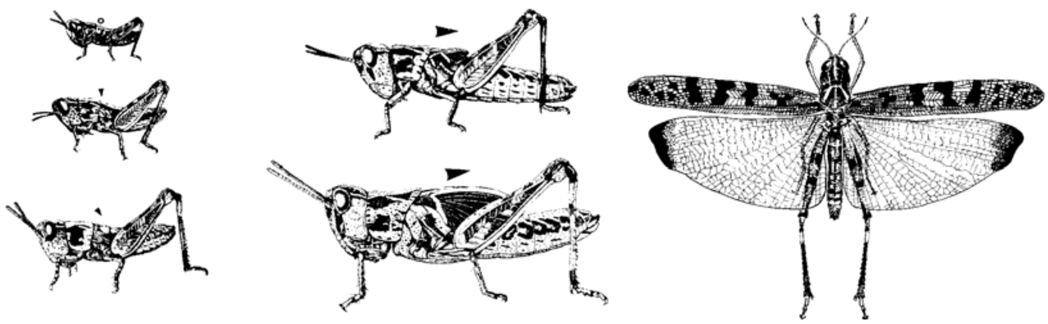


Fig. 120. Australian plague locust (APL) (*Chortoicetes terminifera*). ***Left:*** 5 nymphal stages of hoppers. Size and orientation of wingbuds differentiates stages. ***Right:*** Adult **APL**. Photo© NSW Dept of Industry and Investment.

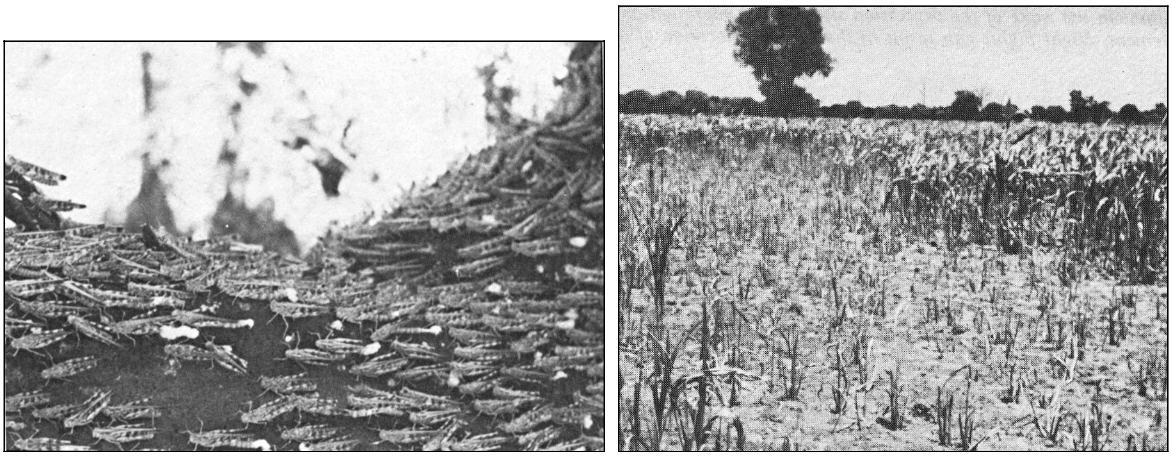


Fig. 121. Locusts. ***Left:*** A swarm of locusts shelter in the shade of a tree during the heat of the day. ***Right:*** Damage to sorghum, probably by migratory locusts. Photo© NSW Dept of Industry and Investment.

Pest cycle

There is a **gradual metamorphosis** (egg, nymphs (5 stages) and adult). There may be 3 overlapping generations during spring, summer and autumn. Females deposit pale yellow banana-shaped eggs in the soil in batches (**egg pods**) of 30-50. Up to 4 egg pods may be laid by a single female but rare for females to survive that long. A concentration of egg pods is termed an **egg-bed**. During outbreaks, eggs may be laid in a variety of situations, including fallow and stubble paddocks as well as among grass roots in sandy soil. Egg beds may vary from a few to several hundred square meters scattered irregularly throughout an area. Eggs need warmth and moisture to hatch.

- **Nymphs move away from egg beds** as solitary insects, as numbers increase they form dense **bands** of hoppers which vary in size from a few square meters to several hectares. Hopper bands may merge and increase to several kilometers with a distinct front.
- **After the final moult**, adults concentrate in **swarms** which make low drifting flights up to 50 meters high and can cover 10-20 km per day, but can migrate over much larger distances during the night.
- Research into how to prevent locusts from forming bands and swarming is ongoing.

'Overwintering'

- **Usually eggs** laid in soil in autumn over-diapause (in a state of arrested development) and hatch in spring as soil temperatures increase. During dry weather eggs become quiescent and may survive for 8-10 months.
- **'Overwintering' nymphs** over-diapause in the 3rd stage but few survive until spring.

Spread

- **Late stage hoppers** can travel up to 500 meters/day when in dense bands.
- **Adults flying in swarms assisted by wind** can extend an outbreak up to 200 km from the breeding area in a single generation during night migration.
- Outbreaks in areas of intensive agricultural production are typically the result of an influx from breeding in inland areas.

Conditions favouring

Locusts have occurred in plagues since the earliest of times, destroying crops even then. Droppings were considered lethal. Moderate outbreaks of the **APL** occur in most years in the interior of Australia. Major plagues occur less frequently. Locust outbreaks occur:

- **In seasonally arid areas of NSW, Qld** and **SA** (annual rainfall less than 300 mm) outbreaks are infrequent and can be the result of successful breeding in response to widespread rainfall. Such outbreaks tend to collapse suddenly with the return to unfavorable breeding conditions or with emigration. Migrants from these short-lived outbreaks often start secondary outbreaks in other areas to the south and east.
- **In regions with a more uniform and higher rainfall** (300-500 mm) frequent outbreaks result from local buildup or breeding by immigrants. These outbreaks may persist and develop into plagues.
  - Locust numbers multiply rapidly in seasons of above-average rainfall, particularly when the previous season had below-average rainfall or drought conditions. At such times, locust numbers may increase **simultaneously** over a vast area.
  - Egg laying by 1st generation females may be concentrated resulting in localized high density hatchings which then form hopper bands.
  - This 2nd generation which is crucial in the development of an outbreak, produces locusts in numbers sufficient to form dense swarms.
  - The swarms may move long distances, expanding the infested area and damaging pastures and crops.
- **Distance traveled** by swarms varies greatly and depends on factors such as age of adults, swarm size, density of locusts in the swarm, stage of the outbreak process and prevailing weather conditions, eg wind speed, temperature.
- **Long distance migration will occur at night** in suitable weather and if green feed has been available to enable fat accumulation.
  - They may simply disperse within a local area or the majority may take off at dusk reach considerable altitudes and travel downwind until conditions for flight become unsuitable.
  - Locusts can travel up to 500 km in a single night, leading to a sudden 'overnight' relocation of an outbreak.
- **Swarms** flying during the day tend to follow well-defined pathways determined to some extent by barriers such as timberlines along rivers or chains of hills.
- The introduction of farming, land clearing and grazing has provided them with the ideal environment to build up numbers and swarm.

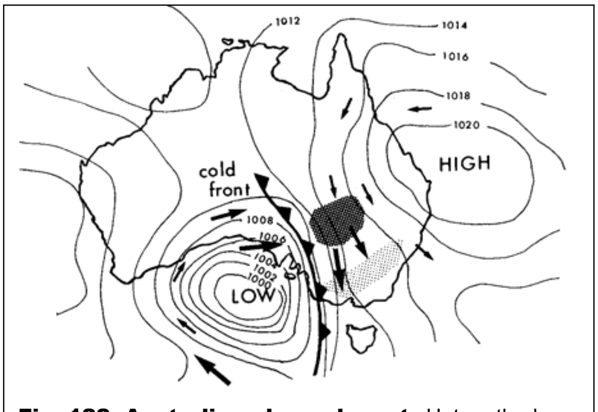


Fig. 122. Australian plague locust. Hot northerly winds ahead of a depression (often associated with a cold front) may induce mass take-off at dusk and long distance migration downwind during the evening. **Cold conditions** in the wake of the depression stop further migration and prevent any return movement. **Night flights** can result in sudden relocation of plagues. Photo© NSW Dept of Industry and Investment.

Management (IPM)

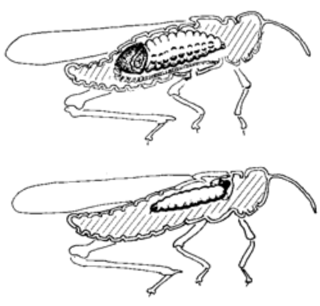
Some state legislation requires landholders to report the presence of plague locusts on their land to a designated authority and to control locusts when the nymphs band together. Insecticide is provided free of charge and can be obtained from your local authority office. Advice is usually available on the state department's website.

1. **Access/prepare a plan**. As part of a program of preventative control the **APLC (Australian Plague Locust Commission)** begins treatment when populations are low and before they reach crops. The aim ideally is to prevent plagues from occurring. The **APLC** engages in operations designed to combat outbreaks, which in the opinion of the Commission are likely to result in damage to rural industries in another State. Protection of crops is **not** the responsibility of the Commission although on occasion that may occur as a consequence of controlling a significant band or swarm target. In some states, landowner are levied a fee to assist with locust control.
2. **Crop, area, region.** Which crop, which State? Recognize variations. Coastal cities, towns and home gardens are less vulnerable.
3. **Identification**. Species must be identified accurately (Diagnostics page 182) or consult a diagnostic service (page xiv).
4. **Monitor, forecast.** The **APLC** conducts **regular surveys** to assess the current size of any concentrated bands of nymphs (hoppers) and adult swarms and issues **Monthly Locust Bulletins**. The printed version of the Locust Bulletin is produced monthly during the spring-autumn period and includes a general summary for each major locust species, details of known distributions with regional forecasts, and maps of locust distributions and rainfall events.
   - **Good records** must be kept.
   - **Forecasting** involves actual observation, monitoring rainfall and weather systems and field surveillance work (driving around rural areas and surveying for locusts).
   - **A Decision Support System (DSS)** integrates large amounts of weather data with locust surveys, reports and light trap records, to predict where an increase in locust activity is likely to occur during favorable weather conditions. Forecasts are published in the Locust Bulletin: www.daff.gov.au/animal-plant-health/**locusts**
5. **Threshold**. Treatment to protect **pasture** alone is not usually warranted unless hopper bands or adult swarms are causing **significant** pasture damage and food for stock is limited. **Crops** are sprayed only if there are swarms or hopper bands in the crop causing significant damage.
6. **Action**. Action must be **coordinated** with authorities before locusts become winged adults if possible, since hopper bands are denser, easier and cheaper to control by aerial or ground spraying than swarms. Home gardeners usually settle on non-chemical methods.
7. **Evaluation.** Review **IPM** program to see if it worked or not. Recommend improvements if required.

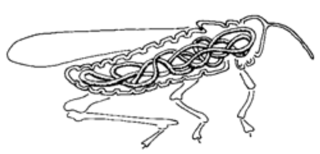
Control methods

Legislation. Effective suppression of locusts can only be achieved by the combined cooperation of the Australian Plague Locust Commission **(APLC)**, State/Territory governments, local councils and private landholders.
www.affa.gov.au/**aplc**
www.daff.gov.au/animal-plant-health/**locusts**

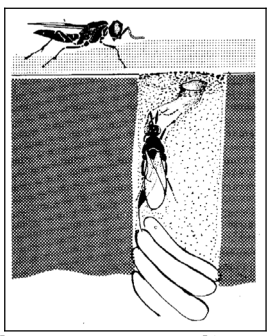
- The **APLC** is a highly specialized unit responsible for the monitoring and forecasting plague locust populations that pose a major threat to agriculture it is jointly funded by the Commonwealth, NSW, Vic, SA and Qld. The **APLC** is a good example of how cooperation between the Commonwealth and State governments can achieve good outcomes.
- **APLC's** role is to:
  - **Manage outbreaks** of the **APL**, spur-throated locust and migratory locust which are considered an **interstate** threat.
  - **Assist States** to manage locust outbreaks in their area of responsibility.
  - **Seek to improve effectiveness** and **safety** of locust field operations.
- **Within a State**, **APL** outbreaks are coordinated and supervised by Departments of Agriculture/ Primary Industries, through local bodies such as the Pastures Protection Boards.
- **Local government** may also undertake spraying operations within their own area.
- **Landholders.** Under provisions of State/ Territory legislation in affected States, landholders have an obligation to report and control hopper bands on their properties. Landholders in some states pay Livestock Health and Pest rates which contribute to the operations of the **APLC**.



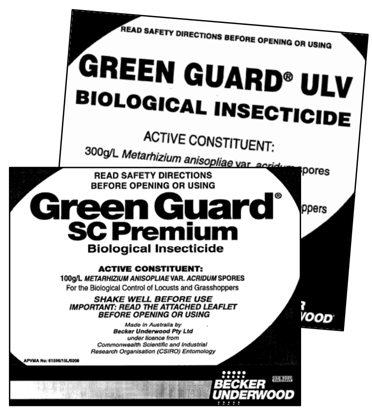
Grasshopper parasites feed internally on the locust. The locust usually dies after the parasite emerges. Photo© NSW Dept of Industry and Investment.



Parasitic nematodes. Photo©NSW Dept of Industry and Investment.



Grasshopper egg parasite (*Scelio* sp.). A small, black wasp burrows through the froth plug of the locust egg pod soon after it is laid and deposits a small egg in each locust egg. Wasp larva feeds on the yolk of the locust egg, pupates inside the egg, and emerges as a wasp 1-2 weeks after un-parasitized eggs have hatched. The parasites are sometimes abundant and can destroy vast numbers of locust eggs. Photo© NSW Dept of Industry and Investment.



Biocontrol agent (*Metarrhizium* sp.)
www.**beckerunderwood**.com/en/home

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Fig. 123. Examples of natural and commercial biological controls.

- **Obtain advice**.
  - Regulations under the relevant Acts prescribe methods of control to be adopted.
  - If an infestation develops on a property, it must be reported to the nearest administering office.
  - Log onto State/Territory websites (page xiv).

Cultural methods. Cultivation of **egg pods** particularly in agricultural areas could destroy eggs, but is not very effective as most egg pods will be missed.

Biological control.

- **Natural enemies**. All stages of locusts may be attacked. The degree of control depends on number of parasites and predators, size of the locust population and the season.
  - **Parasites** include various flies, and wasps.
  - **Predators** include birds, small marsupials, feral pigs, dogs and foxes, lizards, frogs, ants, bugs, ants, spiders.
  - **Diseases** include various fungi, nematodes and protozoa especially in high rainfall areas.
- **Commercial biocontrol agents**.
  - **Green Guard** (*Metarhizium anisopliae* var. *acridium*) has been developed from a naturally occurring fungus as a biocontrol agent for organic properties and environmentally sensitive areas. This fungal strain **only** attacks locusts and grasshoppers and is harmless to all other kinds of organisms. Fungal spores are suspended in a mineral or vegetable oil (to prevent drying out) and sprayed onto locusts using conventional aerial and ground spraying equipment. The live spores germinate on the body of the insect, grow through the skin and eventually kill up to 90-95% of locusts after 7-20 days, but locusts can still damage plants for a number of days after they are infected. Ants and other scavenging insects eat the dead insects and so they are often difficult to find. Further information and a newsletter are available on the **APLC** website.

Physical and mechanical methods.
In gardens netting or shade cloth can be used to protect special or expensive plants.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Insecticides.
Chemical control is difficult. Specific areas or bands or swarms are targeted (Table 37). Blanket spraying over large areas is **not** carried out.

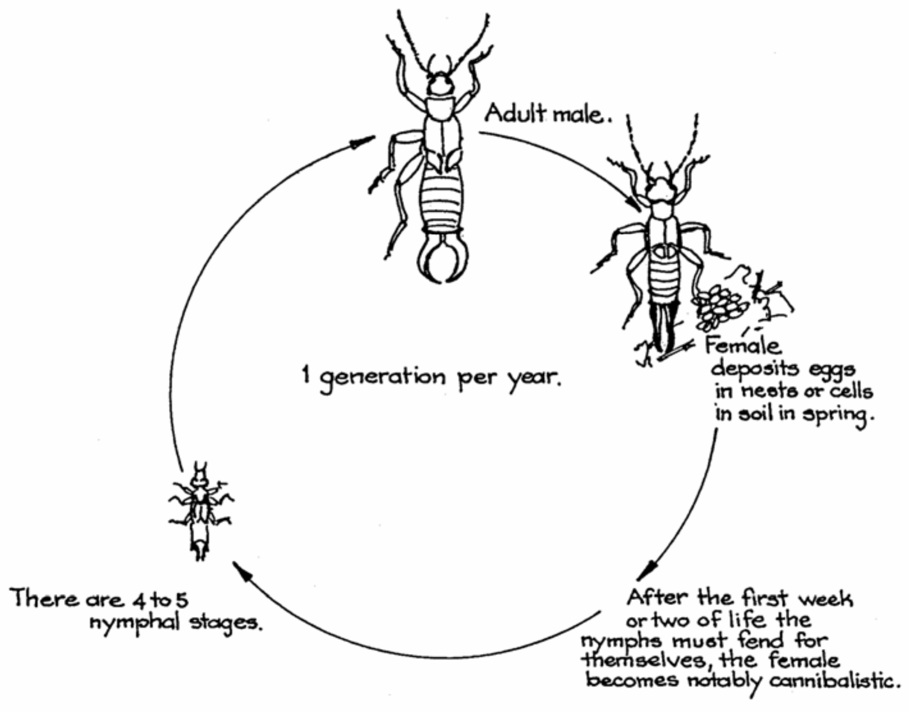
- **Timing**.
  - **Hopper bands**. Treating small areas of dense masses of hoppers can effectively control potentially damaging populations. However, more than 1 application may be needed because eggs may hatch over a period of several weeks. Coordinated use of appropriate sprays on hopper bands can reduce an infestation from a potential major plague to a minor outbreak. Should control measures taken against hoppers fail, swarms may migrate from the breeding area and a plague may develop.
  - **Control of flying locusts** is beyond the scope of an individual landholder. Adult locusts can be controlled by treating swarms with aerial **ULV** applications of an insecticide. Differential Global Positioning Satellite **(DGPS)** units are fitted to spray aircraft to ensure precise application within target areas in pastoral areas inland. **Crop protection** is primarily the responsibility of the grower who should **report** incidence of locusts and obtain information from the local council or appropriate organization.
- **There are 'no spray' buffer zones** of 1.5km between sprayed areas and sensitive areas downwind, eg residences, dams and waterways. In addition no pesticides are applied within 5km of beehives or crops being pollinated by bees.
- **Impact of pesticides on the environment**, eg researching the impact of pesticides on dunnarts (*Sminthopsis macrour*), a small marsupial that looks like a hopping mouse. Dunnarts gorge on locusts and store body fat for the coming winter. So they will ingest a small amount of pesticide.
- **Application equipment**. Locust control is through a combination of ground and aerial pesticide spraying (landholders and **APLC**). Pesticide application methods are improving all the time, eg drift reduction and improved adherence to regulations and other safety requirements.
- The **APLC** also provides advice to landholders and state agencies. **APLC** becomes involved in control when the magnitude of control is beyond the realms of the individual landholder or stage agency and where particular groups of locusts are a threat to interstate agriculture.

Table 37. Australian plague locust – Some insecticides and biocontrol agents.

What to use?	When & how to apply?
CHECK WITH YOUR LOCAL AUTHORITY **Registered insecticides vary from state to state and depend on the situation, crop, etc**. **Group 1A**, eg carbaryl **Group 1B**, eg chlorpyrifos, fenitrothion, maldison **Group 2B**, eg Regent®, various (fipronil) **PERMITS MAY BE REQUIRED** **Group 3A**, eg Tempo® (beta-cyfluthrin) is registered for control of **grasshoppers** on turf, native plants, ornamentals in domestic, and certain other situations.	Locusts can be controlled chemically at the nymph (hopper bands) and adult stages (swarms). Some insecticides may be too persistent for use on some crops and in some situations. Withholding periods must be observed.
Fungal biological control agents GreenGuard™ (*Metarhizium anisopliae* var. *aecidium*.) - various formulations	Various formulations of GreenGuard™ is used by **APLC** against the **APL**, migratory locust, spur-throated locust and wingless grasshopper in situations where insecticides cannot be used to control locusts, eg **certified organic pastoral properties or environmentally sensitive areas**.

ORDER DERMAPTERA

Earwigs

NO. SPECIES IN AUSTRALIA	More than 60 species. Mainly nocturnal, hiding in crevices or forest litter during the day. The common pest is the **introduced** European earwig. The name earwig comes from a European myth that these insects had a habit of crawling into human ears. However, the name more likely originated from the ear-shape of the hind wings. www.ento.csiro.au/education/insects/**dermaptera**.html
SOME DISTINCTIVE FEATURES	**ADULT** **Body** 1. Small to medium dark coloured elongated insects. 2. Body is somewhat flattened with hard outer covering. 3. Highly distinctive 5-50 cm long. **Wings** 1. Two pairs of wings 2. Forewings are very short and hardened (**tegmina**). 3. Hindwings membraneous, ear-shaped and intricately fold under the forewings when not in use. 4. Some species are wingless. **Abdomen** Terminates in a pair of horny forceps termed **'cerci'**. Usually shape of the cerci varies according to the sex, males curved, females straight with a slight inward pointing tip. Cerci are also used to hold food and carry prey after it has been killed. **NYMPHS** Similar to adults but smaller and paler, may be wingless.
LIFE CYCLE **European earwig** About 12-20 cm long	There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. The life cycle has not been studied in detail in Australia, but it appears that there may be only 1 generation per year. 
METHOD OF FEEDING	**ADULT** **NYMPH** All stages have **chewing** mouthparts. Some are valuable predators, others are generally omnivorous (feed on all kinds of food). Earwigs are **nocturnal** feeding at night and sheltering during the day.

PLANT DAMAGE

DIRECT CHEWING DAMAGE

Plant damage is caused by both nymphs and adults feeding. Feed on a wide range of living and dead plant and animal matter. Several species have become cosmopolitan and are pests in some areas.

LEAVES
FLOWERS
FRUIT
SEEDLINGS
SEEDS
ROOTS

Characteristic chewing damage.

INDIRECT DAMAGE

- Presence of earwigs on harvested produce is unpleasant.
- **Droppings** (pellets of excreta) may make plants unsightly and messy.
- Also contaminate windrows at harvest time.
- Potential to become a much worse problem.
- Prop roots of maize and sorghum damaged so that plants lodge (fall over).
- Poor crop establishment.

LIST OF SOME SPECIES

	COMMON NAME	**SCIENTIFIC NAME**	**HOST RANGE (not exhaustive)**
	European earwig Introduced pest species	*Forficula auricularia* **12-20 mm long**	Wide range of plants including ornamental flowers, eg dahlias, roses and zinnias are favored ornamental hosts, fruit, vegetables and field crops. May also feed on seedlings, roots, mosses and lichens. European earwigs also feed on foodstuffs, living and dead insects.
Adults are black and shiny with forceps, probably overwinter as females and lay eggs the following spring	**Black field earwig** Native pest species .	*Nala lividipes* **About 12 mm long** Pest species in Qld and NSW	Usually feeds on decaying material but also eats newly sown and germinating seeds, seedlings, stems, roots, ringbarks stems of crops, eg leucaena, sunflower, summer and winter cereals, azuki beans, beetroot, maize sorghum. Prefers cultivated soil rather than zero till.
Valuable predators	**Common brown earwig** Native species	*Labidura truncata* **About 30 mm long** Found throughout most of Australia and may be common in backyards	A large native earwig that prefers to feed on caterpillars both larger and smaller than itself. They may also feed on other insects including other earwigs if hungry enough. Attacks codling moth larvae searching for cocooning sites.
	Giant earwig Native species	*Titanolabis colossea* **Up to 55 mm long**	One of the world's largest earwigs lives in the wet forests of the east coast. Giant earwigs feed on organic matter and other insects.
	Native earwig	*Gonolabis michaelseni*	Lack the black body and pincers of the European earwig.

European earwig

Scientific name

Forficula auricularia (Dermaptera). Can be a serious pest of some crops, but often just a nuisance or minor pest in a home garden.

Host range

Earwigs are omnivorous feeders and may feed on a range of living and dead plant and animal material.

Crops. Many different types of plants, including **ornamentals**, eg chrysanthemums, dahlias, zinnias, **fruit**, eg grapevines, passion fruit, **vegetables**, eg beans, lettuce, rhubarb, **field crops**, eg barley, canola, lupins, also mosses, lichens and algae.

Others. **Insects.** Both dead and living insects may be eaten. **Foodstuffs.** Houses close to infested areas may be entered and flour, starch, sugar, fat and meat may be eaten. **Clothing and carpets.** May enter houses and chew holes in clothing and carpets. **They prey on a wide range of insects** and mites that might occur in a vineyard, consider its usefulness before using control measures.

Description & damage

Adult earwigs have characteristic pincers (cerci) at the end of the abdomen and are about **12-20 mm** long, brown and have a flattened body. On the upper surface of both the 2nd and 3rd abdominal segments is a pair of pores from which the earwig can eject a liquid with an offensive odour to a distance of **7-10 cm**. Adult earwigs have well developed wings but seldom fly. They are **nocturnal** and usually found during the day hiding in flowers, fruit clusters, vegetable flower head clusters, eg broccoli, rubbish and under bark. **Nymphs** are similar to adults except they are smaller and paler in color.

Plant damage.

- European earwigs tend only to become a problem if populations become large.
- **Emerging seedlings** are damaged to the extent that re-seeding may be necessary.
- **Leaves and flowers (petals)** may become ragged in appearance, ragged holes. Fruit and pods may be chewed. Earwigs also spoil plants by their presence and their excreta.
- **Grain and crop seed** may be contaminated and need cleaning.
- **May be a pest in machine-harvested** fruit in grape vines. Can be a nuisance around packing sheds.

Diagnostics.

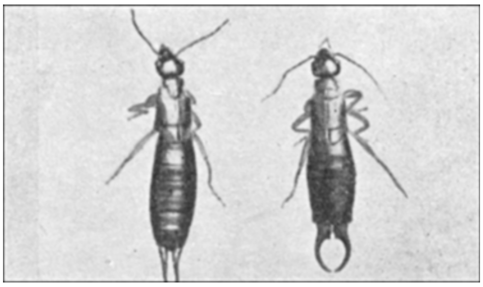
- **The European earwig** is smooth shiny dark brown with pale yellow legs, pincers and shoulders and **12-20 mm** long. **Do not confuse with other earwigs or other insects**, eg
  - **Black field earwigs** which are shiny, black and **12-15 mm** long and which also damage crops.
  - **Native beneficial earwigs** (several species) generally have reddish brown foreparts and legs with a darker abdomen and pincers. They are widespread and mainly feed on leaf litter and other organic matter. They rarely cause any damage to plants. The **common brown earwig** is larger than pest species and up to **30 mm** long.
  - **Rove beetles** which have **no** pincers and are predators living in soil or leaf litter, some feed on dung and fungi.
- **Do not confuse damage** with that caused by other **chewing** pests, eg caterpillars, beetles, grasshoppers, snails and slugs. Earwigs hide in crevices and soil during the day, and are not readily seen.

Pest cycle

There is a **gradual metamorphosis** (egg, nymph and adult) with only 1 generation each year. The female lays 2 batches of 20-80 white oval eggs, the 1st in spring and the 2nd early in summer. Eggs are deposited in burrows in topsoil and hatch in 2-3 weeks. Females guard their eggs until they hatch and may stay for some time with the small, developing earwigs in the nest. The young earwigs grow by a series of moults (thought to be 6 in Australia) until they become winged adults. The 1st and 2nd stage nymphs do not wander far from the nest and quickly retreat to them if disturbed. Both nymphs and adults are nocturnal.

'Overwintering'

As adult earwigs in stubble, under mulch, ground cover, other plant debris, etc.



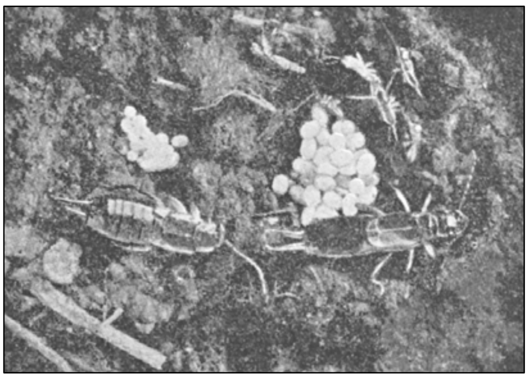


Fig. 124. European earwig (*Forficula auricularia*). Photos© NSW Dept of Industry and Investment.
Left: Female (left) with straight pincers and male (right) with curved pincers.
Right: The female earwig in the nest with the newly hatched nymphs.

Spread

- By nymphs and adults **crawling**, adults have wings but seldom use them. They may slowly spread from around houses and sheds through gardens into neighboring properties.
- Mainly spread by **human activity**, eg
  - Transport of hay, machinery, soil in nursery stock, ornamental plants, bulbs, pot plants, also on contaminated seeds and cardboard boxes.
  - Infestations in caravan parks infest caravans and tents are transported to other parks.

Conditions favoring

- Cool moist weather. Most active during spring and autumn and rarely troublesome during very cold or hot weather. Heavier soil.
- Intensive cropping and stubble retention practices improve the habitat for earwigs. Large populations can build up in stubble from relatively undamaged crops to damage subsequent emerging crops, eg build up in lupin stubble, to devastate later emerging crops of canola. It may be necessary to reseed some crops.
- Use of mulching material and groundcovers.
- Also damage mature crops. After harvest they migrate to windrows where they feed on pods when windrows are put through the harvester to extract seed, the harvester is contaminated and may require cleaning.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Plan** in advance. **IPM** programs are available for some other earwigs, eg black field earwigs on various crops, eg sweetcorn, providing information on monitoring, thresholds and action levels.
2. **Crop, region.** Obtain **information** on **local** pest species and their control.
3. **Identification** of species must be confirmed. Earwigs are only a problem if numbers are large. Distinguish between local pest and beneficial species. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** earwigs and/or damage weekly early in the season if they were a pest the previous season, record results. For vegetable crops, lightly scrape soil and sieve to detect adults and nymphs prior to planting, use germinating seed baits, etc. For grapevines, knock vines sharply to dislodge any sheltering earwigs, band with corrugated cardboard and examine soil around trunks.
5. **Thresholds** have been established for some crops. How much damage can **you** accept? If so, what are they, eg economic, aesthetic, environmental? Do you need to calculate your own thresholds?
6. **Action.** Take appropriate action when decided threshold is reached. Home gardeners usually settle on non-chemical methods eg sanitation, traps.
7. **Evaluate** procedures to see how well they worked. Recommend improvements if required

Control methods

Sanitation. Removal of rubbish, decaying plant material and other debris, where earwigs might breed and shelter during the day, assist control. See also Plant quarantine below.

Biological control. No biological control agents are available for purchase or been released.

- Birds are well known predators of earwigs.
- They may be parasitized by some insects and a nematode. The offensive fluid they eject may repel some predators and parasites.

Plant quarantine.

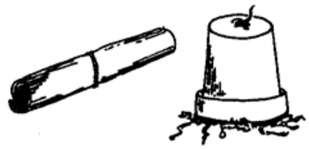
- **State/regional quarantine.** The European earwig was discovered a few years ago in WA. The **Industry Resource Protection Program**, **Agriculture WA**, is surveying the extent of infestation. Occurrences in WA should be reported to Agricultural Protection Board in your district, so their spread can be restricted.
- **Ensure that all machinery**, vehicles and equipment arriving on your property has been cleaned. Also ensure that you minimize the risk of spreading them in WA.

Pest-tested planting material.

- Check seed and plant material for live earwigs before bringing them onto your property. Only plant earwig-free material.

Physical & mechanical methods.

- **Indoors.** Earwigs can be swept up and destroyed as found. They breed outdoors and invade houses. Put in plastic bag and leave in sun for a day.
- **Crops.** Burning stubble has shown some success but is not a preferred option because of the risk of wind erosion and environmental pollution.
- **Garden traps.** Earwigs hide during the day and can be attracted to shelter traps placed in areas where they are a problem.
  - Rolled newspapers or rolled corrugated cardboard.
  - Upturned flower pots filled loosely with straw or crumpled or torn paper.
  - Examine traps twice per week and destroy earwigs by shaking into a bucket of soapy water. Paper rolls could be destroyed directly by burning if permitted.



Insecticides. Control with contact insecticides is difficult because earwigs shelter under mulch, bark, organic matter, in fence posts and other inconspicuous places. Baits are used in some crops (Table 38).

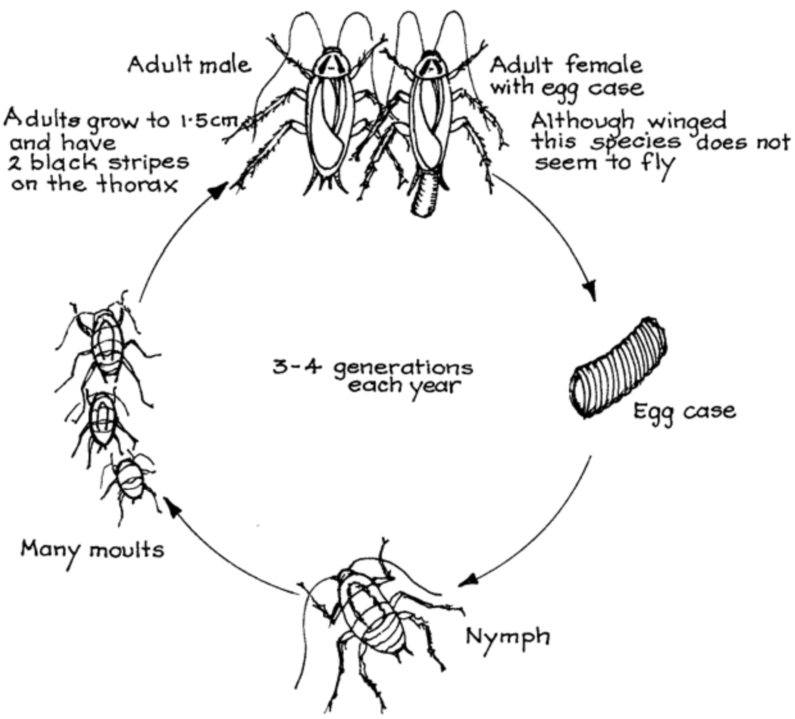
ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 38. European earwig - Some insecticides.

What to use?	When and how to apply?
OUTDOORS **Group 1A**, eg various (carbaryl) – some residual activity **Group 1B**, eg various (chlorpyrifos) - **baits** **Group 22A**, eg Avatar® (indoxacarb) **Various home garden products**, eg pyrethrins; Beat-A-Bug® Insect Spray (chilli/garlic/pyrethrins); Baythroid® (cyfluthrin)	Home gardeners should **not** need to use insecticides. Commercially, **grain baits** containing insecticide, **seed dressings** and **sprays** offer some protection. Baits may be more effective if earwigs are present on the ground. No insecticides may be registered for your crop. **Seek advice for spray/bait recommendations for your region and your crop.**
SEED TREATMENT **Group 4A**, eg.Picus® Seed Treatment Insecticide (imidacloprid) is used to control **black field earwigs** in **certain crops**	Only apply to healthy seed.
INDOORS	Remember earwigs breed outside. Shovel up earwigs found inside and if necessary control earwigs **outside**.

ORDER BLATTODEA

Cockroaches

NO. SPECIES IN AUSTRALIA	Over 450 Australian species, most live under stones, logs and bark, some are useful predators, most are not pests. The best known cockroaches are the **introduced species** that infest houses, restaurants and other buildings. Due to global changes, evolution scientists warn that pest animals such as cockroaches and rats will flourish at the expense of more specialized wild organisms. www.ento.csiro.au/education/insects/**blattodea**.html www.amonline.net.au/factsheets/**cockroaches**.htm
SOME DISTINCTIVE FEATURES	**ADULT** **Body** 1. **Oval shape,** up to **70 mm** long. The body is **flattened** so they can make use of tight hiding places, eg cracks and crevices. 2. **Thorax** covered by a large plate (**pronotum**) which extends partly over the head. 3. Two **compound** eyes, two simple eyes (**ocelli**). 4. Long many segmented antennae. 5. Prominent cerci. **Wings** 1. Winged or wingless, two pairs wings when present. In winged species females are wingless. Many do not fly. 2. Hardened forewings (**tegmina**) cover membranous hindwings. Wings folded left over right when at rest. **Legs** 1. They can run quickly if disturbed. 2. Long spiny legs. **NYMPH** Generally resemble adults, except for their wings, genitals and sometimes body covering.
LIFE CYCLE **German Cockroach** Up to 15 mm long Although winged, this species does not seem to fly Probably the most widespread and successful species that co-exists with humans in buildings	There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. Eggs are laid in an egg case (capsule) containing 16-40 eggs. In some species this is carried by the female, protruding from the end of her abdomen. 
METHODS OF FEEDING	**ADULT, NYMPH** Both adults and nymphs have **chewing mouthparts** with **strong toothed mandibles**. Cockroaches are **nocturnal**, usually hiding during the day and coming out to feed at night.

PLANT DAMAGE

DIRECT CHEWING DAMAGE

Pest species **will eat almost anything**. Native species are often found in flowers and on foliage of a wide range of native or exotic plants but do not seem to do any harm, they probably also feed on detritus associated with surface leaf litter and some can feed on and digest the rotting logs they live in. Some native species feed on pollen, others on honeydew.

NEW ROOTS AND SHOOTS Cockroaches gnaw on soft tissue in greenhouses, crops.

INDIRECT DAMAGE

- Spoil food with their **excreta** and their **characteristic odour**.
- **Spread disease** by physically **transporting disease organisms.** *Salmonella* organisms are passed on to food in this way.
- General annoyance, allergy, bites.

LIST OF SOME SPECIES

Introduced pest species can be difficult to tell apart (Gerozisis and Hadlington 2001)

Many more pest cockroaches overseas

Many more native species, some are endangered

COMMON NAME	SCIENTIFIC NAME	HABITS
INTRODUCED PEST SPECIES (various families)		
German cockroach, Russian cockroach Probably originated in Asia	*Blattella germanica*	Domestic and commercial kitchens and other food handling areas. Will eat almost any organic material found in these areas, eg crumbs, built-up grease
American cockroach	*Periplaneta americana*	Largest cockroach that infests buildings. Pest of buildings, will eat almost any food (like the German cockroach). Adults can survive for **3-4 months** without food
Australian cockroach Probably originated in Asia, warm subtropical to tropical areas	*P. australasiae*	Prefers food of plant origin. Often found under bark or leaf litter in gardens, wood piles, also other locations that offer moist decaying vegetable matter, eg greenhouses, sub-floor voids, wall cavities, garages and sheds. May fly in warm weather
Oriental cockroach	*Blatta orientalis*	Commonly encountered outdoors under leaf litter and bark and in damp sub-floors around drainage systems. Feeds on a variety of decaying organic matter in garbage disposal areas, starches, wall paper sizing and books may be attacked
Brownbanded cockroach	*Supella longipalpa*	Relatively small, tends to be an indoor pest often infests the dwelling parts of the buildings as well as offices, kitchens. Scattered throughout buildings
Smokybrown cockroach	*P. fuliginosa*	Prefers food of plant origin and is often a pest in greenhouses, bush houses, nurseries, gardens, indoor plants, ferns, epiphytic orchids
AUSTRALIAN SPECIES (various families)		
Giant burrowing cockroach Rhinoceros cockroach	*Macropanesthia rhinoceros*	Lives in tunnels in soil in north Qld. Females feed their young on dead leaves. It can reach up to **70 mm** in length, weigh up to **30 g**, may hiss when threatened. May be kept as pets; they live for years. www.**insectfarm**.com.au/
Wingless cockroach	*Calolampra* spp.	Nips off seedlings at ground level, eg cotton, sunflower, sorghum, maize, leucaena, summer cereals
Nullarbor caves cockroach	*Trogloblattella nullarborensis*	Lives in caves, is blind and restricted to cave life

'OVERWINTERING'	• All stages, eg adults, nymphs, but varies with the species.
SPREAD	• Some winged species fly short distances in warm weather, eg American and Oriental cockroaches. • Transportation on ships, containers, aeroplanes, trains, etc.
CONDITIONS FAVOURING	• Warm moist weather, plenty of food. • Active during warmer months. • Conservation tillage, which also favours other soil pests.
INTEGRATED PEST MANAGEMENT	**STEPS IN IPM** Are you a commercial grower or home gardener? 1. **Access/prepare a plan** if there is a history of cockroach infestation. Obtain advice from your local department of agriculture. 2. **Crop, region.** Is your situation a crop, glasshouse, or domestic premises? 3. **Identify** the species causing the problem and prepare a prescription sheet so that you know its life history. Consult a diagnostic service if necessary (page xiv). 4. **Monitor.** Depending on location, check premises/crops at **night**; set suitable traps (see above). If cockroaches are present during the **day** infestation is serious. 5. **Thresholds**. In food areas there is a **nil** threshold. In crops how much damage can you accept? Have any thresholds been established? 6. **Action.** Choice of appropriate controls often realistically involves the use of an insecticide and sanitation measures, whether it is in a crop or a building. 7. **Evaluation** must include continual monitoring **after** treatment, recording results and recommending improvements/continued treatment.
CONTROL METHODS	Cockroaches may be difficult to control, but their tendency to form groups assists control. **LEGISLATION** • Health legislation requires that pest species be controlled. Inspections, fines and closures occur. **CULTURAL METHODS** • Reduce water availability. • Balance conservation tillage against degree of infestation. **SANITATION** • Do not leave crop debris lying around in greenhouses and bush houses. • Store food in tight cockroach proof containers. Regularly clean up food remains and empty garbage. In houses seal cracks in cupboards, etc. **BIOLOGICAL CONTROL** • Predators include birds, marsupials, lizards, frogs, mice. • Parasites such as hatchet wasps lay their eggs in cockroach egg capsules. **PHYSICAL & MECHANICAL METHODS** • **Sticky traps** placed in appropriate places will capture some cockroaches but on their own do not achieve high levels of control. They are useful for monitoring for the presence of cockroaches in **IPM** programs. • **Inspection** at night by torchlight is useful for determining numbers. **INSECTICIDES** • **Insecticides may be applied to:** – **Crops**, eg seed dressings and baits may be applied, some by air. – **Commodities**, eg fumigants. – **Buildings**. ❑ Cleanup before application. ❑ Surface sprays to skirting boards, cracks. ❑ Space sprays indoors may be applied as high pressure aerosols, mists or fogs. Occupants must vacate the premises. ❑ Aerosol and bombs. ❑ Dusts applied to their body are ingested during grooming. ❑ Baits. ❑ Fumigants. • **Re-infestation** may occur some time after treatment due to subsequent hatching of eggs not directly affected by insecticides. • **Follow Resistance Management Strategies** on insecticide labels.

ORDER PHASMATODEA

Stick insects, leaf insects, phasmatids

NO. SPECIES IN AUSTRLIA

There are over 150 species. Most species are relatively rare and of unusual appearance to the extent that they can be purchased and are often kept as pets. There is a 'Friends of the Phasmid' website which is the gate way to information on the critically endangered stick insect (*Dryococelus australis*):

www.ento.csiro.au/education/insects/**phasmatodea**.html

www.**friendsofthephasmid**.org.au/ www.**insectfarm**.com.au

SOME DISTINCTIVE FEATURES

ADULT

Body

1. Medium to very large insects.
2. Most are long and thin, **3–30 cm** long, or flattened.
3. Most species resemble sticks, grasses, leaves, etc. Stick and leaf insects are usually **well camouflaged**, blending well with twigs and green or dead leaves when motionless.
4. Do not confuse members with praying mantids (Order Mantodea, page 195).

Wings

1. **Wings mostly absent**. In winged species, there are 2 pairs, males have developed wings, females usually have very small wings but are unable to fly.
2. Forewings are small and leathery (**tegmina**) to protect and cover part of the large membraneous hind wings.
3. Hindwings are small relative to the size of the insect. Leading edge of the hindwings is often hardened.

Legs Forelegs are **not modified** for catching prey.

NYMPH Usually resemble wingless adults. Occasionally 1st stage nymphs may be brightly coloured, mimicking ants.

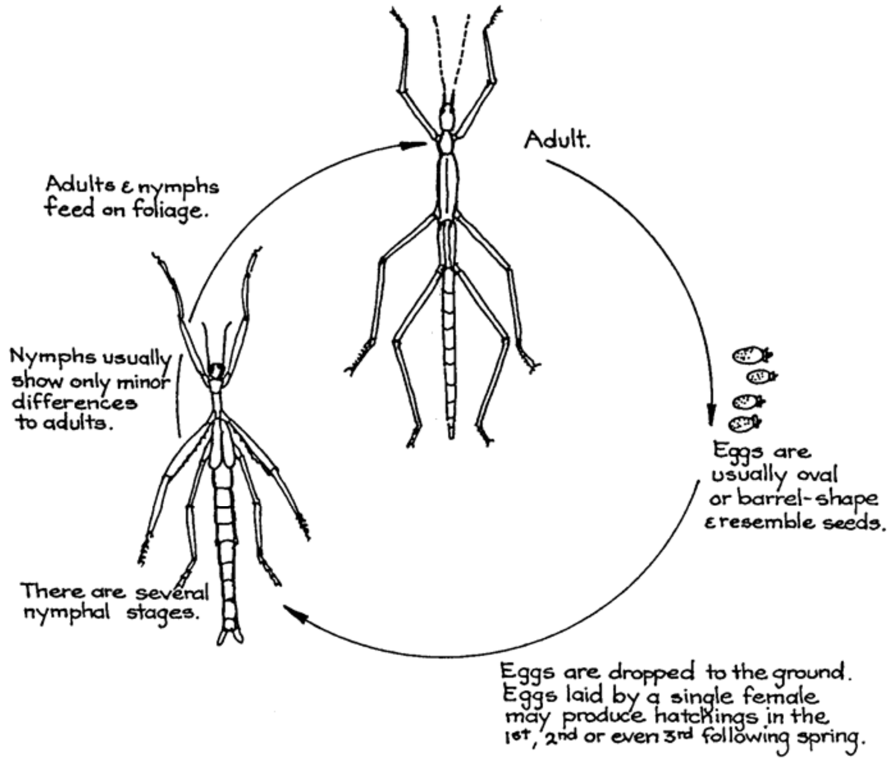
LIFE CYCLE

There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult.

Stick insect

Compare with Mantodea

Length of life cycle varies from 1-3 years



Phasmatid **eggs** may be eaten by ants and other insects, lizards and mice or parasitized by tiny wasps. **Adults and nymphs** may be eaten by reptiles, birds and other insects including praying mantids.

METHOD OF FEEDING	**ADULT NYMPH**	All stages have chewing mouthparts and feed on the leaves of a large variety of plant species. All species feed on the leaves of trees and shrubs, although a few species are known to eat grasses.
PLANT DAMAGE	Not really a horticultural or garden pest but at least three species are major pests of eucalypt forests. Most species are uncommon, but some species reach plague proportions at irregular intervals and defoliate forests. **DIRECT CHEWING DAMAGE** **LEAVES** Eucalypts in forests may be completely defoliated. Several species may reach **plague numbers** at irregular intervals. Rarely a problem in urban areas. **INDIRECT DAMAGE** • Can give handlers a painful bite.	

LIST OF SOME SPECIES	**COMMON NAME**	**SCIENTIFIC NAME**	**HOST RANGE (not exhaustive)**
Brock, P. D. and Hasenpusch, J. W. 2009. *A Complete Field Guide to Stick and Leaf Insects of Australia*. CSIRO Publishing	Stick insects	*Acrophylla spp.* **adult 36 cm long**	Leaves of a wide range of plants, usually solitary and rarely warrant removal. Wülfing's stick-insect, giant walking stick (*Acrophylla wuelfingi*) is often kept as a pet
	Goliath stick insect	*Eurycnema goliath*	Found over much of northern Australia and down the east coast. Females grow up to 25 cm
Plagues	Ringbarker phasmatid	*Podocanthus wilkinsoni* **adult 8 cm long**	May reach **plague numbers** and defoliate whole eucalypt forests
	Spiny leaf insect	*Extatosoma tiaratum* **adult 20 cm long**	Can cause significant damage to **eucalypt forests**, but rarely a garden pest. Also feeds on *Acacia* spp., other plants. Often kept as a pet.
Plagues	Spurlegged phasmatid	*Didymuria violescens* **adult 18 cm long**	May reach **plague numbers** and defoliate whole eucalypt forests. One of the few pests which has **required aerial application** of an insecticide to protect native forests from excessive damage
Plagues	Tessellated phasmatid (Australia-wide)	*Ctenomorphodes tessulatus* **adult 22 cm long**	May reach **plague numbers** and defoliate whole eucalypt forests, may kill forest red gums (*Eucalyptus tereticornis*) Associated with eucalypt dieback. Also attacks *Allocasuarina, Lophostemon*. The ten-inch stick (*Ctenamorphodes briareus*) is often kept as a pet
Endangered	Lord Howe Island stick insect, land lobster	*Dryococelus australis* **adult15 cm long** Became extinct and re-discovered 2001 Resembles a big brown sausage with spiny legs	The world's **oldest and rarest species** of insect feeds on tea tree bushes. Eggs and nymphs eaten by introduced rats. Three insects were found in 2001 on Balls Pyramid, a volcanic rock without rats, jutting out of the sea north of Lord Howe island

ORDER MANTODEA

Mantids, praying mantids

NO. SPECIES IN AUSTRALIA

More than 160 species in Australia. About 18,000 species worldwide. Mantids are considered to be beneficial, preying on insects of all kinds. Some large species will feed on frogs and small lizards. Owing to their low numbers they are unlikely to significantly affect populations of beneficial insects. Green mantid (*Orthodera ministralis*) is a common garden species.

www.ento.csiro.au/education/insects/**mantodea**.html
www.brisbaneinsects.com/brisbane_hoppers/**Mantids**.htm

SOME DISTINCTIVE FEATURES

Have a characteristic way of standing with forelegs held together as if in prayer while waiting for prey

Members of this order are fairly homogeneous in appearance. The praying mantis is so called because of its praying pose as it sits in wait for passing insects. Mantids usually occur as single individuals in tree tops to ground level.

ADULT

Body
1. Generally fairly large and elongated, **1-12 cm** long.
2. Most mantids are green or brown and well camouflaged.

Wings
1. Two pairs. Forewings are **narrow and thickened** and cover membranous hindwings, broad and folded in longitudinal plaits when at rest. Some species have reduced wings or are wingless.
2. Males of most species are fully winged and can fly while females have either reduced wings or no wings at all.

Legs Front legs modified with 1 or 2 rows of spines for seizing prey from ambush (**raptorial legs**).

Head
1. **Triangular head** which moves freely.
2. Antennae long and thin.
3. Large compound eyes and 3 simple eyes (ocelli).

NYMPH Similar to adults but wingless, light in colour, often eaten by other insects, spiders and birds.

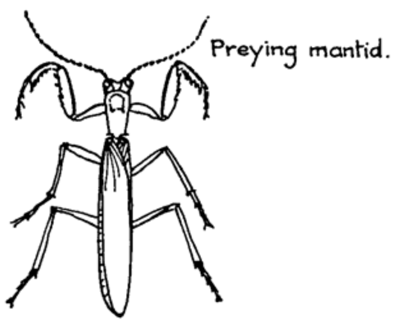
LIFE CYCLE

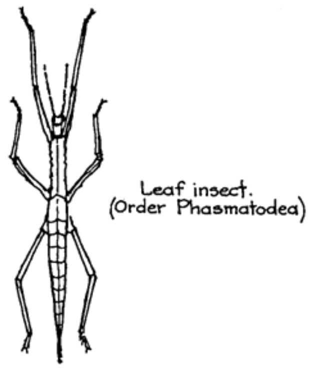
There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult with 1 generation each year in colder climates. In the tropics 2 overlapping generations may occur each year.

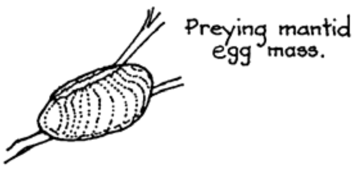
Praying mantid

Compare praying mantids with leaf insects (Phasmatodea) which do **not** have raptorial legs

Some lacewings (Neuroptera) also have raptorial front legs.







Praying mantids lay their eggs in a frothy mass attached to branches and trunks of plants or placed on the ground under logs or stones. The frothy mass hardens, emerging nymphs resemble wingless adults. Eggs hatch and each little mantid forces its way through the opening at the top of the egg case. The surface of the hardened egg mass often has small round emergence holes of wasps which have parasitized and destroyed the mantid eggs inside. Ants, small mammals and birds may eat the eggs.

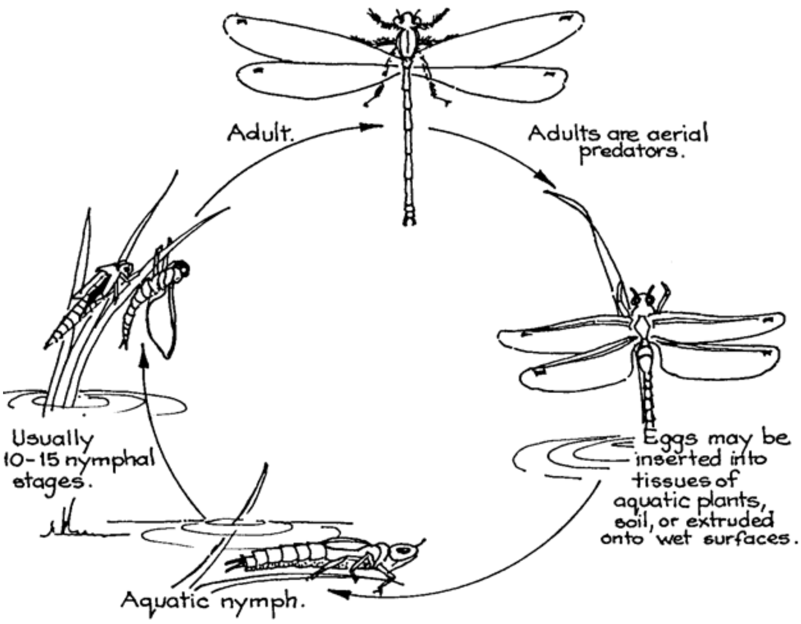
METHOD OF FEEDING

ADULT
NYMPH

All stages have **chewing** mouthparts. All mantids are **predators**, eating insects of all kinds. They adopt a ‘sit and wait’ method for capturing prey. Very large species in northern Australia may eat small frogs, birds and lizards. Males and female mantids may eat their young, females may eat males. Mantids may bite if handled.

ORDER ODONATA

Dragonflies, damselflies

NO. SPECIES IN AUSTRALIA	More than 300 species in Australia. As both adults and nymphs eat large numbers of mosquitoes and other insects, they are considered to be **beneficial insects**. Nymphs and adults are eaten by fish, frogs, birds and platypuses. Some are endangered, eg giant dragonfly (*Petalura* sp.). www.ento.csiro.au/education/insects/**odonata**.html Lucid Key: *Dragonflies of the World* www.**lucidcentral**.com/ Theischinger, G. and Hawking, J. 2006. *The Complete Field Guide to Dragonflies of Australia*. CSIRO Publishing.
SOME DISTINCTIVE FEATURES **Do not confuse with:** • Damsel **bugs** which have a sucking beak (also predatory) or • **Flies** which only have 1 pair of wings	**ADULT** **Body** 1. Long slender bodies up to **7.5 cm** long. about 15cm long. 2. Abdomen long, slender, cylindrical and soft. 3. Short legs. 4. **Dragonflies** – Internal gills. **Damselflies** – Have **3 leaf-like gills** for extracting oxygen at the tip of the abdomen. **More colorful** bodies than dragonflies. **Head** 1. Two large compound eyes on the side of the head. 2. Three simple eyes (ocelli) between the compound eyes. The simple eyes assist in stabilizing their flight. 3. Very small antennae. **Wings** 1. Two pairs long rigid membranous wings of similar shape and size. **Dragonflies** – Hind wings **slightly broader** than forewings. Wings held **horizontally** when at rest. **Damselflies** – Fore and hind wings about the **same size**. Wings held **vertically** when at rest. 2. Strong fliers, in fact they are aeronautical marvels, no small aircraft can surpass them. **NYMPH** **Aquatic** (fresh water). Only slightly similar to wingless adult, with mouthparts specially modified for catching prey. Adults are commonly found near fresh water though some roam far afield.
LIFE CYCLE **Dragonfly** Some variations, eg nymphs of some species in Qld have been recorded as being terrestrial, some dragonflies in Carnarvon in WA lay eggs in young stems of French beans	There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult with 1 to several generations each year depending on the species. 
METHOD OF FEEDING	**ADULT** **NYMPH** All stages have **chewing** mouthparts. Adults are **aerial predators** while nymphs are **aquatic predators**.

ALLIED PESTS - Springtails

Class Collembola

Scientific name

Class Collembola, Phylum Arthropoda. There are more than 1600 species in Australia.
www.ento.csiro.au/education/hexapods/**collembola**.html

Species include:

Garden springtails (*Bourletiella* spp.)
Mushroom springtails (*Hypogastrura* spp.)
Purple scum springtail (*H. vernalis*)
Rootfeeding springtails (*Onychiurus* spp.)
White springtail (*Folsomia candida*)
Lucerne flea (*Sminthurus viridis*) is a serious introduced pest of lucerne, vegetables, etc.

The Toohey forest collembola (*Dinaphorura tooheyensis*) is being assessed by the threatened species scientific committee.

Beneficial springtails.

- Litter and soil species play a role in the maintenance of soil fertility by helping to breakdown organic matter through grazing on fungi and vegetable matter.
- The grazing of large populations of the sewage springtail (*Hypograstrura viatica*) controls excessive algal growth in sewage beds.

Host range

Adults and nymphs feed on the **same material**. Springtails are mainly scavengers feeding on fungi, algae, pollen but **under exceptional conditions** may injure soft plant tissue of a range of plants, eg

- **Mushrooms** and **mushroom compost** where they feed on decaying organic matter and fungi.
- Occasionally healthy **seeds** and **seedling roots** and **shoots** are attacked.
- Some species are found in **turf cores**.
- **Compost, potting mixes** and **soil**.
- **Bulbs** and **corms** are also damaged.
- Some species live amongst **moss**.
- Springtails may live in **perennial** plant production systems; **field crops** can also be injured.

Description & damage

Adult springtails are generally **< 6 mm** long with the most frequently observed species being **white or gray** and about **1-3 mm** long. Rarely up to 10mm long. Some are green or yellow with irregular darker markings; or blue-black, red or banded with a metallic sheen. They are primitive insects and the bodies of some species are covered with scales or hairs. **Springtails** have:

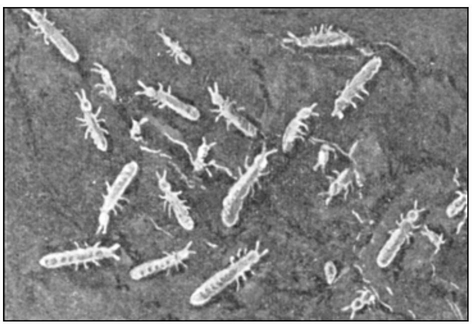
- A bilaterally symmetrical body.
- An exoskeleton (outer hard covering to body).
- A segmented body.
- Three pairs of legs.
- One pair of antennae.
- Simple eyes.
- Entirely and primitively **wingless**.
- Many have a forked **furcula** on the abdomen for jumping. The popular name of 'springtail' has been applied because some species bear a 'spring', a pair of partly joined appendages, at the end of the abdomen which enables them to spring or jump when disturbed.

Nymphs resemble adults but they are smaller.

Damage. Springtails have tube-like chewing mouthparts sunk into the head. Springtails are often found in very large numbers in mushroom compost where they can damage the crop if present in high enough numbers. Seeds and seedlings may also be damaged, corms rot. Delicate foliage of growing plants may occasionally be attacked.

Diagnostics.

- Springtails are so small that they are seldom noticed except by those looking for them. Some are more easily seen with the aid of a microscope or hand lens.
- Most commonly noticed after rain as small 'grayish scum' floating in their hundreds in puddles of water ceaselessly moving or springing on top of soil or pools in open drains, where the water is still, **not** moving.
- They are sometimes mistaken for **thrips** moving over potting media especially after plants have been irrigated.



White springtails on soil.

Side view of springtail

View from above

Fig. 125. Springtails (Class Collembola) commonly 1-3 mm long.
Photos© NSW Dept of Industry and Investment.

Pest cycle

There is **no metamorphosis** (eggs, 5-6 nymphal stages, adult) with several (3-4) generations each year. Adults continue to grow and alternate between a **stage** that usually does not feed, but can reproduce, and one that cannot reproduce but does most of the feeding. Each generation takes about 3-5 weeks. The female springtail lays minute semi-spherical eggs in small groups in the soil or among organic matter where adults may be feeding. The eggs hatch into young which resemble the adult in general form and grow by a series of moults.

'Overwintering'

Probably as eggs in soil among organic matter but they may occur all year round if moisture is present and it is not too hot or cold.

Spread

- By floating on water in drainage channels, pots, streams.
- Movement of decaying vegetable matter or soil containing such.
- Movement of turf sod, containers, etc.

Conditions favoring

- Favoured by prolonged cool, damp or wet weather in autumn and spring.
- Common following rain or heavy watering. Springtails float on the surface of drainage water.
- Stagnant water.
- Decaying moist organic matter, eg compost heaps, leaf mould.
- Numbers decrease during warm summer months when soils are drier.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** if necessary, that fits your situation.
2. **Crop, region.** Remember springtails may be generally beneficial and only occasionally damage some crops, eg mushrooms, seedlings.
3. **Identification** of pest must be confirmed. Do not confuse with thrips (page 130). Consult a diagnostic service if necessary (page xiv).
4. **Monitor** populations of springtails and beneficials especially during cool, damp weather, where there is stagnant water and they are known to be a problem. Remember you need to know **when, where, what and how to monitor** (page 39). Record findings.
5. **Threshold.** How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic or environmental? Do you need to calculate your own threshold?
6. **Action.** You may need to reduce irrigation, improve drainage and encourage natural enemies by minimizing insecticide use. It is **not** necessary to use insecticides in the home garden.
7. **Evaluation.** Review the **IPM** program. Adjust control strategies if required.

Control methods

Cultural methods. Reduce moisture. If planting seedlings in soil heavily infested with springtails, liming and frequent turning over of the earth before planting will reduce their numbers and the risk of injury to plants. Reduce irrigation, improve drainage.

Biological control. Natural enemies include ants, beetles, bugs, mites and probably spiders. Birds will feed on them.

Insecticides. In a **home garden** situation pesticides are not recommended. In **commercial crops** insecticides may be applied to soil or plants only if monitoring indicates there is likely to be there is to be economic injury to seeds or seedlings.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 39. Springtails – Some insecticides.

What to use?	When and how to apply?
SPRAYS, eg **Commercial crops only**, eg **Group 1B**, eg Lorsban®, various (chlorpyrifos) is registered to control springtails in young cotton plants. **Insecticides are not necessary in the home garden**.	Springtails occasionally may require control in some commercial crops, eg cotton, mushrooms, turf, vegetables. It may be necessary to add a wetting agent. **Insecticides should only be applied:** • After springtails have been identified, and numbers indicate damage is likely to occur. • When cultural control methods such as reduced moisture do not bring about a quick reduction in numbers and • If seeds or seedlings of commercial crops are likely to continue to be injured.

ALLIED PESTS - Mites

Class Arachnida, Order Acarina

NO. SPECIES IN AUSTRALIA

Probably several hundred species in Australia and approximately 30,000 species world wide. Most mites are too small to be seen with the naked eye, so that identifying them as the cause of a plant problem can be difficult.

www.ento.csiro.au/education/allies/**acarina**.htm

Lucid keys *Mites of Quarantine Importance, Mites in Soil, Invasive Mite Identification*
www.**lucidcentral**.org/

SOME DISTINCTIVE FEATURES
.

ADULT **Body**

1. **Two main body regions** (fused head/thorax, abdomen). However, the body **appears** to have just 1 body segment Compare with insects which have 3 obvious body regions.
2. Small in size.
   Mites - Up to **1mm** in length, many are much smaller.
   Ticks - Larger than mites.
2. No antennae or wings.
3. Simple eyes.
3. Globular or pear-shaped.

Legs

1. Usually 4 pairs (some nymphs have 3 pairs).
2. Eriophyid mites have only 2 pairs of legs.

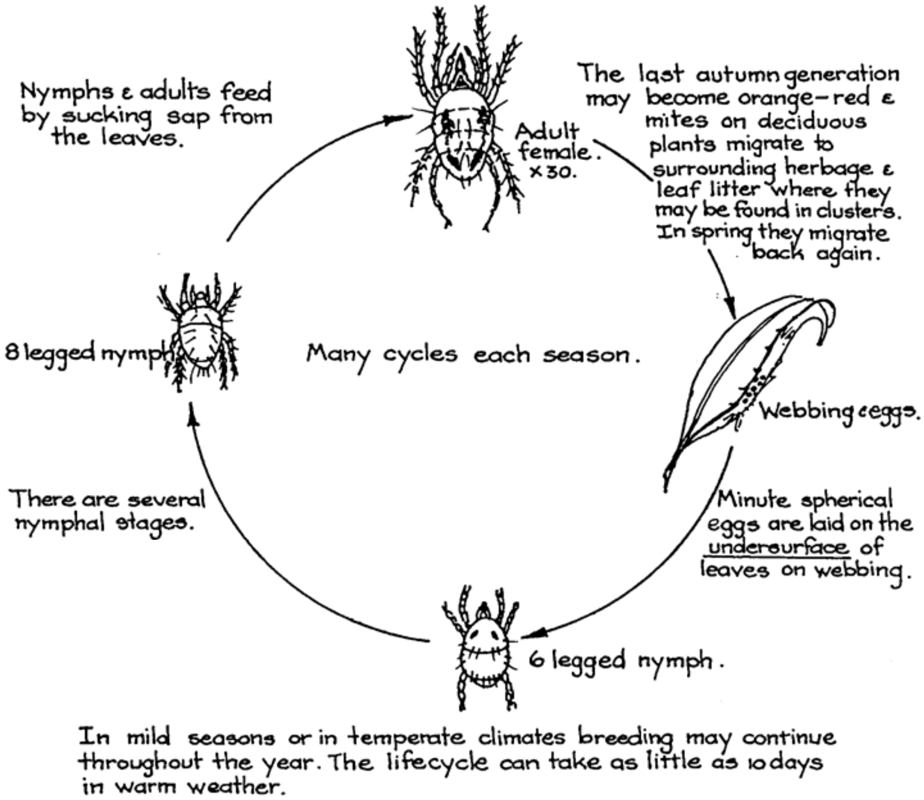
NYMPH Usually similar to adults but smaller, some only have 3 pairs of legs.

LIFE CYCLE

There is a **gradual metamorphosis** – egg, nymph (**several stages**) and adult.

Twospotted mite
(red spider)

Adults are about **0.5 mm** long, but are difficult to see without a hand lens



METHODS OF FEEDING

ADULT All stages have piercing and sucking mouthparts. Mites feed on a

NYMPH variety of plants and animals, both living and dead.

PLANT DAMAGE

DIRECT SUCKING DAMAGE

LEAVES SHOOTS
- **Blisters, curls**, eg grapeleaf blister mite, pearleaf blister mite, walnut blister mite, native eriophyid mites, broad mite
- **Bud mites**, eg camellia bud mite
- **Chlorosis** (sandy stippling, may turn grayish), eg twospotted mite
- **Defoliation**, eg twospotted mite (large populations on many plants)
- **Erineum**, eg grapeleaf, pearleaf and walnut blister mites
- **Leaf rolling**, eg twospotted mite (on apples)
- **Pigmentation**, eg European red mite (bronzing), grapeleaf blister mite (pink)
- **Silvering**, eg peach silver mite, earth mites on grasses, etc
- **Witches' broom**, eg lucerne bud mite, native eriophyid mites

BULBS,
- **Rotting**, eg bulb mite

STORED PRODUCTS
- **Droppings, odour**, eg flour mite

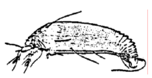
FRUIT
- **Malformation**, eg citrus bud mite
- **Russetting**, eg citrus rust mite, tomato russet mite

STEMS
- **Bronzing**, eg tomato russet mite
- **Galls**, eg Chrondilla gall mite on skeleton weed (bio-control agent)

INDIRECT DAMAGE

- Webbing by spider mites.
- Virus disease transmission (unusual), eg fig mosaic virus.
- Grass itch mite (*Odontacarus australiensis*) and scrub typhus mite (*Leptotrombidium deliense*) suck blood from wild birds and animals, domestic cats and humans causing intense irritation.
- Varroa mite (*Varroa destructor*), about the size of a pinhead, is an external parasite of bees. Australia is the last major beekeeping country free from this serious pest of honey bees which weakens and kills honey bee colonies and can also transmit honey bee viruses.

LIST OF SOME SPECIES



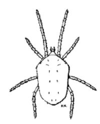
Eriophyid mite

ERIOPHYID MITES (Family Eriophyidae)

1. Very small, **0.2 mm** in length
2. Elongated, tapered body
3. Only **2 pairs legs** located at head
4. Cannot be seen with naked eye and is hard to see with a hand lens

There are more than 1000 species of eriophyid mites which infest plants worldwide; many do little harm to their hosts - a x40 lens is needed to see them

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Camellia rust mite	*Acaphylla steinwedeni*	Camellia
Citrus rust mite	*Phyllocoptruta oleivora*	Citrus, esp. oranges, mandarins
Citrus bud mite	*Eriophyes sheldoni*	Citrus
Couch mite	*E. tenuis*	Bent, couch, kikuyu
Couchgrass mite	*E. cynodoniensis*	Bent, couch, kikuyu
Hibiscus erineum mite	*E. hibisci*	Malvaceae, eg cotton, *Hibiscus* spp., eg okra, Rosella
Native eriophyid mites	Various genera	Eucalypt, *Angophora*, *Acacia*, *Leptospermum*
Tulip bulb mite, onion mite	*Aceria tulipae*	Bulbs (Alliaceae, Liliaceae)
Olive bud mite	*Oxycenus maxwelli*	Some varieties of olive, entered NSW since 1996
Grapeleaf blister mite	*Colomerus vitis*	Grapes
Pearleaf blister mite	*Eriophyes pyri*	Pear, overseas apple, related plants
Walnut blister mite	*E. tristriatus*	Walnut
Tomato russet mite	*Aculops lycopersici*	Tomato, other Solanaceae, eg eggplant, capsicum, petunia, weeds, eg black nightshade



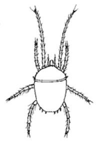
Redlegged earth mite

EARTH MITES (Family Penthaleidae)

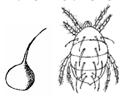
1. Adults **1 mm** long.
2. Red legs.
3. **No** webbing.

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
Blue oat mite	*Penthaleus major*	Cereals, pasture
Redlegged earth mite	*Halotydeus destructor*	Cereals, pasture

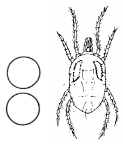
LIST OF SOME SPECIES
(contd)



Brown almond mite
1. Nearly 1 mm long
2. Front pair of legs longer than others

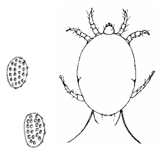


European red mite
1. Up to 0.5 mm long
2. Four rows of long curved spines on back
3. Eggs distinctive



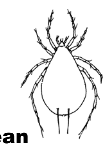
Twospotted mite
About **0.5 mm** long just visible to the naked eye

Not known in Australia



Broad mite
Adults 0.2 mm long, wider than other mites

Not known in Australia



Chilean predatory mite
Adults 0.7 mm long

List of suppliers: www.goodbugs.org.au

COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
SPIDER MITES (Family Tetranychidae)		
SPIDER MITES WHICH DO NOT PRODUCE WEBBING		
Brown almond mite, bryobia mite	*Bryobia rubrioculus*	Deciduous stone trees, hawthorn
Bamboo spider mite	*Schizoteranychus bambusae*	Bamboo
European red mite	*Panonychus ulmi*	Deciduous fruit trees, especially apples, ornamental trees and shrubs, eg elm, rose
Citrus red mite	*P. citri*	One of the world's worst pests of citrus, also mulberry, hawthorn, etc
SPIDER MITES WHICH DO PRODUCE WEBBING		
Twospotted mite, red spider	*Tetranychus urticae*	Variety of crops, ornamental plants
Bean spider mite	*T. ludeni*	As above, beans, cucurbit
Carmine spider mite	*T. cinnabarinus*	Wide variety of crops ornamental plants
Banana spider mite	*T. lambi*	Banana, weeds
Hydrangea spider mite	*T. hydrangeae*	Hydrangea
Oriental spider mite	*T. orientalis*	Citrus
Red spider mite	*T. piercei*	Cotton, banana, groundnut, pawpaw
Southern red mite (SRM) (eradicated)	*Oligonychus ilicis* (smaller than *Tetranychus*)	Azaleas, camellia, other hosts overseas
Spruce spider mite	*O. unungus*	Conifers, eg fir, juniper, pine, spruce
Tea red spider mite	*O. coffeae*	Citrus
TARSONEMID MITES (Family Tarsonemidae)		
Broad mite	*Polyphagotarsonemus latus*	Wide range, ornamentals, fruit, vegetables, weeds are a source of infestation in orchards
Bulb scale mite	*Steneotarsonemus laticeps*	Amaryllidaceae, eg hippeastrum
Cyclamen mite	*S. pallidus*	Strawberry, begonia, cyclamen, African violet, other ornamentals
FALSE SPIDER MITES (Family Tenuipalpidae)		
Passionvine mite	*Brevipalpus phoenicus*	Passionvine
Bunch mite	*B. californicus*	Grape, citrus, camelia, tea, fuchsia, hydrangea, other plants
Privet mite	*B. obovatus*	Privet, palms, roses, fuchsia, azalea
Chilean red spider mite	*B. chilensis*	Grapevines
STORED PRODUCT MITES (Family Acaridae)		
Bulb mite	*Rhizoglyphus echinopus*	Ornamental and vegetable bulbs
Flour mite	*Acarus siro*	Broken grain, etc,
PREDATORY MITES (Family Phytoseiidae)		
Chilean predatory mite **0.7 mm long**	*Phytoseiulus persimilis*	Twospotted mite, bean spider mite
Hypoaspis soil dwelling mite	*Stratiolaelaps miles*	Fungus gnat larvae in potting mixes, Western flower thrips pupae in soil
Predatory mite	*Typhlodromus occidentalis*	Twospotted mite
Predatory mite	*T. pyri*	European red mite
Predatory mites	*Amblyseius* spp.	Twospotted mite, broad and cyclamen mites, thrips
Predatory mite	*Neoseiulus cucumeris*	Some mites and immature thrips
Predatory mite (soil-dwelling)	*Hypoaspis (=Geolaelaps) aculeifer)*	Bulb mites, thrips and fungus gnats

OTHER BENEFICIAL MITES

- **Mites can be used as indicators** of the amount of nitrogen or phosphate in soil or the presence of particular minerals. Analysis of the soil mite community could give foresters an idea of the soil chemistry of a plantation.
- **Fungal-feeding mites** feed on sooty mould and other fungi, up to 150 can be found on some leaves. In the soil mites, beetles springtails, protozoans, free-living nematodes and earthworms feed on fungi, bacteria, decaying leaves.

Twospotted mite, Red Spider

An example of a spider mite

This is a **serious pest of a wide range of plants** during warm weather both indoors and outdoors. Plant materials such as fruit carrying more than a certain number of mites may be refused entry to some countries. The most important pest of ornamental plants and cut flowers in Australia. Most common spider mite and a severe problem wherever it occurs.

Scientific name

Tetranychus urticae (Class Arachnida, Order Acarina). Twospotted mite is a spider mite (Family Tetranychidae). Other spider mites include:

Banana spider mite (*T. lambi*)
Bean spider mite (*T. ludeni*)
Hydrangea spider mite (*T. hydrangea*)
See also page 201.

Host range

This is a **world wide pest** which feeds on a variety of plants, eg
Ornamentals, eg indoor plants, eg umbrella tree, palms; carnation, fuchsia, orchids, roses, violets.
Fruit, eg deciduous fruit trees, especially apple and pear, trailing berries, strawberry.
Vegetables, eg bean, cucumber, tomato.
Field crops, eg cotton.
Weeds, eg various.

Description & damage

Plant damage is caused by the nymphs and adults sucking plant sap from the leaves.

Adult mites are just large enough to be seen without a hand lens (about 0.5 m long). They are pale greenish or yellowish, the colour varying somewhat on the different host plants, and have 8 legs. The mites have **distinctive** dark markings on either side of the body. These markings are particularly large and prominent in the adult female. The females are rather pear-shaped, can move actively and spin fine webbing over the surface on which they are feeding. The males are smaller and narrower. **Nymphs** initially have 6 legs but later nymphal stages have 8 legs.

Leaves. Infestation usually starts on the more mature leaves and moves upwards. Mites feed mostly on leaf **undersurfaces** and in heavy infestations they also feed on the **upper surfaces**. Feeding mites cause leaf mottling or speckling. Often quantities of webbing are seen and adult mites are easily seen with a hand lens. Yellowing of leaves may occur; leaves may die and finally fall. On some hosts, eg apple and beans there may be bronzing of leaves and an uprolling of leaf margins. Mites can crawl all over the plant and envelope it in a mass of webbing. This is used as an aid to wind dispersal.

Fruit. **Apples** may be undersized and red varieties may fail to colour evenly and fully. Fruit may also become sunburned due to excessive exposure to sun caused by defoliation. Common pest of strawberry.

Limbs may become sunburnt due to defoliation. Green twigs of citrus may have yellow spots.

General. Repeated severe infestations year after year can result in weakening of trees and affect root growth. Herbaceous plants may die.

Diagnostics.

- Twospotted mites are **identified** by the distinctive markings on each side of the body (pages 199 and 203, Fig.126).
- Do not confuse twospotted **injury** to leaves with that caused by some sap sucking insect pests (see Table 40 below).
- If in doubt contact a diagnostic service.
- Diagnostic tools for mite identification are continually being developed including for **DNA**-based technologies.
- **Lucid keys**, eg *Mites of Quarantine Importance, Mites in Soil*, *Invasive Mite Identification* are available at www.**lucidcentral**.org/

Pest cycle

There is a **gradual metamorphosis** - egg, nymph (several stages) and adult with as many as 9 generations during warmer months (Fig. 126). Each female lays 70-100 eggs, the life cycle takes 7-14 days in summer. In coastal areas continues throughout the year but in colder areas females become inactive. Females change colour from greenish to orange in winter and become inactive.

Table 40. Comparison of damage caused by twospotted mites and some sap sucking insects.

LEAVES	TWOSPOTTED MITE	VARIOUS LEAFHOPPERS	GREENHOUSE WHITEFLY	LACE BUGS Azalea, olive	GREENHOUSE THRIPS
UPPER SURFACE	Sandy speckling (leaf stippling)	Speckled feeding patterns	Sandy speckling	Sandy speckling	Silvering
UNDER SURFACE	Mites, webbing	Insects if present, fly if disturbed, possibly a few cast skins, but surface may be clean	Whiteflies, white stationary nymphs, honeydew, sooty mould	Lace bugs, spiny nymphs, **black** tarry drops of excreta	Adults and nymphs often dark coloured, **black** tarry drops of excreta

‘Overwintering’

- In cold areas, most males die as the temperature drops. A few survive and these, with mature females, change colour to bright red (**‘red spider’**) and hibernate.
- On deciduous plants, eg roses and apples, mites descend from plants and ‘camp’ on the lower parts of the main stem, in cracks or damaged bark and under debris at the base of main stems.
- Some mites migrate to nearby **perennial weeds** where they may feed and reproduce at a very slow rate during winter.
- On evergreen hosts, eg violets, females also change colour but often remain on the plants, feeding and reproducing at a very slow rate.
- In greenhouses, mites continually reproduce.

Spread

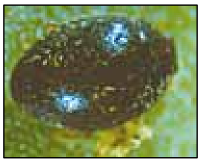
- By crawling from plant to plant.
- On windblown leaves, clothing, plant debris, visiting insects.
- By movement of infested leafy plants in pots. Between nurseries on plants. Cuttings.
- By propagation from infected plants (with leaves).

Conditions favoring

- **High temperatures** during dry or humid conditions. Outdoors most damage is caused during the warmer summer months. Bodman et al (1996) calculated the time required for a population to **double** at particular temperature:

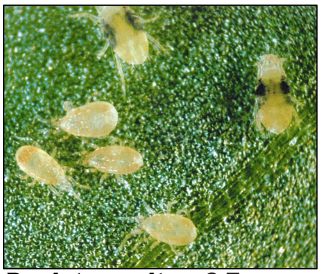
13 days	16.5°C
7 days	21°C
4 days	25.5°C (optimum temperature)
3 days	29.5°C

- **Heavy falls of rain** or good irrigation can reduce the effects of infestation.
- **Broad spectrum** miticides and insecticides which eliminate naturally occurring predators, eg when carbaryl is used extensively on apples to control other pests, populations of the twospotted mite's natural enemies are reduced or killed off. Synthetic pyrethroids may also cause **upsurges** of mites due to adverse effects on beneficials.
- **Application of fruit fly baits** too high in the tree disrupts predatory mites causing outbreaks of twospotted mites especially in Meyer lemons.
- **Water-stressed** plants.
- **House plants** are susceptible during winter months especially if artificial heating is used.
- **Development of resistant** mite populations due to continued use of one miticide.



Tiny black mite-eating ladybird (*Stethorus* spp.) about **2mm long**, often found on the back of mite-infested rose leaves.

Predatory mite



Predatory mites, 0.7mm long and pear-shaped; ***Top and Right:*** Twospotted mites.

Fig. 126. A spider mite (*Tetranychus* sp.). Probably **bean spider mite**, adults of which are red and do not have 2 distinctive markings on either side of their body. Photo©NSW Dept of Industry and Investment (E.H.Zeck).

All magnified about x30
1. Underside of leaf showing eggs
2. 6-legged larvae and 8-legged nymphs
3. Adult mites

Actual size
4. Bean plants injured by spider mites (0.5 mm long)

Management (IPM)

Are you a commercial grower or home gardener?

1. **Access/prepare a plan** that fits your situation. Various **IPM** programs are available, eg for citrus, cotton, roses, strawberries and other crops.
2. **Crop, region**. Recognize variations.
3. **Identification** can be difficult, ensure damage is not caused by other mite species or by sucking insects. Consult a diagnostic service if required (page xiv).
4. **Monitor** mites, predators and damage regularly (page 39). **Know when, where, what and how to monitor**. Monitor with a small hand lens or employ a monitoring service. Inspection and trapping of 2-spotted should start when plants/cuttings first arrive and continue until day of plant sale (also for whitefly, aphids etc). This will alert you to hot spots or flare-ups **early** so that you can order predators or handpick badly affected leaves and help prevent other pests, diseases and nutritional issues. Different crops require different monitoring procedures. Access information for your crop, eg roses, citrus, cotton.
5. **Thresholds** have been established for some crops.
   - **Growers** may have to accept **some damage**, providing it is not causing economic loss.
   - **Citrus pest and predators**. Threshold is more than 20% fruit or leaves infested.
6. **Action/Control**. Take appropriate action when any threshold is reached, eg
   - **Do nothing**, use cultural and sanitation controls or water sprays.
   - **Release predators**. Do not spray chemicals hazardous to predatory mites. It may be necessary to apply a **corrective** selective miticide to assist predators if monitoring shows a need.
   - **Apply a selective miticide** just before mite population increases to the stage of overcrowding when they are likely to 'escape'.
   - **Delay spraying** to control twospotted mites as long as possible.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required. Continue monitoring after treatment and consult previous year's records for comparison.

Control methods

Cultural methods.

- Appropriate irrigation of outdoor and indoor plants can reduce the effects of infestation. Used in greenhouse flower-growing sometimes.
- Outdoor container plants can be moved from hot sunny positions to cooler, more sheltered sites. Plants such as violets in hot sites can be replanted in cooler, shaded areas.

Sanitation.

- Destroy weeds and old crop residues which harbour mites and help to buildup mite populations.
- Keep glasshouse clean. Avoid handling infested material and brushing clothes by infested plants.

Biological control.

- **Natural enemies.**
  – **Predators** include tiny black mite-eating ladybird (*Stethorus* spp.), native mites (*Euseius victoriensis, E. eliniae*), lacewing and fly larvae, thrips (*Scolothrips sexmaculatus*).
  – **Fungal diseases** (*Neozygites* spp., *Hirsulella thompsonii*) in coastal areas. Naturalis-O (*Beauveria bassiana*) is available overseas.
- **Commercial predatory mites** move over leaves and other plant parts and prey on eggs, nymphs and adults of twospotted mites. Predators are also dispersed in wind from cooling fans and on workers' clothing. Two insecticide-resistant predatory mites have been released in Australia.
  – ***Typhlodromus occidentalis*** to control twospotted mite in apple orchards and rose gardens in **IPM** programs.
  – ***Phytoseiulus persimilis*** can be purchased from several private companies for use in **IPM** programs. Adult *Persimilis* eat from 5-20 prey (eggs or mites) per day but they must have prey to feed on. IPM will not eradicate 2-spotted but will manage them at a level where there is no economic damage. *Persimilis* move faster than 2 spotted mites, are orange and pear shaped are easy to recognize using a hand lend or x10 (page 203, Fig. 126).
  – **Suppliers provide information** on when to release predators, how to use them effectively and which pesticides may be used. Predators are **not** resistant to all pesticides. Home garden packs of predatory mites are available. It is usually recommended that predators be released in spring, eg early September. Follow release instructions provided by the supplier. Regular introductions are more effective in roses and ornamentals in glasshouses.
    List of suppliers www.**goodbugs**.org.au/
  – **Monocultures**. It is easier to biologically suppress twospotted mites where only one crop is grown, eg in apple orchards, orchids, rose gardens and cucurbit crops. It is more difficult to use them successfully in a home garden situation or in glasshouses where many different plants are grown.
  – **Banker plants** aid in the development and dispersal of predators for control of plant pests, especially twospotted mites. They enhance persistence of predatory mites and improve. Banker plants in light weight containers can be moved to increase long-range dispersal of predators and be removed from direct harmful pesticide or fertilizer applications.

Resistant varieties.

- Where twospotted mites are a constant problem, consider planting less susceptible species or varieties if practical.
- Umbrella and cocos palm have some resistance.

Plant quarantine.

- **Local quarantine.** Avoid re-introducing infested plant material to properties. Plants brought into a nursery or onto a property should be thoroughly inspected and treated if necessary. Avoid introducing plants from areas where resistance to miticides is a problem.

Pest-tested planting material.

Avoid taking cuttings from infested plants or introducing/transporting infested plants.

Physical & mechanical methods.

- **Brushing**. 40 strokes twice daily or shaking of plant shoots has been shown to consistently reduced mites (and thrips) populations on some greenhouse plants.
- High volume high pressure **water sprays** can temporarily suppress populations by dislodging mites but may damage soft foliage.

Miticides control/suppress certain mite species.

- **Follow Croplife Science Resistance Strategies and Resistance Warnings on labels.**
  – Twospotted mites have developed resistance to most organophosphates and organochlorines.
  – Most serious mite infestations can be traced to **continued use of one miticide**, resulting in development of a resistant population. Generally the more often a chemical has been applied the greater the resistance problem.
  – Use insecticides **selectively and/or from alternate** groups to prolong use of and avoid development of resistance.
  – Check **resistance** recommendations on labels.
- **Application**. Mites generally inhabit leaf under-surfaces and are difficult to contact with sprays. In orchards, high-pressure, high-volume sprays thoroughly drench trees and leaf undersurfaces. If dense foliage interferes with mite control, prune trees to open up the canopy. Webbing is inclined to repel spray droplets. Poor spray coverage and time of year can result in poor mite control.

- **Timing.** Outdoor tree/bush crops. Commence in early spring at first sign of mite infestation (from September onwards). If this spray can be applied before mites have settled on leaves and before they have produced webbing, control is better.
- **Different life stages of mites** (Table 41).
  - Information on using miticides on some crops is available (Learmonth 2008).
  - **Some miticides** are more effective against eggs than motile stages (nymphs and adults) and vice versa. The miticide chosen depends on the **most** abundant stage present at a particular time.
  - **Ovicides** (effective against eggs) and **larvicides** (effective against nymphs) reduce mite populations **more slowly** than those that are effective against all motile stages (nymphs and adults). Remember this **lag time**. Ovicides ideally should be applied when egg numbers are high and significant populations of active stages have developed.
  - **Adulticides** (effective against adults) quickly eliminate the **feeding** stages of mites and damage stops soon after the spray is applied. Their use can be delayed right up to the point where economic damage is imminent. Some adulticides are slower-acting than others and need to be applied earlier than more effective products to prevent damage.
- **Where predatory mites are being used** to control twospotted mites. Suppliers indicate which pesticides may be used to control other pests and to supplement the control of twospotted mites by predatory mites. Avoid spray drift.
- **Where only pesticides are used.** Use **selective** pesticides, eg miticides not toxic to naturally occurring predators of other pests. Avoid indiscriminate use of broad spectrum insecticides, eg carbaryl, synthetic pyrethroids.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 41. Some miticides – Stages effective against ***(not necessarily twospotted mite).***

Insecticide Mode of Action Group	TRADE NAME Active constituent	STAGES OF MITES effective against	COMMENTS (Although some are selective miticides, some also control other insects)
1B	**Folimat** (omethoate) **Malathion** (maldsion) **Rogor** (dimethoate) **Benthion** (azinphos methyl)	**Nymphs, adults**	All broad spectrum, kill predators
3A	**Mavrik** (tau-fluvalinate) **Procide, Talstar** (bifenthrin)	**Nymphs, adults** **Nymphs, adults**	Mavrik suppresses mite populations. Fast knockdown.
6	**Avid, Gremlin**, **Vertimec** **Agrimec**, various (abamectin) **Ultiflora, MilbeKnock** (milbemectin)	**Nymphs, adults** **Eggs, larvae, nymphs adults**	Used where resistance does not occur. Twospotted mites on ornamentals, strawberries
10A	**Apollo** (clofentezine) **Calibre** (hexythiazox)	**Eggs, early nymphs** **Eggs, early nymphs**	Residual. Not toxic to predatory mites, beneficials. May control some resistant mites.
10B	**Paramite, Stealth** (etoxazole)	**Eggs, early nymphs** mite growth regulator	Adults lays sterile eggs, stops existing eggs and nymphs developing
12A	**Pegasus** (diafenthiuron)	**All stages**	Residual for 14 days, used in IPM.
12B	**Torque** (fenbutatin oxide)	**Nymphs, adults**	Residual. Low toxicity to *P. persimilis.*
12C	**Betamite, Omite** (propargite)	**Nymphs, adults**	Low toxicity to predatory mites.
	Secure, **Intrepid** (chlorfenapyr)	**Nymphs, adults** (stomach acting, ingested)	Twospotted mite, no cross resistance has been recorded. Persistent.
21A	**Pyranica** (tebufenpyrad)	**Eggs, nymphs, adults**	Long lasting control.
	Sanmite (pyridaben)	**Eggs, nymphs, adults**	A few adult mites remain for 3-4 weeks, a week later most will have disappeared.
12D/UN	**Masta-mite** (dicofol/tetradifon)	**Eggs, nymphs, adults**	Do not use with IPM programs or if mites are known to be resistant to dicofol.
UN	**Acramite, Floramite** (bifenazate)	**Adults, nymphs,** some activity against eggs	Selective miticide, quick knockdown thro' contact activity & good residual activity, relatively inactive against predacious mites and beneficial insects
UN	**Azamax, Eco-neem, Neemazal** (azadirachtin)	**Nymphs, adults** (insect growth regulator, must be ingested or contacted)	Twospotted mite, consistent applications necessary, toxic to bees, **do not use on plants that produce food for human or animal consumption**
UN	**Kelthane, Miti-Fol** (dicofol)	**Nymphs, adults**	More effective against broad mite and cyclamen mite. Long residual.
Fungicide Group M2	Lime sulphur®, Wettable sulphur®, Sulphur Dusts	**Nymphs, adults**, prevents buildup of mite populations	Contact, fumigant and smothering effects on mites
Spray oils	**Petroleum oils** Winter Oil®, Stifle® Dormant Oil Summer® Spray Oil, White Oil®, Pest oil® **Paraffinic oils** BioPest® Oil, BioClear® Eco-Pest® Oil, EnSpray® 99, Trump® Spray Oil **Botanical oils** Eco-Oil®	**Eggs, nymphs** Spray oils are not selective and may harm predatory mites and other beneficials but they leave no residues and their effect is short-lived. New predators can colonize treated surfaces. Oils can damage plants, if used judicially they can be useful.	• **Winter spray oils** (dormant, semi-dormant) do **not** significantly reduce numbers of twospotted mites which 'overwinter' as adult females on herbage. • **Summer and other spray oils** smother eggs, nymphs. Also predators. • **Spray oils** may be used on hot spots where 2-spotted has built up to damaging numbers, well ahead of perennial buildup.
Other sprays	**Soap sprays**, eg Natrasoap®, various (potassium salts) **Home garden sprays**, eg Rose Spray and Insect Killer® (tau-fluvalinate/myclobutanil)	**Nymphs, adults**	**Soaps** dissolve waxy covers, may kill beneficials but only when first applied; new predators can safely colonize treated surfaces. Soap can damage some plants, if used judicially they can be useful.

Grapeleaf blister mite

Example of an eriophyid mite

Generally speaking, this mite is not considered to be a serious pest, but if most of the leaves are attacked, the cropping of vines may be affected and sunburn of berries may occur. This only occurs in localized and limited areas where there are extremely heavy infestations on some vines and not others. Eriophyid mite damage in grapevine in Australia is considered to be the common cause of the widespread "Restricted Spring Growth" syndrome (Bernard et al 2005).

Scientific name

Colomerus vitis (Class Arachnida, Order Acarina, Family Eriophyidae). There are two forms of this mite, one which infests leaves and another which infests growth buds. They look **identical**.

Host range

Grapevines (*Vitis vinifera*).

Description & damage

Adult eriophyid mites are **0.2 mm** long and less than half the size of spider mites. Under a x10 hand lens eriophyid mites will only look like specks of dust. You will need at least a x40 magnification to see their shape. They are white or creamy in colour and worm-like with **2 pairs of legs** situated near the head end. They may be found in the felt-like areas on the undersurface of the blistered areas of the leaves during the growing season and in the buds during winter.

- **Blister mite form**.
  - **Leaf undersurfaces.** Mites suck plant sap from leaf undersurfaces in spring. Initially small yellow areas up to 6 mm or more across develop on the leaf undersurface. These areas have a felt-like appearance (erinose) due to the production **by the host plant** of densely packed fine hairs. This mat of hairs becomes darker and rusty brown with age. Mites may be seen in amongst the hairs with the aid of a microscope.
  - **Leaf upper surfaces.** The upper surfaces of the felty areas develop **blisters** (page 207, Fig. 127). In severe infestations the raised blisters may run together and most of the leaf surface may be covered.
  - **Fruit.** If leaves are severely damaged bunches may be sunburnt.
- **Bud mite form**.
  - **Buds, shoots and canes.** There is stunting of the canes, shortened internodes at the base, zig-zagged shoots, dead 'overwintering' buds and abnormal development of buds. Failure of buds to develop normally causes some reduction in yield. In severe infestations buds may fail to burst. Bud mites spend most of their lives in the buds. Feeding in the bud results in a bubbling or wart-like appearance of plant tissue. The amount of shoot damage apparent in spring depends on the level of infestation of new buds during the previous season(s). Shoots that develop from infested buds may have distorted basal leaves, shortened internodes and more extensive 'bubbling' of the tissue around the base of shoots. If bunch primordials are attacked clusters will be deformed.

Diagnostics.

- **Morphology of the mites**. Bud mite and blister mite are identical in appearance so it is difficult to distinguish blister and bud mite forms. Mites are difficult to see, you need a compound microscope and even then can be hard to find. Placing affected leaves in a paper in a plastic bag for day or so at room temperature can make them more active, bring them out of the erinose and easier to see.
- **Damage.**
  - **Blister mite damage**. During the growing season the blister-like distortion (Table 42) on young foliage may misdiagnosed as:
    - ❑ Downy mildew.
    - ❑ Pubescence (having fine short hairs).
    - ❑ Powdery mildew.
  - **Bud mite damage** can be determined in winter by examining dormant winter buds for mites or 'bubbling' of the tissue inside the outer bud scales using a microscope. Bud mites tend to infest **basal** buds so sampling should focus on these. Soon after budburst, at the leaf rosette stage bud mites may be found in leaf axils and internodes of growing shoots. Small newly developing buds can contain mites almost as soon as they begin to develop when 2-3 leaves are separated. Often misdiagnosed as:
    - ❑ Boron deficiency or toxicity.
    - ❑ Bud mite damage is generally patchy, rust mite damage is commonly spread across a whole block or vineyard).
    - ❑ *Phomopsis* damage.
    - ❑ Cold damage.
    - ❑ Restricted spring growth (RSG).
    - ❑ Symptoms of fan leaf virus.
    - ❑ Herbicide injury.

Table 42. Comparing blister mite damage to leaves with fungal diseases and pubescence.

LEAVES	BLISTER MITE DAMAGE	NATURAL PUBSCENCE (on some varieties)	DOWNY MILDEW SYMPTOMS	POWDERY MILDEW SYMPTOMS
UPPER SURFACE	Blisters	Healthy appearance	Flat **oily** areas, leaves may wither	White powdery patches
UNDER SURFACE	White or reddish patches of erinose	White hairs dispersed evenly all over leaf. Many varieties smooth/glossy, not pubescent	White patches of fungal spores in **humid** weather	Occasionally white powdery patches

Pest cycle

There is a **gradual metamorphosis** (egg, nymph, adult) with many generations each year.

- **Blister mites** in spring move from bud scales to undersurfaces of emerging leaves. Males and females multiply in the protection of the felty areas during spring, summer and autumn. In late autumn mites move back to buds for protection. Damage begins at budswell in spring with the first generation produced by the 'overwintering' female mites. Usually the first 3-5 leaves on the cane are blistered and then the auxiliary leaves are damaged by the next generation. All remaining leaves on the developing canes will be affected.
- **Bud mites.** Similar life cycle except that mites spend most of their life in buds.

'Overwintering'

As non-feeding adults under outer bud scales in dormant buds, also in cracks on canes and under rough bark at bases of canes.

Spread

- By mites crawling over a plant or crop (they have limited ability to crawl).
- By wind or on insects, birds, etc.
- Infested canes, cuttings, nursery stock.

Conditions favoring

Warm moist weather, wet springs.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation.. Where mite damage is suspected, sampling and identifying the mites is necessary to the implementation of a successful control program.
2. **Crop, region**. Most states and viticulture organizations have management plans for pests and diseases of grapevines.
3. **Identification**. Mites can be found in dormant buds but **they can be difficult to find** and differentiate one from the other. Using a diagnostic service if necessary (page xiv) confirm that the problem is eriophyid mites. Misdiagnosis often leads to inappropriate chemical applications which can have a negative effect on mite predators.
4. **Monitor** mites and damage in areas of the vineyard where mites have been a problem in previous seasons and **record** results (page 39). Accurate monitoring methods have been developed which involve washing leaves and collecting mites and predators in a series of fine mesh sieves.
   - **Blister mite.** Monitor at regular intervals before making a decision to apply an insecticide, eg examine 5 terminals of 6 widely spaced locations throughout the grape crop.
   - **Bud mites** are found in greater numbers in the basal 2-3 buds. Bud mite presence can be determined in winter by examining dormant winter buds for mite or **'bubbling'** of the tissue inside the outer bud scales using a dissecting microscope (x30). Given that bud mites tend to infest basal buds sampling should focus on these buds. Soon after budburst at the leaf rosette stage bud mites may be found in leaf axils and internodes of growing shoots. Small newly-developing buds can contain mites almost as soon as they begin to develop when 2-3 leaves are separated.

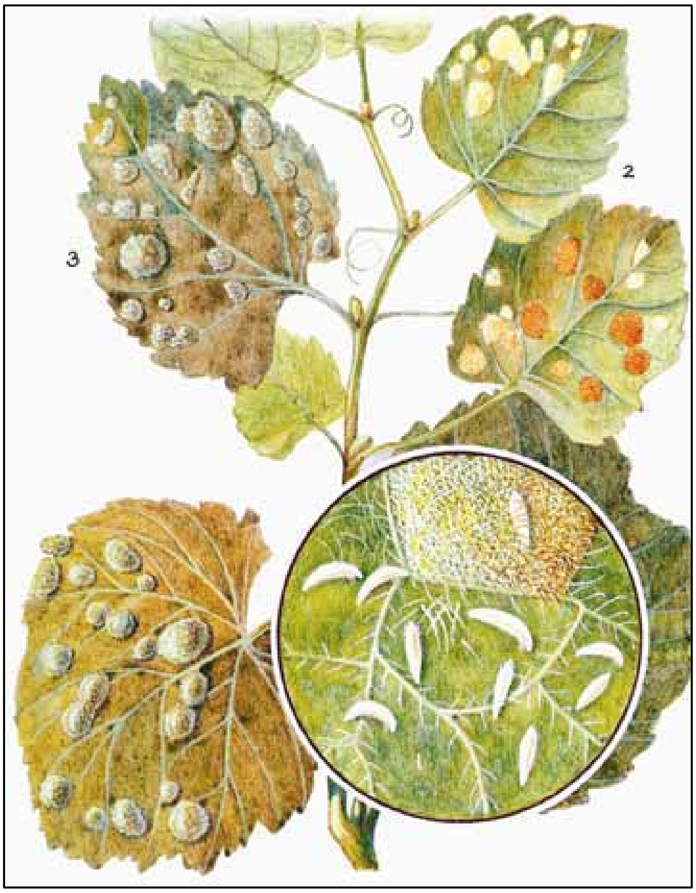


Fig. 127. Grapeleaf blister mite (*Colomerus vitis*). Photo©NSW Dept of Industry and Investment (E.H.Zeck).

Enlarged about x70

1. Mites on undersurface of leaf; note erinose development

Actual size

2. Undersurfaces of leaves showing hairy development of erinose condition caused by the mites feeding; early erinose is yellowish, old erinose is reddish
3. Upper surface of leaf showing blister-like formations caused by the mites feeding below

Management *(contd)*

5. **Thresholds**. Have any thresholds been established? If so, what are they, eg economic, aesthetic? How much damage can you accept?
   - **Blister mite**. Control for Waltham Cross is required if any blistering (or cane malformations) occurs on 5% of young spring growth.
6. **Action/Control**. Take appropriate action when any threshold is reached. Research tentatively indicates that most effective management for bud mite may be the protection and/or introduction of mite predators. The preferred pesticide treatment for blister mite is a dormant spray of lime sulphur after pruning and before budswell. After vines have broken into leaf control is more difficult.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required. Monitor trees after treatment during growing season. Next year spray lime sulphur before leaf buds burst if records indicate a need.

Control methods

Mild infestations do not affect yield.

Sanitation. Where only a few shoots or leaves are affected, these may be pruned out when they appear during the growing season.

Biological control.

- **Natural controls** include predatory mites, thrips, hover fly larvae and lacewings.
- **Predatory mite** (*Galendromus occidentalis*) feeds on bud mites inside buds in early spring. Introduction and protection of predatory mites from harmful chemicals may be the best treatment option for **bud mite** in the future.
- **For purchase**. A general mite predator (*Euseius victoriensis*) is available for control of eriophyid mites (rust mites, bud mites) and broad mites in vines and citrus.
- List of suppliers www.**goodbugs**.org.au

Resistant varieties. Muscats are generally regarded as being particularly susceptible.

- **Blister mite form.** More **susceptible** varieties include European varieties (*Vitis vinifera*), Gordo Blanco, Black Hamburg, Black Muscat, White Shiraz and Rutherglen Tokay. It also occurs on Zante currant. **More resistant varieties** include American varieties (*Vitis labrusca*), Isabella and Golden Muscat and the European variety, Sultana. Currants and sultanas (rarely attacked) are relatively resistant.
- **Bud mite form** appears to be present on most varieties but seems to do no harm except on **Ohanez** and **Waltham Cross**.

Pest-tested planting materials.

- Do not introduce mites on cuttings.
- Only plant mite-free cuttings.

Miticides.

- Viticulture Spray Guides are available.
- **Blister mites**. See Table 43 below.
- **Bud mites**.
  - Bud mites are **protected** inside the buds and not accessible to sprays except for a very short time when they begin to move into newly developing buds at the base of new leaves. This is when the first new leaves of new shoots are unfolding.
  - Preliminary work suggests that bud mites might only be **vulnerable** to sprays when **2-3 leaves** are separated, just before most mites have moved into the newly-developing buds in the leaf axils when they become inaccessible. The length of the spray window is not yet clear. Where mites are a problem spray at budswell the following season. Control may be required during summer. Omit sprays harmful to predators.
  - Recent research in Victoria has shown that lime sulphur applied with a knapsack sprayer at woolly bud stage had no impact on bud mite numbers, nor did wettable sulphur at budburst or greening.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 43. Grapeleaf blister mite – Some miticides.

What to use?	When and how to apply?
DORMANT SPRAYS **Group M2 (fungicides)**, eg Lime sulphur (sulphur polysulphides). Just before bud burst. **Spray oils**, eg Winter Dormant Oil, Winter Spray Oil, Stifle™ Dormant Spray Oil (**petroleum oil**) Apply mid-winter after pruning to ensure vines are fully dormant.	• Mites 'overwinter' under bud scales. • Where **severe mite injury** has occurred the previous season, lime sulphur may be applied after pruning and just before budswell during the dormant season (as close to budswell as possible). This will give complete control during the following growing season. Thorough spraying is essential. • Lime sulphur can stain trellises etc. Do not use after new leaves have appeared. • Do not apply sulphur if temperature is >30°C (on some crops not if >24°C), or within 1 month of an oil spray.
GROWING SEASON SPRAYS **Group M2 (fungicides)**, eg wettable sulphur formulations (during budburst/growing session) **Group 1A (insecticide)**, eg carbaryl (stimulates egg production in spruce spider mites but is generally very effective against eriophyid mites) **Group UN (insecticide)**, eg Kelthane® (dicofol)	• Control is **more difficult** to achieve during the growing season. These sprays will **not** eliminate existing damage but will help to prevent further damage. • Check label for precise timing, eg when shoots are about 7 cm long. • During summer build up of mites is checked by sulphur sprays for powdery mildew. • Do not use any sulphur if > 30°C (also see above).
FUNGICIDE SPRAYS **Group M3 (fungicides)**, eg thiram, ziram, zineb - **note they are not registered for grapeleaf blister mite**	• **These protectant fungicides** used to control certain fungal diseases during late spring and autumn have given some protection against blister mites.

ALLIED PESTS - Spiders

Class Arachnida, Order Araneida

NO. SPECIES IN AUSTRALIA

Scientists estimate that there are more than 10,000 species in Australia, only about 2,500 have been described. Only a few spiders are poisonous. Most are beneficial and could be used as indicators of environmental health because they respond to disturbance, are abundant and easily sampled.

www.ento.csiro.au/education/allies/**araneae**.html

Lucid Key: *Spiders of Australia* www.**lucidcentral**.org/

SOME DISTINCTIVE FEATURES

ADULT **Body**

1. **Two main body regions** (cephalothorax (fused head and thorax) and abdomen).
2. **No antennae or wings**.
3. No compound eyes, **8 simple eyes** (some only have 3). No true jaws. Fangs and chelicerae.
4. Lung 'books' and/or spiracles for **breathing**.
5. All spiders spin **silk** from various types of silk glands. Many spin webs to climb on and to catch insects for food, others form nets, triplines, etc. Females of most species enclose their eggs in a silk egg sac. Spiderlings use silk for dispersion after hatching.

Legs

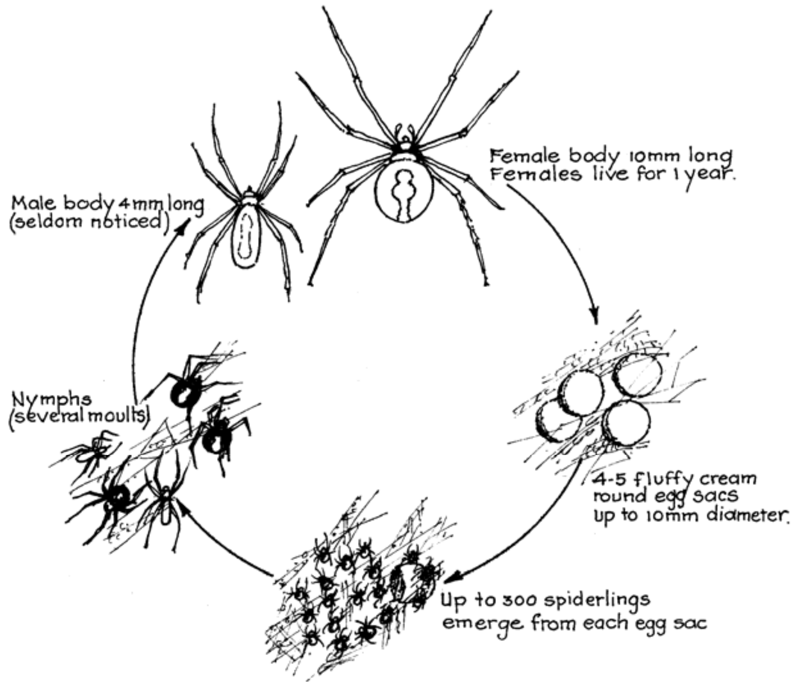
1. **Four (4) pairs of walking legs**.
2. **Limb regeneration**. When a limb is lost, there is no bleeding, a thin membrane grows over the stump. After 1-2 moults a new limb grows from the stump but it never quite reaches the same length as its predecessor.

LIFE CYCLE

There is a **gradual metamorphosis** - egg, nymph (**several stages**) and adult. Some spiders take **several years** to reach maturity.

Redback
Females are about 10 mm long

The red colour warns of poison



METHODS OF FEEDING

ADULT NYMPH

Spiders have a **liquid diet** and do not eat solid food. They feed on other spiders, insects, slaters, native snails and frogs, caught either directly by ground dwelling spiders or in webs of web spinners. Spiders kill their prey by means of a poison **(venom)** which is pumped through sharp hollow fangs located near the mouth and injected into the victim. The spider then squeezes out juice from its prey and **sucks** it up into its stomach. Most spiders are nocturnal, hunting for prey at night. Cannibalism occurs amongst spiders especially where there is overcrowding, females may eat males.

Large spiders may feed on birds in Qld

PLANT DAMAGE

DIRECT CHEWING DAMAGE

- **Spiders are carnivorous and rarely eat plants**. However, the jumping spider (*Plexippus validus*) has been seen eating *Euryopis splendens*.

INDIRECT DAMAGE

- **Spiders web foliage on citrus and other plants**, which interferes with the normal development of foliage and fruit and protect pests such as mealybugs and scale. They can annoy pickers harvesting the fruit.
- **They inhabit flowers, leaves and bark** where they catch insects and other prey. However, their presence may be a quarantine problem. Spiders hitch rides on second hand cars.
- Some species are **venomous**. Spiders may arouse strong negative feelings, eg arachnophobia (a fear of spiders).

LIST OF SOME SPECIES

Tree funnel web spider (*Hadronche formidabilis*) usually lives in trees, is very toxic but is not often encountered.

Gerozisis,J., Hadlington,P. & Staunton,I. 2008. ***Urban Pest Management in Australia.*** UNSW Press, Sydney.

COMMON NAME TOXICITY	SCIENTIFIC NAME	HABITS
GROUND-DWELLING SPIDERS (various families)		
Sydney funnelweb Aggressive. Very toxic. Male more toxic than female.	*Atrax robustus* Adopts a threatening position if threatened	Favours moist dark situations. Long silken tube through litter in ground. Active during late summer and autumn
Sydney brown trapdoor Not aggressive. Not toxic. Bites usually painful.	*Misgolas rapax*	Inhabits drier situations in exposed areas. Lid not usually over hole but leaves or litter may cover it
Mouse spiders Not aggressive. Toxic. Strong fangs, bite may be painful.	*Missulena* spp.	Females live in holes (with double doors) in the ground. Holes may be extensive. Adult male roams looking for female
Wolf spiders Not aggressive. Some toxic. Bite may be painful for a short while.	*Lycosa* spp.	Inhabits gardens, making holes in ground covered with litter. Moves rapidly when disturbed.
ORB WEAVING SPIDERS (Family Araneidae)		
Garden orbweaving spider Not aggressive. Not toxic. Seldom bites.	*Eriophora* spp.	Orb-web, hides on foliage during day and constructs orb-web at night
St Andrew's cross spider Not aggressive. Not toxic.	*Argiope keyserlingii*	Orb-web, hangs in web with legs in shape of cross
Leaf-curling spider Not aggressive. Not toxic.	*Phonognatha graeffei*	Orb-web, hides in curled leaf or paper at centre of the web
OTHER SPIDERS (various families)		
Redback spider Not aggressive. Very toxic. Females bite, male does not. Very painful.	*Lacrodectus hasselti*	Makes a loose web in protected sites, rubbish, tin cans, bricks, unsewered toilets, under houses.
Daddy-longlegs spider Not aggressive. Very toxic venom, but fangs too short to penetrate human skin.	*Pholcus phalangioides*	Dark corners of buildings, houses, eaves
Black house spider Not aggressive. Toxic. Bite produces pain, nausea, sweating. No fatalities.	*Badumna insignis*	Felted webs at the centre of which is a tunnel, sheds, toilets, windows, under guttering
Brown house spider Probably as for black house spider	*B. longinqua*	Foliage of fruit trees in boundary rows near scrub webbed together to catch insects
Flower spiders Harmless.	*Diaea* spp., others	Live among flowers and leaves of native shrubs, eg grevillea
Whitetailed spider Not aggressive. Bites cause local pain and blisters, tissue necrosis.	*Lampona cylindrata*	Found under bark of trees, often inside bathrooms, houses
Huntsman spider Not aggressive. Not toxic. Bites can be painful but rare	*Isopeda immanis*	Lives under bark, emerges at night, often enters houses
Endangered: Intertidal trapdoor spider	*Idioctis yerlata*	Mangroves, Cape Tribulation, Qld
Not known in Australia: Goliath birdeater tarantula	*Theraphosa blondi*	Frogs, mice, insects, but is not known to eat birds

A FEW HINTS

Emergency
FIRST AID
A Quick Guide

Always seek medical advice if bitten

Poison Information Centre

13 1126

FIRST AID

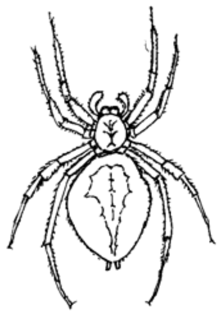
- **Venomous qualities.** Some species can pose a threat especially to the safety of children. Many spiders are so small that their fangs will not penetrate human skin; others have only a low toxicity which causes little more than local swelling and irritation. However, there are a few which cause nausea, vomiting and even **death**.
- Have reliable up-to-date **FIRST AID** advice on hand. Obtain a copy of the St John Ambulance’s **Emergency FIRST AID : A Quick Guide**.

IN THE HOME GARDEN

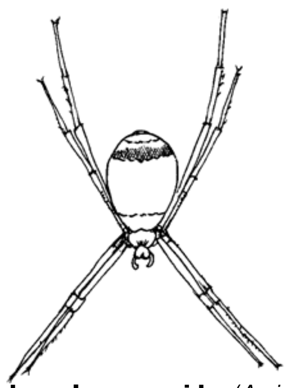
- **Wear gloves** when gardening and handling containers, soil or rubbish and **sensible shoes** when walking outside, particularly at night when most ground-dwelling spider are active.
- **During excavations**, landscaping, digging or gardening, be alert for disturbed ground-dwelling spiders which may enter buildings. Clean up piles of rocks, old tyres, etc, which may harbour redback spiders.
- Do not leave **toys**, clothes or other such articles on the ground particularly overnight. Wandering spiders may use them as a temporary resting site.
- Be aware that **ground-dwelling spiders** may wander:
  - After long periods of very **wet weather**.
  - During the **warmer months** (January to March) when spiders are **mating**, males may wander into yards and buildings in search of a female.
  - After widespread application of **insecticides**, spiders which are not directly contacted and killed may be disturbed and wander more than usual.
- Check camping gear, sleeping bags, etc after storage.

REMEMBER.

- Most spiders are **beneficial** but some are **poisonous**. Spiders play a key role in controlling insect populations, avoid eradicating harmless species.
- Spiders are **food** for birds and lizards, wasps feed spiders to their young.
- **Insecticides are registered** for domestic and/or commercial use. Spot spraying by hand can be successful after breaking up thick webs with a stick.
- **Identify spiders** which are a problem in your area. Seek advice if necessary.
- Action will depend on the **situation or crop**, eg garden, house, commercial premises, pots in greenhouses, fruit trees. Seek advice for your situation.
- Where some species have been a problem **keep look out** for webbing, etc.

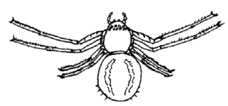


Garden orbweaving spiders (various species) build a new web each evening, tearing it down in the morning before hiding under a branch or elsewhere.



St Andrews’ cross spider (*Agriope keyserlingii*) hangs head downward usually with legs spread out on a cross. May decorate their webs to attract prey.

Leafcurling spider (*Phonognatha* sp.) curls a dead leaf with silk to form a hiding place.



Flower spider (*Diaea* sp.) are mostly quite small, harmless, display a variety of forms and colors and are common on grevillea and other flowering shrubs.

Fig. 128. Spiders commonly found in the garden (all approx x 1).

ALLIED PESTS - Slaters, pillbugs, woodlice

Class Malacostraca, Order Isopoda

Scientific name

Slaters and pillbugs belong to the Class Malacostraca, in the Phylum Arthropoda. Crabs, prawns and lobsters which are seas dwellers also belong to this Class. Slaters and pillbugs live on **land**, but breathe by means of **gills** which must be kept moist. Pillbugs are roughly similar in shape to slaters, but are able to roll up into a tight ball when disturbed.

Common slater (*Porcellio scaber*) exotic
Common pillbug (*Armadillidium vulgare*)

Pest species are introduced, some native species are considered to be endangered.

www.ento.csiro.au/education/allies/**isopoda**.html

Host range

Slaters and pillbugs are important in **recycling** natural forests and vegetation. They mainly feed on **decaying organic matter**, but may attack seedlings, young tender plants, soft fruit like tomatoes, ferns, young roots of orchids and other plants in glasshouses, conservatories, old shaded gardens and cause considerable damage. Staghorns, in particular, are very susceptible to attack as, in addition to providing food and shelter, they provide attractive breeding places.

Description & damage

Adult slaters are gray-brown, oval, semi-flattened and commonly **9-15 mm** long. They have 2 prominent tail-like appendages. Slaters have:

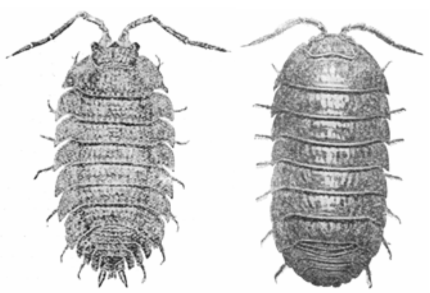
- A bilaterally symmetrical body.
- An exoskeleton (outer hard covering).
- A segmented body, most 8 thorax and 6 abdominal segments.
- Four or more pairs of jointed legs.
- Two pairs antennae but 1 pair may be hard to see.
- Eyes usually on stalks.

Plant damage. Slaters are usually found hiding during the day about the bases of plants, under flower pots and stones, under damp leaves, in compost heaps and in similar damp places. They feed by chewing and may do considerable damage to roots and tender growth near the ground of any plant. May chew on soft leaves and strawberries in contact with the ground. Because they come out to feed at night, when the risk of dehydration is less, they are not usually observed feeding. **Pillbugs** damage plants in a similar manner to slaters but mainly feed below ground. Mostly feed on organic matter but give the perception that they feed on roots.

Remember many slaters in a particular place are not generally a cause for concern. Overall they are more beneficial than harmful.

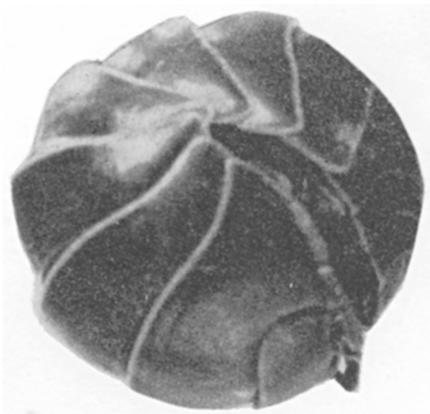
Diagnostics

- Slaters and pillbugs are easy to recognize, but damage is more difficult to pinpoint.
- Do not confuse the name **pillbug** with **billbug**. Billbugs are weevils, the larvae of which feed on rhizomes, stolons and crowns of turf grasses.
- Slaters **cannot** roll up into a tight ball like pillbugs.



Slater Pillbug

A group of slaters.



Pillbugs **can** roll into a ball for defense.
Slaters **cannot** roll up into a tight ball.

Fig. 129. Slaters (various species) commonly 9-15 mm long. Photo©NSW Dept of Industry and Investment

Pest cycle

Slaters have **no metamorphosis**, the young resemble the adults except that they are smaller and paler in colour. It takes about a year for the young slaters to reach maturity. The adults live for about 2 years and each female can produce 60 or more young in one season, usually in 1-3 broods of 6-40 young during late winter, spring, summer and autumn. The young are carried in a pouch beneath the body of the female until they are ready to feed.

'Overwintering'

All stages in sheltered places.

Spread

- By crawling.
- By transport of infested plants, containers, soil, compost, wood chips, bark and other materials.

Conditions favoring

- Cool, damp dark places (slaters breath through gills).
- Australia is fairly dry so there are not so many species.
- Plants damaged by other agents are susceptible to attack.
- Pillbugs are more tolerant of dry conditions than slaters and often live in open, well-drained areas.
- Activity is mostly at night on dark wet days and warmer months in cooler parts of Australia.
- Lots of organic matter, mulch, compost and regular watering.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Management (IPM)

Limited need in this case. Are you a commercial grower or home gardener?

1. **Plan**. If slaters are an ongoing problem, prepare a control plan that fits your situation.
2. **Crop, area**. Locate plants or areas where control may be required.
3. **Confirm identification**, locate main breeding areas, be familiar with its life cycle, etc. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** pest and/or damage to indicate when peak populations are likely to occur. Remember slaters are nocturnal so not seen during the day. **Know when, where, what and how to monitor**.
5. **Thresholds** only need to be determined for crops at risk. Occasionally slaters pose an aesthetic problem in nurseries.
6. **Action/control**. Slaters are a good example of where cultural and sanitation methods are most effective. Baits or dusts are only useful in protecting specific plants in unusual problem situations.
7. **Evaluation**. Review program to see how well it worked. Recommend improvements if required.

Control methods

Cultural methods. Reduce moisture and increase air circulation by raising plants off the ground.

Sanitation. This is the best control method in a home garden situation, eg

- Remove rubbish, rock piles, other hiding and breeding places, eg piles of rotting timber, decaying vegetable matter.
- Remove decaying low fallen fruit.
- Clean up old plant debris, remove old leaves.
- Keep mulch away from seedlings and cuttings.

Biological control. No biological control agents are available, though there are a range of natural enemies, eg birds, chooks.

Physical & mechanical methods. Slaters shelter in scraped out potatoes or orange peel. Inspect traps daily and destroy slaters.

Insecticides.
See Table 44 below.

Table 44. Slaters – Some insecticides.

What to use?	When and how to apply?
BAITS **Group 1A**, eg Baysol® (methiocarb) **Others**, eg Multiguard® (iron-EDTA complex)	• Only after damage has been **confirmed** in commercial crops. • Distribute bait as directed.
SPRAYS, GRANULES, AEROSOLS **Group 1B**, eg chlorpyrifos (commercial use only) **Various outdoor garden products**, eg pyrethrum/eucalyptus, cyfluthrin/pyrethrin	

ALLIED PESTS - Millipedes

Class Diplopoda

Scientific name

Millipedes belong the Superclass Myriapoda, Class Diplopoda in the Phylum Arthropoda. Species include:

Black Portuguese millipede (*Ommatoiulus moreletii*), a major pest in South Australia, Tasmania, Victoria and Western Australia.
Flat brown millipede (*Brachydesmus superus*)
White millipede (*Blaniulus guttulatus*)

Numerous native species, eg *Dimerogonus orophilus, Oncocladosoma clavigerum*

Some species are not known in Australia, eg the American giant millipede (*Narceus americanus*). The giant African millipede (*Archispirostreptus gigas*) is one of the largest millipedes, is up to 28cm long, lives for 7-10 years and is often kept as a pet.

Most state departments of agriculture/primary industry have fact sheets on Portuguese Millipedes.
www.csiro.au/resources/**BlackPortugueseMillipedes**.html
www.ento.csiro.au/education/allies/**diplopoda**.html ok

Host range

Black Portuguese millipede are not harmful to humans but can occur in plague numbers, invading houses, contaminating food and infesting carpet and bedding. It is one of the few millipede species that are attracted to lights at night. Once inside they usually die, they do **not** breed inside.

- Millipedes feed on **decaying organic** matter but may attack **crops** growing in **damp soil** and are occasional pests of **greenhouses**.
- **Plagues** may occur and destroy seedlings and fruit and vegetable crops Millipedes are important in soil formation, breaking down leaf litter and enriching the soil.

.

Description & damage

Adult millipedes are elongated, dark brown in colour and up to **30 mm** long. They possess:

- A bilaterally symmetrical body.
- An exoskeleton (outer hard covering to body and legs).
- A segmented body (at least 11 body segments) which is round in cross section.
- 10 or more pairs of tiny legs (2 pairs per segment), no poison fangs.
- 1 pair of short antennae.
- May give off an offensive odour.

Plant damage. Millipedes may chew roots of plants in containers and pots under damp conditions. They may also feed on soft leaves, fruit and other plant material close to the surface of damp soil.

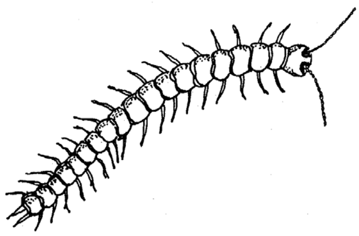
Diagnostics.

- Millipedes have **2 pairs of legs** per body segment.
- The **smooth cylindrical body** of the Portuguese millipede distinguishes it from the native variety common around Adelaide. The latter's body segments give it a bumpy look.
- Millipedes are often confused with **centipedes** (Table 45 below) and occasionally with **wireworms or false wireworms** which are the larvae of beetles which have only **3 pairs** of short legs on the thorax.

Pest cycle

There is **no metamorphosis**, the young look like the adults except that they are smaller in size, have fewer segments and only **3 pairs of legs** initially. There is probably only 1 generation each year. Eggs are laid singly or in groups in soil, under logs or on leaf litter. Adults of Portuguese millipedes that invade houses are probably about 2 years old but some species of millipedes live much longer.

Table 45. Distinguishing millipedes from centipedes.

Millipedes (Class Diplopoda)	**Centipedes** (Class Chilopoda)
• At least 11 body segments. • Round body (in cross section). • **'Thousands'** of legs, two pairs legs per segment, no poison fangs. • One pair of short, segmented antennae. • Mainly **vegetarian**. • May have an offensive odour.	• At least 19 body segments. • Flattened body (in cross section). • **'Hundreds'** of legs (15-181 pairs of legs), one pair legs per segment, first pair modified to form **poison fangs**. Most fast moving and aggressive. • One pair of antennae. • Almost exclusively **predatory**.
 Millipede	 Centipede

'Overwintering'

Millipedes 'overwinter' as adults outdoors in soil, under logs and under leaf litter in sheltered places.

Spread

- By crawling, adult millipedes can probably walk a maximum of several hundred meters each year.
- Transportation of soil, pots or container plants from infested areas.
- Transportation of wood chips and compost from infested areas.
- On/in tyre treads of vehicles.

Conditions favoring

- Damp undisturbed organic mulch, leaf litter.
- Areas where winter weeds such as soursob form a more or less continuous ground cover.
- Millipedes are generally not numerous in lawns, cultivated areas or bare ground.

Management (IPM)

Are you a commercial grower or home gardener?

1. **Plan.** If millipedes are an ongoing problem, then prepare a management plan.
2. **Crop, region.** Recognize variations. Locate plants or main breeding areas where control is required.
3. **Confirm identification** and be familiar with their life cycle, conditions which favour their development and where they 'overwinter' when they are not a problem, etc. Consult a diagnostic service if necessary (page xiv).
4. **Monitoring** millipede numbers and damage will indicate when peak populations are likely to occur (page 39). Millipedes are observed at night. Record results.
5. **Thresholds** should be determined for crops at risk. How much damage can you accept, eg economic, aesthetic, environmental?
6. **Action.** Take appropriate action when any threshold is reached. Remember, only if seeds or seedlings are being injured should treatment be considered.
7. **Evaluation.** Review **IPM** program to see how well it worked. Recommend improvements if required.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Control methods

Sanitation.

- These pests are best controlled by cleaning up the areas where they breed, so that the supply of food and shelter is reduced as much as possible. This is the best way of controlling them in a home garden situation.

Biological control. Several biological control agents are being research including:

- **A parasitic fly** which is a natural enemy of the black Portuguese millipede overseas, is being researched and quarantined in Australia prior to its possible release. It is important to be sure that the parasitic fly does not attack native millipedes.
- **A nematode** (*Rhabditis necromena*) has been released in **SA** to control the Portuguese millipede. It attacks **only** millipedes and not other animals or plants. The millipedes ingest numerous nematodes which then perforate the gut of the millipede. The nematodes are active during late autumn and winter After introduction, they take several years to reduce millipede numbers. Householders living next door to areas of bushland report that nematodes do not reduce the numbers of millipedes invading houses probably because of the many millipedes living in the bushland nearby.

Physical and mechanical methods.

- These are mainly used to control the black Portuguese millipede which invades houses and include barriers of various types and light traps.

Insecticides.

- See Table 46 below.

Remember that although millipedes (and earwigs) invade houses, they do not breed inside the house. They can be swept up and disposed.

Table 46. Millipedes – Some insecticides.

What to use?	When and how to apply?
HORTICULTURE SITUATIONS **Baits**, eg **Group 1A**, eg Baysol® Snail & Slug Bait (methiocarb) **Sprays**, eg **Group 1A**, eg various **Group 1B**, eg various **Group 3A**, eg various **Garden surface sprays**, eg various	• Insecticides should only be applied after plant damage had been **confirmed**.

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

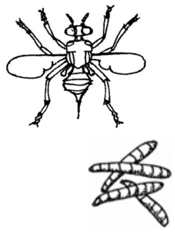
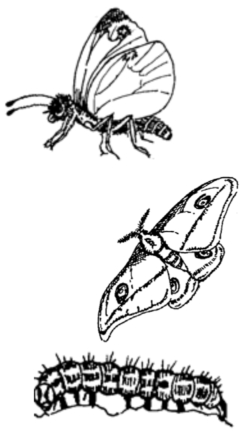
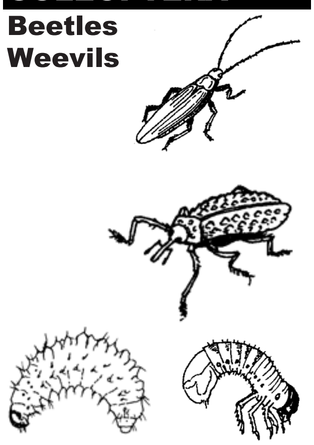
1. List the **parasitic** and **non-parasitic causes** of plant problems.
2. List **distinctive features** of the Phylum Arthropoda (Insects & Allied Pests).
3. List the **distinctive features** of the following **members** of the Phylum Arthropoda:
   Insects, Spiders, Slaters, Mites, Millipedes, Springtails, Centipedes
4. Be able to identify, draw and know the **function** of the following **external parts** of an **adult insect**:
   Head, Thorax, Abdomen
5. Draw diagrammatically the **3 types of insect life cycles**. Name 1 example of each.
6. Describe how insects **grow**.
7. **Recognize by sight**, 4 common types of **larvae**. Name 1 example of each.
8. Explain 3 common types of **host range**. Name 1 example of each.
9. Describe 3 ways that insects may **feed on plants and cause damage**. Name 1 example of each.
10. Recognize by observation, 3 examples of **direct and indirect damage** to plants.
11. Describe 5 ways by which insects **overwinter/ oversummer**. Name 1 example of each.
12. Describe 4 ways in which insects may **spread**. Name 1 example of each.
13. Describe **3 conditions favouring** insect development. Name 1 example of each.
14. List and describe the 7 steps in **IPM**.
15. List **8 control methods** for insect pests of plants. Describe 1 example of each.
16. Name the 3 main requirements of the **Organic and Biodynamic Products** domestic standard to be met by growers wishing to label their products 'organic' or 'biodynamic'.
17. Explain the meaning of the following terms as they apply to the **mode of action** of insecticides and name 1 example of each:
   Non-systemic and systemic
   Selective and non-selective
   Contact, stomach and fumigant action
18. Explain why insecticides must be applied **at the correct time**. Describe 2 examples.
19. Provide the active constituent, some trade names, mode of action and some uses for selected **insecticides/miticides** in the following groups:

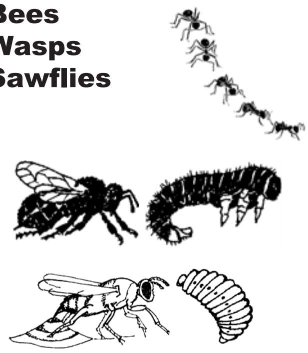
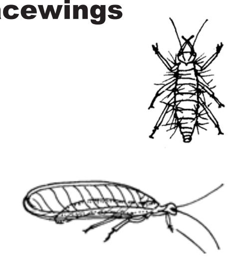
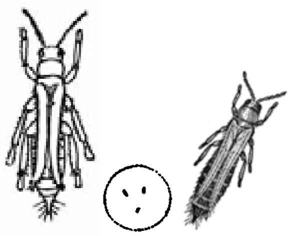
Mode of action groups:	**Others:**
Group **1A**	Spray oils
Group **1B**	Soap sprays
Group **3A**	Pheromones
Group **4A**	Food attractants
Group **11**	Bio-insecticides
	One of your own choice

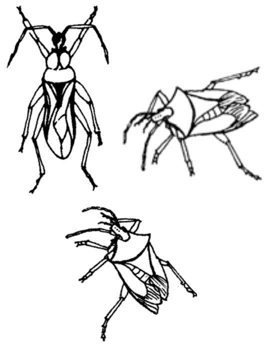
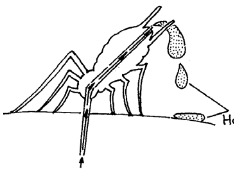
20. Select 2 **commercial insecticide/miticides**, indicate how you know which resistance group they belong to and how you would use them to **prevent** the development of resistance.
21. **Classification**. List the **main features of insects** used to classify them into orders.
   21.1. List the **10 most important** pest and beneficial insect orders from a horticultural point of view.
   21.2. List those with a **complete** metamorphosis and those with an **incomplete** (gradual) metamorphosis.
   21.3. Fill in the following **summary pages** for Insects & Allied Pests (pages 217-223).
22. **For each order**, of insects and allied pests (springtails, mites, spiders, slaters and millipedes), be able to do the following:
   22.1. List the key **distinctive features** of adults and larvae/nymphs.
   22.2. Draw the **life cycle** diagrammatically.
   22.3. Name the stage(s) which **cause(s) plant damage**, how they **feed** and the types of **direct and indirect damage** caused. Name 1 example of each type of damage.
   22.4. Recognize by sight, local **pest** species (if applicable).
   22.5. Recognize by sight, local **beneficial** species (if applicable).
   22.6. Recognize by sight, **damage** caused by local pest species.
   22.7. Describe State/Territory/Commonwealth **legislation** providing for the control of local pest species.
   22.8. **Provide the following information** for selected local pest species:
   Common name, Host range, Description & damage, Diagnostics, Pest cycle, 'Overwintering', Spread, Conditions favouring, **IPM** and Control
   22.9. Prepare/access an **IPM** program for an insect or mite pest at your work or in your region.
23. **Diagnostics**.
   23.1. Distinguish between **damage** caused to **leaves** by selected **chewing** insects, eg caterpillars, leafeating beetles and weevils, and sawflies on selected plants.
   23.2. Distinguish between **damage** caused to **leaves** by selected **sucking** insects, eg lace bugs, leafhoppers, mites, thrips and whiteflies on selected plants.
   23.3. Where would you obtain advice and information on the **identification** of insects and allied pests.
24. **Locate resource material** and know where to obtain advice on how to **control** local pest species.

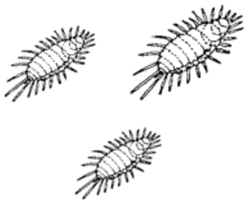
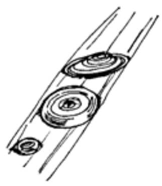
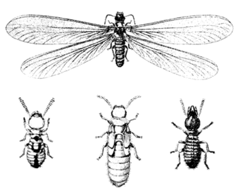
REVIEW QUESTIONS AND ACTIVITIES *(contd)*

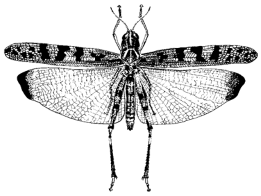
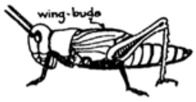
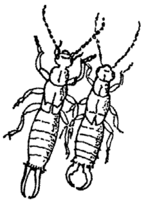
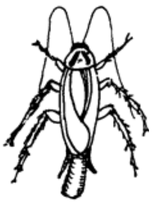
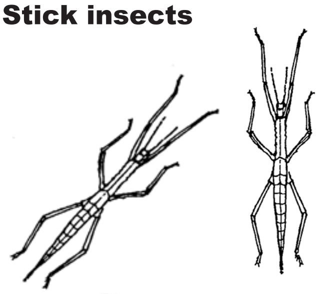
SUMMARY OF INSECT ORDERS

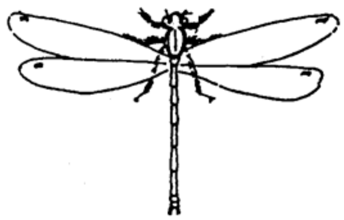
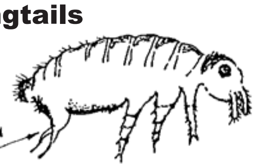
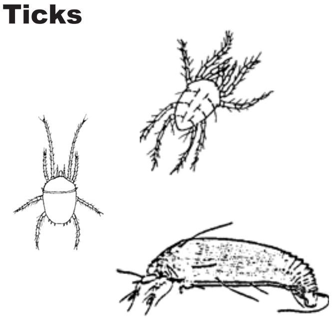
INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
DIPTERA **Flies** 	**ADULT** Wings Eyes Mouth **LARVA** Names Legs Other **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Galls eg Leafmining eg **Fruit** Maggot damage eg **Stems** Borers eg Galls eg **Bulbs** Maggot damage eg **INDIRECT DAMAGE** • Introduction of decay organisms eg • Disfigurement eg **BENEFICIAL DIPTERA**
LEPIDOPTERA **Butterflies** **Moths** 	**ADULT** Flight Colour Antennae Wings Mouth **LARVA** Names Legs Mouth **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Leaves eaten eg Leafmining eg Skeletonization eg **Flowers, buds** Chewing damage eg **Fruit** 'Worm' damage eg Surface chewing eg **Stems, bark** Borers eg **Seedlings, shoots** Chewing damage eg **INDIRECT DAMAGE** • Frass eg • Formation of structures eg • Introduction of decay organisms eg
COLEOPTERA **Beetles** **Weevils** 	**ADULT** Flight Body Head Antennae Mouth **LARVA** Names Body Legs Head Mouth **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Eaten eg Leafmining eg Skeletonization eg **Flowers, buds** Chewing damage eg **Fruit, seed** Chewing damage eg **Stems, bark** Bark eg Borers eg Surface chewers eg **Roots, tubers** Gouging eg **INDIRECT DAMAGE** • Transmit diseases eg **BENEFICIAL COLEOPTERA**

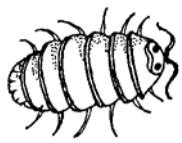
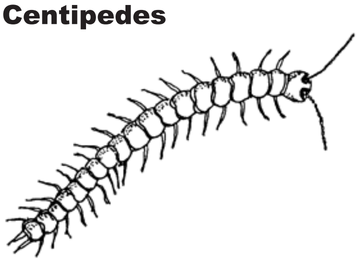
INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
HYMENOPTERA **Ants** **Bees** **Wasps** **Sawflies** 	**ADULT** Wings Body Waist **LARVA** Names Legs Mouth **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Eaten eg Leafmining eg Skeletonization eg Galls eg **Stems** Galls eg **Trunks** Borers eg **Fruit** General pest eg **INDIRECT DAMAGE** • Unsightly eg • May sting eg **BENEFICIAL** **ANTS, BEES, WASPS**
NEUROPTERA **Lacewings** 	**ADULT** Body Head Wings Abdomen **LARVA** Names Legs Mouth **LIFE CYCLE** **METHOD OF FEEDING**	**BENEFICIAL**
THYSANOPTERA **Thrips** 	**ADULT** Body Wings Mouth Legs **NYMPH** Names Legs Mouth **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Distortion eg Galls eg Leafrolling eg Silvering eg **Flowers** Dead areas eg Distortion eg **Buds** Distortion eg **Fruit** Prevent fruit set eg **Corms** Rotting eg **INDIRECT DAMAGE** 1. Excreta eg 2. Transmission of virus diseases eg **BENEFICIAL THRIPS**
HEMIPTERA – BUGS **Summary** **How can you distinguish a bug from a beetle?**	**ADULT** Wings 1. **Heteroptera** (**different** wing) - true bugs, eg crusader bug. 2. **Hoppers** (**same** wing), eg leaf hoppers, plant hoppers. 3. **Aphids, lerps, mealybugs, scales, whiteflies.** Soft bodies and usually **no wings**, although some may have forewings only, adult whiteflies have 2 pairs. Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	

INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
HEMIPTERA **Bugs** 	**ADULT** Wings Antennae Mouth Odour **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Mottling eg Spots eg Wilting eg **Flowers** Distortion eg **Fruit** Marking eg **Shoots** Wilting eg **INDIRECT DAMAGE** • Disfigurement with excreta eg **BENEFICIAL BUGS**
HEMIPTERA **Hoppers** 	**ADULT** Wings Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Mottled eg Wilting eg **Stems, buds** Egg laying eg **INDIRECT DAMAGE** • Honeydew (sooty mould) • May transmit virus diseases eg **BENEFICIAL LEAFHOPPERS**
HEMIPTERA **Aphids**   	**ADULT** Wings Cornicles Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Death eg Distortion eg Galls eg **Flowers, buds** Distortion eg **Fruit** Distortion eg Reduction in size eg **Stems, trunks** Death of shoots (dieback) eg Distortion eg Galls eg **Roots** Death eg Distortion eg Galls eg **INDIRECT DAMAGE** • Honeydew (sooty mould) eg • May transmit virus diseases eg **BENEFICIAL APHIDS**
HEMIPTERA **Lerp insects** 	**ADULT** Wings Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Dead areas eg Defoliation eg Mottling eg **INDIRECT DAMAGE** • Honeydew (sooty mould) eg **BENEFICIAL LERP INSECTS**

INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
HEMIPTERA **Mealybugs** 	**ADULT** Body Wings Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Wilting, eg Death, eg **Roots, buds** Death, eg **INDIRECT DAMAGE** • Honeydew (sooty mould), eg • Disfigurement, eg **BENEFICIAL MEALYBUGS**
HEMIPTERA **Armoured scales** **Soft scales** 	**ADULT** Wings Antennae Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Yellowing, eg Defoliation, eg **Fruit** Disfigurement, eg **Stems, trunks** Leaf fall, eg Dieback, eg **INDIRECT DAMAGE** • Honeydew (soft scales), eg • Loss of market, eg **BENEFICIAL SCALE**
HEMIPTERA **Whitefly** 	**ADULT** Wings Antennae Mouth Size Other **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Mottling, eg **General** May not cause much Damage, eg Death of seedlings, eg Reduced vigour, eg **INDIRECT DAMAGE** • Honeydew (sooty mould), eg **BENEFICIAL WHITEFLY**
ISOPTERA **Termites** **'White ants'** 	**ADULT** Worker Soldier King & Queen **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Tubers** Tunnels, eg **Trunks, branches, roots** Tunnels, eg **INDIRECT DAMAGE** • Weakening of structures, eg **BENEFICIAL TERMITES**

INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
ORTHOPTERA **Crickets** **Grasshoppers** **Katydids** **Locusts** 	**ADULT** Body Wings Legs Thorax  **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Eaten, eg **Stems** Eaten, eg **Fruit, seed** Eaten, eg **Roots** Eaten, eg **INDIRECT DAMAGE** **BENEFICIAL ORTHOPTERA**
DERMAPTERA **Earwigs** 	**ADULT** Body Wings Abdomen **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Flowers** Eaten, eg **Fruit clusters** Eaten, eg **Leaves** Eaten, eg **Seedlings** Eaten, eg **Roots** Eaten, eg **INDIRECT DAMAGE** **BENEFICIAL EARWIGS**
BLATTODEA **Cockroaches** 	**ADULT** Body Wings Legs **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Nibbled, eg **New roots, shoots** Nibbled, eg **INDIRECT DAMAGE** • Excreta and odour, eg • Spread disease, eg • Annoyance, allergies, etc, eg **BENEFICIAL COCKROACHES**
PHASMATODEA **Leaf insects** **Phasmatids** **Stick insects** 	**ADULT** Body Wings Legs **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves** Eaten, eg **INDIRECT DAMAGE** • May bite if handled **BENEFICIAL**

INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
MANTODEA **Mantids** **Praying mantids** 	**ADULT** Body Wings Legs Head **NYMPH** **LIFE CYCLE** **METHOD OF FEEDING**	**INDIRECT DAMAGE** • May bite if handled, eg **BENEFICIAL**
ODONATA **Dragon flies** **Damselflies** 	**ADULT** Body Wings Legs Thorax **NYMPH** **LIFE CYCLE** **METHOD OF FEEDING**	**INDIRECT DAMAGE** **BENEFICIAL**
CLASS COLLEMBOLA **Springtails** 	**ADULT** Body Wings Antennae Mouth Legs **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Seeds, seedlings, soft foliage** Chewing, eg **INDIRECT DAMAGE** **BENEFICIAL SPRINGTAILS**
CLASS ARACHNIDA **Order Acarina** **Mites** **Ticks** 	**ADULT** Body Legs Eriophyid mites **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Leaves, shoots** Blisters, eg Chlorosis, eg Defoliation, eg Leafrolling, eg Pigmentation, eg Silvering, eg Witches' broom, eg **Fruit** Malformation, eg Russetting, eg **Stems** Bronzing, eg Galls, eg **Bulbs, roots** Rotting, eg **INDIRECT DAMAGE** • Webbing, eg • Transmit virus diseases, eg **BENEFICIAL MITES**

INSECT ORDER Common names of members	**DISTINGUISHING FEATURES** Life cycle Damaging stages & method of feeding	**PLANT DAMAGE** (not exhaustive)
CLASS ARACHNIDA **Spiders** 	**ADULT** Body Wings Legs Mouth **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** • Rarely eats plants **INDIRECT DAMAGE** • Quarantine problem, eg • Some have venomous bites, eg • Web foliage together, eg • Annoy fruit pickers, eg **BENEFICIAL SPIDERS**
CLASS MALACOSTRATA **Slaters** 	**ADULT** Body Wings Legs Mouth Antennae **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Seedlings,** Nibbled, eg **stems,** **tender foliage,** **fruit** **INDIRECT DAMAGE** **BENEFICIAL SLATERS**
CLASS DIPLOPODA **Millipedes** 	**ADULT** Body Wings Legs Antennae Odour **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**DIRECT FEEDING DAMAGE** **Soft roots,** Chewed, eg **leaves,** **fruit** **INDIRECT DAMAGE** **BENEFICIAL MILLIPEDES**
CLASS CHILOPODA **Centipedes** 	**ADULT** Body Legs Antennae Wings **NYMPH** **LIFE CYCLE** **DAMAGING STAGES & METHOD OF FEEDING**	**INDIRECT DAMAGE** • Fast moving and aggressive, can be frightening, eg **BENEFICIAL CENTIPEDES** • Almost exclusively predatory, eg

SELECTED REFERENCES

CSIRO Australia www.csiro.au/org/Entomology.html
GRDC Pestlinks www.grdc.com.au/
University of Sydney http://bugs.bio.usyd.edu.au/

Fact Sheets by State/Territory Depts. of Primary Industries and Museums are available online.

Ute/Pocket Guides

Agric. Victoria. *Pests of Pome and Stone fruit and their Predators and Parasitoids.*
NSW DPI. *Field Identification Guide : Pests, Diseases, Disorders and Beneficials in Ornamentals.*
NSW DPI. *Insects – Southern Region: The Ute Guide.*
TOPCROP. *Insect Pest Guide: A Guide to Identifying Vegetable Insect Pests and their Natural Enemies in the DryTropics.*

Keys

Lucid keys www.lucidcentral.com/ www.cbit.uq.edu.au/
State websites - simple keys of damage by insects and mite pests of crops, eg canola, cereals, field peas, lucerne, lupins.
Urban Pest Management in Australia OZ Pest
BugKEY www.hortnet.co.nz

Insect collections

Australian Entomological Supplies
☎ (02) 6684 7650 www.entosupplies.com.au
Dahms, E. C., Monteith, G. and Monteith, S. 1997. *Collecting, Preserving and Classifying Insects.* Booklet No.13. Qld Museum, Brisbane.
Upton, M. S. 1991. *Methods of Collecting, Preserving and Studying Insects and Allied Forms.* 4th edn. Aust. Ento. Soc., Brisbane.
Australian Museum www.amonline.net.au/
www.austmus.gov.au
Purchasing insects australian-insects.com/

IPM

Crop monitoring, eg
www2.dpi.qld.gov.au/horticulture/18606.html

Biological control/IPM

List of suppliers www.goodbugs.org.au/
Organic Crop Protectants www.ocp.com.au/
Becker Underwood www.beckerunderwood.com
Bioglobal www.bioglobal.com.au/
Ecogrow www.ecogrow.com.au/

Organic standards.

AS 6000—2009. *Standards Australia Organic and Biodynamic Products.* Standards Australia.
Organic Federation of Australia www.ofa.org.au
Biological Farmers of Australia www.bfa.com.au/
Organic Growers of Australia (OGA) www.organicgrowers.org.au/
National Association for Sustainable Agriculture, Australia (NASAA) www.nasaa.com.au/
USDA National Organic Program www.ams.usda.gov/AMSv1.0/nop
Caldwell, B., Rosen, E., Sideman, E., Shelton, A. and Smart, C. 2000. *Resource Guide for Organic Insect and Disease Management.* www.nysipm.cornell.edu/organic_guide/

Quarantine

Commonwealth quarantine, *Plant Protection News*, etc www.daff.gov.au/aqis
PaDIL - Pests and Diseases Image Library www.padil.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. www.daff.gov.au and search for target lists
Lucid keys of DIRECT Relevance to Quarantine, Plant Health and Invasive Species. avail online

Insecticides/miticides

Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
Croplife Australia www.cropelifeaustralia.org.au/
MSDS http://www.msds.com.au/. Company websites
HerbiGuide http://www.herbiguide.com.au/
Chemical Toxicity to Beneficials www.goodbugs.org.au/
Precision Spray Oils™ www.caltex.com.au/cropprotection/
SACOA Spray Oils www.sacoa.com.au
Regional Orchard Pest & Disease Handbooks
Specific industries and/or crops

Insecticides/miticides *(contd)*

Beattie, A, and Hardy, S. 2005. *Using Petroleum-based Spray Oils in Citrus.* NSW DPI, Agfact H2.AE.5.
Dean, N. (ed). 2005. *Field Crop Fungicide and Insecticide Guide 2.* 2nd edn. Kondinin http://www.kondinin.com.au/
Rhodes, J. 2006. *Pesticides – A Guide to their Effects on Honey Bees.* NSW Primefacts 148. avail online.
Walsh, D., Zalem, F. and Grove, G. 2008. *Horticultural Spray Oils.* An Online Guide to Plant Disease Control, Oregon State University Extension.

General references

Alford, D. V. 2007. *Pests of Fruit Crops: A Colour Handbook.* 2nd. Edn. Manson Pub. UK.
Baker, G.L. 1991. *Parasites of Locusts and Grasshoppers.* NSW Agfact, Sydney.
Baker, G. L. 1996. *Locusts and Grasshoppers of Australia.* NSW Agfact, Sydney.
Bailey, P. T. (ed). 2007. *Pests of Field Crops and Pastures: Identification and Control.* CSIRO Pub.
Beccaloni, J. 2009. *Arachnids.* CSIRO Publishing/The Natural History Museum, London.
Brown, J. D. 2000. *Insect Pest guide: A Guide to Identifying Vegetable Insect Pests and their Natural Enemies in the DryTropics.* HRDC.
Bodman, K., Carson, C., Forsberg, L., Gough, N., Hughes, I., Parker, R., Ramsey, M and Whitehouse, M. 1996. *Ornamental Plants : Pests, Diseases & Disorders.* Qld DPI, Brisbane.
Brough, E. J., Elder, R. J. and Beavis, C. H. S. (eds). 1994. *Managing Insects and Mites in Horticultural Crops.* Qld DPI, Brisbane.
Brunet, B. 2001. *Australian Insects : A Natural History.* New Holland, Sydney.
CSIRO posters, eg *Australian Insects, Insects of Cape York Peninsula, Insect Camouflage, Soil Animals*
CSIRO CD-ROMS, eg *Insects and World of Diversity, Insects: Little Creatures in a Big World.*
CSIRO. 1991. *Insects of Australia.* 2nd edn. CSIRO, Pub.
Elder, R. J., Brough, E. J. and Beavis, C. H. S. 1992. *Managing Insects and Mites in Field Crops, Forage Crops and Pastures.* Qld DPI, Brisbane.
Elliott, H. J. and deLittle, D. W. 1986. *Insect Pests of Trees and Timber in Tasmania.* Forestry Commission Tasmania, Hobart.
Elliott, H. J., Ohmart, C. P. and Wylie, F. R. 1998. *Insect Pests of Australian Forests : Ecology & Management.* Inkata Press, Melbourne.
Farrow, R. 1996. *Insect Pests of Eucalypts.* Identification Leaflets, CSIRO, Melbourne.
Gerozisis, J., Hadlington, P. W. and Staunton, I. 2008. *Urban Pest Management in Australia.* 5th edn. UNSW Press, Sydney.
Goodwin, S., Steiner, M. Parker, R., Tesoriero, L., Connellan, G., Keskula, E., Cowper, B., Medhurst, A. and Rodriguez, C. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* Agrilink. QAL0004, NSW DPI. Sydney.
Goodwin, S. and Steiner, M. (eds). 2000. *The Pests, Diseases, Disorders and Beneficials in Ornamentals – Field Identification Guide.* DPI. will be available as electronic device for use in the field.
Hadlington, P. W. and Johnston, J. A. 1988. *Australian Trees : Their Care and Repair.* UNSW Press, Sydney.
Hangay, G. and German, P. 2000. *Nature Guide to Insects of Australia.* Reed New Holland, Sydney.
Hely, P. C., Pasfield, G. and Gellatley, J. G. 1982. *Insect Pests of Fruit and Vegetables in NSW.* Inkata Press, Melbourne.
Hockings, F. D. 1980. *Friends and Foes of Australian Gardens.* Reed, Sydney.
Horne, P. de Boer, R. and Crawford, D. 2002. *A Field Guide to Insects and Diseases of Australian Potato Crops.* Melbourne University Press.
Horne, P. and Page, J. 2008. *Integrated Pest Management for Crops and Pastures.* Landlinks Press.
Jones, D. L. and Elliot, W. R. 1986. *Pests, Diseases & Ailments of Australian Plants.* Lothian Pub., Port Melbourne.
Mathias, P. 1995. *Handbook of the Major Pests and Diseases of Nursery Plants.* HRDC/NSW Agric., Locked Bag 11, Windsor, NSW 2756.

McMaugh, J. 1994. *What Garden Pest or Disease is That?* Lansdowne Pub., Sydney.
Moulds, G. and Tugwell, B. 1999. *Citrus Growing Manual*. NSW Agric./SARDI, Sydney.
Naumann, I. (ed.). 1993. *CSIRO Handbook of Australian Insect Names : Common and Scientific Names for Insects and Allied Organisms of Economic and Environmental Importance.* 6th edn. CSIRO Pub, Melbourne. new edn. avail online www.**ento**.csiro.au
NIASA. *The Nursery Industry Accreditation Scheme, Australia (NIASA).* cur. edn. Nursery & Garden Industry Australia (NGIA). www.**ngia**.com.au
Nursery & Garden Industry Australia (NGIA) www.**ngia**.com.au
Pedigo, L. P. and Rice M. E. 2008. *Entomology and Pest Management.* 6th ed. Prentice-Hall, NJ.
Smith, D., Beattie, G. A. C. and Broadley, R. (eds). 1997. *Citrus Pests & Their Natural Enemies : Integrated Pest Management in Australia.* HRDC/Qld DPI, Brisbane. Also *Citrus Pests : A Field Guide.*
Somers, T. *Grapevine Management Guide*. cur. edn. National Wine & Grape Industry Centre/Wine Industry Assoc./CSU/NSW Agric.
Sutherst, R. 2000. *Pests and Pest Management : Impact of Climate Change.* Pub.No.00/16, RIRDC, ACT.
Waterhouse, D. F. and Sands, D. P. A. 2001. *Classical Biological Control of Arthropods in Australia.* ACIAR.
Woodward, P. 2001. *Pest-repellent Plants*. Hyland House, Melbourne.
Gurr, G. M., Wrattan, S. D. and Altieri, M. A. (eds). 2004. *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. CSIRO Pub.
Zborowski, P. and Storey, R. 1995. *A Field Guide to Insects in Australia.* Reed Books, Port Melbourne.

References for some orders

Diptera (flies)

www.ento.csiro.au/education/insects/**diptera**.html
www.brisbaneinsects.com/brisbane_**flies**/index.html
Posters Fruit Flies of Australia and the World 2 from Scientific Advisory Service www.**saspl**.com.au/
Bugs for Bugs www.**bugsforbugs**.com.au
Lucid keys www.**lucidcentral**.com/
Identifying Polyphagous Agromyzid Leafminers
Key to the World Genera of Eulophidae Parasitoids (Hymenoptera) of Leafmining Agromyzidae (Diptera)
On the Fly – The Interactive Atlas and Key to Australian Fly Families
Liriomyza Parasitoids in South East Asia
Key. Mallik, M. No date. CD-ROM *Identifying Polyphagous Agromyzid Leafminers*. DAFF, Wagga.
Fruit Fly Research Centre, Sydney University.
Contingency plans for fruit fly incursions www.**daff**.gov.au/
National Contingency Plans for Response to an Incursion of Melon Fly (Bactrocera cucurbitae) and its Allies in Australia. Qld DPI.
National Contingency Plan for the Incursion of Papaya Fruit Fly (B. papayae) & its Allies in Australia. Qld DPI.
Fruit Fly Incursion of Insect Pest Plans. AGWEST.
Fruit Fly. Dept of Primary Industries & Fisheries (DPIFI).
Fruit Fly Contingency Plans. Riverland. PIRSA.
Cantrell, B., Chadwick, B. and Cahill, A. 2002. *Fruit Fly Fighters: Eradication of the Papaya Fruit Fly*. CSIRO Pub./PISC.
Goodwin, S. and Steiner, M. 1996. *Watch Out for Fungus Gnats and Shore Flies.* Aust. Hort., Mar.
Lopachin, P. 1999. *Fungus Gnats*. **GM***PRO*, Mar.
Madge, D. 2007. *Organic Farming: Managing Fruit Fly in Citrus*. DPI Vic.
Sutherst, R. 2000. *Pests and Pest Management : Impact of Climate Change.* Pub.No.00/16, RIRDC, Barton, ACT.

Lepidoptera (butterflies, moths)

www.ento.csiro.au/education/insects/**lepidoptera**.html
www.**floraforfauna**.com.au
Desire Pest Management http://insense.com.au/products.htm
Bioglobal www.**bioglobal**.com.au/
Butterfly House http://lepidoptera.butterflyhouse.com.au/
CSIRO poster, Australian Moths and Butterflies
Braby, M. F. 2001. *The Complete Field Guide to Butterflies of Australia.* CSIRO Pub.
Common, I. F. B. 1990. *Moths of Australia*. Melbourne University Press, Melbourne.

Lepidoptera (butterflies, moths) ***(contd)***

Common, I. F. B. and Waterhouse, D. F. 1981. *Butterflies of Australia*. CSIRO, Melbourne.
Crosby, D. and Quirk, N. 1995. *Victorian Butterflies Database*. CD-ROM, Viridans, Brighton, Vic.
Fisher, R. 1995. *A Field Guide to Australian Butterflies.* Capricornia Press, Sydney.
Kitchen, R. L., Scheermeyer, E, Jones, R. E. and Pierce, N. E. 1999. *Biology of Australian Butterflies.* CSIRO, Melbourne.
Matthew, M. (ed.) 2003. *A Cornerstone of Modern Agriculture*. Food Products Press.
Piper, W. 2001. *Changing Habitat*. Ecos 102. Mar.
Zborowski, P. and Edwards, T. 2007. *A Guide to Australian Moths*. CSIRO Pub.

Coleoptera (beetles, weevils)

www.ento.csiro.au/education/insects/**coleoptera**.html
CSIRO poster, Australian Beetles
CSIRO CD-ROMS, eg *Beetles of the World, Beetle Larvae of the World*
Google *Lucid keys of DIRECT Relevance to Quarantine, Plant Health and Invasive Species*
Lucid Keys www.**lucidcentral**.com/ and search for:
Key to the World genera of Xyleborina
Wood Boring Beetles of the World Part I: Wood Boring Beetle Families
Key to the Christmas Beetles of NSW
Key to the Flower Chafers of NSW
Key to the Dung Beetles of Eastern NSW
Identification Tool for Weevil Biological Control Agents of Aquatic and Terrestrial Weeds in the United States and Canada
Botha, J., Hardie, D. Power, G. 2000. *BlackVine Weevil*. Fact Sheet. AGWEST
Carnaby, K. 1987. *Jewel Beetles of Western Australia.* Direct Colour Printers, Perth.
Commonwealth of Australia. 2001. *Forests and Timber : A Field Guide to Exotic Pests and Diseases.* AFFA, AQIS, Canberra.
Hadlington, P. 1987. *Australian Termites and Other Common Timber Pests.* UNSW Press, Sydney.
Ślipiński, A. 2007. *Australian Ladybird Beetles*. ABRS Publications.

Hymenoptera (ants, bees, sawflies, wasps)

www.ento.csiro.au/education/insects/**hymenoptera**.html
Ants Down Under (Australian Ants Online) http://anic.ento.csiro.au/**ants**/
or www.csiro.au/resources/**AustralianAntsOnline**.html
Lucid Keys www.**lucidcentral**.com/ and search for:
What Wasp is That? An Interactive Identification Guide to Australasian Families of Hymenoptera
Key to the World Genera of Eulophidae Parasitoids (Hymenoptera) of Leafmining Agromyzidae (Diptera)
Baker, G and Hardy, J. 2005. *Survey Black Scale Parasitoids in South Austraian Olives*. Sardi, SA. avail online
CSIRO. 1995. *Insect Pests of Eucalypts on Farms and in Plantations : Sawflies*. Identification Leaflets, CSIRO, Melbourne.
Dollin, A. Batley, M., Robinson, M. and Faulnew, B. 2000. *Native Bees of the Sydney Region : A Field Guide*. Australian Native Bee Research Centre, North Richmond, NSW.
Elliott, H. J., Ohmart, C. P. and Wylie, F. R. 1998. *Insect Pests of Australian Forests : Ecology & Management*. Inkata Press, Melbourne.
Kent, D. 1995. *Eucalypt Sawflies*. Forest Protection Series. State Forests of NSW, Sydney.
Rhodes, J. 2006. *Pesticides : A Guide to their effects on Honeybees*. NSW DPI Primefacts. avail online
Shattuck, S. O. 1999. *Australian Ants : Identification and Description*. CSIRO, Melbourne.
Shattuck, S. O. 2001. *Australian Ants : Biology and Identification*. CSIRO, Melbourne
Woods, B. 1989. *Insect Pests of Wildflowers and Proteas.* Farmnote 90/88. WA Dept of Agric.

Neuroptera (lacewings, antlions, aphidlions)

www.ento.csiro.au/education/insects/**neuroptera**.html
www.brisbaneinsects.com/brisbane_**lacewings**/index.html

Thysanoptera (thrips)

www.ento.csiro.au/**thysanoptera**.html
Lucid Keys www.cbit.uq.edu.au/ and search for:
Thrips ID, Thrips of California
Pest Thrips of the World CD-ROM
AQIS Identification Guide (ThripsID) Thysanoptera

Atkinson, I. 1999. *Greenhouse Insect Screens : Making the Right Selection.* The Nursery Papers, Issue No. 1999/01
McDougall, S. and Tesoriero, L. 2007. *Western Flower Thrips and Tomato Spotted Wilt Virus*. NSW DPI Primefact 713. avail online.
Persley, D., Sharman, M., Thomas, J., Kay, I, Heisswolf, S. and McMichae, L. 2007. *Thrips and Tospovirus*: A Management Guide. Qld DPIF.
Steiner, M. (2003?). *Which Thrips is that? A Guide to the Key Species Damaging Strawberries.* NSW DPI.
Stephens, R. (ed.). 2000. *WFT Insecticide Management*. The Nursery Papers. Issue 2000/01. avail online.
Western Flower Thrips Newsletter. Avail online.

Hemiptera (bugs; hoppers; aphids, lerps, mealybugs, scales, whiteflies)
www.ento.csiro.au/education/insects/**hemiptera**.html
www.austmus.gov.au/factSheets/**cicada**.htm
Lucid Keys www.**lucidcentral**.com/ and search for:
Scale Insects: Identification Tools for Species of Quarantine Significance includes Scale Families, Soft Scales, other Scale, Mealybugs
Platanthera Interactive Key to North America, north of Mexico
Pupal Key to Genera of White Flies Platanthera Interactive Key to North America, north of Mexico
Asante, G. K. 1999. *Seasonal Abundance of Woolly Apple aphid (Eriosoma lanigerum) (Hausmann) and its Important Natural enemies in Armidale, Northern NSW.* Plant Prot. Quarterly Vol.14(1).
Baker, G and Hardy, J. 2005. *Survey Black Scale Parasitoids in South Australian Olives*. Sardi, SA. avail online
Bodman, K. and Hargreaves, J. 2000. *Whiteflies in Queensland Crops : A Review.* DPI Note, Qld Agdex 290/622.
Buchan, G. 2008. *Soft scales (Coccidae) on Grapevines in Australia.* Vic DPI AgricNote AG1369
Collett, N. 2001. *Biology and Control of Psyllids, and possible causes for Defoliation of Eucalyptus camaldulensis Denh. (river red gum) in south-eastern Australia - a review.* Australian Forestry 64: 88–95
Morgan, F.D. 1984. *Psylloidea of South Australia.* Series: Handbook of the Flora and Fauna of South Australia. SA Government, Adelaide.
Moulds, M. 1990. *A Guide to Australian Cicadas*. UNSW Press, Sydney.
Qld DPI. 2002. *Inspection and Treatment of Plants for Spiralling Whitefly* (ICA-35). Qld DPI, Brisbane — *Property Freedom of Plants for Spiralling Whitefly* (ICA-36)
Smith, D., Beattie, G. A. C. and Broadley, R. (eds). 1997. *Citrus Pests & Their Natural Enemies : Integrated Pest Management in Australia.* HRDC/Qld DPI, Brisbane — Also *Citrus Pests : A Field Guide*.

Isoptera (termites, 'white ants')
www.ento.csiro.au/education/insects/**isoptera**.html
http://australianmuseum.net.au/**Termites**
Andersen, et al. 2000. *Termites of Northern Australia*. CSIRO TERC Publication
Crefield, J. W., 1996. *Wood Destroying Insects : Wood Borers and Termites.* 2nd edn. CSIRO, Melbourne
Gerozisis, J., Hadlington, P. W. and Staunton, I. 2008. *Urban Pest Management in Australia.* 5th edn. UNSW Press, Sydney.
Hadlington, P. W. 2001. *Australian Termites and Other Common Timber Pests*. 2nd edn. UNSW Press, Sydney.
Hadlington, P. and Johnston, J. 1996. *Australian Trees : Their Care and Repair.* UNSW Press, Sydney.
Mann, A. 2009. *Personal Correspondence*. Canopy Tree Experts, Canberra, ACT.

Orthoptera (crickets, grasshoppers, locusts)
www.ento.csiro.au/education/insects/**orthoptera**.html
www.austmus.gov.au/factSheets/**grasshoppers**.htm
Australian Plague Locust Commission (APLC) www.daff.gov.au/animal-plant-health/**locusts**
Irwin, J. 2000. *Beef Cattle and Fenitrothion Plague Locust Spray.* NSW Agnote, Yanco, NSW.
Rentz, D. 1996. *Grasshopper Country*. UNSW Press: Sydney.
Zborowski. 1998. *Field Guide to the Locusts and Related Grasshoppers in Australia*. APLC, GPO Box 858, Canberra, ACT 2601.

Dermaptera
www.ento.csiro.au/education/insects/**dermaptera**.html
http://australianmuseum.net.au/Earwigs

Blattodea
www.ento.csiro.au/education/insects/**blattodea**.html
www.amonline.net.au/factsheets/**cockroaches**.html

Gerozisis, J., Hadlington, P. W. and Staunton, I. 2008. *Urban Pest Management in Australia.* 5th edn. UNSW Press, Sydney.

Phasmatodea
www.ento.csiro.au/education/insects/**phasmatodea**.html
www.friendsofthe**phasmid**.org.au/
www.insectfarm.com.au/**pets**.htm
Brock, P. D. and Hasenpusch, J. W. 2009. *The Complete Field Guide to Stick and Leaf Insects of Australia*. CSIRO Publishing.

Mantodea
www.ento.csiro.au/education/insects/**mantodea**.html
www.brisbaneinsects.com/brisbane_hoppers/**Mantids**.htm

Odonata
Lucid Keys www.**lucidcentral**.com/ and search for:
***Dragonflies** of the World: Interactive Identification to Subfamilies*
Silsby, J. 2000. *Dragonflies of the World*. CSIRO, Melbourne.
Theischinger, G. and Hawking, J. 2006. *The Complete Field Guide to Dragon flies of Australia.* CSIRO Pub.

Springtails
www.ento.csiro.au/education/hexapods/**collembola**.html

Mites
www.ento.csiro.au/education/allies/**acarina**.htm
Lucid Keys www.**cbit**.uq.edu.au/ and search for:
Invasive Mite Identification
Mites in the Soil www.**lucidcentral**.com/
Phytoseiidae of New Zealand 1.0
Soil Microarthropods v1.0
Orbatid Mites
List of suppliers www.**goodbugs**.org.au/
CSIRO poster *Soil Mites*
Beccaloni, J. 2009. *Arachnids*, CSIRO Publishing/The Natural History Museum, London.
Bernard, M. B., Horne, P. A, and Hoffmann, A. A. 2005. *Eriophyid Mite Damage in Vitis Vinifera (grapevine) in Australia: Calipitrimerus vitis and Colomerus vitis (Acarina:Eriophyidae) as the Common Cause of the Widespread "Restricted Spring Growth" Syndrome.* Experimental and Applied Acarology 35: 83-109
Bower, C. C. and Thwaite, W. G. 1995. *The Mite Management Manual : A Practical Guide to Integrated Mite Control in Apples.* NSW Agric.
Braybrook, et al. 2000. *Mites : The Classic 'Who Done It?'*. The Australian Grapegrower & Winemaker, 438:28-31.
Halliday, R. B. 1998. *Mites of Australia* : A Checklist and Bibliography. CSIRO, Melbourne.
Hunt, G. S., Norton, R. A., Kelly, J. P. H., Colloff, M. J., Lindsay, S. M., Dallwitz, M. J. and Walter, D. E. 1998. *Oribatid Mites CD-ROM: An Interactive Glossary of Oribatid Mites, An Interactive Key to Oribatid Mites of Australia.* CSIRO Pub.
Learmonth, S. 2008. *Using Miticdes in Western Australia Deciduous Fruit Tree Crops* 2008-2009. Farmnote 281, WA Dept of Agric. avail online
Magarey, P. A., Macgregor, A. M., Watchel, M F. and Kelly, M. C.1999. *The Australian and NZ Field Guide to Diseases, Pests and Disorders of Grapes.* Winetitles, Adelaide.
Walter, D. and Proctor, H. 1999. *Mites : Ecology, Evolution and Behaviour*. UNSW Press, Sydney.

Spiders
www.ento.csiro.au/education/allies/araneae.html
Lucid Keys www.**lucidcentral**.com/ and search for:
Spiders of Australia: Interactive Identification to Subfamilies
Key to Insects and Spiders in Tropical Rice
Lindsey, T. 1998. *Green Guide : Spiders of Australia.* New Holland, Sydney.
Simon-Brunet, B. 1994. *The Silken Web : A Natural History of Australian Spiders.* Reed, Sydney.
St John Ambulance Australia. *Emergency FIRST AID : A Quick Guide.* cur. edn. St John Ambulance Australia.

Slaters, Millipedes, etc
www.csiro.au/org/**Entomology**.html
www.csiro.au/resources/**Black-Portuguese-Millipedes**.html

Snails and Slugs

Snail damage to broccoli leaves.

BIOLOGY & IDENTIFICATION

Phylum Mollusca, Class Gastropoda

NO. SPECIES IN AUSTRALIA

About **10** of the **50 introduced** species have become **serious pests** of agricultural and horticultural crops in Australia. There are more than **1000 native species**, none are important pest species. Many Australian land molluscs are endangered and some Australian species are already extinct. There is no evidence that exotic species have affected the survival of Australian native species, as most introduced pest species invade places only after humans have destroyed the habitat of native snails. Museums are identifying and data-basing virtually all the available collections of Australian Land Snails.

Land Snails of Australia – Museum Collections
www.environment.gov.au/biodiversity/abif/bat/**snails**.html

SOME DISTINCTIVE FEATURES

Slugs and snails are many-celled animals with a true digestive cavity.

SHELL

1. Unsegmented soft bodies of snails and slugs are covered with a **mantle** (layer of tissue) that usually secretes a limey shell.
2. **Snails** have an external, spirally-coiled shell carried on the back, into which the snail withdraws when alarmed or at rest.
3. **Slugs** resemble snails in general appearance but the shell is either absent or reduced to a shield-like structure borne on the forehead of the back. In some slugs the back has a leathery covering.

BODY

1. Snails and slugs have similar bodies.
2. **Bodies** are broad and elongate, usually light or dark grey and of variable length depending on the species. They bear 2 pairs of retractile tentacles on the head.
3. **Eyes** are at the tips of the 2nd and longer pair of tentacles.
4. **Mouth**, below the tentacles, contains a file-like organ or radula which is used for rasping off portions of food.

MOVEMENT

If betting on snail races put your money on the least slimy snail, making slime uses energy

Snails and slugs glide along by undulating the muscles of the foot over a slippery track of mucous secreted by glands in the foot. The mucous solidifies on exposure to air, this is the **silvery trail** left by snails.

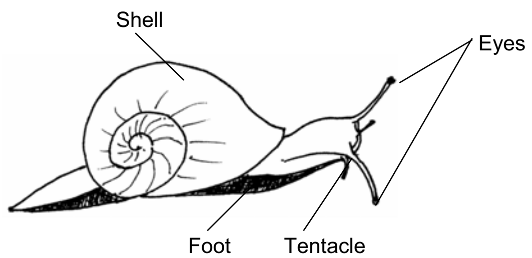


Diagram of a snail

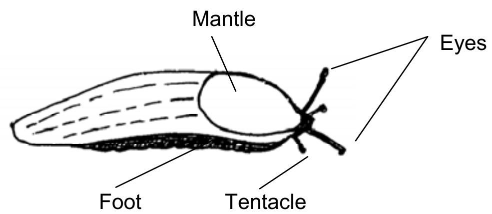


Diagram of a slug

METHOD OF FEEDING

Snails and slugs feed by rasping the surfaces of a wide range of plants. They feed at **night** and return to hide under debris, stones and plants during the day. They only feed **during the day** during **prolonged wet weather**. Slugs can eat their body weight in a day and eat large areas of newly emerging crops.

FEEDING AND PLANT DAMAGE

Slugs are an increasing problem worldwide, Some species are known to eat 1/3rd of their body weight each day

Snail and slug numbers can be fantastic - up to 7 million snails/hectare have been recorded in Australia!

Skeletonisation of gazania leaves by snails

DIRECT FEEDING DAMAGE

Slugs are primarily pests of ground crops, eg annuals, vegetables, potato tubers, seedling crops, weeds. Snails and slugs may damage emerging crops so much that re-sowing is necessary and can cost growers million of dollars each year in lost production. Snails and slugs are minor pests of ornamental crops but infrequent control may lead to persistent problems.

SEEDLINGS	**Completely consumed**, eg emerging seedlings, cuttings, new growth can be extensively damaged. The cotyledons are eaten, killing the young plant before its roots can be established.
LEAVES	**Holes chewed** (older snails), eg begonia, cabbage **Skeletonization** (young snails), eg gazania
FLOWER BUDS	**Eaten around edges of petals**, eg daffodils, iris **Holes chewed**, eg orchids
PASTURE, CROPS	**Chewing damage,** slime
FRUIT, BULBS	**Holes**, eg strawberry
TUBERS	**Tunnels bored**, eg potato
TRUNKS,	**Chewed bark**, eg citrus
ROOTS	**Chewing damage**, eg roots exposed in soil cracks

INDIRECT DAMAGE

- **Slimey trails** and coiled threads of spaghetti-like excreta make plants look unsightly and unsaleable; stock will not eat slime covered grass.
- **Contaminated stored grain** is downgraded because of snail infestation or increased moisture content because of the crushed snails. May contaminate harvested citrus fruit. Crushed snails may damage harvesting machinery.
- **Transmission of plant diseases**. Overseas, snails and slugs are known to have transmitted tobacco mosaic virus and various fungal diseases, eg *Phytophthora, Fusarium* and rusts of European plants.
- **Transmission of animal and human diseases**
  - **Introduced helicid snails**, eg *Cochlicella, Helix, Theba,* in SA are commonly infected with a **flatworm** that can infect humans.
  - Snails may eat **rat faeces** contaminated with **parasitic worms** (*Angiostrongylus cantonensis*) and may then contaminate vegetation depositing the parasitic worm in its mucous trails. Rats can be re-infested by eating infested snails (May 1998).
  - **Snails** (*Lymnaea* spp.), 4-10 mm, long are the intermediate hosts for **liver fluke** (*Fasciola hepatica*) which is a major parasite of sheep, cattle, goats, pigs and wildlife in south-eastern Australia.
- **Introduction of decay organisms**.

CLASSIFICATION, IDENTIFICATION, DIAGNOSTICS

CLASSFICATION AND IDENTIFICATION

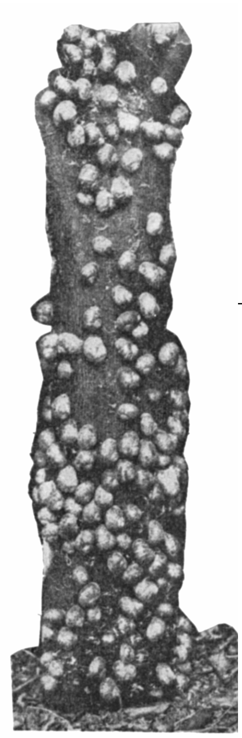
- Snails and slugs belong to the **Phylum Mollusca, Class Gastropoda.**
- **Snail identification** is based on the features of the **shell** and size, shape, colour and culture of the snail itself. **Slug identification** is based on size, shape, colour and culture of slugs.
- **Identification tools include**:
  - **Pocket Guides** are available for both snails and slugs.
  - **Fact Sheets** for local species by State Depts. of Primary Industries.
  - **Web sites** include: *Land snails of Australia – Museum Collections* www.environment.gov.au/biodiversity/abif/bat/**snails**.html
  - **Lucid key** *A Key to the Families Non-Marine Molluscs of Quarantine Concern in Australia* www.**lucidcentral**.org/

DIAGNOSTICS

Do not confuse pest with beneficial species

- **Damage by adult snails and slugs** is easy to recognize on most plants.
- **Look for silvery slimy trails and excrement casts** which are long and curly and adhere to feeding sites.
- **Young snails** may skeletonise surface of leaves of plants such as gazania. Damaged leaves then shrivel up and are then difficult to recognize as snail damage. Snails and slugs may eat from the edge of the leaf as well as from within the leaf margins.
- **Do not confuse snail or slug damage** with that caused by **chewing** insects, eg caterpillars, beetles, cutworms, or birds on certain plants, eg
  Cucurbits - Snails, leafeating ladybirds, pumpkin beetle
  Geraniums - Snails, caterpillars of various moths
  Spinach seedlings - Snails and slugs, cutworms, birds
- **Snails and slugs are not** usually seen during the day. Where damage is unexplained, inspect area after say 10 pm on a mild calm night, or put out traps (sacks, etc) or baits, to monitor population densities (page 233).

LIST OF SOME SPECIES	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	SNAILS		
	Brown garden snail, common garden snail **(up to 25 mm long)**	*Helix aspersa* syn. *Cantareus aspersus*	Wide range of all types of plants. Brought to Australia because people wanted to eat it. Commercial snail farms could be established in Australia
	Green snail (WA) **(up to 25 mm across)**	*H. aperta* (WA only)	Ornamentals, vegetables, crops
	Pointed or conical snail **(up to 18 mm long)**	*Cochlicella acuta*	Improved pastures and legume crops, citrus, seedling crops, cereal grains at harvest
	Small pointed snail **(8-10 mm long)**	*C. barbara*	Pastures with perennial clovers, seeding crops cereal grains at harvest, young vines, lucerne
	Sand dune snail, white Italian snail **(up to 24 mm across)**	*Theba pisana* probably the best known pest of agriculture in Australia	Emerging seedling crops, climbs cereal stalks, clogs machinery, contaminates grain, dried fruit, clover, beans, oil seeds, vines
	Vineyard snail, common white snail **(up to 20 mm across)**	*Cernuella virgata*	Emerging seedling crops, especially barley, field peas, contaminate grain, clog machinery, organic matter
	White bradybaena snails	*Bradybaena similaris* **(up to 15.5 mm across)**	Pest of hanging fruit such as citrus
Not known in Australia Often intercepted in quarantine	Giant African snail **(about 80-200 mm long)**	*Achatina fulica*	Major pest of vegetable & horticultural crops
Not known in Australia	Golden apple snail	*Pomacea caniculata*	Mainly an agricultural pest, especially of rice.
	NATIVE SNAILS		
	Various species	*Placostylus bivaricosus* *Thersiles mitchellae*	Many Australian land snails feed on fungi. Native snails are mostly restricted to natural habitats
Endangered Many native species are endangered	Cumberland land snail	*Meridolum corneovirens*	Like many other native land snails it feeds on fungi
	PREDATORY SNAILS		
	Many native species	*Strangesta capillacea*	A common garden snail
	SLUGS		
	Black-keeled slug	*Milax gagates*	Ornamentals, fruit, vegetables
	Keeled slug	*M. budopeskensis*	Ornamentals, fruit, vegetables
	Brown slug	*Deroceras parnormitanum*	Ornamentals, fruit, vegetables, pasture
	Reticulated slug **(up to 25 mm long)**	*D. reticulatum* **The most important pest slug**	Wide range of leafy plants, seedlings, crops, pastures.
	Great striped garden slug **(up to 20 cm long)**	*Limax maximus*	Rotting plant material, also garden plants, rotting pet food
	Great yellow slug	*Lehmannia flava*	Decaying plant and other material
	PREDATORY SLUGS		
	Native spp. mostly in natural habitats	*Atopos australe*	Thought to prey on other slugs
	Introduced species	*Testacella haliotidea*	Preys on earthworms



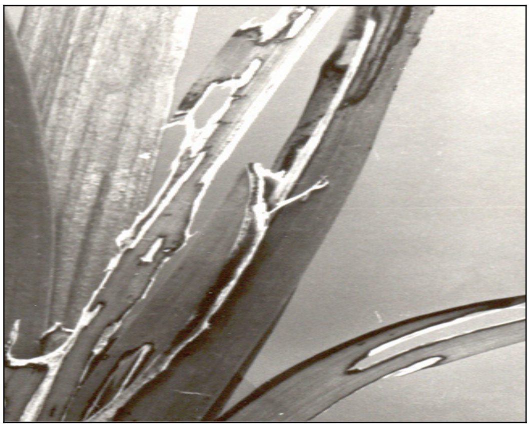


Fig. 130. Common garden snail (*Helix aspersa*). ***Left:*** Adult snails on the trunk of a citrus tree. Photo© NSW Dept. of Industry and Investment. ***Centre & Right:*** Damage to cabbage and kangaroo paw. Photo©CIT, Canberra (P.W.Unger).

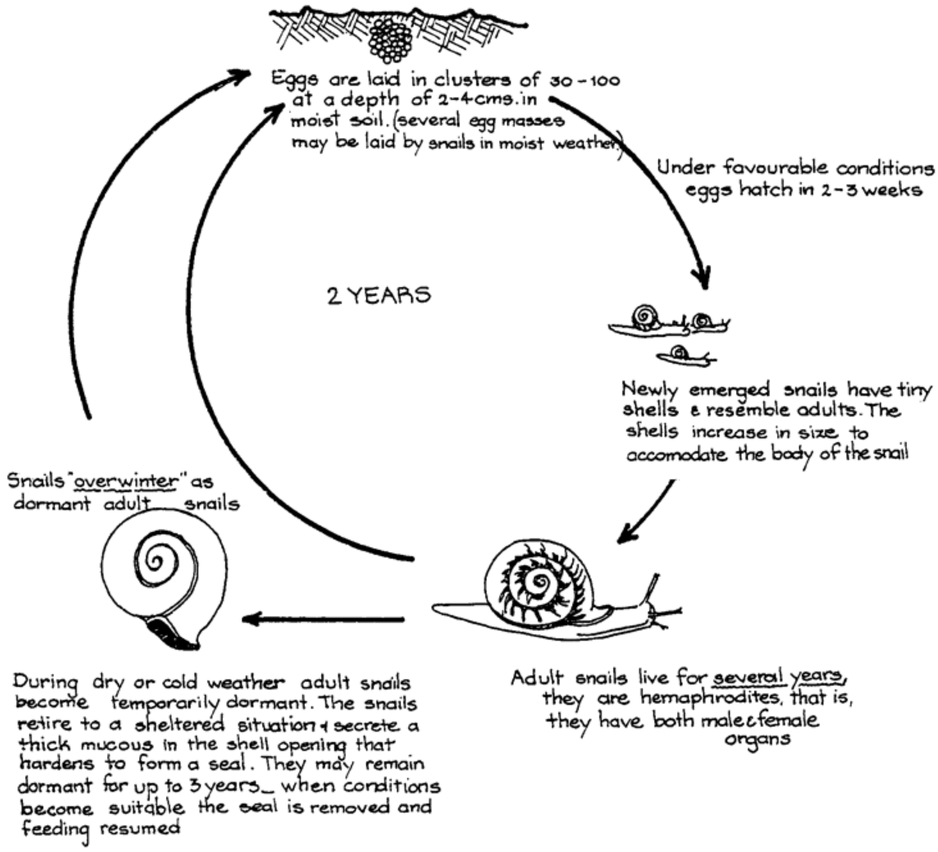
PEST CYCLE

SNAILS

During cold weather, snails hibernate in the topsoil. The life cycle of the common garden snail:

Snails are hermaphrodite (individuals have both male and female sex organs) and can fertilise each other

Garden snails are up to **25 mm** across



SLUGS

- **The life cycle** of slugs is similar to that of snails. But there are some slight differences.
- **Slugs take 1-2 years** to mature to adults and may live for a few months or a few years, depending on the species.
- Adult slugs are mostly **hermaphrodite** and egg laying, like snails. Self-fertilization may occur in some species.
- **Adults** lay white or pale yellow spherical eggs, 2-6 mm across, in masses of about 30 in decaying organic matter, under stones, boards or clods or in moist soil. Many egg masses may be laid by each slug in warmer weather. Egg laying may also occur during warm spells in winter in warm climates. Under favorable conditions the eggs hatch in 2-4 weeks and the newly emerged slugs, which are dull white, resemble the adults. Young slugs initially feed on humus and grow slowly, assuming the adult coloration when about 1 month old.
- **Unlike snails**, slugs do **not** enter a resting stage during dry or cold weather, instead during adverse cold, hot and dry weather, they may congregate in damp sheltered situations under stones, logs and pots or in cracks in the soil.
- **Slugs are greatly underestimated as pests**. They shelter in cracks in the ground and under litter where the relative humidity is 100%. They may cause damage before and after snails have been feeding.

OVERWINTERING, OVERSUMMERING

- As adults (either feeding or in a non-feeding dormant state).
- As eggs in the ground.

SPREAD	**SNAILS HAVE CAPACITY TO SPREAD** • By their **own movement** over smooth surfaces, depending on the species they can travel up to 1 metre a day. • Snails may migrate from scrubby areas in search of food during autumn and winter to pastures and crops, and can travel from 20-55 metres per month. Snails move in droves in autumn and winter from roadside vegetation into more exposed pasture where they feed and reproduce before returning to the roadside in spring and early summer. They have a good sense of smell and can travel substantial distances to find choice food. • **Hitch-hiking** on cars, trucks, containers, pallets, bailed hay, nursery stock, **long** distances may be covered. This is how **exotic** snails arrive in Australia. • Eggs or newly hatched snails may be transported on empty bags or containers, in **soil in deliveries and in pots**. • Pointed or conical snails **gradually spread** north through Vic and NSW. • Shell souvenirs, food carried by airline passengers.
CONDITIONS FAVOURING Snails are most active in **moist, cool conditions** so a good time to look for them is **after** heavy dew or irrigation Slugs are likely to be greatly underestimated as pests as they shelter in cracks in the ground, under litter and are not usually visible during the day	**EXACT CONDITIONS VARY ACCORDING TO SPECIES** • **Wet weather** especially during autumn, winter and spring, **Big spring rains** followed by a mild damp summer and autumn; but not heavy rain or wind. Mediterranean climates. Only a problem in higher rainfall districts. • **Cool climate areas**. Cool moist shady places such as under mulches, boards, stones, benches, in pots, debris, leafy weeds, broadleaved plants growing close to the ground as shelter on hot sunny days. Cloudy or foggy days. Mild temperatures (15-25°C) and calm periods. • **Limey soils** increase the fertility of both snails and slugs; population densities are greatest with a soil pH of 6.3-6.7. White Italian snail (*Theba pisana*) only thrives in areas of alkaline sandy soil with a high calcium content mainly near the coast. **Slugs are favoured by heavier soils** and do not survive well in fine, light or compacted soil. • **Smooth** surfaces on which to move. • **Ground cover plants** and weeds provide ideal moisture levels and shelter. Perennial and cover crops between trees and vines allow large populations of slugs to develop. Often a problem occurs on the edges of crops adjacent to weedy fence lines and around uncultivated islands within crops. • **Preceding crops** are important. Damage to crops is usually heavier after peas, clovers and some Brassicas. • **Pet food left unattended** in gardens attracts great striped garden slugs. • **Large amounts of organic matter**, eg dug-in vegetation, remains of straw or manure, help increase soil moisture and are a source of food. • **Conservation Tillage (CT)** with minimum/no tillage, stubble retention and direct drilling practices help slugs survive (increased shelter, moisture, food). Slugs are listed as one of the major pests that benefit from these practices. • Reduced burning of crop stubble. • Most pest snails and slugs are introduced so few natural enemies.

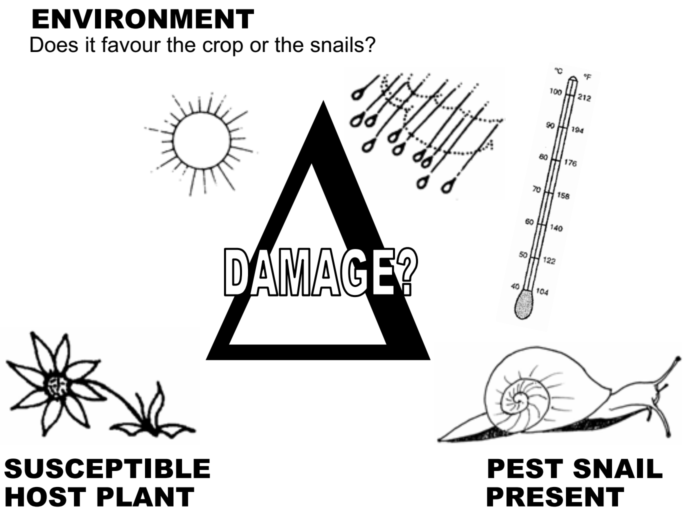


Fig. 131. Pest triangle.

INTEGRATED PEST MANAGEMENT (IPM)

MAIN STEPS

Early detection of invasion is important

1. **Plan** well in advance to use an **IPM** program that fits your situation. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides.
2. **Crop/region**. **IPM** programs are available for different species of snails and slugs on a range of crops in particular regions. List the crop problems in your region.
3. **Identification** can be difficult. Be familiar with local species. Consult a diagnostic service if necessary (page xiv). Identification is important because **certain baits** are more effective against some species than others and **rates of bait** depend on the species, eg for conical snails use bait with smaller pellet size. Obtain fact sheets to understand life cycles, conditions favouring, etc.
4. **Monitor populations before** planting, sowing, harvesting, spraying or baiting, etc, as there is a relation between snail and slug numbers and plant damage. **Know when, where, what and how to monitor**. Monitor damage to plants. Although it may seem that the best time to 'catch the pests in action' is to look for them at night, their colour makes them difficult to locate. Detect slugs early in the season using shelter traps, eg moist hessian bags laid on soil. Slugs invade from the crop edges.
5. **Thresholds** are important and will depend on your crop, economics and any legal requirements, eg quarantine. It might be 20/m^2 white snails/m in cereals and 5/m^2 in canola. Some baits are more effective than others **if snail numbers are high**.
6. **Action**. **Compliance** with quarantine, snail-freedom, organic standards, etc may be required. Many control methods will be **preventative**, eg sanitation, rough mulches. Choose appropriate control measures **strategically and early** to avoid potential major pest problems. Move fast if numbers large. Baiting or spraying may work better in some combinations in commercial crops while hand control may be sufficient for home gardeners, combined with traps and baits. Toxicity of chemicals to children and pets must be a consideration. Populations of some snails, eg common garden snail, need to be excessively large and pasture availability limiting **before** control is warranted. Chemical control is more effective **when** used in combination with other control methods.
7. **Evaluate** your current program. Recommend improvements if required. Differences in success depend on the snail species, the crop and the cropping system.

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Pest-tested material
Physical/mechanical
Pesticides
Organic, BMP, etc
Combinations

CONTROL METHODS

LEGISLATION, STANDARDS, ETC

- **Seed Acts** may prohibit the presence of snails in seed.
- **Plant Quarantine** prohibits entry of exotic snail and slug species and regulates compliance with importing countries regulations (page 234).
- **Pesticide and Safety Acts** regulate molluscicides (baits and sprays). Permits may be required for minor crops, eg herbs.
- **Threatened Species and Conservation Act 1995** in NSW provides for conservation and recovery of threatened species.
- **AS 6000-2009.Organic and Biodynamic Products** outlines minimum requirements be met by growers wishing to label their products 'organic' or 'biodynamic.

CULTURAL METHODS

- **Use trickle irrigation** instead of sprinklers where possible to reduce moisture and breeding and sheltering, especially of slugs.
- **Cultivation** kills eggs and adults providing a sterile habitat from which survivors migrate. A short fallow period can improve this effect. Cultivation **in spring** can drive snails from cover crops or weeds into young foliage.
- Slashing, grazing and cultivation **during summer** can reduce snail numbers by exposing them to increased soil surface temperatures, killing them.
- **Water early in the day** to minimize moist areas.
- It can be beneficial to change crop sequences.
- **Skirt trees** to provide fewer access points for snails and minimize risk of snails climbing trees. Raise plants off the ground.
- Coco mulch is an inbuilt snail repellent.

SANITATION

- **Good sanitation** increases the effectiveness of treatments especially baits. Remove/control weeds. Eliminate places they can hide during the day and breeding sites, eg rubbish, pallets, boards and rocks, old plant pots and flats.
- **Collecting snails by hand** is suitable for small areas in home gardens, but not so easy for slugs. Collect immediately after rain, or irrigation which draws out snails and slugs for collection at night with a torch. Crush, drown in water, or putt them in a plastic bag and placing in the freezer for several hours then tipping into garbage or compost. Stomp on them in situ. Start daily and continue weekly until the population has decreased. Aestivating snails can be dislodged from fence posts, etc.
- **Place fruit bins** in snail-free areas to prevent snails from climbing onto field bins and being transported into packing sheds.
- **Inspect** inside and outside of all containers that enter or leave the property.

BIOLOGICAL CONTROL.

- **Predators**.
  - Naturally occurring predators of snails and slugs include birds, rats, frogs, nematodes and lizards but none provide much control. Some extinction of land snails on Lord Howe Island is possibly due to rats and possibly pigs. Poultry scratch the ground.
  - **Ducks** are used to control snails and slugs in citrus orchards. About 5-8 ducks/ha are sufficient if run continually. Use only active breeds such as Khaki Campbell or Indian Runner. Have only 1 drake per flock of about 12 ducks. House ducks in or near the orchards and lock them up at night. Feed ducks only in the evenings and at their quarters. Do not allow ducks access to water in which they can swim. Do not use poison baits where ducks are run. In a small orchards and urban gardens, ducks may be messy, a nuisance and damage many herbaceous plants.

Snail baits may kill natural predators

  - **The decollate snail** (*Rumina decollata*) is a voracious predator of snails and slugs and their eggs; also feeds on plant matter.
  - **Several native species** of snails and slugs are also predators.
- **Predators**.
  - **Nemaslug**® (*Phasmarhabditis* sp.) parasitizes snails and is available overseas for high value protected crops. Newly hatched snails are very susceptible to nematodes some of which occur naturally. Practices which increase the number of bacteria-feeding soil nematodes, eg soil organic matter, may increase mortality of young snails. Other species are researched in Australia.
  - **A parasitic female fly** (*Sarcophaga penicillata*) places larvae (maggots) in the opening of shells of the **pointed or conical snail** (*Cochlicella acuta*) which is a major pest cereal crops in SA. Fly larvae feed on resting snails, pupate and emerge as adult flies from the dying snail after about 128 days. It is hoped that the fly can regulate pointed snail numbers below the level of economic concern, that it will become established in infested areas and eliminate the need for molluscicides.
  - A blowfly (*Amenia imperialis*) parasitizes the **garden snail** (*Helix aspersa*).

RESISTANT, TOLERANT VARIETIES.

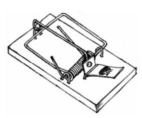
- Where desired plant species are not as important as in home gardens, avoid plants very attractive to snails and slugs, eg honesty (*Lunaria* sp.), hosta.

PLANT QUARANTINE.

- **Australian Quarantine & Inspection Service (AQIS).**
  - **The giant African snail (GAS)** has already reached Australia several times and is regularly seized during quarantine inspections on cargo and containers from East Timor and north of Australia. The **European edible snail** (*Helix pomatia*) is also a prohibited import to Australia. Copper-based repellents on containers can discourage snails from entry to Australia.
  - **To be approved as a citrus exporter** to the US, citrus growers in Australia must go through a snail approved and accreditation program to ensure fruit is not contaminated with a small brown snail (*Microxeromagna vestita*).
  - **Soil** which might carry snail eggs, etc is a prohibited import.
  - **Lucid key** - *A key to the Families Non-Marine Molluscs of Quarantine Concern in Australia.* www.**lucidcentral**.com/
- **Interstate and Regional Quarantine.** The **green snail** was introduced into WA from Southern Europe and North Africa and eradication has been unsuccessful. It is hoped that it will not spread to the eastern states. Cut flowers in WA must be inspected and certified free from green snails before sale to the eastern states. If you suspect green snail in WA has moved into you garden or property contact your local Dept. of Agriculture office.
- **'Local' quarantine.** Snails can be carried on plants or they may hitch a lift on containers purchased from nurseries and especially fetes. Check material being brought into your property. Control movement of machinery and produce to reduce further spread of snails on property.

PEST-TESTED PLANTING MATERIAL.

- Specially developed screens float snails off during wheat harvest operations.
- A maximum limit of 1 snail/200g Australian lupin seed is allowed at present.

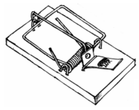


PHYSICAL & MECHANICAL METHODS.

- **Traps**
  - **Food traps. Beer** (fermented malt) can trap, poison and drown nearby slugs and snails. Check traps daily and maintain regularly to ensure beer is fresh and deep enough for drowning. A little brown sugar or treacle and a small amount of flour increases its efficiency. Other attractants include milk, solutions of Marmite® or Vegemite®, small heaps of fresh bran sweetened with a minimum amount of castor sugar. Snails or slugs may recover from their drunken stupor and climb out so the sunken beer traps must be vertical to prevent them from crawling out.
  - **Shelter traps** include upturned pots, sacks, boards, orange skins. The hiding places must be inspected daily and sheltering snails and slugs destroyed. Check traps daily and remove accumulated pests.

Beer trap

CONTROL METHODS
(contd)



- **Barriers**
  - **Rough mulches** around plants act as a barrier to snails and slugs which require a moist smooth surface on which to move. This has limited practicality as snails and slugs (and eggs) must be outside the barriers when these rough mulches are put in place and there must be no bridges across them. Suitable mulches include coarse wood chips, coco mulch, bark, sawdust, sand or wood ash (2-3 cm deep), crushed egg shells (keep in frig or microwave a couple of days before using).
  - **Mosquito netting** can be placed over young seedlings.
  - **Copper** repellent barriers, eg **bands,** tape, copper-coated pot feet, and rings **and paint strips** 10 cm wide, can be used to band **planter boxes** and tree trunks. **Copper tape** can be partially buried in the ground and copper can be spread around legs of benches. When snails and slugs make contact there is a toxic reaction which repels them. Do before warm weather when snails become active. Lines of lime, copper sulphate are repellent and used to prevent migrations into crops.
  - **Tiny electric fences** (10 cm above soil) are effective but extremely expensive.
  - **Do not use salt** to destroy snails and slugs as it will increase media salinity.
- **Treating standing stubble**
  - **Rolling, harrowing or slashing** stubble kills resting snails by dislodging them from vegetation onto the ground on a hot day (temperature > 32°C below 50% humidity) forces them to move over hot ground, they die by desiccation. Best - soil surface is > 40°C, day temp > 35°C, low humidity, nights warm and dry.
  - **Burning** infested stubble or herbicide-killed pasture, precipitates wind erosion and interferes with stubble retention methods of farming. There must be a sufficient fuel load and few rocks for snails to hide under.
  - **Rakes** on the front of harvesters could reduce contamination of harvested grain.

Burning before rolling can greatly reduce the populations of snails and slugs

- **Robot-type machines** are being researched overseas which sweep over the ground identifying slugs by their shape, picking them up, dropping them in a hopper at the rear of the machine. There bacteria digest the slugs at the same time as releasing a gas to power the machine.
- **Keep pots off ground** (about 3 cm) using easy-to-handle boards (30 cm x 30 cm) to allow snails and slugs to crawl underneath.

MOLLUSCICIDES

- Chemical control is most effective when used in **combination with sanitation**.
- **The main molluscicides** are **metaldehyde, methiocarb, iron-edta, iron phosphate** and **copper.** They can be expensive and their effectiveness is influenced by soil and weather conditions.
- **Resistance.** Exposure to prolonged periods of metaldehyde can induce resistance in white bradybaena snails (*B. similaris*) overseas (Salmijah et al 2000). Some slug species may be naturally tolerant to methiocarb.
- **On edible crops**, check current registration status.
- **Barriers.** Copper can be spread around the legs of benches.
- **Baits** (page 236, Table 47).
  - **Taste deterrents.** Some types of baits must be formulated with taste deterrents.
  - **Some types of baits are mould resistant**. Decaying pellets on plants such as lettuce can promote mould development.
  - **Pellets** and **granules** are more weather resistant than powders.
  - **Defender**® (metaldehyde) breaks down rapidly in direct sunlight. It kills snails and slugs by dehydration, as a snail's body is 90% water, when dead there is only an empty shell! Do not water heavily for at least 3-4 days after application, as they may rehydrate and recover. Toxic to non-target animals. Do not allow contact with any edible portions of any food or feed crop. Phytotoxic to some plants, eg daylilies, clematis, don't apply to dry soil. Metaldehyde baits are **less effective** during damp, overcast weather than those containing methiocarb, but are cheaper to purchase.
  - **Baysol**® (methiocarb) is an anticholinesterase compound, affecting the nervous system of snails and slugs. Toxic to non-target animals.
  - **Multiguard**® (iron-edta) contains iron which is toxic to snails and slugs but has low toxicity to non-target animals.
  - **Enviroguard**® (iron phosphate) contains iron which is toxic to snails and slugs but has low toxicity to non-target animals.
  - **Socusil**® (buffered copper complex).
  - **To improve performance** of baits mow, cultivate or spray weeds along tree and fence lines prior to baiting. **As snails congregate** along crop edges, fencelines, etc. It can be cost effective to apply baits in these regions, before they invade large areas especially if numbers are large.
  - **Home gardeners** would mostly use baits as snails and slugs are mostly hiding underneath bricks and pots, where aerosols and sprays would not be effective.

Home made baits. Just because a pesticide is a natural botanical extract it should not be assumed that it is safe. If improperly handled and prepared, it can be just as hazardous, if not more so, than a ready-mixed bait.

Table 47. **Molluscicides**.

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	**Mode of action**	**CROPS, SITES TREATED**	**PESTS CONTROLLED, SUPPRESSED**
1 Acetylcholinesterase inhibitors **INSECTICIDES**	**1A.** **Carbamates**	**BAYSOL, MESUROL SNAIL AND SLUG BAIT** methiocarb **BLUE BAIT** **Formulated** with Bitrex™ Pet Taste Deterrent. Blue is attractive to snails and slugs but unattractive to birds. Stands up well to wet weather and is suitable for use in glasshouses Mesurol is available as a bait or spray but **not for home garden use**	**Contact action** **Stomach action** Has to be eaten, affects their nervous system. Non-systemic in plants, toxic to fish, bees, earth worms, poultry, pets. Snails do not recover	Non-crop, certain seedlings, garden beds, fruit, ornamentals, vegetables, field crops, pastures, cereals, long residual control	**Snails & slugs** certain species **Insecticide** fungus gnats, slaters, millipedes 
	1B **Organo phosphates**	**SUPRACIDE** methidathion Extremely hazardous **DANGEROUS POISON S7**	**Non-systemic** **Contact action** **Stomach action** Long residual effectiveness	Commercial orchids, used on some other plants to control many insects & mite pests	**Molluscicide** slugs and snails **Broad spectrum insecticide** especially sucking insects, eg aphids, thrips, scales, also mites
Others	**Miscell-aneous**	**DEFENDER, SLUGGER, SLUGOUT, VARIOUS** metaldehyde **GREEN BAIT**, granules, pellets, powder, aerosol, emulsifiable concentrate **Some products formulated** with Bitrex™ Pet Taste Deterrent and/or Petrepel™	**Dehydration** **Stomach action** Kills snails & slugs by dehydration, more effective if dry, sunny or windy weather follows baiting. If damp over-cast weather follows baiting, snails may recover.	Non-crop. ornamentals, garden beds, vegetables, seedlings, do not apply to edible parts of plants	**Snails & slugs** certain species 
	Inorganic metals 	**MULTIGUARD SNAIL AND SLUG PELLETS** iron-edta complex **RED BAIT**, colour change to **YELLOW** is proposed **Formulated** with a taste deterrent to discourage children.	**Iron toxicity** **Stomach action** Snails and slugs are very susceptible to iron in their blood, snails crawl back to shelter to die	Non crop, garden beds, field crops Harmless to domestic & mos wild animals, & environment. Not a scheduled poison	**Snails & slugs** certain species, persists about 2 weeks depending on weather, less in wet weather, longer in dry weather. Breaks down to add iron to the soil
		ENVIROGUARD FERRAMOL, NEUDORFF'S SLUG AND SNAIL BAIT iron as iron phosphate **BAIT**	**Stomach action** **No contact action** Apply bait in evening, reapply as it is consumed	Home gardens, safe for pets animals, birds, earthworms & other non-target spp.	**Snails & slugs** stop feeding immediately & go back to their resting place to die in 3-6 days
		SLUGIT, VARIOUS copper as buffered complex copper	**Surface barrier** **Repellent activity**	Home gardens	**Snails & slugs** certain species
		VARIOUS copper sulphate	Controls & destroys snails	Fresh water aquariums	**Snails** certain species
	Garlic	**GARLIC SPRAYS** garlic oil/extract	Creates a **snail proof barrier** around plants, pots, paths and garden furniture	Certain ornamentals, fruit, vegetables	**Slugs & snails** certain species **Insecticide** aphids, thrips, etc

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

contd

When is best for the snail species in your area

If using sprays of any kind when you want to bait, apply the spray first, wait for it to dry then apply the baits so they are not tainted by the spray.

– **Timing**. is the critical and will depend on the region/crop. Considerations include:
  - Aim to have a reduced snail and slug populations at beginning of the growing season **before** planting seedlings or crops emerge. Seek advice on the most effective time, eg spring or autumn etc, and understand why.
  - Bait when snails and slugs are likely to be hungry, before they get a chance to lay their eggs, when there is little feed to compete with baits, when rainfall is unlikely to reduce the life of baits.
  - Apply baits when snails or slugs are active during **cool, damp weather**, thunder storms in summer, or after irrigation; when damage is first appears.

- **Sprays**. May be used if snails or slugs are feeding on tree foliage or high above ground, and if pest species do not consume baits, eg white bradybaena snail (*Bradybaena similaris*) in areas of NSW and SA.
  - – **Timing**. Sprays are most effective if applied when snails and slugs are active, ie early in the morning.
  - – **Mesurol sprays** are restricted pesticides. They have a **long withholding period** when used on fruit crops. Follow label directions for use.
  - – **Copper products** registered for snail control act primarily as repellents but may kill young snails and slugs if they are actively feeding at the time of spraying. Copper sprays can burn fruit and cause fruit drop especially in hot weather.
  - – **Various home made sprays** may repel snails but some, eg wormwood, are not recommended for vegetables that are going to be eaten soon after.

Table 48. Molluscicide safety.

SPRAYS.	**USE SPRAYS OR AEROSOLS**. • Where there is a danger to **children, dogs and other animals** from baits.
BAITS. Baits are **hazardous** to children and domestic pets. Use commercial bait traps to reduce hazards and protect baits from moisture **Poison Information Centre** **131126** or seek **Medical Advice**	**IF USING BAITS**. • **Apply and scatter pellets, granules and powders according to label directions**. Packet 'openings' can make this difficult. Do not overtreat or pile baits into heaps. Granules can be easier to scatter than pellets. Scatter any accidentally spilled heaps. Apply bait in evening and reapply as it is consumed. Pellets can be placed inside a pet-safe pellet holder. • **Bittering agents**. Certain baits **must be** formulated with a bittering agent, eg Bitrex™ which acts as a **taste deterrent** to discourage children and pets from eating it, but some pets may still find the bait attractive and eat it. The bittering agent does not affect their attractiveness to snails and slugs. • **Smell repellents**. Baits may also contain a **smell repellent,** eg PetRepel™. • **Children,** dogs and other pets can be accidentally poisoned by eating baits. Snail and slug baits contain cereal, eg wheat, bran, protein materials, casein, which is attractive to snails, slugs, dogs and other pets**.** Dogs particularly seem to be attracted to these materials and so can consume large quantities of bait if it is left around in heaps. Watch pets carefully after pellets are spread if there is any sign of eating pellets remove pellets and clean up. If in doubt contact your vet. Toxic to blue-tongue lizards. • **Oral toxicity to children.** Snail baits, depending on their active constituent, vary in toxicity. If bait has been eaten by a child, **immediately** contact the **Poison Information Centre** or seek **medical advice**. • **Some molluscicides** may be **absorbed through the skin** and so must not be handled with the bare hands. • **Brown/beige** metaldehyde pellets, the colour of fowl feed may be available. • Lock packets of snail baits securely away from children and pets. • Prevent access to treated area.
SIGNAL HEADINGS Observe withholding periods, rates, store away from children and pets	**Pellets, granules and powders** of these products registered for use usually have the following signal headings (in order of **decreasing** hazard):

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List the **distinctive features** of snails and slugs (Phylum Mollusca).
2. Draw diagrammatically the **life cycle** of a snail or slug.
3. Recognize by sight **local pest** and **beneficial** species.
4. Recognize by sight, **snail and slug damage** to the leaves, flowers, buds, stems and tubers of a range of local species of ornamental, fruit, vegetable and other plants.
5. **Locate** typical slug and snail hiding places on your property.
6. **Distinguish** snail and slug damage from similar damage caused by other agents including caterpillars, various leafeating beetles and birds.
7. **Provide the following information** for local pest species of snails/slugs:

Common name	'Overwintering'
Host rang	Spread
Description & damage	Conditions favouring
Pest cycle	**IPM** & Control

8. Prepare/access an **IPM** program for a snail or slug pest at your work or in your region.
9. Locate **reference material** and know where to obtain advice on the identification and control of snails and slugs.

SELECTED REFERENCES

Land Snails of Australia – Museum Collections. www.environment.gov.au/biodiversity/abif/bat/**snails**.html

Helix Consulting. *The Full-cycle Snail Farming: A multimedia course on farming Helix Aspersa and Helix Pomatia* (CD-ROM) www.**helixconsulting**.com/en/cdrom.htm

Snails Bon Appetite has developed commercial *Snail Farming Kits*. www.**snailsbonappetite**.com.au/

Fact Sheets by State/Territory Depts. of Primary Industries are available online, eg
Commercial Snail Farming
Organic Snail Control
Snails and Slugs
Control of Snails & Slugs

Pocket Guides

GRDC Pocket Guides & Publications
Bash 'em, Burn 'em, Bait 'em. - Integrated Snail Management in Crops and Pastures.
Snail Identification and Control
Slugs in crops

Keys

Lucid keys www.**lucidcentral**.com/
A Key to the Families Non-Marine Molluscs of Quarantine Concern in Australia

Organic standards

AS 6000—2009. *Standards Australia Organic and Biodynamic Products*. Standards Australia.

Organic Federation of Australia www.**ofa**.org.au

Quarantine

Commonwealth quarantine www.**daff**.gov.au/**aqis**

PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.**padil**.gov.au

Target lists of weeds, insects, plant and animal pests and diseases. www.**daff**.gov.au and search for target lists

State websites have information of snails and quarantine restrictions in their states, eg
Quarantine WA. 2009. *Protocol for the Movement of Green Snail (Helix aperta) Host Material to other States and Territories of Australia.* Version 3.5 – June.

Molluscicides

Pubcris. APVMA. Canberra www.**apvma**.gov.au

Infopest, Qld www.dpi.qld.gov.au/**infopest**

Croplife Australia www.**cropelifeaustralia**.org.au/

MSDS www.**msds**.com.au/

Company websites provide MSDSs and Labels

General

Baker, G. and Charwat, S. 2000. *Release of Fly Spells Disaster for Snails.* Farming Ahead No. 105. Sept.

Jones, D. L. and Elliot, W. R. 1986. *Pests, Diseases & Ailments of Australian Plants.* Lothian, Melbourne.

Lush, A. 2005. *Field and Post harvest Control of Snails in Citrus.* Horticultural Australia, Sydney.

Lush, A.L. (2008) *Snail Monitoring in Vineyards - Getting Started.* The Australian and New Zealand Grapegrower and Winemaker, June.

May, P. 1998. *Parasite Highlights Need for Effective Control of Snails, Rats.* Prof. Pest Manager June-July.

McMaugh, J. 1994. *What Garden Pest or Disease is that?* Lansdowne Pub., Sydney.

Micic, S., et al. 2007. *Identification and Control of Pest Slugs and Snails for Broadcare Crops in Western Australia.* W.A. Dept. of Agriculture and Food, 2007.

Naumann, I. (ed.). 1993. *CSIRO Handbook of Australian Insect Names : Common and Scientific Names for Insects and Allied Organisms of Economic and Environmental Importance.* 6th edn. CSIRO, East Melbourne. new edn. avail online www.**ento**.csiro.au

RIRDC publications:
Farming Edible Snails – Lessons from Italy
Free Range Snail Farming in Australia
Breeding and Growing Snails
Nematodes as Biocontrol Agents of Helicid snails

Salmijah, S., Chan, M. K., Kong, B. H., Maimon, A. and Ismail, B. S. 2000. *Development of Resistance in Achatina fulica Fer. and Bradybaena similaris Fer towards Metaldehyde.* Plant Prot Quart. Vol.15(1).

Zborowski, P. 2007. *Spiders, Snails and other Minibeasts of Australia.* Young Reed, Sydney.

Vertebrate Pests

Fruit bat

BIOLOGY

Phylum Chordata

NO. SPECIES IN AUSTRALIA

Feral animals together with environmental weeds and salinity, are considered to be one of Australia's biggest environmental threats.

Many vertebrate pests **are** native to Australia, eg kangaroos, cockatoos, and find introduced crops, forest trees and ornamental and fruiting plants, a welcome addition to their diet especially when the bush dries off. There are more than **1000 native species**, but none (?) are as important pests as the **introduced rodents and rabbits**. Some vertebrate pests have a dedicated website, eg cane toads.

Invasive Animals CRC www.**invasiveanimals**.com/
Feral animals www.daff.gov.au/brs/land/**feral-animals**
Animal welfare www.daff.gov.au/**animal-plant-health/**

DAMAGE

Cockatoo damage to soft rose canes in spring

The loss of flying foxes in some Pacific islands could lead to widespread extinctions of mammals that depend on the fruit of trees that the flying foxes pollinate.

DIRECT DAMAGE

FLOWERS	**Eaten/ripped off**, eg cockatoos
FRUIT, NUTS	**Eaten**, eg birds, fruit bats, possums, rats
STEMS, TRUNKS	**Tip prune new shoots**, eg cockatoos, rosellas **Tear open stems**, eg cockatoos **Eat bark**, eg horses
SEEDLINGS	**Eaten**, eg birds
SEEDS	**Eaten**, eg cockatoos, rosella, emus, geese, rats, mice
ROOTS	**Eaten**, eg feral pigs
GRASS	**Eaten**, eg rabbits, kangaroos, wallabies
CROPS	**Eaten**, eg birds, mice
STORED GRAIN	**Eaten and contaminated**, eg mice, rats

INDIRECT DAMAGE

- Rabbits, pigs and goats compete with stock for scarce pasture and water. Trees may be ring-barked. Donkeys, horses, camels and deer damage trees because of their reach.
- Flatten crops, eg duck, emus, geese, in their quest for food.
- Birds damage the playing surface of turf seeking scarab grubs.
- Habitat degradation, eg water buffalo in northern Australia, feral pigs. Loosen roots by scratching, eg birds, dogs; feral pigs in crops, pasture and the bush.
- Feral pigs feed on plant roots, spread weeds, contaminate water, and ruin pasture.
- Roosting by some may damage trees, eg Indian Mynahs, fruit bats.
- Spread weeds, eg birds, feral pigs.
- Affect biodiversity, eg cats and foxes feed on native animals. Predators of native animals, eg cane toads eat native frogs; pigs eat snake eggs, bandicoots.
- Some are toxic, eg cane toads.
- Cattle manure smothers pasture; pigeons soil buildings; people slip on bird poo.
- Parts of Victoria and Kangaroo Island have too many koalas.
- Rats and mice eat vast quantities of food in field and in store throughout the world, and contaminate the remainder with faeces causing food poisoning (*Salmonella* bacteria).
- **Cost of lost production**, **repairing damage**, eg electric cables damaged by rats, fences damaged by kangaroos and wombats, **cleaning buildings** to remove bird faeces.
- **Harbour diseases** already in Australia and exotic diseases should they enter, eg
  - **Dogs, cats, bats or foxes** may spread **rabies virus** via a bite of an infected animal to other warm blooded animals including humans, with fatal consequences.
  - **Rats** transmit the Black Death (bubonic plague) to humans via in the Oriental rat flea.
  - **Feral pigs** are wild hosts for **foot and mouth virus disease**, if it should enter Australia.
  - **Bats and flying foxes** may be affected by viruses which can be transmitted to humans, other bats and possibly other mammals. Bacteria may contaminate their droppings.
  - **Bird lice** is spread by starlings.
  - **Psittacosis** is a contagious disease of birds, especially parrots which when communicated to humans causing bronchial pneumonia.
  - **Birds** may spread **avian influenza** which mostly affects birds, but can also affect humans and animals such as cats and pigs. **Swine flu** can also spread to humans.

BENEFICIAL ASPECTS

- Birds and some species of fruit bats feed on insects and pollinate plants.
- Some are used for food and commodities, eg rabbits, camels, crocodiles, kangaroos, goats, buffalo. Rats are eaten in some countries.
- Dogs and cats as pets.
- Some have been trialed for weed control, eg goats, camels.
- Cattle and sheep are used to graze weeds, etc.

LIST OF SOME VERTEBRATE PESTS

BIRDS

- **Cockatoos, rosellas**
  - **Fruit and nuts**, eg almonds, pome fruits, walnuts.
  - **Flowers**, eg daffodils, roses. Parrots and other birds tear open the canes of new spring growth of **roses** and other flowers seeking to eat soft green tissue.
  - **Shoots, stems**, eg eucalypts, wattles, especially pistachio. They **tip prune** new shoots during their quest for **seed** and **tear open stems** of young trees in plantations to prey on larvae of various borers.
  - **Conifer leaders** are damaged by their efforts to obtain **cones**.
- **Sparrow, starlings, silver eyes, wattle birds, currawongs**
  - Vegetable seedlings after planting out, eg lettuce, spinach, beet.
  - Strawberry fruit and soft-skinned fruit, eg stone fruit, grapes.
  - Currawongs eat whole berries on grapevines.
- **Ducks, emus, geese** eat seed and flatten crops, leaving messy droppings.
- **Magpies** swoop people during spring to protect their young in nests.
- **Bell miners** have been associated with the psyllid infestations on eucalypts in some plantations resulting in tree decline, to the extent that the association has been listed as a key threatening process under the Threatened Species Conservation Act.
- **Silver gulls** have profited from access to unlimited food at rubbish tips and are a hazard to aircraft at airports. **Pigeons** leave droppings in urban parks and buildings. Seagulls in coastal towns.
- **Birds with sharp beaks** seeking scarab grub larvae damage turf and lawns.
- **Birds may spread diseases** such as avian flu and psittacosis.
- The **Australasian Pest Bird Network** was developed to encourage discussion on pest birds, keep up-to-date with current research and provide an avenue for requesting information. **Global Flyway Network** (GFN) in Broome check long distance migrating shorebirds, eg magpie geese.
- Noise complaints, customer complaints.
- Tracey et al (2007) has written a **comprehensive treatise** on managing bird damage to fruit and other horticultural crops.

Fruit bat

FRUIT BATS, FLYING FOXES

- **Fruit bats, flying foxes** (*Dobsonia* spp., *Pteropus* spp.) **are protected wildlife**. They live in colonies in trees during the day. At night they leave to feed on mostly native fruits but will also feed on soft cultivated fruit and attack orchards for mangoes, nectarines and peaches, etc. Bats can travel over great distances. Some fruit bats are important **pollinators** of native plants. Some native animals feed on the fruit of trees pollinated by fruit bats.
- **Insectivorous bats** eat up to half their body weight in insects, eg moths, beetles, flies, flying ants, each night. It is not possible yet to establish the effect of bats on reducing plant pests. May be seen at night in urban areas around street lights.
- **Bats may carry viruses**, eg Australian bat lyssavirus **(ABL)** and the equine morbillivirus (affects horses), both of which can infect humans. Bats and flying foxes constitute a particularly fertile source of virus.
- **Bat droppings** may contaminate swimming pools, drinking water.

Rodents have chisel-like front teeth for gnawing

RATS AND MICE

- **Prodigious rate of reproduction**. A single pair of mice under optimum conditions can produce >300 mice in 21 weeks (5 months). A mouse plague in SA (1993) cost an estimated A$100 million in crop, stored grain and other losses, in SE Asia it is common for villagers to lose half their rice crop to rats.
- **Rats and mice are serious agricultural and horticultural pests**.
  - Both introduced and native species can be pests.
  - They damage crops, pastures, stored grain, vegetables in storage, etc. and contaminate it with their faeces. They also eat bulbs, rhizomes, seeds, macadamia nuts and other plant materials. Rats also eat young chickens, eggs etc.
  - **Rats harbour diseases** and pose a serious threat to human health, eg bubonic plague bacteria is spread to humans by the Oriental rat flea.
  - Rats in sugarcane in north NSW and Qld spread typhus and other diseases.
  - Toxoplasmosis which causes huge losses of life in livestock is a serious problem in humans in the USA and other countries. The parasite (a protozoan) passes from rats to cats to humans.
- **Rodents are, in general, increasing in numbers**.
  - **Evolution scientists** warn of damage to the global environment with animals and plants such as **rats**, cockroaches, nettles and thistles flourishing at the expense of more specialized wild organisms.
  - **Factors contributing** to the rise in rat numbers in the UK include global warming, privatized water authorities and associated continuing decay of urban sewerage systems, use of plastic building materials which can be more easily eaten by rats, fast food outlets contributing to increased levels of rubbish, reduced pest control funding by local authorities, **pesticide-resistant rats** and an unwillingness of some people to use rodenticides.

LIST OF SOME VERTEBRATE PESTS *(contd)*

There has probably been more written about the rabbit than any other vertebrate pest in Australia

RABBITS

- Rabbits because of their **prodigious rate of reproduction** are probably the best known vertebrate pest in Australia. They:
  - Cause millions of dollars damage to agriculture in Australia each year.
  - Eat vast quantities of pasture, crops; damage trunks of young trees, newly planted nursery stock and native vegetation that provide food and shelter for native animals.
  - Change pasture composition, compete with livestock.
  - Erode soil by digging their burrows and have been responsible for more ecological damage in the history of Australia than any other single factor to date.
- Rabbits are a good example, **how difficult vertebrate pests** are to manage. Despite the rabbit-proof fence, metal trapping, harbor destruction by burning and warren destruction by ripping, fumigating warrens, poison baiting and the use of virus diseases, we still have rabbits!!!!
- **Rabbits and rats** pose a severe threat to **World Heritage values on Macquarie Island**. Impacts include devastating effects upon native fauna, flora, geomorphology, natural landscape values and nutrient recycling systems. A Draft Plan for the Eradication of Rabbits and Rodents on Macquarie Island has been developed which includes baiting and other options such as using dogs to find any remaining rabbits, as necessary. Rabbits will need to be monitored for several years after eradication to ensure that no rabbits escaped the program.
- The **Rabbit Scan Website** is designed for farmers and landowners to plot the spread and distribution of rabbits and warrens on their land. A map of rabbit populations Australia-wide from there they can work to eradicate problem areas. The Australian Wildlife Conservancy (**AWC**) controls 6.2 millions of Australian bushland which has been fenced off from feral animals allowing return of native animals and plants in these areas.
- **Rabbits in bushland** may be monitored by counting small clumps of pellets, scoring seedling abundance, regeneration and overall rabbit impact, before and after rabbit removal. An Australian Government, Bureau of Rural Resources website provides an overview of rabbits in Australia.

Rabbits: A Threat to Conservation & Natural Resource Management.
www.feral.org.au/content/speces/**rabbit**.cfm

KANGAROOS, WALLABIES, POSSUMS

- **Kangaroos and wallabies** consume grass in pasture and native areas, cereal and other crops when available, and newly planted nursery stock.
- **Possums** in urban areas feed on new buds on grapevines, pistachio and other plants, also on fruit, eg pome and stone fruit, and nuts, eg walnuts. Major pest in New Zealand.

DOGS, FOXES, DINGOES, CATS

Dogs and cats are not parasitic on plants but can **damage lawns**, dig up plants.

- Cats may soil gardens and scratch the bark of trees. Eat a range of wildlife, including wrens, parrots, frogs, native mice.
- Wild dogs in Nature Reserves adjacent to agricultural areas attack sheep.
- Dogs may attack people, especially children.

SPREAD, CONDITIONS FAVOURING

Know why pests are attracted to an area

1 pair of rabbits can produce more than 180 offspring in 18 months

The source of vertebrate pests in Australia are from many sources, including:

- Many were brought into Australia in the early days of settlement for food, recreation, etc.
- Others entered Australia accidentally, eg on containers, refugee boats.
- Some were deliberately and **legally** brought in for various reasons, eg cane toads for the biological control of sugarcane grubs.
- Some have been brought in deliberately and **illegally**, eg by air travelers.
- **Within Australia** by natural spread, and deliberately, eg Indian Myna. Camels, horses, goats were let loose after their farming needs were met.
- **Numerous conditions** favour both exotic and native vertebrate pests, eg
  - **Lack of predators** for introduced feral species.
  - Australia farming is **extensive** and often inadequately fenced.
  - **Environmental**. Mouse plagues after mild winters so that females survive to breed in spring and autumn. Above average rainfall may trigger a mouse plague.
  - **Breed prolifically**. The expression 'breed like rabbits' is well known. Most vertebrate pests breed prolifically when conditions are favourable.
  - Some are **long lived**, eg bats live for 20 years.
  - **Plentiful food** for mice from higher yields, continuous cropping, irrigated crops, increased stubble retention in minimum tillage.
  - **Shelter**. Mice look for warmth and shelter in burrows in the soil, raised beds, storage areas, minimum tillage farming. Rabbits retreat to their burrows in weed thickets. Indian mynahs nest in garden conifers.

INTEGRATED PEST MANAGEMENT (IPM)

MAIN STEPS

Efforts to keep them in check cause conflict in both rural and urban areas

Control programs for certain vertebrate pests are ongoing and require diligence year after year by growers, approved commercial operators and members of the community. Many pest control companies offer a complete management package. Principles and strategies of pest management are outlined on the following website:
www.daff.gov.au/brs/land/**feral-animals**/management/strategies

PLAN
PLAN
PLAN

1. **Plan** well in advance. Keep records of the crop, eg weather, planting/sowing/ harvesting dates. Define the problem. Determine management objectives and options, some may be considered unacceptable by the community.
2. **Crop, region**. Be aware of specific local vertebrate pest problems which may occur on your own and neighbouring properties, eg
   - **Contacting** your local council or shire about the pest problem. Local community groups may deal with a local problem, eg Indian mynas.
   - Various **Threat Abatement plans**, eg rodents, foxes, feral dogs and goats.
   - The '**National Rabbit Control Training and Extension Package'** promotes effective and consistent long term rabbit control by the use of **IPM**.

3. **Correctly identify the pest species.** Vertebrate pests themselves are easy to identify but their damage might not be so easy. You need to know the exact breed of dog, species of bird etc. Damage caused by possums and rats may appear similar. Droppings and collections of dead snails may indicate the proximity of rats. You may need to seek advice (page xiv) or contact a licensed pest controller. Understand the pest life cycle, how it moves around, what local conditions attract it (food, shelter, roosting sites, etc), bird behaviour, etc. Obtain a Local Fact Sheet.

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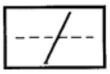
5678

4. **Monitor** the presence of the pest. Monitoring accessories are available from some pest control companies. **Know when, where, what and how to monitor**. Monitor pest numbers or impact? Is the pest protected, noxious, beneficial, new to area, seasonal or constant, etc. Monitoring and observation of mice numbers early can provide sufficient warning to prevent much mouse damage. Map the problem.



5. **Thresholds** will depend on whether treatment is mandatory under State/Territory/ local regulations. Do you need to calculate your own threshold based on economic, aesthetic or environmental requirements?

?

6. **Action/Control/Decision making**. Many control methods will be **preventative**, eg minimizing food sources, bird netting. Steps should be taken to prevent pest numbers exploding. Take appropriate action at the correct time when a prescribed threshold is reached. There may be **legal** and/or **organic standard** requirements. Pest numbers found may not constitute enough potential damage to warrant any action. Often area-wide management is necessary to coordinate effects.
   - **For pests not yet in Australia or in a state/territory** – entry can be prevented by quarantine.
   - **For new arrivals** spread can be minimized by early detection. Response Programs assist control of specified pest outbreaks. Noxious pest legislation and other regulations are most effective during these early stages of invasion, when eradication could be attempted. Available pest control methods do not eradicate pests unless they have been selected for a national or state eradication program.
   - **For established pests** the best we can hope for is containment using appropriate control methods, for most eradication is probably impossible. Commercial harvesting is an option for kangaroo, goats, etc.

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Pest-tested material
Physical/mechanical
Pesticides

✓ X

7. **Evaluation**. Review **IPM** program. Recommend any necessary improvements, based on information about pest population movements and numbers.

CONTROL METHODS

COMMONWEALTH LEGISLATION, REGULATIONS

The Australian Government plays a role in coordinating pest animal management through the Vertebrate Pest Committee, Invasive Animals Cooperative Research Centre (**IACRC**) and the Australian Pest Animal Management Program (**APAMP**):
www.agriculture.gov.au/browse/health/**pests/vertebrate**

- **APAMP** collaborates with state, territory and local governments, to reduce the damage to agriculture caused by pest animals:
  www.daff.gov.au/brs/land/**feral-animals**
- The *Environment Protection and Biodiversity Conservation Act 1999* (the **EPBC Act**) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. **Threat Abatement Plans** must conform to the requirements specified:
  www.**environment**.gov.au/
- The Invasive Animal Cooperative Research Centre (**IACRC**) is Australia's largest integrated invasive animal research program.
  www.**invasiveanimals**.com/.
- Guidelines for the control and appropriate treatment of pest animals have been developed by the National Consultative Committee on Animal Welfare (**NCCAW**):

CONTROL METHODS *(contd)*

Each State/ Territory/Council has Information Sheets on Vertebrate Pest Control

STATES/TERRITORIES/REGIONAL LEGISLATION, REGULATIONS

State/Territories have their legislation relating to vertebrate pests which can be accessed online via their environment or primary industry websites.

- **Domestic 'pets'**, in order to protect the environment, humans and reduce noise levels and are coming under more regulation.
- **Rural Lands Protection Boards** have a responsibility to enforce the Act which says landholders under the Act must suppress and control **declared** noxious animals on their properties (private or public).
- **All native animals** are **protected by legislation** and permits to destroy them must be obtained from the appropriate government department, eg
  - Birds, eg parrots, honeyeaters.
  - Kangaroos, wallabies, possums, fruit bats.
- **Recent invasions** by vertebrate pests, eg the cane toad may require that sightings be notified.
- **Noxious** animals are **proclaimed under legislation**, and include rabbits, feral pigs, dingoes.
  - Animals declared noxious, **vary** according to location within Australia. A pest in one area can be an endangered species in another.
  - Contact the **local** responsible authority for control information and your responsibilities.
  - Control measures of **noxious** animals are usually prescribed by **legislation**.
  - Supply and use of pesticides to control vertebrate pests is often **restricted**.
  - Federal Government may financially assist farmers to carry out pest control especially after drought.

CULTURAL METHODS

- **Modifying habitats.** Bush areas adjacent to cultivated fields often increase pest problems in agriculture. Many types of vertebrate problems have been minimized by modifying the habitat of these surrounding areas, eg 'clean' farming that eliminates cover along fence rows and field margins, however, it is generally frowned upon by conservationists.
- **Alternate food sources.** Troublesome vertebrates such as ducks and geese, can be controlled to some extent by providing them with alternate food and water sources preventing damage. About one third of the birds that attack grapes are thirsty so provision of drinking water may save some fruit. Overseas diversionary crops keep rats from wanted crops. In some countries early crop lures are used to attract rats for destruction before the main crop is planted.
- **In certain areas of Australia damage to eucalypt stems** may be reduced by preventing parrots and other birds from flying through the surrounding vegetation by planting areas with wattles which may act as a physical barrier to the birds.
- **Destroy shelter for pests**, eg controlling blackberries which harbour rabbits.
- **Culling and relocating bats** in Melbourne Botanic Gardens.
- **Some plants attract animals**, eg cats to catnip (*Nepata cataria*).

SANITATION

- Slash and burn/destroy blackberry thickets which act as a refuge for pests.
- Compost heaps attract rats and some exotic birds, eg blackbirds, so contain compost heaps and do not leave food around.
- Farm hygiene, eg minimize spilt stock food.

BIOLOGICAL CONTROL

- Biological control aims to **regulate populations** rather than eradicate them.
- **The use of predators** to control vertebrate pests has generally not been very successful as the predator may itself become a pest, eg if rabbits are controlled then foxes have to look elsewhere for food.
  - **Dogs and cats.** Probably the best known use of predators to control vertebrate animals in a localized situation is the use of cats and dogs, eg Jack Russells, to control mice and rat populations.
  - **The intentional introduction of predators** to control troublesome species of vertebrates should not be undertaken until all potential ecological consequences have been carefully scrutinized. Examples of instances where this has not been carried out include the introduction of the:
    - ❑ Fox into Australia to control the rabbit.
    - ❑ Cane toad to control cane grubs in sugarcane in Qld.
    - ❑ Weasels, stoats and ferrets into NZ to control the rabbit.
    - ❑ All of these introduced predators not only failed to accomplish their task, but themselves became pests.
  - **Native predators.**
    - ❑ Dingoes prey and exert some control of kangaroos in certain areas.
    - ❑ Owls in sugarcane field in Queensland eat an average of 5 rats per night.

CONTROL METHODS *(contd)*

BIOLOGICAL CONTROL *(contd)*

- **Disease organisms**
  - **Rabbits. Myxomatosis**, caused by the myxoma virus of the South American forest rabbit is spread from rabbit to rabbit by mosquitoes and rabbit fleas. It was introduced into Australia in the early 1950s and was spectacularly successful in controlling rabbits, but over many years the rabbit has developed resistance to the virus. **Rabbit Calicivirus Disease (RCD)** was accidentally released in 1997. At least 10 species of insects are vectors including 5 species of blowflies, a carrion fly, 2 species of mosquitoes and the European rabbit flea. **Myxamatosis** and **RCD** occur seasonally throughout southern Australia. Genetic changes in the **RCD** virus are already apparent. New strains of the calicivirus are to be introduced to Australia in a bid to halt rapidly spiraling rabbit numbers. Domestic rabbits can be vaccinated against the virus.
  - **Pigs.** Overseas, there have been many unofficial attempts to control wildlife populations with diseases, eg the 100% successful project to eliminate wild pig populations on an island off California by introducing the hog cholera virus.
  - **Birds.** There is much published data on the occurrence of potential disease-causing organisms in **wild birds** but as yet no practical application has been made of them, possibly because few, if any, are host specific.
  - **Cats.** In Australia, it has been suggested that feral cats could be controlled by a virus disease, registered domestic cats could be immunized against the disease.

- **Controlled breeding** Many techniques are still experimental.

  Invasive Animals **CRC** www.**invasiveanimals**.com/

  - **Genetic engineering**
    - **Virally-vectored immune contraception.** In the future rabbits could be vaccinated with a myxoma virus which has been **genetically engineered** to carry a **gene** which would make rabbits infertile. This technique could also be used to control breeding of mice, foxes and other vertebrates.
    - **Mice.** Focus is on using either a mouse-specific virus or bait as a vehicle to vaccinate mice and induce infertility which would be long enough to prevent mouse populations building up into plagues.
    - **Cane toads.** Attempts to use a viral vector to transfer a gene which would prevent tadpoles of the cane toad metamorphosing into adults.
  - **Chemosterilants**
    - **Regulating birth rates**. Chemosterilants, eg birth control, spermatocidal and immunological drugs, artificially regulate the birth rate of populations of wild vertebrates that live in semi-naturalistic situations and are troublesome to humans and the environment.
    - **FeralMone™ Spray Attractant** ('Synthetic Fermented Egg' ('SFE')) is an aerosol spray used to attract foxes and wild dogs to bait stations.

      Animal Control Technologies www.**animalcontrol**.com.au
  - **Desexing**
    - More and more local councils are moving towards the compulsory de-sexing and chipping of domestic dogs and cats in urban areas.

RESISTANT, TOLERANT VARIETIES

Overseas, the search for **bird-resistant varieties of cereal grains** continues and aims to yield long lasting results; however, early results have been disappointing.

ANIMAL QUARANTINE

- **AQIS (Australian Quarantine Service).** Like many plant pests, vertebrate pests have been introduced from abroad, eg cane toads, rabbits, starlings, sparrows. Many still occur overseas that would be unwelcome in Australia, eg certain species of rats.

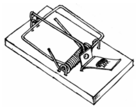
  Commonwealth quarantine www.daff.gov.au/**aqis**

- **State/Regional Quarantine.** Within Australia, both introduced and native vertebrate pests may occur in certain areas and not in others, eg starlings which do not occur in WA, are trapped on the Nullarbor Plain.
- **Local Quarantine**. Indian mynahs are inadvertently encouraged into gardens by plantings of dense conifers which provide ideal nesting sites. Some new suburbs adjacent to bushland have been designated 'no free-roaming cats'. Night curfews have been suggested for cats.

PEST-DAMAGED PLANTING MATERIAL

Seed, grain, bulbs, tubers and other vegetative propagation material may be eaten and contaminated with faeces. Damaged seed may not germinate, or may geminate but seedling may not develop normally, eg French bean seedlings with no growing tips, the stem above the cotyledons is a bare stump, seedlings may die or shoots develop in the axils of the cotyledons.

CONTROL METHODS *(contd)*



PHYSICAL AND MECHANICAL METHODS

These are the most common, best known and often the most effective means of controlling some vertebrate pests.

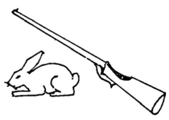
Physical methods

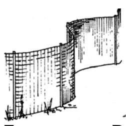
- **Frightening devices**. Where times of protection are **short** or where methods can be **varied continually**, as in a home garden, these devices may keep pests, chiefly birds, from crops. Frightening devices include:
  - **Visual scaring devices** include:
    - Scarecrows.
    - Flying kites of hawks, owls, flattened cats, balloon eyes.
    - Displays of dead birds, fish or other animals.
    - Flashing mirrors, such as Eagle Eye, aluminum foil, flags. Strings and bottle tops over roses and seedlings will provide some protection to seedlings.
  - **Acoustic devices** include:
    - Widely used in country areas to disperse birds, eg rotating gas guns, which produce loud explosions at variable intervals. Maximum sound levels have to be observed.
    - Humming lines, chimes, holograph tape.
    - Rustling plastic shopping bags, etc.
  - **Others** include:
    - Iridescent metallic tape with patterns of eyes of an owl or snake. As light hits the tape a scary 3D effect occurs, the tape rattles in the breeze.
    - Electric grids.
- **Communication signals** may be:
  - **Attractive,** eg food-finding, courtship calls. These have so far not been used as a method of vertebrate pest control.
  - **Repellent,** eg **distress or alarm calls**, can control vertebrate pests, especially birds. Animals avoid protected areas. Units can be expensive.
    - **Bird-repelling** systems for commercial crops include **Bird Gard**, eg Bird and Bat Control, Flower Fruit Scarer, and **Crop Gard**. Bird-call recognition software might solve bird problems in orchards.
    - **Electronic Garden Pest Repellers** beam ultrasonic sound into a small area keeping dogs, cats, rabbits, some rodents and possums away.

Habituation

- **Habituation** seems to be less of a problem with **communication signals** than with **frightening devices.**
  - **Where habituation does occur**, changing the signal usually restores effectiveness. Since most species have a variety of alarm signals, this is usually easy to do.
  - **Distress and alarm calls move the pests**, but do **not** destroy them. Usually the birds find alternative food that is not economically important.

Mechanical methods



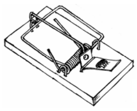


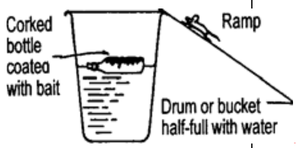
Fences

Prickly shrubs

- **Operations.**
  - **Shooting** to control their numbers, eg geese, kangaroos, wild dogs. Assisted with night vision, thermal imaging, helicopters. Not suitable for urban areas.
  - **Neck dislocation** of pest birds caught in traps.
- **Barriers** are a humane method for **excluding** vertebrate pests.
  - **Fences** control the movement of rabbits, dingoes and kangaroos; The most famous one being the rabbit proof fence to stop rabbits spreading to WA from the eastern states. Dingo fences protect sheep flocks from dingoes which also regulate kangaroo and emu numbers.
  - **Sealed containers/packets** protect seed and other foods from rats and mice.
  - **Flying pests.** Netting, bags and stockings protect fruit from birds and other pests. **Individual bunches** of bananas, grapes, may be bagged.
    - **Bird netting. Entire fruit crops** may be covered with **netting** (complying with ISO 9002 and other Standards) to protect them from birds and hail, enable better use of chemicals, reduce drift, break rain into fine mist, reduce evapo-transpiration, wind and sunburn damage, increase temperature and prevent frost damage. **'Vine-net'** (for vines) also protects tropical fruit, eg lychees, from birds and insects, eg fruit-piercing moths. **Bird netting** excludes birds from stadiums. **A canopy of foliage** can act as a barrier against birds, as they fear ambush. Prune to provide leaf cover and concealment. netting protects tree trunks.
    - **Bat netting** is used for fruit bats and larger birds. Growers in some areas can apply for low interest loans to erect exclusion netting for fruit bats as part of a Special Conservation Scheme.
    - **Wires, lines** protect roses from birds, netting over seedlings of vegetables.
    - **Roost inhibitors** include bird coils and spikes. **Electrified ledge landing sites** on buildings (Bird-shock Flexi-Track) prevent birds settling on buildings and can be incorporated into the design of buildings.

CONTROL METHODS *(contd)*





Mechanical methods *(contd)*

- **Traps**
  - **Track traps.** Metal traps are in breach of Prevention of Cruelty to Animal acts. Sticky traps have been used to catch mice. Both methods involve a degree of cruelty in that the animals are left to struggle (often in pain) until traps are inspected.

    Animal welfare www.daff.gov.au/**animal-plant-health/welfare**/nccaw/guidelines/pest
  - **Food traps.** The familiar household mouse or rat trap is basically a food trap with a device for killing the animal after it has been attracted. A modification of this trap is used for dealing with large numbers of mice.
    - ❑ **Possums** in urban areas can be trapped and relocated in another area.
    - ❑ . **Bird traps** have been used to catch starlings flying into WA across the Nullarbor Plain. Indian Myna birds are trapped in the ACT and euthanized.
- **Capture and relocation**
  - **Greyheaded flying foxes** (*Pteropus poliocephalus*) Royal Botanic Gardens Melbourne, tried noise, smoke, trapping and some culling caused public controversy and limited success. Capturing and relocation may not completely rid the garden of bats but should reduce the colony to a more manageable level.
  - **Koalas** have been relocated to Kangaroo Island (where they are now a pest).

PESTICIDES **(Repellents, rodenticides)**

- Almost all pesticides that are registered for controlling vertebrate pests are also **highly toxic** to humans and their domestic animals. State/Territory Pesticide Acts regulate their use and many are **available only to authorized and licensed persons** (pages 244, 249). Seek advice from your local Council/State/Territory authority.
- Even with generally poisonous materials, danger can be lessened by careful use; many are refused by humans and domestic animals. Some contain a taste deterrent.
- Pesticides for controlling rodents are generally applied as baits (solid or liquid) or fumigants.
- Overseas animal repellents for home garden use are available for almost any animal, eg snakes.

RATS AND MICE

- **Rodent** bait stations are available which are lockable and tamper-resistant.
- Some rodenticides (page 249) contain Bitrex® - a human taste deterrent.
- **Anticoagulants** interfere with the action of **Vitamin K** and reduce coagulating powers of blood. **Mice and rats** eventually die from internal haemorrhage.

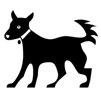
Advantages include:	**Disadvantages** include:
• Non-development of bait shyness in rats • Lack of danger to birds and other mammals • Existence of a good antidote (vitamin K)	• Resistance develops • Toxic to humans

RABBITS

- Rabbits are easily killed by using rodenticides, eg pindone or fumigants. Most of these compounds are **highly toxic** and their use is restricted.
- Units designed to inject liquid **LPG** into rabbit warrens are available for hire from local boards.
- For several reasons, poison baiting may not always be effective. In WA during dry summers both 1080 and pindone were equally effective but in wet seasons, 1080 was not so effective, possibly due to its solubility in water. Also over a period of years in there has been a marked decline in the effectiveness of poison baiting, thought to be due to selection for neophobia (tendency to avoid the new) in rabbit populations (Oliver et al, 1982).

BIRDS

- Various bird repellents are used by home gardeners.
- Although there is a reluctance to use chemicals to kill birds, some are registered for use by trained professionals.
- Repellent sprays are **no longer registered for use on fruit crops**. New repellents are being researched and may be available in the foreseeable future.
- Small numbers of trapped birds may be euthanased with carbon monoxide.
- Tracey et al (2007) has written a comprehensive treatise on managing bird damage to fruit and other horticultural crops.

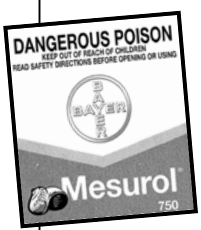


DOG AND CAT REPELLENTS, BAITING WILD DOGS

- Dogs and cats are not parasitic on plants but can **damage lawns**, dig up plants, etc. Their control is dealt with here for convenience (page 248, Table 49).
- Most dog and cat repellents for use in the home garden are not pesticides, do not require to be registered and are exempt from poison scheduling.
- There are many home made remedies, eg ammonia, pepper.

Table 49. Repellents (dogs, cats, possums, rabbits) and Avicides

- Many pesticides, especially insecticides, are **very toxic** to birds.
- Some pesticides used to control birds are **restricted** and available only to **trained/licensed** persons.
- Some dog and cat repellents **do not require to be registered as pesticides** and are exempt from poison scheduling. They are included here for convenience.
- Although there is a reluctance to use chemicals to kill birds, many **bird repellents** are **very toxic**.

CHEMICAL TYPES/GROUPS		THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name **Active constituent**	**Mode of action**	**CROPS, SITES, TREATED**	**PESTS CONTROLLED, SUPPRESSED**
REPELLENTS  	**Botanical oils**	**SKEDADDLE DOG & CAT DETERRENT, DETOUR, VARIOUS** citronella oil eucalyptus oil	**Repellent, smell** pleasant to humans, but disliked by dogs	Garden areas, lawns, paths, verandahs	**Dog & cat repellent** useful as a training aid for dogs & cats
		POSS OFF garlic, citronella capsicum oleoresin	**Natural possum repellent** Bitter tasting	Plants	**Possum repellent** possums
 	**Others**	**D-TER ANIMAL & BIRD DETERRENT** aluminium ammonium sulphate + sucrose octa-acetate + denatonium benzoate	**Repellent**, repels animals. Acts on the senses of **taste** and **smell**, animals entering treated areas are warned of **repulsive food and smells**	Garden areas, around homes, buildings, plants, seeds, bulbs, vegetables, fruit, ornamentals	**Animal & bird repellent** dogs, cats, rats, mice, rabbits, possums, wallabies, parrots, effectiveness varies from species to species, repels for up to 8 weeks, depends on weather
		GET OFF, KEEP OFF DOG & CAT REPELLENT SPRAY aluminium ammonium sulphate	**Repellent smell** to dogs and cats. Non-toxic to plants.	Non-crop, eg fences, gates; around plants, lawns	**Dog & cat repellent** dogs, cats; may be used as a training aid
		SCAT BIRD & ANIMAL REPELLENT aluminium ammonium sulphate	**Repellent smell** Non-toxic to plants.	Non-crop, eg fences, gates, around ornamental plants, vegetables, seedlings, lawns	**Bird & animal repellent** birds, pets, wildlife rabbits, rats & mice
		GET OFF MY GARDEN, KEEP OFF DOG & CAT REPELLENT methyl nonyl ketone	**Repellent smell** Dogs and cats find it offensive.	Assists in training dogs and cats avoid your garden	**Dog & cat repellent** dogs & cats; may be used as a training aid
		SEN-TREE whole egg solids/ acrylic polymer adhesive/silicon carbide grit	**Odour and grit deterrent**	Certain tree seedlings	**Browsing deterrent** certain wallabies, rabbits & Tasmanian paddymelons
		SCARECROW BIRD REPELLENT, CYNDAN polybutene	**Perching & roosting repellent** Slow drying sticky jelly, treated perches become messy & must be cleaned	Urban roosts, ledges etc. Commercial & industrial buildings	**Bird repellent** pigeons, sparrows, starlings etc; birds feel insecure on the jelly, fly to other sites, discourages roosting
 	**1A** Acetylcholin esterase inhibitors **INSECTICIDE**	**MESUROL BIRD REPELLENT & SNAIL & SLUG SPRAY** methiocarb **DANGEROUS POISON**	Bird repellent spray, non-systemic, also kills snails & slugs, certain insect pests	Ornamentals	**Bird repellent** black-birds, sparrows, starlings, Indian Mynas, **Snails & slugs** certain species
AVICIDES	**1B** Acetylcholin esterase inhibitors **INSECTICIDE**	**AVIGEL, CONTROL-A-BIRD AGENT** fenthion	**Only to be used supplied to & used by licensed pest control operators**	Industrial & commercial premises	**Unwanted pest birds** pigeons, starlings, Indian mynas, sparrows
		SCATTERBIRD 4-aminopyridine **DANGEROUS POISON**	**Bait** **Only to be used supplied to & used by licensed pest control operators**	Commercial & industrial areas, domestic, public service areas, agric buildings, farm situations	**Birds** pigeons, sparrows, starlings, Indian mynas
		ALPHA-CHLORALOSE alphachloralose **DANGEROUS POISON**	**Narcotic**, renders birds easier to kill by other means, birds may fall and die from exposure	Buildings. **Only to be used supplied to & used by licensed pest control operators**	**Birds** Pigeons **PERMIT ONLY**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 50. Rodenticides (mice, rats, rabbits, foxes)

- Most rodenticides are **highly toxic** to children, pets, domestic animals and wildlife. Some are only to be used in a lockable bait station. Some contain Bitrex® human taste deterrent. Most are not allowed in crops.
- Some are **restricted pesticides** and only to be supplied to and used by **licensed pest control operators**. Consult local council or shire for information on vertebrate pests.

CHEMICAL TYPES/GROUPS		THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	Method of control	CROPS,/SITES TREATED	PESTS CONTROLLED, SUPPRESSED
ANTI-COAGULANTS	**Coumarin** **Non-crop use**	**KLERAT, RODEX, TALON** brodafacoum	**Bait** One dose is effective. Eliminate alternate food	Non-crop, buildings, crop edges	**Rats & mice** **various species**
		BROMAKIL, BROMARD bromadiolone	**Bait** 1-2 feedings will control a population	Within & around buildings or in enclosed spaces	**Rats & mice** **various species,** poultry are very sensitive
		RACUMIN coumatetralyl	**Bait** Continuous feeding is necessary for control	Non-crop, buildings. Young pigs are very sensitive	**Rats & mice** **various species**
		RATSAK, VARIOUS warfarin	**Bait** Repeated ingestion needed	Non-crop, buildings. Hazardous to wildlife, domestic animals,	**Rats & mice** **various species,**
		STORM, STRATAGEM flocoumafen	**Bait** Lethal in a single dose, non-food blue colouring, human taste deterrent	In & around industrial, domestic and agricultural buildings	**Rats & mice** controls rats and mice **resistant** to warfarin
		SOREXA PRO RODENTICIDE difenacoum may be formulated with alpha-cypermethrin	**Bait** blocks, wax, paste, pellets	In & around buildings **Professional pest control product**	**Rats & mice** including those resistant to other anticoagulants
	Indandione **Non-crop use**	**PINDONE, VARIOUS** pindone-sodium RESTRICTED PESTICIDE POISON	**Bait** (usually carrots, dyed green), less likely to be eaten by birds. Degrades in soil and water.	Non-crop, very small risk of secondary poisoning (domestic dogs)	**Rabbits** **Consult state authority on vertebrate pests**
		RAMIK GREEN BAIT BITS diphacinone POISON	**Ready to use nugget baits**	Commercial, agric & domestic buildings	**Mice**
OTHERS **These products are all extremely hazardous and must only be supplied to and used by licensed pest control operators**		**RAMPAGE** cholecalciferol (Vit D3) DANGEROUS POISON	**Bait** Mobilises store of calcium from bones to plasma in the body of rodents	In & around domestic, commercial and agric buildings. **Only to be used in lockable bait stations**	**Rats & mice** including anticoagulant resistant species
		VARIOUS zinc phosphide DANGEROUS POISON	**Bait** (sterilized wheat seed coated with zinc phosphide). One grain is lethal to mice.	Agricultural situations, sugarcane **Must not be used around farm buildings**	**Mice, rats** **large scale plagues,** minimal risk to non-target native animals, birds or reptiles
		1080, VARIOUS sodium fluoroacetate DANGEROUS POISON	**Bait** Lethal to domestic dogs & some wildlife, native animals have some tolerance.	Non-crop. DANGEROUS POISON, RESTRICTED PESTICIDE	**Wild dogs & foxes, vermin** **consult state authority on vertebrate pests,**
FUMIGANTS **All chemical fumigants are extremely hazardous and must only be supplied to and used by licensed pest control operators (see pages 58, 60 & 267 for mode of action groups)**		**CHLORFUME, LARVACIDE** chloropicrin (tear gas)	**Soil fumigant** Often used as a **warning agent** with other fumigants	Pre-planting soil fumigation, soil heaps, rabbit warrens	**Fumigant** rabbits, soil fungal & bacterial diseases, nematodes, weed seeds
		FUMITOXIN, VARIOUS aluminium phosphide	**Fumigant**	Non-crop, buildings, seed, stored grain, pasture	**Commodity fumigant** storage pests & mice, rabbits
		CSSP PHOSPHORUS PIG POISON carbon disulphide + phosphorus	**Bait**	Restriction on where it may be used.	**Feral pigs**
		DEN-CO-FUME CARBON MONOXIDE FUMIGANT CARTRIDGE sodium nitrate + charcoal +	**Fumigant cartridge** **Very toxic, explosive**	Natal fox dens	**Foxes** humane asphyxiation of **foxes** in natal dens
VIRUSES		**MYXOMA VIRUS** myxomatosis virus	For the initiation of myxomatosis in rabbits		**Wild European rabbits**
		CALICI VIRUS rabbit haemorrhagic disease virus	Injection & baits		**Wild European rabbits**
		CYLAP RCD VACCINE rabbit calici virus	Injection to control calici virus in European rabbits	For prevention of calicivirus in cats, rabbits	**Domestic rabbits & cats**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List local pest vertebrates.
2. Describe **identifying features** of vertebrate pest damage to selected crops.
3. Recognize by sight, **damage** to ornamental plants, fruit, vegetables and other crops by local pest vertebrates.
4. **Compare** bird damage to fruit with environmental damage, hail damage.
5. Name vertebrate pests in Australia which are controlled to some extent by **biological control** agents.
6. Explain why **physical & mechanical methods** of control are widely used to control vertebrate pests.

.7. Describe State/Territory/Commonwealth **legislation** for the control of a local pest species.

8. Provide the active constituent, some trade names, mode of action and some uses for selected **rodenticides**, **bird repellents**, dog and cat repellents belonging to the following groups:

Rodenticides	Bird repellents	Dog & cat repellents
Anticoagulant	Taste repellent Smell repellent Perch treatment	Taste repellent Smell repellent

9. Provide **options for controlling** local pest vertebrates including:
   Mice and rats in a greenhouse
   Mice damaging stored seed
   Birds damaging cherry crops
   Possums eating walnuts
   Fruit bats damaging ornamental trees
   Cockatoos damaging ornamental trees
   Birds nesting in urban street trees
10. Prepare/access an **IPM** program for a vertebrate pest at your work or in your region.
11. Locate **reference material** and know where to obtain advice on the control of rats, mice and other local pest vertebrates.

SELECTED REFERENCES

IACRC (The Invasive Animal Cooperative Research Centre) www.**invasiveanimals**.com/
Vertebrate pests www.agriculture.gov.au/
Controlling pest animals www.**daff**.gov.au/animal-plant-health/**welfare**/nccaw/guidelines/pest
Animal welfare www.daff.gov.au/**animal-plant-health**/
Threat abatement plans www.environment.gov.au/**biodiversity**/**threatened**/tap.html
Feral animals www.**daff**.gov.au/brs/land/**feral**-animals and search for:
APAMP (Australian Pest Animal Management Program) which replaces the National Feral Animal Control Program (NFACP)
PESTPLAN (A guide to setting priorities and developing a management plan for pest animals),
NCCAW (National Consultative Committee on Animal Welfare)

Fact Sheets and Vertebrate Pest control manuals by State/Territory Depts of Primary Industries are available online, eg
Rabbits, Mice, Feral Goats, Mice, Foxes, etc.

Legislation
Legislation - State/Territory and Council websites
EPBC Act (Environment Protection and Biodiversity Conservation Act 1999) www.**environment**.gov.au/

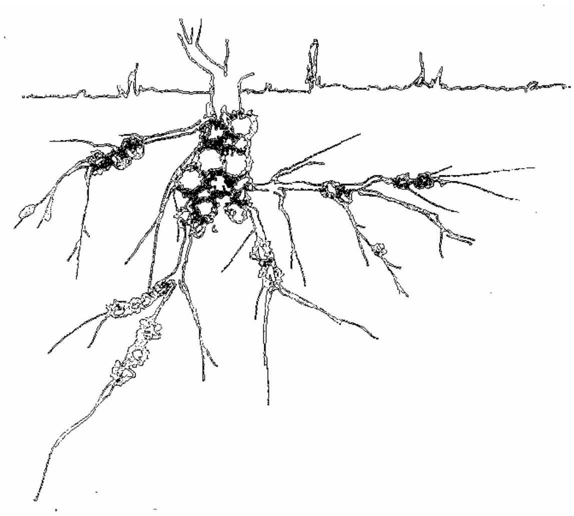
Keys
Lucid keys www.**cbit**.uq.edu.au/
Key to the Pest Rodents of Southeast Asia and the Pacific

Quarantine
Commonwealth quarantine www.daff.gov.au/**aqis**
Target lists of weeds, insects, plant and animal pests and diseases. www.**daff**.gov.au and search for target lists

Rodenticides,
Local Councils/Shires
Pubcris. APVMA. Canberra www.**apvma**.gov.au
Infopest, Qld www.dpi.qld.gov.au/**infopest**
Croplife Australia www.**cropelifeaustralia**.org.au/
MSDS www.**msds**.com.au/
Company websites make labels and MSDSs available

General
Breed, B. & Ford, F. 2007. *Native Mice and Rats*. CSIRO Pub., Melbourne.
Caughley, J., Bomford, M., Parker, B., Sinclair. R., Griffiths, J. and Kelly, D. 1998. *Managing Vertebrate Pests : Rodents*. BRS, Canberra.
Gerozisis, J. & Hadlington, P. 2008. *Urban Pest Management in Australia*. 5th revised edn. UNSW Press, Sydney.
Hall, L. & Richards, G. 2000. *Flying Foxes : Fruit and Blossom Bats of Australia*. UNSW Press, Sydney.
Hone, J. 2007. *Wildlife Damage Control*. CSIRO Pub., Melbourne.
McCarthy, P. & Bache, S. 2010. *Managing Pest Birds*. UNSW Press, Sydney.
Oliver, K.J. Wheeler, S. H. & Gooding, CD. 1982. *Field Evaluation of 1080 and Pindone Oat Bait, and the Possible Decline in Effectiveness of Poison Baiting for the Control of the Rabbit, Oryctolagus Cuniculus*. Aust. Wildlife Research 9(1) 125-134.
Olsen, P. 1998. *Australia's Pest Animals : New Solutions to Old Problems*. Kangaroo Press, Sydney.
Singleton, G. R., Hinds, L. A., Leirs, H. & Zhang, Z. 2000. *Ecologically-based Rodent Management*. ACIAR, Canberra.
Tracey, J., Bomford, M., Hart, Q., Saunders, G. & Sinclair, R. 2007. *Managing Bird Damage to Fruit and Other Horticultural Crops*. Bureau of Rural Resources, Canberra.

Nematode Diseases



Root knot nematode galls (up to 25 mm across).

BIOLOGY AND IDENTIFICATION

Nematode diseases

NO. DISEASES IN AUSTRALIA

Nematodes occur in soil, plants, animals and humans. More than 300 species are known to be parasitic on plants and it is considered there may be up to 1 million species worldwide. Nematode populations are related to soil properties and so are useful indicators of soil conditions (Hodda et al 1999). Nematode plant pests cost about 10 per cent of world food production (Hodda 2008).

Nematoda www.ento.csiro.au/science/**nematode**.html
CBIT Nemasys www.cbit.uq.edu.au/software/**nemasys**/
Biological Crop Protection www.**biolcrop**.com.au/
Australasian Association of Nematologists nematologists**.org.au/**

SOME DISTINCTIVE FEATURES

Do not confuse nematodes with earthworms or some fly larvae, eg fungus gnats, both of which are larger

BODY

1. **Many celled animals** with a true digestive cavity.
2. **Mainly microscopic (x 10)**, some visible to the naked eye.
3. **Generally 0.5 - 3.0 mm long**, a few species are longer.
4. **Generally 'eel-like'**, adult females of some species are spherical or pear-shaped. More or less transparent.
5. Body is **unsegmented** with no legs or other appendages.

MOVEMENT They move by means of special muscles in **water films** between and around soil particles.

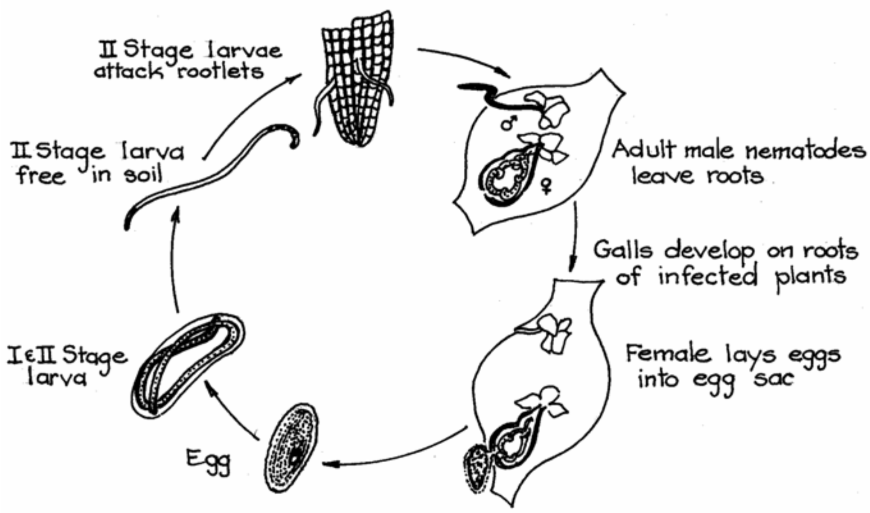
Do not confuse nematodes (Phylum Nematoda) with earthworms (Phylum Annelida) or some fly larvae, eg fungus gnats, both of which are larger.

LIFE CYCLE

Root knot nematode

Many variations, eg foliar nematodes, stem and bulb nematodes

Life cycles of most plant parasitic nematodes are similar, eg eggs, juveniles (which look like adults) and adults (males and females). The sexes are usually separate, however, males may be missing. Also females may reproduce parthenogenically. At optimum temperature and moisture a life cycle may take from 2-4 weeks.

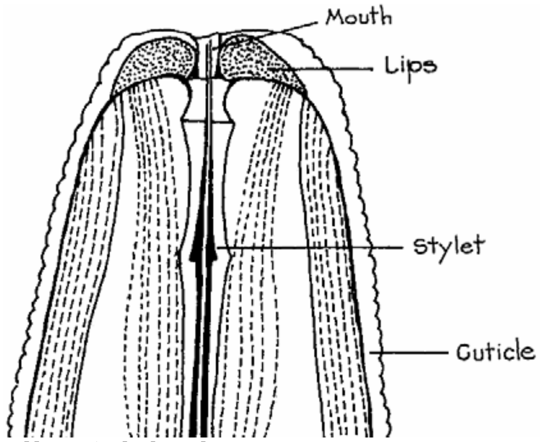


METHOD OF FEEDING

NEMATODE HEAD

The digestive system is developed for handling a liquid diet.

Most plant parasitic nematodes have a **hollow stylet or spear** which can be thrust forward (like a tongue) from its mouth to puncture holes in plant cells. It then withdraws or "sucks out" the contents, including the nutrients, from the plant cell.



Nematode head. A hollow digestive tube extends from the mouth to the anus (adapted from Agrios, 1997).

SYMPTOMS

DIRECT FEEDING DAMAGE.

The mechanical injury caused by nematodes feeding causes only slight injury to plants. Most plant damage is caused by the nematodes **secreting saliva** which they inject into plants during feeding. This may result in:

- **Tissue breakdown**, eg rotting
- **Abnormal cell enlargement and cell multiplication**, eg galls
- **Abnormal cell division**, eg large number of lateral roots
- **General stunting** of tomatoes, turf, etc
- **5-10% of crop production is lost to nematodes** in developed countries

Above ground symptoms

LEAVES

Chlorosis (non-specific water stress/deficiency type symptoms due to nematodes feeding on or in the root), eg root knot and root lesion nematodes

Dead areas, scorches, blotches, eg foliar nematodes

Leaf distortion, eg stem and bulb nematode

Spicules (tiny lumps), eg stem and bulb nematode

Below ground symptoms

ROOTS

Excessive root branching, eg beet nematode

Galls, eg root knot nematodes

Injured root tips, eg root lesion nematodes

Rotting, eg stem and bulb nematode in bulbs

INDIRECT DAMAGE.

- **Transmission of virus diseases.** In Australia, only a few species of nematodes can transmit virus diseases of plants, eg the dagger nematode (*Xiphinema* sp.) can transmit the grapevine fanleaf virus, stubby root nematodes (*Paratrichodorus* spp.) can transmit at least 6 plant viruses. The nepoviruses (nematode-transmitted, polyhedral particles) are a group of about 46 viruses that infect many plant families that cause probably the most serious viral diseases of horticultural crops, particularly perennial woody and bulb crops. Many have not been recorded in Australia.

Disease complexes

- **Nematode-bacterial disease complexes. Annual ryegrass toxicity (ARGT)** is the poisoning of livestock by toxins contained in bacterially-infected annual ryegrass (*Lolium rigidum*). The toxins are produced by bacteria (*Rathayibacter toxicus,* formerly *Clavibacter toxicus*) which are carried into the ryegrass by a **seed-gall nematode** (*Anguina funesta*).
- **Nematode-fungal disease complexes.** The fungus is not transmitted by the nematode. Plant varieties susceptible to a particular soil fungus are damaged even more when the plants are infected with nematodes, the damage being considerably more than the sum of the damage caused by the nematode, eg root knot, or the fungus, alone, eg *Fusarium* and *Verticillium* wilts, *Phytophthora* and *Rhizoctonia* root rots.

BENEFICIAL.

Nematodes also feed on algae, lichens and are often found on healthy trees

- **Breakdown organic matter**. Bacterial-feeding nematodes in the soil increase the turnover of plant nutrients (specifically nitrogen); fungi also feed on nematodes and nematodes can feed on fungi and organic matter, etc.
- Some species are used as **biological control agents**.
- Numbers and species of nematodes in soil can act as **indicators of biodiversity**.

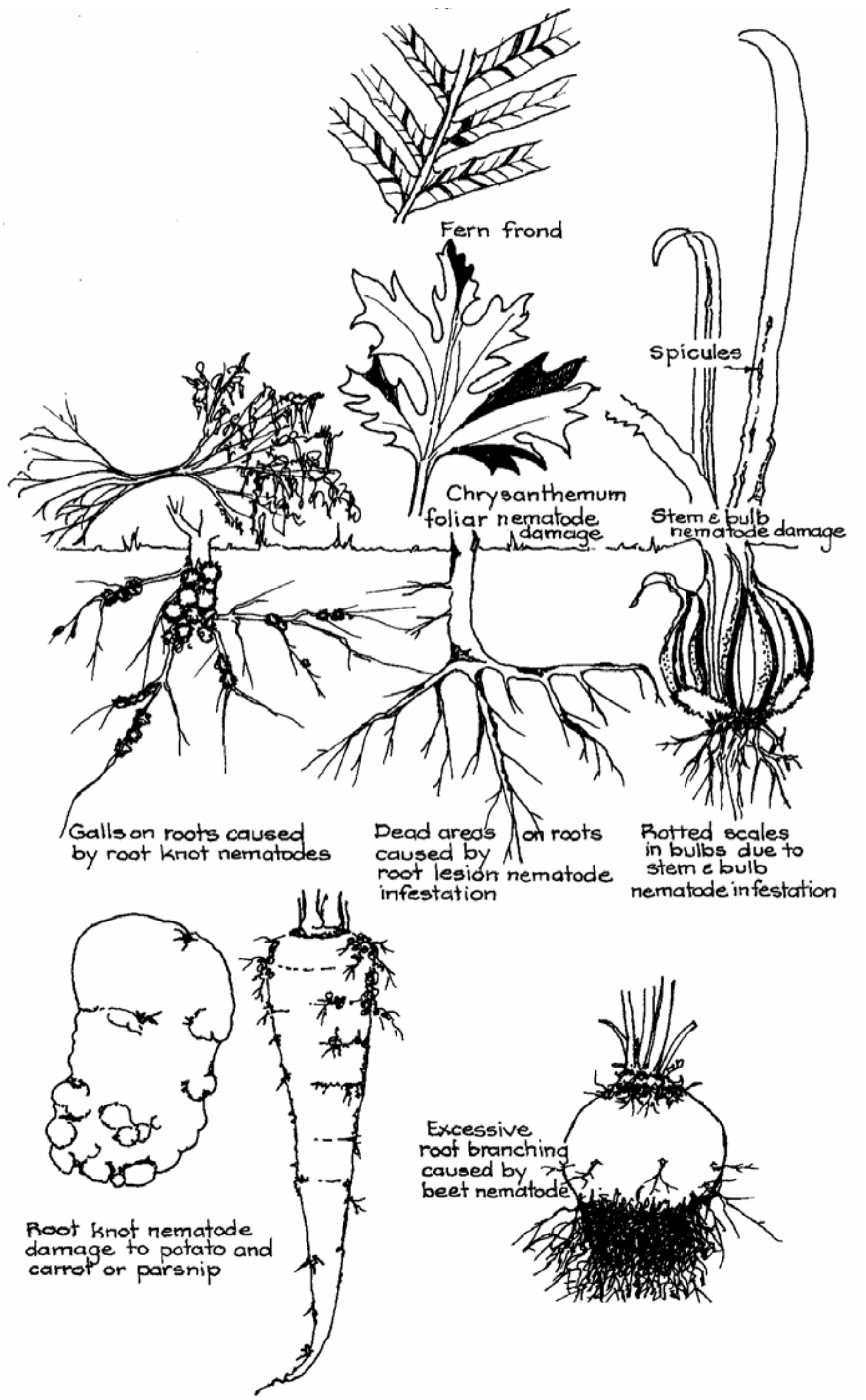
SYMPTOMS *(contd)*	**ABOVE GROUND** **NON-SPECIFIC SYMPTOMS** • Root knot nematodes. • Root lesion nematodes, etc. • Damage is largely the result of nematodes feeding on or in **roots**. Symptoms are similar to those of water stress, nutrient deficiencies, etc. Plants may wilt on hot days, show poor or stunted growth and poor yields. For a positive diagnosis, plants must be removed from soil and roots examined. • Non-specific symptoms make diagnosis **difficult** for the average horticulturist.	**ABOVE GROUND** **SPECIFIC SYMPTOMS** • Foliar nematodes. • Stem and bulb nematode. • Damage is largely the result of nematodes feeding on or in **aerial parts**. Symptoms have a distinctive appearance.

LEAVES

Above ground symptoms

ROOTS

Below ground symptoms



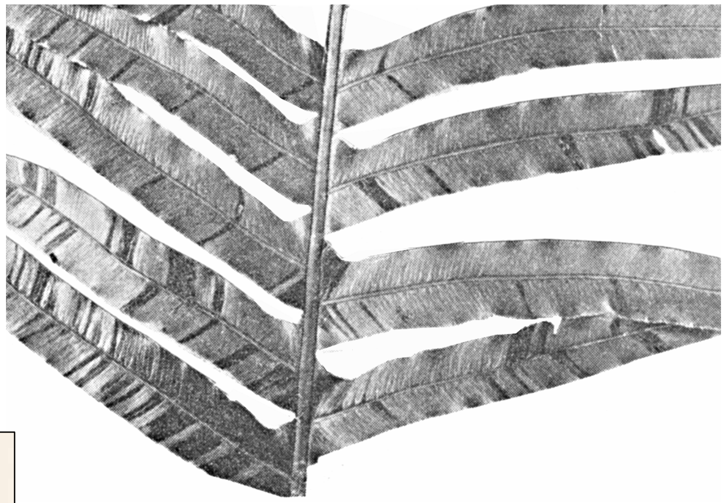


Fig. 132. Foliar nematode (*Aphelenchoides* spp. Foliar nematodes swim up stems and across leaves in films of water and enter leaves and stems through stomates. ***Upper left:*** Infested chrysanthemum leaves. Note wedge-shaped area bordered by leaf veins in early stages of infection. These are red, yellow or purple at first, turning brown with age. ***Upper right:*** Portion of infested fern frond. The dark areas between the veins are the infested areas. Photo© NSW Dept of Industry and Investment. ***Lower left:*** Symptoms may be confused with overwatering and other environmental problems. All symptoms suspected of being caused by nematodes must be confirmed by laboratory investigation. Photo©CIT, Canberra (P.W.Unger).

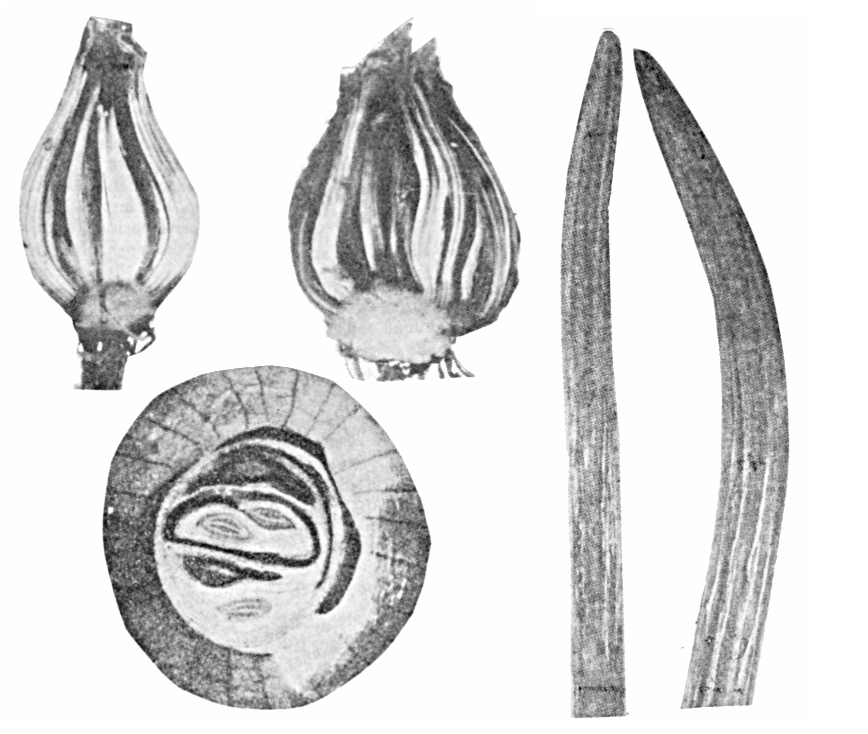


Fig. 133. Stem and bulb nematode (*Ditylenchus dipsaci*). ***Left:*** **Bulbs** cut longitudinally to show browning of scales due to the nematodes feeding on the fleshy leaf bases. Do not confuse with fungal rots. Cross section at neck of bulb shows rings of brown scales. ***Right:*** **Leaves** showing raised blister-like streaks which are full of nematodes. Nematodes move into new leaves causing blisters. Photo© NSW Dept of Industry and Investment.

CLASSIFICATION

All plant parasitic nematodes belong to the **Phylum Nematoda**. There are several orders, sub-orders and families into which they are classified mainly according to their morphology, eg

- Presence or absence of stylet, size and structure of the style itself.
- Position of the oesophageal glands.
- Structure of the female reproductive system, number of annules in the lip region. Tail shape can be used to identify nematodes at a species level.
- Also occasionally, the plant organ attacked, symptoms and mode of parasitism.

IDENTIFICATION, SAMPLING

Symptoms

VISUAL EXTERNAL SYMPTOMS

- **Below ground symptoms** can be quite distinctive, eg root knot on carrots, but they do not indicate which species of root knot nematode. Also, root knot galls could be confused with nitrogen-fixing nodules on some hosts.
- **Foliage symptoms**.
  - **Foliage nematodes**. Similar symptoms can be caused by various non-parasitic agencies, so get to know your crop.
  - **Root nematodes.** The presence of nematodes can be suspected if crops/turf lack vigour and do not respond to fungicides, irrigation or fertilizers.

MORPHOLOGY/MICROSCOPY

- **Simple nematodes** can be seen with a **dissecting microscope (x 10).**
- **Not all nematodes** seen under microscope are pests, eg on rotting bulbs, saprophytic nematodes may be feeding on and biodegrading organic matter.
- **Various keys** based on morphology have been developed to help identify plant-parasitic nematodes but identification to species requires a **specialist nematologist** in a diagnostic laboratory. Sometimes nematodes cannot be identified using morphological features alone.
- While tools such as **DNA** bar-coding may provide rapid identification, studies of all nematodes in soils must embrace their morphology, biology, soil structure and moisture, available nutrients, microbial populations, ecological relationships, eg pathogenicity to plants, invertebrates, etc.

NEMATODE DIAGNOSTIC SERVICES provide information on:

- Sampling and/or extraction procedures.
- Handling and storage of samples prior to dispatch.
- Planning **IDM** programs.

Soil

Plant material

Indicator plant

IDENTIFICATION BY SPECIALISTS

- **Soil and plant analysis.**
  - **Soil** sampling. Obtain information from the diagnostic laboratory on when and how to collect samples and dispatch them. Generally, collect soil samples before planting, store at 10-15°C until dispatch. They will extract, identify and count nematodes present and interpret results. Traditional extraction techniques may fail if populations are low or in the dormant stage.
  - **Plant material**, eg roots, leaves (above ground parts).
- **Bio-assays.**
  - **Variations in host range** can occur within a species and these can only be detected by testing the nematode against a range of plant species.
  - **Indicator plants.** In root knot nematodes the juvenile is the only stage found in the soil. Since all species have morphologically similar juveniles a bioassay on selected indicator plants may be used to distinguish species.
  - **Detecting low populations of root knot nematodes**. Susceptible plants, eg tomato seedlings, are grown in soil samples for about 1 month and then the root system is removed and examined for galls. Their occurrence indicates the presence of root knot nematodes. Large samples can be processed, also eggs in soil can hatch and infect the plant. Samples must be collected at least 1 month before planting.
  - A nematode count is the only way to quantify their presence and determine whether the numbers present will be detrimental to plant health.
- **Other diagnostic tools.**
  - **Rapid and reliable diagnostic procedures for major pest nematodes** are continually being developed; including computer based analytical tools and **DNA** technologies for identifying and quantifying nematodes.
  - **Field tests** are being researched using **immunochemical** devices to identify nematode species, eg *Anguina tritici, A. funesta, Meloidogyne javanica.*
  - **Molecular assays** for soil-borne pathogens in **cropping** soils **PreDICTA B** by SARDI, eg pathogenic oomycetes, fungi and nematodes, beneficial fungi.
  - **Keys, eg** *Plant Parasitic Nematodes* (Lucid key) www.lucidcentral.org/
    Key to the Nematodes of Australia www.ento.csiro.au/science/nematode.html
  - **Nepo viruses** are transmitted by nematodes and a generic test is being developed for the whole nepovirus group.

DNA

- **Routine DNA-based testing service** for soilborne diseases in Australia so that likely losses can be **predicted** well before the crop is planted. Growers can change cultivars, crops, modify cropping programs where risk of crop loss is high.
- **Many soil pests and diseases** can be identified from a single soil sample.
- **Training programs** are available so that results of testing can interpreted accurately at the farm level.

LIST OF SOME SPECIES	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	Root knot nematodes	*Meloidogyne* spp.	Wide host range, more than 2000 plant species
	Root lesion nematodes	*Pratylenchus* spp.	Wide host range, cereals, fruit trees, roses, turf
Not known in Australia	Celery eelworm	*Pratylenchus hamatus*	Celery and parsley in the USA, **not known** to occur in Australia
	Stem and bulb nematodes	*Ditylenchus dipsaci*	Bulbs, phlox, oats, medics, clovers, *Vicia faba*
		D. myceliophagus	Mushroom mycelium in mushroom crops
	Foliar nematodes (leaf nematodes)	*Aphelenchoides ritzemabosi*	Chrysanthemum, Coleus, others
		A. fragariae	Strawberry, anemone, kangaroo paw, others
		A. composticola	Mushroom mycelium in mushroom crops
	Citrus nematode	*Tylenchulus semipenetrans*	Citrus, other Rutaceae, grapevines, olives, other plants
	Dagger nematode	*Xiphinema index*	Fig, grapevine, stone fruit, turf, may transmit plant viruses
	Cereal cyst nematode	*Heterodera avenae*	Wheat, oat, barley, wild oats, barley grass, ryegrass, triticale. Important and damaging
Limited distribution	Potato cyst nematode (PCN)	*Globodera rostochiensis*	Potato, other Solanaceae, eg capsicum, eggplant, tomato, nightshade
	Stubby root nematodes	*Trichodorus* spp.	Fruit, vegetables, annuals, turf
		Paratrichodorus spp.	Mostly horticultural crop plants, turf, occasionally bush soils. May transmit plant viruses.
	Spiral nematodes	*Rotylenchus* spp. *Helicotylenchus* spp.	Annuals, turf, etc
Not known in Australia	Pinewood wilt nematode	*Bursaphelenchus xylophilus*	Pines.
	Burrowing nematodes	*Radopholus* spp.	Banana, sugarcane, fruit, vegetables, weeds
	Beet nematode	*Heterodera schachtii*	Beets, some *Brassica* spp., radish, rhubarb, spinach, dock

Nematode-disease complexes

Nematode-bacterial disease complexes (page 253)
Nematode-fungal disease complexes (page 253)

Humans and animals

Some nematodes are human and animal parasites, including:

- Hookworms in humans, dogs and cats.
- Heartworms in dogs.
- Filiariae in humans and animals.
- Threadworms, pinworms especially in children.
- Trichinae in humans from eating contaminated pig meat.
- Some strains of *Paecilomyces lilacinus*, a common fungus associated with *Meloidogyne* egg masses, has potential to be a threat to human health (Walker 2006).

Indicators of soil conditions

Free-living, soil-dwelling nematodes are useful as indicators of soil conditions because of their high abundance, widespread occurrence and rapid response to change (Hodda et al 1999, Stirling et al 1999).

- **Fungal-feeding** nematodes are more abundant under **conventional** tillage.
- **Bacterial-feeding** nematodes are more abundant under **direct** drilling.

Nematodes as natural enemies			
	Predatory nematodes	Many genera	Prey on plant parasitic **nematodes** in soil, **possible commercial use**
	Predatory nematodes	Many genera	Prey on plant parasitic **fungi** in soil, **possible commercial use**
	Saprophytic nematodes	Many genera	Feed on **organic matter** in the soil

LIST OF SOME SPECIES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)

Biological control agents

Some beneficial nematodes are symbiotically associated with bacteria which they carry within their intestinal tract, often within a specialised vesicle. The **nematodes seek out natural openings on insects**, eg mouth, anus, spiracles, and move into the bloodstream, where they release the bacteria causing septicaemia. Most insects are susceptible and given enough nematodes they will die.

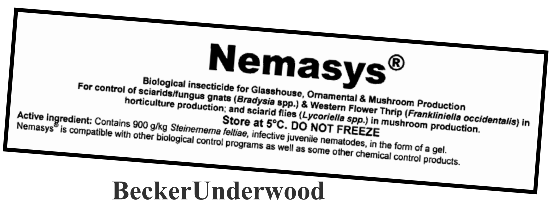
- **ENs** are now so widely used in the world, they are second only to *Bacillus thuringiensis* (***Bt***) in biopesticide sales.
- The best species and strain for a particular pest can be selected.
- Sold as the 3rd stage larvae which is the only stage that can survive outside the host.
- 3rd stage larvae enter the body openings via the anus or spiracles (*Steinernema*) or through the skin (*Heterorhabditis*).
- Once inside the nematodes release the bacteria causing septicemia.
- Nematodes in larva increase in numbers, eventually they leave to look for new hosts.
- Infected larvae become yellow to reddish brown and cease to feed before dying.
- Nematodes can be applied via trickle irrigation, or by conventional equipment. Apply at dusk because they are sensitive to drying and UV radiation.
- Barrier to developing nematodes as biocontrol agents has been technical difficulties involved in culturing and storing them and applying them to target pests in the field. Emphasis is now on strategies for improving field efficacy:
  – Beneficial nematodes do not have an extended shelf-life
  – Make sure nematodes are alive when applied.
  – Pre-water area prior to application (they require moisture to move through soil effectively.
  – Apply immediately at temperatures less than 32°C. Temperatures greater than this reduce survival rate of infective juveniles, apply in evening.

Nematodes seeking out openings in a larva of the black vine weevil.

	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
		Beddingia siricidicola	Sirex wasp in *Pinus radiata* plantations
		Steinernama feltiae	Currant borer moth. Used to disinfest **currant cuttings** of currant borer moth larvae in Tasmania. Kills 99.8% caterpillars in cuttings, may need to be re-introduced at regular intervals.
		S. feltiae	Mushroom fly, fungus gnat
		S. feltiae	Fungus gnats, sciarids and Western flower thrips in greenhouse horticulture production.
		S. carpocapsae	Banana weevil borer, cutworm, armyworm, house termites, cat flea
		S. carpocapsae	Ground-dwelling insects and certain borers
		Heterorhabditis zealandica	Argentine stem weevil, African black beetle, Argentinian scarab, black-headed cockchafer, red-headed cockchafer, bill bug weevil
		H. bacteriophaga	Black vine weevil larvae
Not in available in Australia	Nemaslug®	*Phasmarhabditis* sp.	Parasitizes snails in high value protected crops. Newly hatched snails are susceptible to nematodes some of which occur naturally.

NEMATODES 50 MILLION
(50 MILLION INFECTIVE JUVENILES)

Ecogrow
www.ecogrow.com.au/



BeckerUnderwood
www.beckerunderwood.com/

Fig, 134. Nematode bio-insecticides

DISTRIBUTION WITHIN PLANTS


Female nematodes on gall


Foliar nematode damage

In terms of **habitat**, plant parasitic nematodes are either **endoparasitic** or **ectoparasitic**.

ENDOPARASITIC NEMATODES

Species that enter the host and feed from **within the host**.

- **Sedentary.** Species which **do not move** around extensively once inside the plant, eg root knot nematodes.
- **Migratory.** Species which **do move** around extensively inside the plant, eg foliar nematodes and stem and bulb nematode, root lesion and citrus nematodes.

ECTOPARASITIC NEMATODES

Species that do not normally penetrate root tissue but feed only on the cells near the surface.

- **Sedentary.** Species do **not** move around on the outside of the plant, they find a place to feed and stay there, eg ring nematode.
- **Migratory.** Species feed on the cells on the root surface but do not become attached and move around from place to place, eg dagger nematode.

EGG HATCHING

- Most nematode eggs hatch freely in water.
- However, the eggs of some species are stimulated to hatch by substances produced by the roots of the surrounding host plant, which diffuses into the surrounding soil.

OBLIGATE PARASITES

- Plant parasitic nematodes are **obligate parasites** - they can only complete their life cycles on living plants. This can be a weakness and exploited in control.

DISEASE CYCLE


Host


Host, host debris


Host, host debris, soil

Although all plant parasitic nematodes are obligate parasites and so only attack and complete their life cycle on **living plants**, many stages of their life cycle may be found in soil, plant debris, corms, tubers, bulbs, seed, etc.

HOST ONLY

- In some plant parasitic species, all stages (eggs, larvae and adults) may be found in or on the host plant, while in other species **only one or two stages** may be found in or on the host plant.
- Depending on the species, various stages (eggs, larvae and adults) may be found in or on **roots, stems, leaves, seed, corms** and other plant parts.

HOST AND HOST DEBRIS

- Plant debris from infected plants may carry various stages of nematodes (eggs, larvae and adults).

HOST, HOST DEBRIS AND SOIL

- Most **plant parasitic nematodes live part of their lives in soil**.
- Large numbers are usually also found around the **roots of host plants** so that the **depth** at which nematodes can be found and should be **sampled,** will depend on the type of crop being grown, previous crops, soil type and the method of growing the crop.
- In **vegetables crops** nematodes will be concentrated in the surface layers, eg **20-30 cm** for carrot crops, while in other crops nematodes may be found as deep as **150 cm.**
- **Seek advice on the depth and methods of sampling soil** for nematode testing for your crop.

OVERWINTERING, OVERSUMMERING

In warm climates on perennial hosts, generations will overlap and so there is often no 'overwintering' as such.


Hosts, weeds

HOST PLANTS

Nematodes may 'overwinter' as dormant infections in the roots of perennial hosts, eg bulbs, weeds. Stem and bulb nematodes may survive quite well in bulbs either in the soil or in storage. In some instances the nematodes clump together to form 'nematode wool' on the outside of bulbs in storage. The nematode wool looks like cotton wool and in this form the nematodes are **highly resistant** to adverse conditions, eg drought.


Seeds

SEED

Nematodes may survive for **years** in seed, eg seed-gall nematode of wheat.

ALTERNATE HOSTS

Nematodes with a wide host range can survive on alternate hosts or weed hosts, eg root knot nematode.

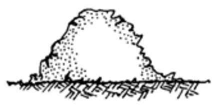

Root debris/soil

ROOT DEBRIS AND SOIL

Nearly all nematodes can survive as **egg masses** in infested plant debris and in soil for **years** in the absence of a suitable host. The population of surviving eggs will decline steadily over a period of months, so that at the end of a prolonged absence of hosts the population may be very low.

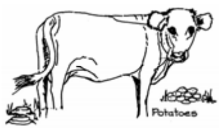
- In soils where annual crops are grown, eg vegetables and flowers, soil-inhabiting nematodes with a wide host range, eg root knot nematodes, have no difficulty surviving until the next crop.
- Leaf nematodes can survive in leaf debris in the soil.
- Wheat seed gall nematode (*Anguina tritici*) as 2nd stage juveniles can survive for decades in a dry dormant state.

SPREAD


Infested soil

INFESTED SOIL

Infested **soil** may be spread on tools, machinery, containers, footwear and in soil deliveries. If healthy plants are planted into infested soil, nematodes move from the soil into the healthy plants. Soil eroded by water or in mud. Soil-inhabiting nematodes and fungi may be transported in **dust**.



Infested manure

INFESTED MANURE

Infested manure may be spread on animal's feet and in manure deliveries. Nematodes in infected produce, eg potatoes, if fed to stock can pass through their digestive system and be eliminated in their excreta.

H_2O

WATER

Irrigation water or rain can splash foliar nematodes onto adjacent plants and facilitate spread from plant to plant if leaves are touching. Flood or water in drainage channels can carry nematodes to areas distant from the site of the original infestation. Nematodes can spread from pot to pot via drainage water; this can be prevented by placing pots on wire mesh. **Foliar or leaf nematodes** move easily up stems and across leaves in a thin film of water, spread by water splash, on tools and by staff.


Seedlings, plants, etc

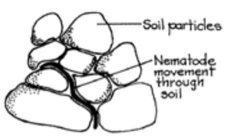
INFESTED SEEDLINGS, PLANTS, TUBERS

Nematodes are introduced into new areas by planting infested seedlings, plants, nursery stock, tubers and bulbs. Golden nematode of potato spreads on infected tubers.

INFESTED CROP DEBRIS, WEEDS

Root knot may spread in debris from infected crops and weeds.


Infested crop debris

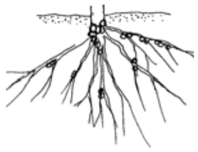


MOVEMENT OF NEMATODES THROUGH SOIL

Under optimum conditions this may only be a few centimetres, certainly no more than 1 metre.

CONDITIONS FAVOURING

Nematodes are well suited to living in the soil because it is well insulated against sudden or large temperature changes and affords protection from the direct lethal rays of the sun.



Symptoms of **root** knot on tomato

SOIL-INHABITING NEMATODES

Most plant parasitic nematodes spend all or part of their lives **in the soil**. Soil structure determines the distribution of nematode species more than anything else (exceptions may be those with moderate host ranges).

- **Soil moisture.** Young and adult nematodes require adequate soil moisture, preferably as a film of moisture around the soil particles. This allows them to move freely and provides adequate aeration for their survival.
- **Aeration.** Nematodes require an adequate oxygen supply for respiration, so that soils should have pore spaces with a diameter of about 20 µm. Smaller pore spaces inhibit plant parasitic nematodes.
- **Temperature.** Nematodes dislike extremes of temperature and sudden or large temperature changes, and generally require temperatures greater than 15°C to increase their numbers.
- **Nematodes prefer a well-buffered soil** where there is unlikely to be sudden changes in acidity or alkalinity.
- **Soils high in organic matter are thought to be unfavourable** for development of plant parasitic nematodes because they have large populations of predatory nematodes.
- **Distribution.** Nematodes occur in greatest abundance in the surface layers (15-30 cm). Some nematodes may be found at much greater depths.
- **Continuous cropping.** Many crops which are relatively tolerant of nematode damage, eg squash and zucchini, may only suffer losses if the area is replanted immediately after a susceptible host has been grown.
- **Stage of crop development.** A well grown crop can withstand significant root infection with nematodes but a 2nd planting of the same crop in the same ground will certainly develop a damaging nematode infection while it is young and will not produce a good crop.
- **Type of tillage practices.** There can be substantial differences in the nematode fauna under tillage practices and probably in the rest of the soil biota as well (pages 257, 263).

Symptoms of **foliar** nematode on chrysanthemum

NEMATODES AFFECTING ABOVE-GROUND PLANT PARTS

These nematodes spend part of their lives in the soil and so are affected by the conditions discussed above.

- Additionally, leaf and stem and bulb nematodes are spread more rapidly when plants are wet. They escape from the soil and swim up on the outside of plants in a thin film of water. Leaf nematodes are favoured by free water on leaf and stem surfaces.

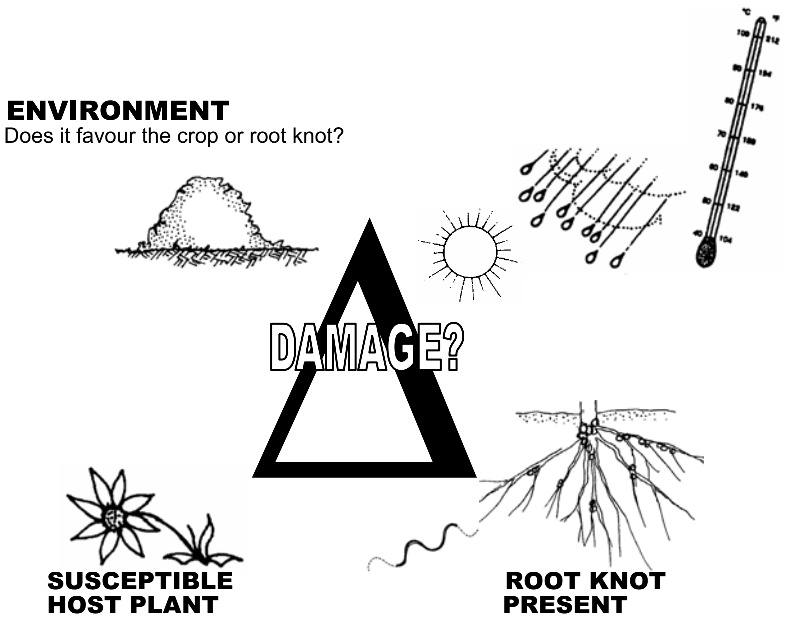


Fig. 135. Nematode-disease triangle.

INTEGRATED DISEASE MANAGEMENT (IDM)

MAIN STEPS

IDM avoids broad spectrum chemicals. Use control measures strategically and early be it chemical or biological or both and potential major pest problems may be avoided. Use control methods which maintain pest populations at acceptable levels

PLAN
PLAN
PLAN

1. **Plan** well in advance of planting the crop. Keep records, eg variety planted, source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides. Training courses are available for consultants and pest managers which include how to sample, monitor, interpret results and apply **IDM**.

2. **Crop, region** List nematode and other plant problems your crop is susceptible to in your region. The **IDM** program will depend on the crop, region. Management programs for nematodes are available for turfgrass, vegetables, etc.

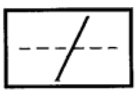
Emphasis today is on diagnostics, especially of soil diseases

An exotic nematode may be in Australia for years before being detected and identified

3. **Identification** Confirm identity of the nematode alleged to be causing damage, it will probably be necessary to consult a diagnostic service to identify the genus and species (page xiv). Obtain a Fact Sheet on the nematode problem so you understand the life cycle, how to prepare soil and plant samples for extraction, etc.
   - **Biological Crop Protection** www.biolcrop.com.au/
   - **NemaSYS** (CBIT, Uni of Queensland) is a multimedia package containing information on nematodes commonly found in crops and pastures around Australia. It provides a greater understanding of the biology of nematodes, and a sound background for monitoring and control.
   - **What can specialist nematode advisory services do?**
     - Provide information on sampling.
     - Identify nematode species.
     - Monitor pest species and natural enemies, keep records of damage thresholds.
     - Interpret results of analysis, evaluate treatments.
     - Provide advice on control options to maintain pest populations at acceptable levels. Results indicate some unnecessary use of nematicides.

1234
5678

4. **Monitoring** **Know when, where, what and how to monitor.**
   - **When to monitor?** Pre-plant nematode soil analysis is necessary where **root knot** and other nematodes have been a problem **in previous seasons**. Monitor crop when **growth is generally unthrifty**, wash potting media from roots and examine under a microscope for evidence of galls. Assess **galling on roots** in the field at the **end of season** to indicate the degree of infestation for the following crop.
   - **Where, what and how?** Seek advice before collecting soil samples, as you will need a professional interpretation of the results.
   - **Why monitor?** Most nematicides are highly toxic and some are being phased out. **Use of most substitutes** requires continuing monitoring of nematodes and more knowledge as they are not equally effective against all nematodes and other diseases organisms. Use should then be limited to situations where a need for the chemical has been demonstrated and the lowest rates required for normal plant growth and yield used, rather than applications on a routine or calendar basis. **Record and interpret** results professionally. Monitoring also indicates the effectiveness of earlier control measures.



In turf, thresholds depend on grass spp., mowing height, soil compaction, soil type, and presence of other root pathogens

5. **Threshold**.
   - There is usually a consistent relationship between **nematode populations** and the level of **crop damage** observed (Stirling 1999).
   - Very low densities of nematodes can cause economic damage in some crops while others can tolerate much higher nematode populations (Stirling 2000). Establish damage thresholds for a particular **species** on a particular **crop** in a particular **region.** Economic thresholds can be difficult to determine and market values cannot always be predicted.
   - Thresholds **vary** depending on the nematode, life cycle, rate of reproduction, survival, crop tolerance and environment. Conditions are important because plants can tolerate more nematodes under good conditions than under stress.
   - A competent nematologist should examine the affected plants and/or do a soil-plant root test to determine whether **threshold levels** of damaging plant parasitic nematodes are present and whether a nematicide application is advisable.

?

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Disease-tested material
Physical/mechanical
Pesticides
Organic, BMP, etc

6. **Action/control** will depend on monitoring and thresholds and applying **preventative** controls at the correct time. Reduction in use of nematicides can be achieved by integrating chemical with non-chemical means of control, eg crop rotations, resistant/tolerant cultivars and rootstocks, quarantine measures, nematode-tested planting material, biocontrol and chemical control. Nematode populations can be managed. Control methods, other than nematicides, are becoming more important and include precision agriculture, improved nematode identification, assessment of nematode populations, genetic engineering of crops and host resistance. Advisory services (extension or private crop consultants) provide effective management of nematodes.

✓ **X**

7. **Evaluation** Review **IDM** program to see how well it worked. Recommend improvements if required.

CONTROL METHODS

Control methods aim to maintain pest populations at acceptable levels. It is hard to quantify some of the non-chemical controls. Expense and type of crop being grown, limit the actual method employed.

LEGISLATION, STANDARDS, ETC

These include Plant Quarantine Acts, Seed Acts. Pesticides Acts, Organic Standards.

CULTURAL METHODS

- Cultural practices that promote root growth will enhance tolerance to nematodes.
- **Crop rotation** is difficult as many nematodes have a wide host range. However, effective rotations, where practical, are an essential part of nematode management.
- **During fallowing**, soil is cultivated once a week and after each period of rain. Nematode eggs hatch during the fallow but without food plants the larvae die. The area is kept free of weeds and other plants (possible hosts for the nematodes), for one whole season. Today fallowing is regarded as environmentally unsound.
- **Soils rich in organic matter** support high populations of predatory fungi and nematodes which feed on plant parasitic nematodes. Although effective, large quantities of compost are not practical for large areas.
- **Conservation tillage (CT)** is considered to promote large numbers of microbial competitors or antagonists of soilborne disease organisms.
- **Avoid overhead irrigation** which spreads foliar and other nematodes which attack the above ground parts of susceptible plants, if nematodes are present.
- **Toxic secretions** of some plants are reputed to diffuse into the surrounding soil and kill some species of nematodes (page 270).
- **Some crops, starting from transplants**, may be more tolerant of nematodes than direct-seeded crops.

SANITATION

- **Maintain good general hygiene**. Keep floors and benches clean of plant debris to prevent cross infection. Wash infested soil from boots, containers, tools and machinery to prevent spread of nematodes to clean areas.
- **Prune out and destroy plant parts** infested with foliar nematodes. Remove badly infected plants. Dig up, together with a spadeful of the surrounding soil, infested bulbs and other infected root parts. This is only suitable for small areas.
- **Burn or destroy** by some other means nematode-infested plant material. Do not placed on compost heaps or feed to stock.
- **Use wire mesh bench tops** to support containers, preventing nematodes swimming in drainage water from infested pots to uninfested pots.
- **Do not use** recycled potting media unless it has been adequately treated.

BIOLOGICAL CONTROL

- **A bacterium, BioNem®** (*Bacillus firmus*), a naturally occurring soil bacterium, is used overseas as a seed treatment to reduce nematode populations and root infestations in soil while stimulating increased yield in vegetables, stone fruit, herbs and flowers. Another bacterium, *Pasteuria* (*Bacillus) penetrans*) parasitizes some species of **root knot nematodes**.
- **A fungus**, *Paecilomyces lilacinus* is being researched in Australia for biocontrol of root knot and cyst nematodes (Holland and Williams 1998). *P. lilacinus* is primarily an egg parasite, hyphae grow on the egg surface prior to invading it. Other fungi being researched include *Dactylella oviparasitica* (an egg parasite) and some mycorrhizal fungi, eg *Gugaspora*, *Glomus*.
- **Trap plants** are sometimes considered to be a form of biological control. Root knot nematodes enter roots of the French marigold (*Tagetes patula*), but cannot complete their life cycle (page 270). A thick cover of marigolds is needed, the marigolds are turned in at end of the season.
- **Bacterial and fungal endophytes** for the biological control of plant parasitic nematodes, eg root knot (*Meloidogyne incognita*), are being researched for tomato, potato and turf. Endophytic fungi may suppress plant parasitic nematiodes.

> **Suppressive soils** are soils in which certain diseases are suppressed because of the presence in the soil of micro-organisms antagonistic to the pathogen.

- **Suppressive soils.** There is a range of natural enemies, eg predatory nematodes, nematode-trapping fungi, parasitic bacteria and fungi, in the soil which assist in controlling plant parasitic nematodes. These organisms could be genetically engineered or enhanced and agronomic practices adopted to improve the physical, chemical and biological properties of soil. This would improve the suppressive nature of the soil and the capacity of plants to withstand nematode attack.
- **Bio-stimulants** (derived from plant extracts and fatty acids) reduce the feeding vigour of plant parasitic nematodes, stimulate certain predatory nematode species and improve a plant's ability to tolerate many pathogens and environmental stresses.
  - **DiTera®** (a natural product from the hyphomycete fungus *Myrothecium* spp., composed primarily of proteins, sugars, and lipids) effectively kills plant parasitic nematodes in the soil by contact.
  - **Furfural** (an industrial chemical derived from a variety of agricultural by-products, eg sugarcane bagasse, corn cobs, oat and wheat bran, sawdust).
  - **Agri-Terra®** (colloidal suspension of potassium mono-phosphate, polysaccharides and surfactants) smothers some species of nematodes and disorientates others, causing them to loose the ability to parasitize plant roots and reproduce.
  - **Sincocin, Agrispon** contain extracts from plants (sesame, wintergreen, citrus oils, neem, Brassica meal and mustard bran).

CONTROL METHODS *(contd)*

For many plants, resistant to root knot nematodes are yet to be found or only partial resistance is available, eg no turfgrass is known to be resistant to the feeding of all nematodes

RESISTANT, TOLERANT VARIETIES AND ROOTSTOCKS

When varieties with desired horticultural qualities of resistance or tolerance and suited to local conditions, are available, their cultivation is the most effective and convenient way of reducing losses from nematodes, especially when used with effective rotation crops.

- **Some newer varieties** are not only resistant to nematodes, but may be resistant to other diseases or pests and be available as disease-tested planting material. The search is on now for varieties of bananas and other crops with resistance to several nematode species **and** soil diseases.
- **Cereal cyst nematodes** (*Heterodera* spp.) and **root lesion nematodes** (*Pratylenchus* spp.) cause significant losses around the world. Screening programs can assess resistance to each of these species.
- **Sugarcane** is subject to more serious nematode infestations than any other crop in Australia, at least 8 genera are reasonably common in most sugar growing countries so crop rotation, minimum tillage residue retention, etc.
- **Crops can be genetically engineered** to be either resistant or at least have some tolerance to a particular species of nematode. Transgenic grapevines and root stocks with resistance to several nematode species could be developed.
- **Synthetic plant resistance** is a new approach to control of plant parasitic nematodes. Plant activators can stimulate the plant's resistance mechanisms.
- **Nematode-resistant rootstocks**.
  – **Some tomato** varieties show some resistance to certain nematodes (and other soil diseases). Their inclusion in a crop rotation can be as useful as growing a **non-host**.
  – **Grapevine** 'Harmony' has some resistance to the dagger nematode and the grape phylloxera (a gall aphid).
  – **Peaches, nectarine, plums and apricots** are generally propagated on peach seedling rootstocks. Seed is usually obtained from cannery seed. Only the seed from a true-to-type Nemaguard® parent tree can be guaranteed to have resistance to root knot nematode, **not** seed from a Nemaguard® seedling.

Exotic nematodes have probably been in Australia for many years before being detected and identified, eg potato cyst nematode

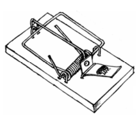
PLANT QUARANTINE

- **Australian Quarantine and Inspection Service (AQIS).** Many plant parasitic nematodes have not as yet reached Australia, eg soya bean nematode, or if they have, their distribution is restricted, eg potato cyst nematode.
  For target lists of insects, plant and animal pests and diseases and weeds, visit:
  www.daff.gov.au/aqis/quarantine/naqs/**target-lists**
  PaDIL (Pests and Diseases Image Library) www.**padil**.gov.au/
- **Interstate and Regional Plant Quarantine.** Health certificates are required for rye seed and hay produced in **SA** and moving into **NSW** and Victoria to limit risk of spreading annual rye grass toxicity **(ARGT)** (page 253). Potato cyst nematode in WA has restricted the movement of potatoes to other States/Territories.
- **'Local' quarantine.** Nematodes can be introduced to nurseries, orchards via:
  – **Infested plant material** (plants, bulbs, seedlings, tubers, nursery stock). Suspect plants should be kept isolated until non-infection is confirmed.
  – **Soil** (in containers, pots, soil deliveries). The roots of all purchases should be inspected and plants kept separate until proven healthy.

To minimize grapevine losses due to nematodes, current management practices include hot water treatment of grapevine planting material, nematode-resistant rootstocks and nematicides

DISEASE-TESTED PLANTING MATERIAL

- **Only** use nematode-tested planting material and only take propagation material from healthy plants and only plant in nematode-free soil (treatment may be required).
- **Infested vegetative planting material** (runners, bulbs, rooted nursery stock, tubers, seedlings) can be effectively treated. Treatments include:
  – Hot water treatments (bulbs, strawberry runners, rose/grapevine nursery stock).
  – Chemical dips (banana corms).
- **Inspect/test all new purchases** (cuttings, seedlings, tubers etc) if appropriate, for nematode infestation, as their introduction by this means often results in rapid spread. Remember they may have been shipped before symptoms were visible.
- **Grow one's own seedlings** and other propagating material as far as possible, and plant in soil or media free from nematodes or in soil which has been pasteurized, fumigated or treated with a nematicide.



PHYSICAL AND MECHANICAL METHODS

Heat is the only physical method used to control nematodes. Usually limited to high value crops and/or small areas.

- **Hot water treatment (HWT)** is used to treat daffodil bulbs, strawberry runners and rose nursery stock; also grape cuttings to rid them of phylloxera, nematodes, root rotting fungi and bacteria. Seek expert advice on treatment.
- **Soil pasteurization.** Heating soil to 60°C for half an hour will rid soil of parasitic nematodes and fungal diseases. Only suitable for small quantities of soil such as in glasshouses and cutting beds.
- **Soil solarization**. Clear plastic stretched over moistened soil, traps solar energy to heat the soil and suppress soil fungi and nematodes. The soil to the depth of 15cm must be consistently heated for at least 3-4 weeks in the hottest conditions (may reach 52°C in the top 5 cm) and for several months in the cooler months.

CONTROL METHODS *(contd)*

Nematicides should only be applied when a nematode infestation has been **confirmed**

NEMATICIDES.

Nematicides are used almost exclusively on high value crops, eg nurseries, flowers, vegetables, strawberries and turf. The number of nematicides available continue to decline due to their toxicity, costs and environmental issues. Some are being phased out, eg the fumigant methyl bromide. Substitutes for methyl bromide are not equally effective against all nematodes so that there is a need for **continual monitoring** to ensure that their use is limited to situations where a need has been demonstrated and the lowest rates required for normal plant growth and yield used rather than applications on a routine or calendar basis. Nematicide applications can be scheduled to get optimum control.

Toxicity.

- Chemicals used to control nematodes are highly toxic, often they were developed as insecticides but nematicidal dosages are much higher than insecticidal ones. They are **hazardous**, their signal heading being either:

  DANGEROUS POISON or **POISON**
- Many products **require permits** for use and can only be supplied to and applied by appropriately trained operators or those working under their direct supervision.
- Most are **persistent** and some have a **long withholding period.**
- Some can be used as **pre-plant applications only** on some crops.
- Some may require **special application equipment**.
- Care must be taken to **avoid environmental problems** to fish and wild life, bees and birds, stock. Organophosphates and carbamates are toxic to birds grazing on treated areas. Many nematicides can contaminate ground water.
- Residual nematicides applications may damage later crops.
- There are no nematicides registered for control of foliar nematodes.
- Nematicides are used for **soil treatments**.
- Nematicides tend to be **nematostatic** rather than **nematicidal**. Nematode activity **resumes** when the concentration of chemical declines below a critical level. Control with is generally maintained for only a relatively short period.

NON-FUMIGANT NEMATICIDES

NON- SYSTEMIC - FOLIAGE

None currently registered

SYSTEMIC – FOLIAGE, eg

Nemacur®, various (fenamiphos)

NON- SYSTEMIC - SOIL, eg

Rugby® (cadusafos)
Vydate® (oxamyl)

SYSTEMIC - SOIL, eg

Nemacur®, various (fenamiphos)
Temik® (aldicarb)

CONTROL METHODS *(contd)*

This is a guide only, it is **not** a substitute for reading all of the label and the MSDS and obtaining up-to-date advice

NEMATICIDES ***(contd)***

- **Nemacur®-accelerated biodegradation (NAB)**. Nemacur® (fenamiphos) and other pesticides degrade in the environment at varying rates due to various processes, eg
  – **The environment**, eg light, temperature, moisture.
  – **Microorganisms** in soil, eg fungi, bacteria, obtain their food from Nemacur®.
  – **Addition of more Nemacur®** allows the microorganisms to proliferate, but at the same time the effective life of Nemacur® may be shortened considerably.
  – **Repeated applications** of Nemacur® makes the problem **worse**.
  – **A free soil testing service** established by Bayer ensures that the Nemacur® non-use period is sufficient to reduce numbers of biodegradation microorganisms.
  – **To maximize life of Nemacur®** use the right rate (underdosing will lead to shorter term control and overdosing may lead to more pronounced biodegradation) and rotate or alternate nematicides.
- **Nematicides** are generally divided into **Non-fumigants** (Table 51) and **Fumigants** (Table 52).

• **Mark nematicides you use at work**, including surfactants. • This is a summary guide only, and not a substitute for reading a currently registered label, MSDS and obtaining up-to-date advice • Insecticides are classified by **Croplife Australia** into mode of action groups.	Contact **Croplife Australia** for updates of the classifications and further information www.**croplife**.org.au Check **current registration** status www.**apvma**.gov.au/ **Infopest** can be purchased www.dpi.**qld**.gov.au/

Table 51. Non-fumigant Insecticides/Nematicides (2009) *examples only*

- **Non-fumigant pre- and post-plant contact soil nematicides** move through the soil as liquids in soil solutions and act as contact poisons. They may be applied as liquids or granules to:
  – The soil in bands, in planting furrows or broadcast.
  – Established commercial turf and other plants as a drench.
  – Seed and bare plant roots as a dip.
  – Usually applied at planting time or when nematode populations are increasing early in the season.
- **Non-fumigant nematicides are not for home garden use**.

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	Mode of action	CROPS, SITES TREATED	DISEASES, PESTS, WEEDS CONTROLLED/SUPPRESSED
1 Acetylcholinesterase inhibitors **INSECTICIDES**	**1A** Carbamates	**FURADAN** carbofuran DANGEROUS POISON	Systemic Contact action Stomach action	Rice, sugarcane, tobacco, wheat, barley	**Nematicide** cereal cyst, other nematodes **Insecticide** leaf hoppers, white rice stem borers, *Helicoverpa*
		ELECTRA, NUDRIN, LANNATE, VARIOUS methomyl DANGEROUS POISON	Systemic Contact action Stomach action ovicide, larvicide	Non-crop, sheds, certain field crops, pasture, cotton, fruit, vegetables	**Nematicide** slight activity only not on labels **Insecticide** wide range of insects
		TEMIK aldicarb DANGEROUS POISON	Systemic absorbed by root system, upwards movement only in the plant	Citrus fruit, cotton, sugarcane	**Nematicide** burrowing, citrus, root knot, root lesion and spiral nematodes **Insecticide** aphids, scale, mealybugs, citrus leafminer, mites, thrips, mirids, wireworm
		VYDATE oxamyl DANGEROUS POISON	Systemic Contact action moves up and down in plant	Bananas, capsicum, tomatoes	**Nematicide** burrowing, root knot and spiral nematodes **Insecticide** banana weevil borer larvae
	1B Organo Phosphates	**RUGBY** cadusafos DANGEROUS POISON	Systemic Contact action	Banana, ginger, sugarcane, tobacco, tomato	**Soil nematicide** burrowing, root knot, root lesion, spiral and stubby root nematodes **Soil insecticide** banana weevil borer, canegrubs
		COUNTER, HUNTER terbufos DANGEROUS POISON	Contact action Stomach action Systemic	Banana, wheat, barley, maize, peanut, sorghum, sunflower, sweetcorn	**Soil nematicide** burrowing, cereal cyst nematodes **Soil insecticide** banana weevil borer, white grubs, whitefringed weevil, wireworms
		FENAMIPHOS, NEMACUR, VARIOUS fenamiphos DANGEROUS POISON and POISON	Systemic Contact action often only pre-plant application	Certain fruit, field crops, vegetables, ornamentals, mushrooms, turf	**Soil nematicide** soil-borne plant parasitic nematodes, foliar nematode **Insecticide** soil insects, eg African black beetle larvae, sucking insects

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 52. Fumigant Insecticides/Nematicides (2009) *examples only*

- All chemical fumigants are **extremely hazardous**, and must **only be supplied to and used by licensed persons**.
- **Most fumigants are used to control insect pests of stored grain, etc.**
- **Fumigants are also used** in many other situations, including for quarantine requirements.
- **Soil fumigation** is mostly used to control **soil-borne diseases** and **nematodes** that buildup in soil where susceptible crops are grown continuously. Soil fumigants are applied **before** planting.
  - **Soil temperature** at time of application is important.
  - Fumigants may be applied as a liquid, granule, wettable powder or gas, but move through soil as a gas.
  - Most fumigants must be **'sealed in'** for a certain length of time for them to be effective (**fumigation time**).
  - Generally an **aeration period** is necessary between **application** and **planting** to allow the fumigant to **escape from soil** before planting. It may take 10-40 days for gases to disappear from soil.

MAIN MODE OF ACTION GROUP and Primary Site of Action	CHEMICAL SUBGROUP or Exemplifying Active constituent	THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name Active constituent	Mode of action	CROPS, PLANTS, SITES TREATED	DISEASES, PESTS, WEEDS CONTROLLED/SUPPRESSED
8 Miscellaneous non-specific (multi-site) inhibitors **INSECTICIDE**	**8A** **Alkyl halides** **BEING PHASED OUT** Produces ozone-depleting gases	**AGRIGAS, METHYL BROMIDE** methyl bromide often formulated with chloropicrin **DANGEROUS POISON**	**Fumigant**	Non-crop, buildings, equipment compost, turf, manure, cane products, straw, timber, plant beds, certain plant products dried fruit, stored grain	**Pre-plant soil fumigant** bacteria, nematodes, insects, weed seeds, fungi (***not*** *Verticillium*), rodents **Commodity fumigant** insects, mites, mills, ships, warehouses **Plant quarantine** various, postharvest, buildings, permits
	8B **Chloropicrin**	**CHLOROFUME SOIL FUMIGANT** chloropicrin (tear gas) often formulated with methyl bromide or 1,3-dichloropropene, below **DANGEROUS POISON**	**Fumigant** also used as a **warning agent** with other fumigants **Pre-plant**	Non-crop, tobacco, crop land, pasture, soil treatments, soil heaps, rabbit burrows	**Pre-plant soil fumigant** certain soil insect pests, nematodes, fungal and bacterial diseases, weed seeds. **Rabbits**
24 Mitochondrial complex IV electron transport inhibitors **INSECTICIDE**	**24A** **Phosphine-**	**VARIOUS** aluminium phosphide **DANGEROUS POISON**	**Fumigant**	Non-crop, buildings, seed, stored grain	**Commodity fumigant** storage pests, rabbits
		VARIOUS magnesium phosphide **DANGEROUS POISON**	**Fumigant**	Non-crop, stored grain, food commodities, stock feed	**Commodity fumigant** storage pests
Other fumigants		**BASAMID GRANULAR SOIL FUMIGANT** dazomet **POISON**	**Fumigant**	Seedbeds, broadacre, bulk soil treatments	**Pre-plant soil fumigant** nematodes, soil-borne insects, soil fungi and germinating weed seeds
		METHAM SOIL FUMIGANT metham-sodium **DANGEROUS POISON or POISON**	**Fumigant**	Certain seedbeds, potting mixes, ornamentals, field and fibre crops, lawns, tobacco, Brassicas,	**Pre-plant soil fumigant** certain soil-borne pests, symphalids, nematodes, fungi, germinating weed seeds
		MILSPOT FUMIGANT ethylene dichloride + trichloroethylene **POISON**	**Fumigant**	Flour mill machinery, food processing plants	**Commodity fumigant** flour beetles, moths, weevils
		TELONE 1,3-dichloropropene, may be formulated with chloropicrin **DANGEROUS POISON**	**Fumigant**	Certain vegetable, field, fruit and nut crops, ginger, nursery crops	**Pre-plant soil fumigant** plant parasitic nematodes
		ENVIROFUME SOIL FUMIGANT potassium monomethyl dithiocarbamate **POISON**	**Fumigant**	Certain ornamental, food and fibre crops, tobacco	**Pre-plant soil fumigant** soil-borne pests and certain weeds, nematodes, symphalids and fungal diseases.
	Bio-fumigant	**FUMAFERT** **glucosinolates** (mustard seed meal, *Brassica juncea*) **+** **neem kernels** (azadirachtin from *Azadirachia indica*) (page 60)	**Biofumigant** glucosinolates decompose releasing volatile gases toxic to many organisms. Indian mustard as a rotation crop has a similar effect	Intensive agriculture, turf, nursery and covered crops, long-lasting	**Suppresses soilborne insects, diseases, nematodes** does ***not*** control weeds **Slow release fertiliser** nitrogen, phosphorus, potassium and trace minerals

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

EXAMPLE OF A NEMATODE DISEASE

Root knot

Root gall, eelworm

Scientific name

Soil-inhabiting nematodes (*Meloidogyne* spp.). Root knot occurs widely in Australia especially in warmer climates causing serious damage to many plants. It is the **world's most damaging nematode genus** and can be serious in glasshouses and is common even in virgin land.

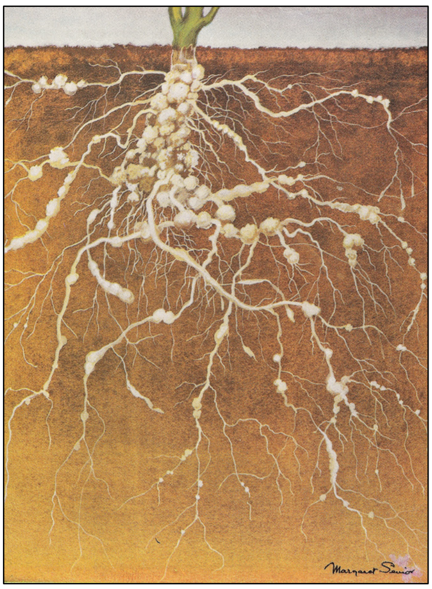
Host range

More than 2000 species of plants, including: **Vegetables,** eg bean, carrot, parsnip, potato, tomato (major nematode pest of vegetable crops). **Ornamentals**, eg cut flowers, carnation, roses, chrysanthemum, dahlia, gerbera, nursery stock. **Fruit**, eg Chinese gooseberries, papaw, stone fruits, grapevines. **Field crops**, eg clover, lucerne, lupin, peanut. **Weeds**, eg many species, eg fat hen. Different strains have different host ranges.

Symptoms

Above ground symptoms. Affected plants often grow slowly, are stunted, paler green or more yellow than normal and wilt readily during hot weather. Plants may die prematurely, reducing yield. Symptoms are similar to those of nutrient deficiencies. Affected roots are unable to supply the aboveground parts of the plant with sufficient water and nutrients. Confirmation of root knot is only possible by removing the plant and examining the roots.

Below ground. Nematodes about **0.5 mm** long, enter roots stimulating the surrounding tissue to enlarge and produce swellings or galls on the roots. These galls vary in size from small to large knots up to **25 mm** in diameter. Galls caused by *Meloidogyne hapla* are much smaller than those caused by other species. In plants with fleshy underground parts such as potatoes, galls look like pimple-like outgrowths, the surface of the tuber may become warty, roughened and discoloured. If one of the outgrowths is cut across, nematodes may be seen as small glistening bodies embedded in the tissue of the tuber.



General. In severe infestations, seedlings and older plants may be killed.

- Affected roots commonly become infected by a range of secondary bacteria and fungi which enter through the roots, eg *Fusarium* wilt, *Pythium, Rhizoctinia*, hastening root breakdown.
- Infection of older crops may or may not reduce yield significantly. Affected plants are not usually killed.
- There is an association between carrot defects and nematodes. The proportions of forked, galled, constricted and split carrots and the weight of unmarketable carrots were correlated with population densities of *Meloidogyne. javanica* in the soil.

Diagnostics

- **Do not confuse root knot:**
  - In leguminous plants, eg peas, beans, clover and lucerne, with galls caused by beneficial nitrogen-fixing bacteria. Root galls caused by nematodes are **not** easily detachable, galls resulting from nitrogen-fixing bacteria are.
  - In Brassicas, with galls caused by club root which are spindle-shaped, larger and less evenly distributed on the lateral feeding roots.
  - In pome fruit, with galls caused by woolly aphid.
  - Generally, galls caused by crown gall (a bacterial disease) are larger and may be up to the size of a large football.
  - Misshapen roots in carrots may also be caused by soil structure, number of passes with a rotary hoe, and other root diseases.
- **Aids to diagnosis**
  - Some can be seen with a hand lens or dissecting microscope (x10 magnification). Specialized knowledge is needed to tell one type of nematode from another. Many nematodes are beneficial.
  - You can detect root knot nematode infestation of soil by growing a susceptible host, eg certain tomato varieties, for several weeks and then washing the soil from roots and examining them for evidence of galling. Cut up galls in water and worm-like nematodes should be easy to see with a dissecting microscope. Mature forms of root knot are shaped like a sac.
  - Confirm diagnosis as above, identification to genus requires professional expertise.

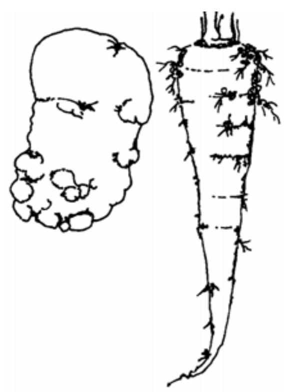


Fig. 136. Root knot (*Meloidogyne* spp.) galls on:
Left: Tomato roots. ***Right:*** Potatoes and carrots.
Photo© NSW Dept of Industry and Investment.

Disease cycle

Root knot nematode is a sedentary and endoparasitic nematode (Fig. 137 below). Most nematodes are found in the root zone from 5-25cm below the soil surface. Only 2nd stage juveniles can infect a susceptible host. Life cycle in 25 days at 27°C, longer at higher or lower temperatures.

'Overwintering'

- Egg masses in soil, infected root debris, etc.
- Dormant infections in roots of perennial hosts.

Spread

- By infested flood or drainage **water**, infested **soil** (on tools, machinery, containers, footwear, soil deliveries), manures. Potting media.
- Nematodes are often **introduced into soil** by planting seedlings, cuttings, tubers or young plants already infected with root knot.
- Purchased plants.
- By **movement of nematodes** through soil, under optimum conditions this may not be more than a few centimetres each season.
- Infested **crop and weed debris**.

Conditions favouring

- Warm moist conditions, but **strains** occurs which **prefer cool** moist weather.
- **Sandy soils** (contain air spaces for respiration).
- Infested annuals may survive and produce flowers if they never suffer from moisture stress.
- Root knot can be a serious greenhouse pest.
- Crops grown in **soil**. Should not be a problem where soil-less media is used.
- Continuous cropping with susceptible hosts.
- Infested soil **not** treated in some way prior to planting.
- Depends on the stage of development of the crop or its place in a cropping sequence. A well grown crop can withstand a significant root infection with nematodes, but a following similar crop in the same ground will certainly develop a damaging nematode infection while young and will not produce a good crop.
- Dormant stages or nematodes are stimulated into growth when roots of a susceptible host plant are close by.

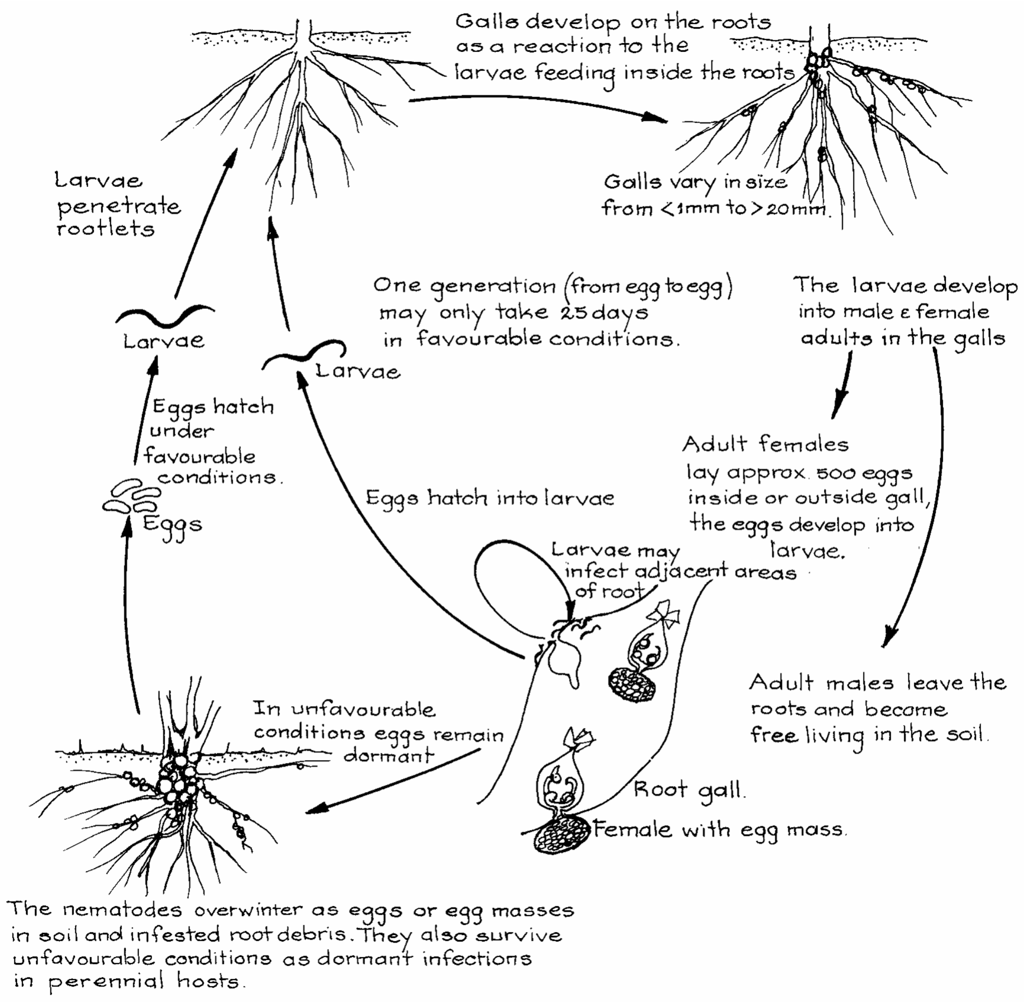


Fig. 137. Disease cycle of root knot (*Meloidogyne* spp.). Males are 1.0-1.5mm long and threadlike, females are pear-shaped and about 0.4-1.3mm long (adapted from Agrios, 1997).

Management (IDM)

For commercial growers **IDM** is essential.

1. **Planning** is **essential** and may start 12 months before planting, eg after previous final harvest plough-out affected crops to expose roots to wind and sun. In greenhouses root knot should not be a problem where routine hygiene and soil-less media are used. Plan the new crop to include appropriate non-chemical methods:
   - Carry out a pre-plant nematode analysis.
   - Use resistant varieties and cover crops as part of your **IDM** program if available
   - Treat affected areas with a recommended nematicide **before** planting **only** if monitoring indicates that it can be justified.
   - Fumigation by appropriately **trained and licensed operators** may be appropriate for seedbeds.
   - Utilize soil conditions suppressive to nematodes, eg minimum tillage, crop rotation, green manuring organic amendments and mulches to enhance biological activity of organisms against nematodes.
2. **Crop, region.** Obtain information from local departments of agriculture on root knot on your crop in your region. Recognize variations.
3. **Identification** must be confirmed. **Galls** caused by root knot nematodes are easy to identify (page 268). **Species** identification is difficult and is only important when resistant varieties and crop rotation are being used as control methods. Check to see if a test for growers has been developed. If not consult a diagnostic service (page xiv).
4. **Monitoring** strategies include:
   - **Pre-plant nematode soil analysis, including nematode counts** of the top 15cm of soil is necessary where root knot has been a problem.
   - Monitoring when **growth is generally unthrifty**, examine washed roots under the microscope for evidence of galls. Record results of monitoring.
   - Checking if **conditions** favour root knot.
   - Assessing **end-of-season galling** in the field to indicate infestation liability for the following crop.
   - Remember **know when, where, what and how to monitor**.
5. **Specific thresholds** are available for some crops, especially tomatoes. For other crops, how much damage can you accept?
6. **Action.** Interpret monitoring. Only apply nematicides if **monitoring** has shown that numbers would cause economic damage unless it was applied.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required.

Control methods

> Once the presence of root knot nematodes in the field is confirmed, it is **almost impossible** to eradicate them. Chemical control is not practical for home gardeners or persons with few resources, **non-chemical** control methods including sanitation are their **preferred options**.

Cultural methods.

- **Cultural care.** Affects of root knot can be offset to some degree by protecting plants from stress. Regular water and fertilizer, the use of mulch and the control of other diseases and pests tend to reduce damage caused by nematodes.
- **Summer fallow.** Keep all vegetation, including weeds, off the infested area for **one growing season**. This is a cheap and effective means of reducing numbers. Cultivate soil after each period of rain to prevent weed growth. Fallowing does not stop nematode eggs from hatching but without food plants, the young nematodes die. Fallowing may lead to wind and rain erosion.
- **Apply organic amendments** and adequate fertilizer to minimize losses.
- **Crop rotation**. Where root knot nematodes are a problem, avoid planting susceptible crops continuously in the same area. **Rotate crops** with resistant, immune or non-host crops such as some grasses, cereal, cabbage, cauliflower, maize, sorghum and sweetcorn and onions which may have some resistance to some root knot species. Rotation crops must have a **high level of resistance** otherwise sufficient nematodes may carry over to damage the next susceptible crop. Crop rotation is useful in management but the difficulty is in determination of host range.
  – **Nemfix** is a cultivar of mustard selected for its glucosilinates (which interfere with the breeding cycle of nematodes) and its potential as a bio-fumigant. **Nemfix** can be a useful green manure crop used in rotation with Coolabah or Swan oats if root knot suppression is desired.
  – **Some growers** use rotation in combination with a weed-free fallow to reduce nematode numbers.
  – **Cover crops** such as sorghum have proven effective in some vegetable growing regions due to its resistance to the common nematode species of root knot nematode.
- **Repellent plants.** Asparagus roots secrete an exudate which is toxic to root knot nematodes.
- **Trap plants.** French marigold (*Tagetes patula*) cultivars, produce exudates that stimulate hatching of nematode eggs. The larvae then enter marigold roots but die shortly afterwards before completing their life cycle. Plant marigolds in 15 cm wide rows about 15 cm apart and grow for about 90-120 days (a whole growing season) to sufficiently reduce the nematode population to grow annuals without further treatment. Often not practical.
- **Providing peat and other components** of potting mixes are obtained from sources **free** of root knot and are not contaminated prior to use, treatment before use is unnecessary.

Sanitation.

- Burn all diseased plants. Do not throw infected crop refuse onto compost heaps or manure heaps. Do not feed infected potatoes, carrots and other plant material to stock unless it has been boiled first to kill the nematodes as they can pass through the digestive tract of animals unharmed.
- Stand pots and other containers on wire mesh rather than solid benches to prevent nematodes swimming from pot to pot in drainage water.
- Wash and disinfect equipment prior to using. Boots and other footwear worn in contaminated areas should also be cleaned thoroughly after use.
- Immediately after final harvest plough-out affected crops to expose roots to wind and sun.
- Maintain high levels of hygiene at all times to prevent introduction of contaminated cuttings, personnel, potting media, water and roots.
- Control volunteer crop regrowth and weeds.

Biological control.

- Many bacteria, predatory fungi and nematodes, exert some control of root knot nematodes, and are being researched for commercial use (page 263.
- **Suppressive soils** prevent nematodes from establishing and from causing disease, and they diminish disease severity after initial nematode damage when hosts are continuously grown (page 263).

Resistant/tolerant cultivars, rootstocks.
Grasses are affected less often than broadleaved plants and show little obvious galling.

- **Avoid planting susceptible crops** in field contaminated with root knot nematodes.
- **For many plant species, resistant varieties** have been developed, eg
  – **Tomatoes**, the hybrids 'Red Supreme' and 'Rich Reward' are tolerant to root knot nematodes.
  – **Rootstocks** with resistance to root knot have been used in the grape and stone fruits industries.
  – **Many pasture legumes**, eg white clover are **very susceptible** to root knot nematode.
  – As new varieties of many crops are continually being marketed, eg strawberries, they need to be evaluated for their resistance to the various strains of root knot nematode. Some varieties may be more susceptible than others.
- **Plant activators** activate a plant's natural resistance mechanisms. **Certain amino acids** mixed into soil or sprayed onto plants may increase local and systemic-induced resistance to root knot.

Plant quarantine

- **Australian Quarantine and Inspection Service (AQIS).** Many **species** and **strains** of root knot nematodes occur overseas which do not as yet occur in Australia.
- **Interstate and Regional Plant Quarantine.** There are no restrictions on the movement of plants or plant material infested with root knot nematodes within Australia.
- **Local quarantine.** Inspect tubers, rooted seedlings and other plants if they are obtained from a nursery or some outside source. Destroy all plants in a batch if even of a few plants only are infected. Preferably grow your own seedlings and other propagating material. Nematodes may be introduced in soil or manure deliveries. Avoid spreading infested soil to clean areas or planting infested plants in clean areas.

Disease-tested planting material.

- If available, **use it**. If not it may be necessary to treat propagation material (next column).
- It is available for crops such as **potatoes**, seed tubers being guaranteed free from virus and other diseases, including root knot nematodes.
- Disease-tested planting material must be planted in **nematode-free soil/media**.
- If disease-tested planting material is **unavailable** only use propagation material preferably from aerial plant parts of plants or from tissue culture.
- **Strawberries** may become infected with one of the 4 common species of root knot, *M. hapla, M. incognita, M. japonica* and *M. arenaria*; the formation of galls on strawberry roots does not indicate *M. hapla* it may be a different species. Ensure runners you plant are **free from all these species** to prevent their introduction and spread.

Physical and mechanical methods.

- **Propagation material** like bulbs and corms can be treated with hot water, eg standard treatment for *Narcissus* stocks is **3 hours at 44.4°C**. Some tulip cultivars can be successfully treated but others are susceptible to damage.
- **Plants** such as young rose plants with infected roots can be freed, during dormancy, from infection by washing off soil and dipping roots in hot water for a prescribed period of time.
- **Soil** can be pasteurized with aerated steam at 60°C for 30 minutes to destroy plant parasitic organisms but not beneficial ones. Avoid re-infestation by planting nematode-free plant material only in nematode-free soil/media. Most potting mixes today do not contain soil.
- **Soil solarization.** Root knot can be controlled effectively in greenhouses with steam sterilizarion of the soil or soil fumigation with nematicides.

Nematicides.

- Few effective nematicides are available, Nemacur (fenamiphos) will soon not be available for use in turf in Australia (page 266).
- One treatment provides satisfactory control for one season only.
- Nematicides are persistent and have a **long with-holding period**. Residues of Nemacur® would be detected above permissible levels in certain vegetables during spot checks.
- Chemical may be applied through the irrigation system but with drip irrigation, especially on sandy soil only the drip zone will be treated. So nematodes beyond the drip zone will become active when soil is moist. The whole area must be thoroughly wet to a depth of 30-45cm. This is difficult for growers with only drip irrigation and with boom spraying it is difficult to put on the volumes required.

Table 53. Root knot nematodes – Some nematicides.

What to use?	When and how to apply?
NON-FUMIGANTS - PRE- AND POST-PLANT See page 266, Table 55 **Group 1A**, eg Temik® (aldicarb); Vydate® (oxamyl) **Group 1B**, eg Nemacur® (fenamiphos); Rugby® (cadufos) DANGEROUS POISON and POISON	• For use by **appropriately trained operators** only. • Mainly used on ornamentals • Ornamental, fruit, seed, tuber and vegetable treatments, • Only treat if monitoring indicates a need.
FUMIGANTS - PRE-PLANT See page 267, Table 56 DANGEROUS POISON and POISON	• For use only by **appropriately trained operators** prior to planting field areas. Could be used in greenhouses. • Fumigants which can be applied after planting are being researched. • Only treat if monitoring indicates a need.
OTHERS CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE	Many products are being researched overseas for controlling nematodes in certain situations (Agrios 2005), eg • Mixing essential plant oils from plant spices into nematode-infested soil before planting. • Abamectin, azadirachtin, methylene bisthiocyanate.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List the **distinguishing features** of plant parasitic nematodes.
2. Draw diagrammatically the **life cycle** of an nematode.
3. Name the **stages** which damage plants, how they **feed** on plants and the types of **symptoms** which may develop on **above** and **below** ground plant parts. Name 1 example of each type of symptom.
4. Recognize by sight, **symptoms** produced on plants by local nematode diseases.
5. **Distinguish between galls** caused by **root knot nematode** infestation from those caused by nitrogen-fixing bacteria and crown gall.
6. **Distinguish between foliage symptoms** caused by **root knot nematode** infestation from those caused by water stress, nutrient deficiencies and excesses and poor vigour.
7. Describe 4 places where plant parasitic nematodes might '**overwinter**'. Name 1 example of each.
8. Describe 4 ways by which plant parasitic nematodes **spread**. Name 1 example of each.
9. Describe **conditions favouring** soil-inhabiting nematodes and foliar nematodes which attack **above ground** plant parts.
10. Describe State/Territory/Commonwealth **legislation** which provides for the control of nematode diseases.
11. List **control methods** for nematode diseases. Describe 1 example of each.

Cultural	Plant quarantine
Sanitation	Nematode-tested
Biological	Physical and mechanical
Resistance/tolerance	Pesticides

12. Provide the active constituent, some trade names, mode of action and some uses, for one **non-fumigant** nematicide.
13. Describe how nematodes are used to **control insect pests of plants**. Name 1 example.
14. **Provide the following information for root knot nematode** or other local nematode pest:

Common name	'Overwintering'
Scientific name/Cause	Spread
Host range	Conditions favouring
Symptoms	**IDM** and Control
Disease cycle	

15. Prepare/access an **IDM** program for a nematode disease at your work or in your region.
16. Locate **reference material** and know where to obtain advice on the identification and control of nematode diseases.

SELECTED REFERENCES

Nematoda (Nematodes or Roundworms)
www.ento.csiro.au/science/**nematode**.html
Biological Crop Protection www.**biolcrop**.com.au/
Australasian Association of Nematologists (AAN)
http://**nematologists**.org.au/
The Australasian Plant Pathology Society (APPSnet)
www.**australasianplantpathologysociety**.org.au/
includes a special section on Soil Diseases
Many publications are available on nematode species present on particular crops, eg bananas, grain crops, sugar cane, pineapple, roses, vegetables.

Fact Sheets by State/Territory Depts of Primary Industries are available online, eg
Root Knot Nematode

Keys
CSIRO *Nematoda* and *Key to the Nematodes of Australia*
www.ento.csiro.au/science/**nematode**.html
Nemasys www.cbit.uq.edu.au/software/**nemasys**/
Lucid keys of DIRECT Relevance to Quarantine, Plant Health and Invasive Species. avail online

Plant quarantine
Commonwealth quarantine www.daff.gov.au/**aqis**
PaDIL - Pests and Diseases Image Library of diagnostic photographs and information www.**padil**.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. **www.daff.gov.au** and search for target lists
State websites have information of nematodes and quarantine restrictions in their states

Organic products, standards
AS 6000—2009. *Standards Australia Organic and Biodynamic Products*. Standards Australia.
Organic Federation of Australia www.**ofa**.org.au
for organic certifiers, products etc
Becker Underwood Australia www.**beckerunderwood**.com
Ecogrow www.**ecogrow**.com.au

Nematicides
Pubcris. APVMA. Canberra www.**apvma**.gov.au
Infopest, Qld www.dpi.qld.gov.**au/infopest**
Croplife Australia www.**cropelifeaustralia**.org.au/
Chemical Toxicity to Beneficials www.**goodbugs**.org.au/
MSDS www.**msds**.com.au/
Company websites provide labels and MSDSs

General
Agrios, G. N. 2005. *Plant Pathology*. 5th edn. Academic Press, NY. also 4th edn 1997.

Bedding, R., Akhurst, R. and Kaya, H. (eds), 1993. *Nematodes and the Biological Control of Insect Pests.* CSIRO Pub.
Bridge, J. and Starr, J. M. 2007. *Plant Nematodes of Agricultural Importance*. (colour). Manson Pub. UK.
Brown, J. F. and Ogle, H. J. 1997. *Plant Pathogens and Plant Diseases.* Rockvale Pubs., Armidale, NSW.
Carson, C. 2000. *Testing Your Own Rice Flower Planting Sites for Nematodes.* DPI Note. Qld DPI, Brisbane.
Goodwin, S., Steiner, M. Parker, R., Tesoriero, L., Connellan, G., Keskula, E., Cowper, B., Medhurst, A. and Rodriguez, C. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* NSW DPI.
Heinz, K. M., Driesche, R. G., Parella, M. P. 2004. *BioControl in Protected Culture*. 2nd edn. Ball Pub.
Hodda, M. (2000). *Nematodes of the Murray-Darling River System and Coastal Fresh Waters of South-eastern Australia.* CSIRO, Canberra. avail online.
Hodda, M. 2008 *International Spotlight on Tiny Worms*. CSIRO Media Release. 14 July 2008.
Hodda, M., Stewart, E., Fitzgibbon, F., Reid, I., Longstaff. B. C. and Packer, I. 1999. *Nematodes : Useful Indicators of Soil Conditions.* No.98/141,RIRDC.ACT.
Holland, R. J. and Williams, K. L. 1998. *Fixing Nematodes with Microbes.* Micro. Aust., May.
Jones, D. L. and Elliot, W. R. 1986. *Pests, Diseases and Ailments of Australian Plants.* Lothian Pub., Melbourne.
McMaugh, J. 1994. *What Garden Pest or Disease is That?* Lansdowne Press, Sydney.
Nobbs, J. M. 2004. *Plant Parasitic Nematodes of Australia* [electronic resource]. SARDI, 2004.
O'Brien, P. C. and Stirling, G. R. 1991. *Plant Nematology for Practical Agriculturalists.* 3rd edn. Qld DPI, Brisbane.
Shurtleff, M. C. and Averre III, C. W. 2000. *Diagnosing Plant Diseases Caused by Nematodes.* APS Press. MN.
Stirling, G. R. 2000. *Nematodes Monitoring Strategies for Vegetable Crops.* No.00/25. RIRDC, ACT.
Stirling, G. R., Harrower, K. and Webb, L. E. (eds). 2008. *Plant and Soil Nematolody in Australia and New Zealand.* Australasian Plant Pathology, 37,3.
van Someren Graver, J. E. 2004. *Guide to Fumigation Under Gas-proof Sheets*. ACIAR.
Walker, G. 2006. *Biocontrol Organisms and Human Health.* Aust. Nem Nos Vol.17. No.1. Jan 2006.
Grewal, P. S., Ehlers, R-U., Shapiro-Ilan, D. I. 2005. *Nematodes as Biological Control Agents*. CABI Pub.

Virus and Virus-like Diseases

Symptoms of hydrangea mosaic

BIOLOGY & IDENTIFICATION

Viruses, viroids, phytoplasmas

NO. DISEASES IN AUSTRALIA

Viruses are a significant and growing threat to crop production worldwide. There are many hundred virus and virus-like diseases of plants. Most plants are susceptible to viruses although trees and Australian native plants seem to have fewer recorded virus disease problems. This may be due to lack of research. New viruses and phytoplasmas are constantly being detected and identified.

The Australasian Plant Pathology Society (APPSnet)
www.**australasianplantpathologysociety**.org.au/
The American Phytopathology Society (APSnet) www.**apsnet**.org/

SOME DISTINCTIVE FEATURES

VIRUSES, VIROIDS, PHYTOPLASMAS

1. Can **only** multiply in **living cells**, however, a few phytoplasmas have been cultured on complex media.
2. Are **infectious** and can spread from one plant to another.
3. Can only be seen with the aid of an **electron microscope**. They are too small to be seen with a light microscope.
4. Vary in **structure and size.**

VIROIDS

1. About 10-50 times smaller than viruses (require a magnification of **x 100,000** or more to be seen).
2. Consist of free ribonucleic acid (**RNA**) with no protein coat.

VIRUSES

1. Require a magnification of **x 10,000** or more to be seen. Some are rigid rods about 15 by 300 nm; many appear as thin threads usually about 10-13 nm wide and range in length from 480 to 2,000 nm long; most spherical viruses range from 17-60 nm in diameter (Agrios 2005).
2. Consist of **RNA or** deoxyribonucleic acid (**DNA**) with a protein coat.

PHYTOPLASMAS

1. Are larger than viruses but smaller than bacteria (require a magnification of **x 5,000** or more to be seen).
2. Have a cell membrane, but no cell wall, cytoplasm and strands of nuclear material. They colonise plant phloem.
3. Phytoplasmas are a group of organisms that cause symptoms similar to viruses and may be spread by insects, but they are **structurally different** and are more closely related to bacteria. They have been included here because they are spread by insects and symptoms generally are more virus-like than bacterial-like.

One nanometer (nm)
= one billionth of a metre
= 0.000,000,001 metres
= 0.000,001 millimetre (mm)

Viroids (x 100,000)

Viruses (x 10,000) (various shapes)

Phytoplasmas and spiroplasmas (x 5,000)

'LIFE CYCLE'

They are obligate parasites because they can only multiply in living plants

Unlike fungi and bacteria, viruses cannot reproduce by themselves but can only multiply inside a living plant or animal.

- Once inside the plant cell, viruses multiply by inducing the host cells to make more virus (Agrios 2005).
- This interferes with photosynthesis and respiration in plant cells so the plant cannot grow properly resulting in stunting, reduced yield, etc.
- An analogy can be made between virus multiplication in a cell and the photocopying of a written page by a photocopier. The virus, like the written page, contains information, and just as the reproduction of the written page is done entirely by the photocopier so the multiplication of the virus is the work of the infected plant cell.

SYMPTOMS

Symptoms are not related to virus concentration in the host but depend on:
- Strain of virus
- Environment, climate
- Duration of infection
- Type, variety, age, physiology, stage of development of host
- Presence of other viruses and disease organisms

GENERAL SYMPTOMS

The interference in photosynthesis, respiration and other cell processes results in a range of symptoms including those described below. Often they cannot be easily observed or quantified. Sometimes a virus disease does not show symptoms in an infected host, eg tobacco mosaic virus infection in African violet and is called a **latent virus**; apple stem pitting virus, apple chlorotic leaf spot virus and apple stem grooving virus are common, economically important, and symptomless in commercial pear and apple cultivars. Other viruses only produce symptoms under certain conditions of light and temperature and are called **masked viruses**. Although virus may infect all parts of the plant, symptoms generally are most obvious in **young foliage**. Leaf symptoms can easily be confused with other plants problems (Table 54 below).

STUNTING May be **so slight** that it is often unnoticeable, especially in the initial stages, or **so severe** that the disease is **called 'stunt'**, affected plants being unproductive.

YIELD Yield may be slightly or severely **reduced.**

PLANT LIFE Life is usually **shortened**, probably only important for perennial plants. Seedlings can be killed.

SPECIFIC SYMPTOMS

Some symptoms are easier to see and identify than others, some are more subtle

Some viruses, eg **cucumber mosaic virus (CMV)** tend to produce the same type of symptoms on all plants they infect regardless of the host species

Others such as tomato **spotted wilt virus (TSWV)** may produce different symptoms on different hosts

LEAVES

COLOUR CHANGES, eg yellowing and reddening
- **Bronzing**, eg tomato spotted wilt virus
- **Line patterns**, eg plum line pattern virus
- **Mosaics**, eg poinsettia mosaic virus
- **Mottling**, eg camellia yellow mottle virus
- **Ringspots**, eg tomato spotted wilt virus
- **Streaks**, eg garlic yellow streak virus
- **Veinbanding**, eg strawberry veinbanding virus
- **Veinclearing**, eg malva veinclearing virus

MALFORMATIONS, eg potato leafroll virus (rolled leaves)
WILTING, eg tomato spotted wilt virus

FLOWERS

Breaking, eg tulip breaking virus (stripes, intensifies colour)
Greening, eg tomato big bud phytoplasma (greening)
Malformation, eg iris severe mosaic virus

FRUIT

Malformation, eg stony pit virus of pear
Ringspots, eg tomato spotted wilt virus
Russet. eg russet ring virus of apple

STEMS

Malformation, eg apple flat limb virus
Streaking, eg tomato spotted wilt virus

OTHERS

Death of plants (not common)

Ringspots on watermelon
Photo©CIT, Canberra (P.W.Unger).

Table 54. Comparison of virus diseases with other plant problems (typical generalizations).

LEAVES, DISTRIBUTION	VIRUS DISEASES	NUTRIENT & TOXICITY DEFICIENCIES	HERBICIDE INJURY	GENETIC ABNORMALITIES
Distribution of affected leaves on plant	Usually uneven, patchy, often only a few leaves show symptoms on the plant, often seen on new growth in spring	Usually either all over plant, only on young leaves, or only on older leaves	Often on new growth, may be on windward side of plant or crop	Usually all over plant, or on one branch or shoot (a "sport")
Distribution of symptoms on leaves	Usually **uneven** pattern on leaf	Usually even, **bilateral** symmetry, often specific pattern	May be **even**, a specific pattern	Often **even** over leaf, tendency to bilateral symmetry
Other features	Some plants are susceptible to specific viruses	Some plants are susceptible to specific deficiencies	Leaves may be distorted. History of chemical applications	Pattern on leaf or fruit usually straight-edged
Distribution of affected plants in the field	Symptoms on a few randomly scattered patches of plants which may gradually spread	Sudden appearance of symptoms on all plants in a crop, or evenly in an area within the crop	Sudden appearance of symptoms on all plants	Rare, 1-2 in a population of plants

HOW VIRUSES INFECT HOST PLANTS

THROUGH WOUNDS MADE

- **By vectors** which are the most common and economically serious method of spread. The most important vectors are insects.
- **Mechanically** by plants rubbing against each other during handling or pruning. This is not so common or important (exceptions).

DEPOSITION IN HOST PLANT MATERIAL

- Viruses may be deposited in plants via **pollen**.
- Scions may become infected when **grafted** onto infected rootstocks.

DISTRIBUTION WITHIN A PLANT

It may be assumed that for all practical purposes, even though symptoms only appear on parts of the plant, all living cells within the plant are infected

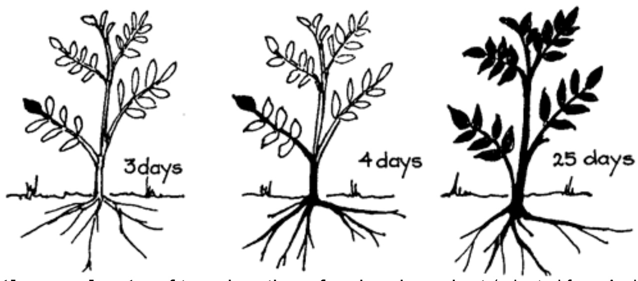
MOVEMENT THROUGH PLANTS

Viruses may move through plants in many ways including:

- **Direct cell-to-cell invasion**, eg in leaves viruses may move through 8-10 cells (about 1 mm) per day.
- **Transportation** through the phloem may occur rapidly, eg 15 cm in 6 minutes. Most viruses take 2-5 days to move from inoculated leaves.

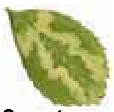
DISTRIBUTION WITHIN A PLANT

- Some viruses are fully systemic while others leave some tissues virus-free, eg the growing points.
- Infected plants usually remain infected for a lifetime (page 283). Plants propagated from such material are usually infected.



Direction and rate of translocation of a virus in a plant (adapted from Agrios 1997).

DETECTION AND IDENTIFICATION



Symptoms of rose mosaic

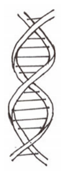
Virus particles

Diseased bud to healthy plant

New growth develops symptoms

Virus protein injected into rabbit

ELISA Testing



DNA tests

SYMPTOMS EXHIBITED BY THE HOST PLANT

- **Some viruses** cause distinctive symptoms in their hosts and so the disease and the virus can be identified from symptoms. However, frequently this is not possible.
- **Some virus symptoms can be confused** with nutrient deficiencies or excesses, herbicide or insect injury (page 275, Table 54).

DETECTION AND IDENTIFICATION BY EXPERTS

- Experts test for the presence of virus in plants, parent stock and certification schemes, eg strawberry, cut flowers, potato, pome and stone fruit, grape. Testing is difficult, slow and expensive.
- **Electron microscopy** identifies the shape of viruses particles (rods, bullets or spheres), in plant sap or ultra-thin plant segments. For some viruses, though, the shape of particles is not a reliable means of identification.
- **Indicator plants**. Some herbaceous plants, eg tobacco, petunia, readily show symptoms when infected with many different plant viruses. A virus can be transferred by budding, grafting, mechanically rubbing the plant with sap, or by a vector, from a **diseased host plant** which **does not** show obvious symptoms, to a **healthy indicator species**, which **does** show characteristic symptoms.
- **Serology.** Virus protein is injected into a mammal, eg a rabbit, resulting in antibodies in the blood system which react **specifically** with the virus antigen injected.
  - **ELISA** (enzyme-linked immunosorbent assay) is a serological test in which one antibody carries with it an enzyme that releases a **colored compound** if virus is present. **Kits** identify some viruses in some hosts, and are a quick, sensitive and specific method of testing large numbers of plant samples.
  - **More sensitive tests** are being developed for viruses that accumulate in low amounts in their natural hosts and escape detection, eg carnation.
- **DNA technology.**
  - **DNA** can be used to detect unknown viruses for which there is no antiserum or information available. Can also be used for detecting woody plant viruses.
  - **PCR** (polymerase chain reaction) multiplies over a million times, a short segment of **DNA**, so that can be seen as a gel.
- **A quick, simple, inexpensive generic test** is being developed for the whole nepovirus (nematode-transmitted) group of viruses. They are a group of about 46 viruses that infect many plant families that cause probably the most serious viral diseases of horticultural crops, particularly perennial woody and bulb crops. Many have not been recorded in Australia so quarantine tests are important.

VIRUS NAMES AND CLASSIFICATION

Symptoms of apple mosaic virus. Photo©CIT, Canberra (P.W.Unger).

A virus causing apple mosaic symptoms on apple is called apple mosaic virus and the disease is called apple mosaic

Plant viruses were originally named after the first host on which they were studied followed by the most obvious symptom caused by the virus on that particular host, eg apple mosaic virus. The disease was called apple mosaic.

Because many viruses were first studied on **fruit, vegetable and field crops**, many viruses affecting **ornamental plants** have names with fruit, vegetable and field crop connotations, eg turnip mosaic virus may infect stock. To further complicate matters the same virus may cause different symptoms:

- On the same host under different environmental conditions.
- On the same host if a different strain of the same virus is present.
- On a different host.
- Also on an individual plant, some 'mosaics' and other 'viral symptoms' may be caused by more than one virus.

Name of virus	Name of disease	Symptoms
Tomato big bud phytoplasma	Tomato big bud	**Tomato** – vertical shoots, hard green fruit, split stems **Petunia** – greening of flower parts
Apple mosaic virus	Apple mosaic	**Mosaics** are more pronounced in spring, new growth in summer on infected trees may only show mild symptoms or be symptom-free.

First host on which the virus was studied

Most obvious symptom caused by the virus on a particular host

The **International Committee on Taxonomy of Viruses** (ICTV) oversees the **naming and classification of viruses** which now shares many features with the classification system used for other biological organisms, eg kingdoms, orders, families, genera and species. Note, however, that some aspects of the naming and classification of viruses differ from that of other biological organisms, eg the genus (ending in virus) comes **after** the species.

All viruses belong to the Kingdom Viruses (Agrios 2005) within which they are divided:

- Into RNA viruses and DNA viruses then further divided on whether they contain **1 or 2 strands** of DNA or RNA and the **type** of DNA and RNA.
- Other characteristics used in virus classification include type of protein units, size, and many physical, chemical or biological properties, eg host range, method of transmission, etc.
- Virus genera (like plant and animal genera) share some significant properties, eg structure, and composition, symptoms, and method of spread.

Some virus genera

Genus names **end** in virus, eg

Potexviruses, eg
- Cymbidium mosaic potexvirus

Potyviruses, eg
- Potato potyvirus Y
- Sugancane mosaic potyvirus
- Turnip mosaic potyvirus
- Tulip breaking potyvirus

Tospiviruses, eg
- Tomato spotted wilt tospivirus

Ilarviruses, eg
- Apple mosic ilarvirus
- Rose mosaic ilarvirus
- Prunus necrotic ringspot ilarvirus

Virus & virus-like organisms		Larger organisms belonging to the plant or animal kingdom	
Common name of virus	**SCIENTIFIC NAME Genus & species**	**Common name**	**SCIENTIFIC NAME Genus & species**
Turnip mosaic virus	*Turnip mosaic potyvirus*	Humans	*Homo sapiens*
Tomato spotted wilt virus	*Tomato spotted wilt tospivirus*	Twospotted mite	*Tetranychus urtica*

species genus

genus species

Animals and plants are generally classified according to their DNA, structural characteristics etc into classes, orders, families, genera and species

Scientific names indicate the relationship of one plant or animal to other plants and animals

Symptoms of tomato spotted wilt virus. Photo©CIT, Canberra (P.W.Unger).

LIST OF SOME VIRUS & VIRUS-LIKE DISEASES	COMMON NAME OF VIRUS	HOST RANGE (not exhaustive)	METHOD OF SPREAD
	Apple mosaic virus	Rosaceae (apple, *Prunus*, rose), hop, horse chestnut	No insect vector, vegetative propagation, mechanical inoculation, contact between plants, probably by pollen to the pollinated plant
Host range. Some viruses only infect 1 species or group of closely related plants, eg **orchid fleck**	Barley yellow dwarf virus (BYDV)	Most grasses, especially wheat, barley, oats, also maize, rise	By many species of aphids, by grafting, not by mechanical inoculation, not by seed, not by pollen. Lost wheat production is estimated at > $8 million/year
Others attack a wide range of plants including weeds, eg **tomato spotted wilt virus**	Beet western yellows virus	Beet, lettuce, spinach, sunflower, etc, native *Cardamine* spp.	By many species of aphids, not by mechanical inoculation, not by contact between plants, not by seed, not by pollen
	Bean yellow mosaic virus (BYMV)	Ornamentals, eg gladiolus, sweet pea, violet; crops, eg legumes, bean; weeds.	By aphids, mechanically
	Camellia yellow mottle virus	Camellia	Vegetative propagation, grafting
	Cucumber mosaic virus (various strains)	Mainly Cucurbitaceae, Solanaceae, wide range of ornamentals, crops, weeds	By more than 60 species of aphids (non-persistent), vegetative propagation, mechanical inoculation (hands, tools), sometimes seedborne
	Cymbidium mosaic virus	Orchidaceae (most commercially grown orchids, eg cattelya, cymbidium)	No insect vector, vegetative propagation, mechanical inoculation, handling, tools, contact between plants
	Iris severe mosaic virus	Iris (overseas also crocus)	By several species of aphid (non-persistent), mechanical inoculation, not by plant contact
	Kennedya yellow mosaic virus	*Kennedya*, *Desmodium*, *Indigofera*	No insect vector, vegetative propagation, mechanical inoculation, not by plant contact, not by seed or pollen
	Prunus necrotic ringspot virus	*Prunus*, rose, hop Overseas, apple	No vector, vegetative propagation, mechanical inoculation, by grafting, contact between plants, by seed (variable), by pollen to seed, by pollen to pollinated plant
Ringspots on **cymbidium**. Photo©NSW Dept. of Industry and Investment (M.Senior).	Tobacco mosaic virus	Wide host range, vegetables (especially tomato), ornamentals, weeds	No insect vector, by vegetative propagation, by grafting, by mechanical inoculation (handling, tools, contact between plants, cigarettes), sometimes by seed
Not known in Australia	Plumpox virus, Sharka disease	*Prunus* spp.	By several species of aphids, by grafting, by other means (?)
	Tomato spotted wilt virus	Wide host range, vegetables, ornamentals, field crops, weeds	By several thrips species eg onion, tomato and Western flower thrips; persistent, mechanical inoculation, by grafting, vegetative propagation, not by seed or by pollen
	Tulip breaking virus (note that some varieties have variegated flowers)	Tulip, lilies	By various species of aphids, mechanical inoculation, grafting, not by contact between plants, not by seed, not by pollen
	Turnip mosaic virus	Mainly Brassicaceae, other families, vegetables, ornamentals, weeds	More than 40-50 species aphids especially cabbage and green peach aphid (non- persistent), mechanical inoculation, not by seed
Tulip breaking. Photo© CIT, Canberra (P.W.Unger).	Wheat streak mosaic virus	Wheat, and other cereals, grasses and grassy weeds	By the wheat curl mite (eriophyid), seed transmission is considered to be extremely low, others?
Emerging diseases	Tomato leaf curl viruses	Mainly Solanaceae, weeds, vegetables, ornamentals	By silverleaf white fly. Not by seed, soil or from plant to plant by handling
Phytoplasmas	*Candidatus* phytoplasma australiense has been associated with Australian grapevine yellows, papaya dieback, yellows, strawberry green petal, etc	Strawberry, papaya, grape-vine, *Citrus paradisi*, red clover, paddy melon, pumpkin, French bean, chickpea, *Cordyline australis*.	By leafhoppers, by vegetative propagation, grafting, other (?)
Greening, virescence	Tomato big bud phytoplasma (greening. viresence	Wide host range, weeds. ornamentals, vegetables	By the common brown leafhopper, vegetative propagation

LIST OF SOME VIRUS & VIRUS-LIKE DISEASES *(contd)*

COMMON NAME OF VIRUS	HOST RANGE (not exhaustive)	METHOD OF SPREAD COMMENTS
VIRUSES AFFECTING CHRYSANTHEMUM		
Many annual and herbaceous plants may become infected with one to several virus diseases in the same way that they might be attacked by several insect pests or fungal diseases. Viruses affecting chrysanthemum include:		
Chrysanthemum B virus	Chrysanthemum	Vegetative propagation, many species of aphids, not by contact or seed
Tomato aspermy virus	Chrysanthemum, tree tobacco	Vegetative propagation, by aphids, not by contact
Tomato spotted wilt virus	Wide host range, ornamentals, vegetables, weeds	Vegetative propagation, various species of thrips
Chrysanthemum chlorotic mottle viroid	Chrysanthemum	Vegetative propagation, vector (if there is one) is not known
Chrysanthemum stunt viroid	Chrysanthemum	Vegetative propagation, contact, (transfer of infected sap from infected plants contacting healthy plants), contaminated knives, staff moving from diseased plants to healthy plants.
BIOLOGICAL CONTROL AGENTS		
Gemstar® (nuclear polyhedrosis virus) (*Helicoverpa* **NPV**)	**Corn earworm** (*Helicoverpa armigera*), **native budworm** (*H. punctigera*) on various crops	
ViVusMax, VivusGold (nuclear polyhedrosis virus) **(NPV)**	**Corn earworm** (*Helicoverpa armigera*) on various crops	
EPVs (entomopoxyviruses)	Locusts, grasshoppers, cane beetles, caterpillars, cockchafers	
Cabbage white butterfly virus	Cabbage white butterfly	
Codling moth virus	Codling moth	
Lightbrown apple moth virus	Lightbrown apple moth	
Potato moth virus	Potato moth	
Bacteriophage (a virus which attacks bacteria)	Bacterial blight of geranium (*Xanthomonas campestris*)	
VIRUS DISEASES OF ANIMALS & HUMANS		
Foot and mouth disease virus	Mostly cloven-hoofed animals, eg cattle, water buffalo, sheep, goats, pigs, antelope, bison, deer rarely humans	
Many, eg HIV (human immunodeficiency virus), influenza, measles	Humans	

Over 16 virus and virus-like diseases can infect chrysanthemum worldwide, not all occur in Australia

Viroids

In practice, it is not always necessary to know the names of all the viruses which can infect a plant, but it is important to be able recognize virus symptoms, know how the viruses are spread and how losses may be minimized

A virus must be **registered** before it can be sold commercially in Australia

Viruses can be **genetically engineered** to increase the **speed** at which they kill infected insects

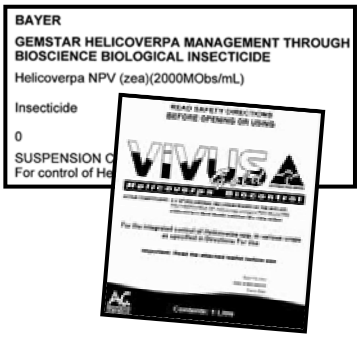


Fig. 138. ***Left:*** Grapevine fanleaf virus symptoms. ***Right:*** Camellia yellow mottle virus symptoms. Photo©CIT, Canberra (P.W.Unger).

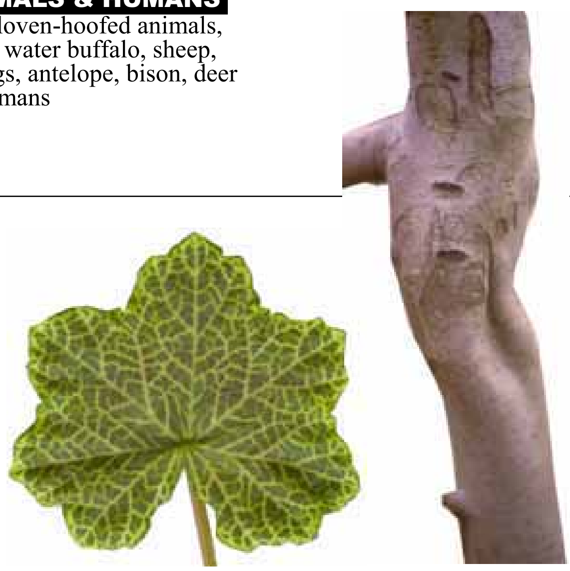


Fig. 139. ***Left:*** Yellow net vein virus symptoms on geranium. ***Right:*** Flat limb virus symptoms on apple (both unconfirmed). Photo©CIT, Canberra (P.W.Unger).

DISEASE CYCLE

HOST ONLY

- **Host plant.** Because viruses can only multiply in living tissue, the host plant is of primary importance in the disease cycle.
- **Weed hosts.** Many viruses can persist in cultivated or weed hosts.
- **Vegetative propagation material.** All vegetative propagules such as cuttings, bulbs, stolons taken from infected plants will carry the virus.
- **Seed.** Many of the known plant viruses may infect the seed of infected plants. Sometimes a virus may be seedborne only on particular hosts.


Host plant


Vegetative propagation material


Seeds

HOST AND HOST DEBRIS

A few viruses, although unable to multiply on host plant debris, can survive for varying periods of time in it, eg tobacco mosaic virus in tobacco leaves.


Host plant

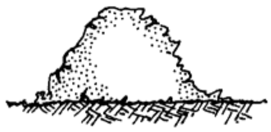

Host debris

HOST, HOST DEBRIS AND SOIL

It is unusual for a virus disease to be soilborne, but some are known to be transmitted by soilborne organisms, eg nematodes and fungi.


Host plant


Host debris


Soil

HOST AND VECTOR.

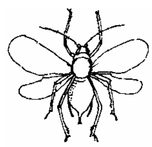
For viruses transmitted by a vector, part of the cycle may take place in the vector. In insects, which are the most common and economically important vectors of virus diseases, viruses may be:

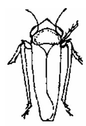
- **Non-persistent.** Virus is acquired by the insect **(usually aphids)** from an infected plant in a few seconds or minutes and can be transmitted almost immediately during feeding to a new host. Aphids only **retain the virus for few minutes** and must acquire the virus again to transmit it again.
  Insecticides can control aphids, but cannot prevent spread because transmission occurs too quickly.

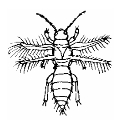
Persistent viruses are acquired from an infected plant during feeding and circulated internally. After passage through insect tissues the virus is introduced into healthy plants again during feeding. These viruses **persist** in the vector for long periods. Some insects will spread virus all their lives and some will persist through moults and/or egg stages.

- **Persistent**. Vector has a much longer feeding time, eg hours, followed by a period, also many hours, during which it is unable to infect plants on which it feeds. Persistent viruses may be:
  – **Circulative.** The virus is **retained** for weeks or for the life of the insect **(aphid, leafhoppers and whiteflies).** Insecticides can reduce spread of virus disease within a crop. If only a few plants in the field are infected by early aphid flights into the crop, it might be possible to control later generations of vectors before they can acquire and transmit the disease.
  – **Propagative.** Some viruses **multiply** in vectors **(aphids, leafhoppers and thrips)** passing to the salivary glands. Insecticides are effective in reducing virus spread, eg tomato spotted wilt virus.
- **Semi-persistent.** These viruses have some characteristics of both non-persistent and persistent viruses.


Host plant


Aphids


Leafhoppers


Thrips

OVERWINTERING, OVERSUMMERING

"Overwintering" may in reality be **oversummering**, perhaps a better term might by **overseasoning**

IN THE HOST PLANT

Once a plant is infected with virus it remains infected for the rest of its life. Viruses with a wide host range, eg tomato spotted wilt, may 'overwinter' in weeds or perennial hosts which are then a potential source of infection for many future ornamental, vegetable and other crops.

Host plant

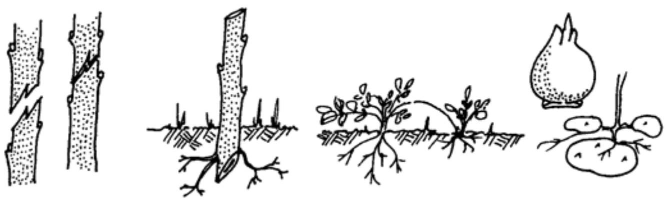
IN SEED

Probably more than 20% of virus diseases are seedborne, some on certain hosts only. Not all seed from an infected plant may carry the virus. Crops grown from virus-free seeds may escape later infection if they are kept away from insect vectors that have access to infected plants.

Seed

IN VEGETATIVE PROPAGATION MATERIAL

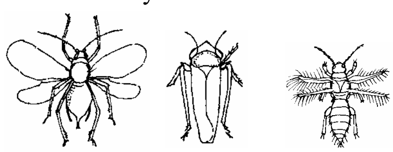
All virus diseases are carried over into new plantings if the new bulbs, corms, tubers, stolons, cuttings and nursery stock are taken from parent plants which are already infected with virus.



Grafting **Cuttings** **Runners** **Bulb, tubers**

IN VECTORS

Persistent circulatory viruses can 'overwinter' in certain insect vectors, eg leafhoppers. Perennial parasitic flowering plants such as Devil's twine (*Cassytha* spp.) could also carry virus.



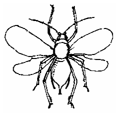
Aphids **Leaf hoppers** **Thrips**

IN PLANT DEBRIS & SOIL (not common?)

Tobacco mosaic virus is spread by mechanical inoculation, by grafting, by seed and by **contact between plants**. It can survive in dead infected tobacco leaves in cigarettes for years and may be passed from them to healthy plants during smoking. It is considered that some viruses, eg tobacco mosaic virus, which infect orchids, could survive in infected leaves in the soil for limited periods of time.

Plant debris **Soil**

SPREAD

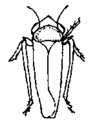


Aphids are the most important insect vectors

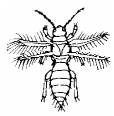
Knowing how a virus is spread is essential for effective management

INSECTS AND OTHER VECTORS

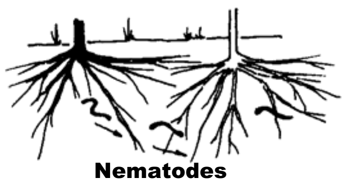
- **Insects**, especially sucking species such as aphids, leafhoppers, whiteflies and thrips, are common vectors of virus diseases. Viruses may be persistent or non-persistent in insects (page 280). Other insects and mites may occasionally transmit virus diseases.
- **Nematodes.** Viruses spread by nematodes are called nepoviruses, eg grapevine fanleaf virus is spread by the dagger nematode. This is presently an uncommon method of spread in Australia but these viruses cause probably the most serious viral diseases of horticultural crops, particularly perennial woody and bulb crops in many plant families, and are of serious concern to quarantine authorities worldwide. Attempts are being made develop a suitable generic test for the whole nepovirus group.
  www.daff.gov.au/ba/publications/**nepoviruses**
- **Fungi.** This is a rare method of spread, eg lettuce big vein virus is spread by a soil-inhabiting fungus (*Olpidium* sp.).
- **Protozoa.** This is also an uncommon method of spread, eg *Polymyxa graminis* can transmit virus diseases in cereal crops.
- **Flowering plants.** Plants such as dodder (*Cuscuta* spp.) which parasitize stems of plants may transfer virus diseases from one plant to another.



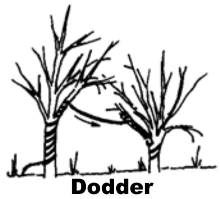
Leaf hopper



Thrips



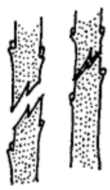
Nematodes



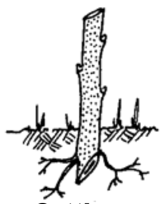
Dodder

VEGETATIVE PROPAGATION

- **Budding, grafting, cuttings, rootstock, scions, tubers etc.** For crops propagated in this manner, this is the **most important method** of spread.
- **Tissue cultures** may also transfer virus particles.

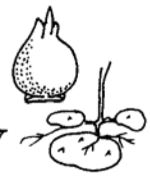


Grafting

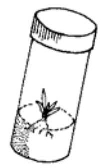


Cuttings

Runners



Bulb, tubers



Tissue culture

SEED AND POLLEN

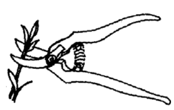
- More than 100 viruses are transmitted by seed. Usually only 1-30% of seed may be infected but 100% of seed can carry virus. Some are only seedborne on some hosts, eg tomato spotted wilt virus is seedborne in beans.
- *Prunus* necrotic ringspot virus is spread by pollen.

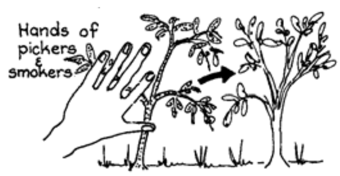
Infected pollen **Healthy plant**

Infected plant **Seed carrying virus**

MECHANICAL TRANSMISSION IN SAP

- A few plant viruses and viroids are spread in plant sap adhering to fingers, secateurs. budding knives, cigarettes, etc, eg tobacco mosaic virus. Some orchid viruses spread when healthy plants contact diseased ones.





Infected ➔ Healthy plant

NATURAL ROOT GRAFTS

- Natural root grafts may occur in orchards and other tree plantings.

EPIDEMIOLOGY

Some virus diseases are spread by only one method, others may be spread by several means

- **Vegetative plant parts and seed** primarily spread viruses between generations resulting in primary infection of plants.
- **Insects** not only bring the virus into the crop but also spread it from infected to healthy plants and during the same growing season (secondary infections). Such virus diseases may have many disease cycles per season (10-20 cycles for aphid transmitted viruses).
- **If spread by vegetative parts, seed and also by insects** there may be an early and total infection of the crop with subsequent severe damage.

CONDITIONS FAVOURING

EXPRESSION OF SYMPTOMS

Severity symptoms of individual plant viruses may vary with the crop variety, locality and from one season to another.

- **Temperature**. Viruses producing yellow or leaf roll symptoms are most severe in the summer whereas mosaics or ringspots are most pronounced in the spring. New growth produced during summer on mosaic- or ringspot-infected plants usually shows only mild symptoms or are completely free from symptoms, eg apple mosaic virus infection causes more pronounced symptoms during **cool springs**.
- **Masked virus** diseases produce symptoms **only** under certain conditions of light or temperature. **Latent virus** diseases do **not** show any symptoms in some infected hosts, eg tobacco mosaic virus infection in African violet.

VEGETATIVE PROPAGATION

Because virus diseases in host plants are transmitted in vegetative propagative material such as bulbs, corms, cuttings, root stock and scions, plants propagated by this means are prone to carry virus diseases, eg carnations, daffodil, potato. Viral infection builds up over generations eventually making some cultivars unproductive.

VECTORS AND AVAILABLE HOSTS

If spread by vectors, large populations of vectors and hosts favour infection.

HANDLING

Virus diseases spread by sap transmission are spread during handling, eg cucumber mosaic virus is usually spread through a crop of cucumbers during the first picking.

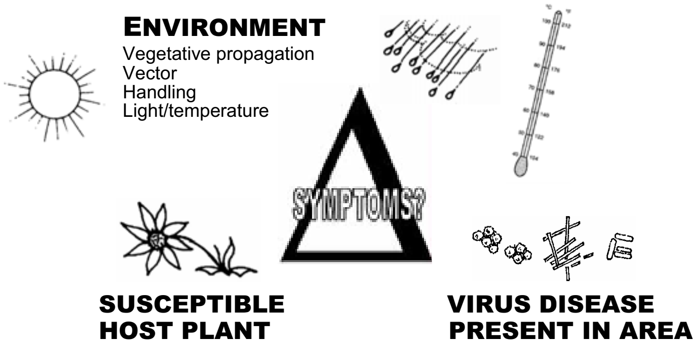


Fig. 140. Virus disease triangle.

INTEGRATED DISEASE MANAGEMENT (IDM)

MAIN STEPS

You need to know how the virus is spread to carry out the right control measures at the right time

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Disease-tested material
Physical/mechanical
Pesticides
Organic, BMP etc

1. **Plan** in advance an **IDM** program that fits your situation. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides.
2. **Crop/region**. List the problems your crop/region gets. **IDM** programs are available for different species of viruses on a range of crops.
3. **Identification** can be difficult. Be familiar with local virus diseases. Consult a diagnostic service if necessary (page xiv). Be aware that virus symptoms may mimic those of other diseases, eg nutrient or spray injury (page 275). Understand the life cycle, spread, etc of the virus. Obtain Fact Sheets on your virus.
4. **Monitoring**. **Know when, where, what and how to monitor**. Growers of susceptible crops should regularly monitor crops or indicator plants for symptoms of virus. There are specific tests for some viruses. Vectors which spread the virus can be monitored using sticky traps.
5. **Threshold**. This depends on the virus, the crop and the region and any legal requirements. You may need to calculate your own threshold, domestic or commercial for economic or aesthetic damage tolerance. There may be nil tolerance for quarantine or other situations.
6. **Action/control**. For all practical purposes infected plants in the field **cannot** be freed of virus after infection. Commercial growers can **prevent** initial infection by selecting resistant/tolerant varieties and planting virus-tested material when ever possible. Commercial growers can control insect vectors and weed hosts. Parent stock must be tested regularly and kept virus-free and measures taken to prevent subsequent spread. Home gardeners can purchase good quality stock/seed (usually free of virus) and tolerate any subsequent virus or rogue out seriously affected plants.
7. **Evaluation**. Just how effective **was** virus control? Commercial growers should test parent stock plants for virus every year. Recommend improvements if required.

CONTROL METHODS

LEGISLATION

Relevant legislation includes Plant Quarantine Acts, Seed Acts, etc.

CULTURAL METHODS

- **Overplanting and later thinning** can be useful for home gardeners to assist in controlling tomato spotted wilt in tomatoes (see roguing below).
- **Proper fertilizing and watering** can often offset the adverse effects of infection, eg daphne plants infected with virus diseases.
- **Planting at times** when vectors are absent or low.

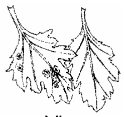
Sanitation may assist in controlling certain virus diseases, eg if plum pox virus arrived in Australia protocols would probably include destruction of infected trees and constant monitoring for disease

SANITATION

- **Insect-transmitted viruses.** Do not plant young crops near virus-infected crops or crop residues. Destroy surrounding **weeds hosts** and **infected dying crop plants** as soon as practical after harvest as vectors may migrate to healthy crops. Clean out all autumn crops grown in greenhouses where spring crops will be grown.
- **Rogueing.** As there is no cure for virus-infected plants, rogue infected crops, especially herbaceous crops, eg ornamental flowers, bulbs and vegetables. Because symptoms caused by virus diseases are often more obvious in the cooler months, rogueing should be carried out during spring and autumn. For viruses that 'overwinter' in host debris in the soil, remove diseased plants.
- **Handling plants.** Some virus diseases are spread during handling, eg tobacco mosaic and cucumber mosaic. Handle plants as little as possible. Wash hands when moving between sections of a collection of plants.
- **Sterilize pruning** implements by heating to red heat or dipping in 10% trisodium phosphate solutions for 10 minutes after every plant or plant group (check that this is appropriate for your situation). Thoroughly clean tools first.
- **Personnel hygiene.** Wash hands, clean clothes, foot baths with disinfectant can be placed at the entrance to greenhouses. Do not smoke when handling Solonaceous plants (page 282).

BIOLOGICAL CONTROL

- To date it is not possible to control virus diseases biologically.
- **Vectors**, eg thrips, have potential for biological control (page 139).
- **Trap plants**, eg rows of tall plants around fields of beans. Incoming aphids which carry virus diseases that attack beans, will first stop and feed on tall ryegrass. Most aphid-borne viruses are non-persistent in the aphid so many of the aphids will lose the bean-infecting virus by the time they move to feed on the beans (Agrios, 2005)



Virus-resistant plants reduce the use of insecticides to control **vectors**

RESISTANT, TOLERANT VARIETIES

Resistant varieties provide a long-term approach for control of virus diseases, eg

- **Traditional plant breeding** programs whereby hybrids are produced which have resistance to a specified virus disease.
- **Genetic engineering (GE)** allows the **transfer of genes for resistance** into susceptible crop varieties, eg grapevine fanleaf virus. Genes can also be **silenced**.
- **Vaccination** with attenuated strains of the problem virus can protect some plants from virulent strains and extends their commercial life. This may be inherited, eg barley yellow dwarf virus.
- **Cross protection** describes the protection of a plant by infecting it with a mild strain of a virus, which prevents later infection by more severe strains of the same virus, eg citrus tristeza virus, papaya ringspot virus.
- **Systemic acquired resistance (SAR).** Plants may be treated with chemicals which **activate the plant's natural resistance mechanisms**, eg tobacco mosaic virus.

PLANT QUARANTINE

- **Australian Quarantine & Inspection Service (AQIS).** Recent arrivals include Iris yellow spot virus (IYSV) which infects onions and leeks and Capsicum chlorosis virus (CaCV) which infects capsicum, peanut and Hoya. For the many virus diseases and their vectors which occur overseas, contingency plans are in place should they enter Australia.

  Target list of diseases which might enter Australia
  www.daff.gov.au/aqis/**quarantine**/naqs/**target-lists**
  PaDIL - Pests and Diseases Image Library www.**padil**.gov.au
- **Interstate and Regional Plant Quarantine.** Some virus diseases (or strains of), occur only in certain regions. NSW legislation aims to prevent the introduction of Tomato Yellow Leaf Curl Virus (TYLCV) and its vector, silverleaf whitefly, into NSW because diseases caused by similar strains of TYLCV in other states, cause severe economic losses in tomato crops overseas.
- **Local quarantine**. Virus diseases may be introduced into gardens and nurseries by the purchase of infected plants, eg roses.

DISEASE-TESTED PLANTING MATERIAL

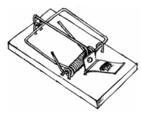
As virus-infected plants usually remain infected for a lifetime, plants propagated vegetatively from such material are infected.

- **Certification schemes** provide propagation material, conforming to cultivar characteristics and guaranteed free from the diseases for which it has been **tested and found to be free from**. Periodic testing of parent plants producing such propagation plants is necessary to ensure their continuous freedom from viruses.

CONTROL METHODS *(contd)*

The use of virus-tested seed, tubers, budwood, etc, is the **most important measure** for managing virus diseases of many crops especially those lacking insect vectors

- **Certification schemes *contd***
  - **Advantages of disease-tested planting material** include increased crop yields and uniformity, improved flower or fruit quality, improved scion and rootstock compatibility and fewer budding failures.
  - **Seed certification schemes** must comply with the minimum legislative requirements, eg various State/Territory Seed Acts. Tolerance limits are set, eg a Certified French bean seed scheme operates and there is a 1% tolerance of peanut mottle virus and bean common mosaic virus.
  - **Vegetative propagation schemes.** Many plants are propagated vegetatively because seeds do not reliably produce plants which are true-to-type. Most certification schemes for vegetative propagation material are directed towards controlling virus and virus-like diseases of ornamentals such as carnation and roses, most fruit and some vegetable crops, eg seed potatoes. Examples of such schemes include the Strawberry Runner scheme, a national Vine Accreditation Scheme, citrus bud certification scheme, the Almond Improvement program.
- **Management of disease-tested planting material.**
  - **Use** disease-tested planting material if available, to ensure the crop starts free of specified viruses, diseases and pests.
  - **Purchase** from reputable suppliers who guarantee the material is insect, virus and disease-free.
  - **Manage** disease-tested planting material to reduce the risk of it becoming infected with virus disease which can lead to significant crop loss.
  - **Isolate** elite parent stock from diseased plants to avoid contamination.
  - **Replace** parent stock each year to guarantee continuing disease-freedom.
  - **Handling** plants must be kept to a minimum to ensure there is no cross-contamination between varieties.
  - **Disinfect** secateurs or scalpels and never use them on more than 1 plant at a time before disinfecting them again.



PHYSICAL & MECHANICAL METHODS

All plant material treated to eliminate virus must be **tested** after treatment to ensure that it **really** is free from virus disease for which it has been treated. Effective treatments of plant material to eliminate virus diseases include:

- **Heat** (by experts using specialist equipment)
  - **Hot water treatments (HWT)** are used in certification schemes to inactivate phytoplasma and other disease organisms within dormant propagation material, eg dipping in hot water at 35-45°C for a few minutes or hours.
  - **Dry heat treatments**. 5 days at 70°C or 1 day at 80°C inactivate some seedborne viruses, eg tomato mosaic virus.
  - **Prolonged dry heat**. Actively growing plants in greenhouses kept at 35 - 40°C for several days, weeks or months depending on the host, **may** inactivate the virus in some plants or produce buds which are free of specified viruses. The buds can be removed and tested for presence of virus.
- **Tip culture.** Many disease organisms including viruses, do not invade the growing tissue of plants, so that culture of short tips (0.1 mm to 1cm or more) of apical or root meristems especially at elevated temperatures (28 - 30°C) may produce plant material which is virus-free. **All plants** produced from tissue cultures **must** still be tested for freedom from virus.
- **Insect-proof greenhouses** if properly constructed and managed, keep insects out of greenhouses. They are expensive and generally only routinely used for plant quarantine purposes and valuable crops derived from virus-tested planting material, which may later become infected with viruses spread by insects.
  - **Insect-proof screens** with prescribed mesh sizes covering vents prevent entry of vectors of virus diseases, eg aphids, thrips, whiteflies.
  - **Overseas ultraviolet-absorbing (UV) screens** serve as optical barriers to protect crops from insect pests (and virus). The elimination of a portion of the **UV** range of the light spectrum interferes with the **UV** vision of insects which affects their ability to orient onto the crop.

Foliar applications of insecticides are particularly ineffective against **aphid** vectors

PESTICIDES (viricides, insecticides)

- **There are presently no chemicals** (viricides) which will protect plants from viruses or kill viruses once they have invaded the host. **Ribovirin**, applied as a spray or injected into plants may reduce symptoms drastically. **Gibberellic acid** (a growth regulator) applied to the foliage, may overcome the stunting, induced by some viruses and may stimulate the growth of virus-suppressed auxiliary buds in virus infected plants (page 404). **Plant resistance activators** and other methods are being researched.
- **Insect vectors** can be controlled to a limited extent with **insecticides** in commercial crops. **Home gardeners** should **not** attempt to control vectors.
  - **Foliar sprays often are not very effective**. Follow **Resistance Management Strategies** to help conserve effectiveness of existing products.
  - **Oil sprays**, in addition to killing insects by smothering, inhibit spread of viruses by aphids (non-persistent viruses) and some that are mechanically transmitted by people.
  - **Seed treatments**. Picus® Seed Treatment Insecticide (imidacloprid) assists prevention and spread of barley yellow dwarf virus by aphids in cereal crops.
  - **Soil fumigation** can reduce losses caused by nematode transmitted viruses.

EXAMPLES OF VIRUS & VIRUS-LIKE DISEASES

Tomato spotted wilt

Cause

Tomato spotted wilt virus **(TSWV)**, spotted or bronze wilt. **TSWV** occurs wherever its vectors occur. Losses can be serious and are likely to increase because the exotic Western flower thrips **(WFT)** is a very efficient vector of **TSWV**, has a very wide host range, readily develops resistance to insecticides and can reach very high numbers on host plants. There are different strains of the virus.

Host range

Has the **widest host range** of any plant virus. It can attack over 900 species of plant, including:
Vegetables, eg tomato, potato, capsicum, lettuce, celery, eggplant, spinach.
Ornamentals, eg aster, chrysanthemum, dahlia, Iceland poppy, nasturtium, petunia, zinnia.
Fruit & nuts, eg peanut.
Field crops, eg cowpea, lupin, tobacco.
Weeds, eg dandelion, lamb's tongue, nightshade.

Symptoms

TSWV may be **symptomless** on some plants. On other hosts a variety of symptoms may be produced which are dependent on plant species, cultivar, growing environment and virus strain. Symptoms start to show 14-21 days after infection and may occur on **leaves, stems and fruit**. Plants may be distorted, stunted and show reduced vigour. In some cases leaves and/or whole plants may die.

Vegetables.
Tomato. Small areas of bronzing develop on the upper side of **young leaves** in the terminal growth and spread over the whole leaf (bronze wilt). **Older leaves** have bronze spots, rings or crescents up to 3 mm long between the veins. These spots may extend and join up. Affected leaves may wither and die and tissues blacken and shrivel until the shoots look as if they have been scorched by flame. **Leaf stalks and stems** may develop dark streaks. **Young vigorous plants** may be killed in a few days but in **older plants** disease may take several weeks to develop. **Fruit** on more mature plants may show irregular or circular blotches as they ripen (Fig. 141). Symptoms are usually obvious. Taste is not affected. Young fruits shrivel and fall.
Broad bean. Tips of main shoots blacken and may die, dark streaks may develop on stems and black sunken lesions on pods.
Capsicum. Leaves show yellowish parallel lines or concentric rings, the fruit is marked with yellow rings and blotches up to 10 mm across which may not show up until the fruit ripens. Rings and blotches may darken.

Ornamentals.
Chrysanthemum leaves are marked with irregular wavy lines, one inside the other. Leaves in very susceptible varieties go brown and die.
Dahlia. Leaves develop yellow spots or rings. Later concentric yellow or brown rings or wavy lines appear. Symptoms are clearest on the first formed foliage, especially in early-planted dahlias. As the plant grows, new leaves formed during summer may only show slight mottling or no symptoms at all. Young stems may have brown to purplish streaks (Fig.143).
Arum lily. Leaves develop yellow spots or streaks parallel to the veins (Fig. 144). The stunted and yellow appearance is distinctive.
Nasturtium. Leaves develop straw-colored spots, become cupped, distorted, enlarged (Fig. 145).

Diagnostics. Diagnosis of **TSWV** can be quite difficult. Symptoms are similar to, and can be confused with, nutritional disorders, pesticide injury, genetic patterns, etc, depending on the host (page 275, Table 54).

- **Leaf symptoms** usually occur initially on a few scattered patches of plants which gradually spread as thrips transmit **TSWV** to healthy adjacent plants. Knowledge of typical leaf symptoms on a specific host is required. Considerable experience is needed for a confident diagnosis.
- **Fruit symptoms** are usually easier to recognize.
- **Plant tests**. Confirm diagnosis with an on-site test, or send a plant sample to a diagnostic service (page xiv). Nepo viruses and their diagnosis www.daff.gov.au/ba/publications/**nepoviruses**

'Overwintering'

- In infected weeds, diseased stock plants, other host plants, eg volunteer crop plants, cuttings.
- **TSWV** is not seedborne, except for broad bean.

Fig. 141. Tomato spotted wilt. ***Left:*** Circular blotching of tomato fruit. ***Right:*** Ringspots and other dark streaks on capsicum. Photo©CIT, Canberra (P.W.Unger).

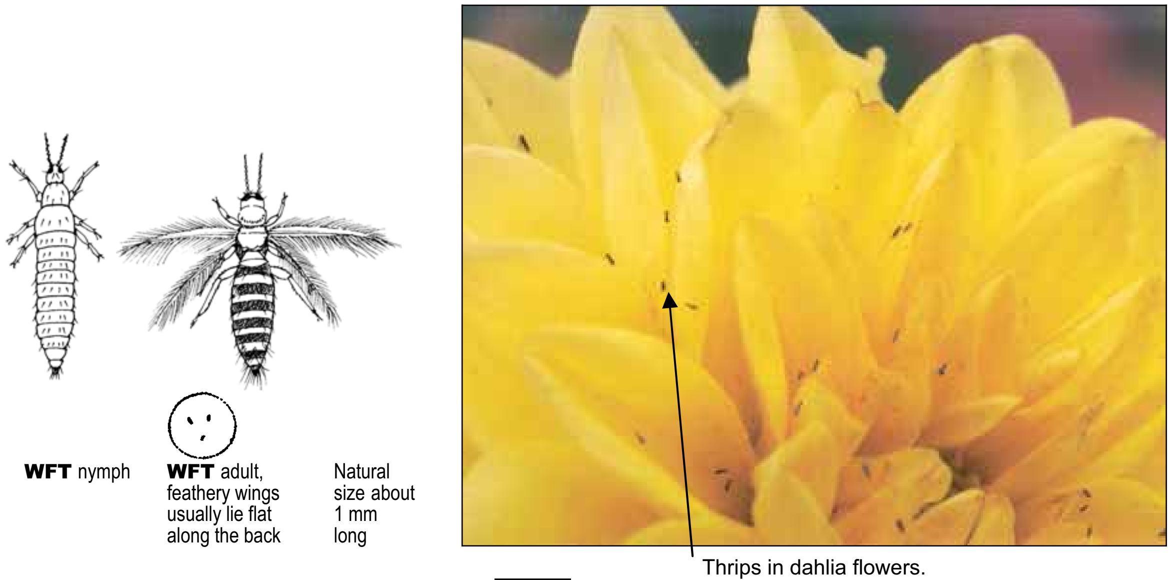


Fig. 142. Various species of thrips transmit the tomato spotted wilt virus. Western flower thrips **(WFT)** (*Frankliniella occidentalis*) is the most efficient vector, it feeds on flowers, new leaves and buds and other plant parts. Photo©CIT, Canberra (P.W.Unger).

Fig. 143. Tomato spotted wilt - symptoms on dahlia.
Left and centre: Concentric yellow or brown rings or wavy lines on leaves.
Right: Brown or purplish streaking on young dahlia stems. Photo©NSW Dept. of Industry and Investment.

Fig. 144. Tomato spotted wilt symptoms. Yellow spots on leaves **of arum lily**. Photo©NSW Dept. of Industry and Investment.

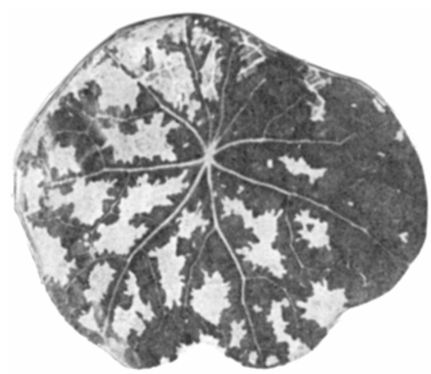


Fig. 145. Tomato spotted wilt symptoms. Irregular whitish blotches or green and yellow mosaic on leaves of **nasturtium**. Photo©NSW Dept. of Industry and Investment.

Spread

- **By thrips** which are poor fliers and spread by wind, on plants, people or on equipment, eg Western flower thrips **(WFT)** (*Frankliniella occidentalis*)*,* onion thrips (*Thrips tabaci*), common blossom thrips (*F. fusca*) and tomato thrips (*F. schultzei*). More species overseas.
  – **WFT is the most efficient vector of TSWV** and can feed on a many ornamentals, vegetables and weeds (pages 138, 139).
  – **Only nymphal stages of WFT** can acquire the **TSWV**, while only **adults** can transmit it. **WFT** nymphs must feed on an infected plant for as little as 15 minutes to become a carrier. Having picked up the virus, the virus moves through the gut and into the salivary glands, after 5 days of incubation they can transmit it during feeding to healthy plants for the rest of their adult life (30-45 days). Adult **WFTs** cannot transmit the virus to their offspring (other thrips species may vary slightly).
  – **Not all WFT** are infected with **TSWV**.
- **By vegetative propagation** from infected plants.
- **Rarely by seed**, except broad bean.
- **Not** by contact between plants.
- **Not** by pollen.
- **Movement** of infested plants, seedlings.

Conditions favoring

- After hot dry weather, thrips migrate to ornamental and vegetable crops when the weed hosts on which they have been breeding and feeding have matured and dried out.
- High thrips numbers.
- Overlapping crops, the carrying over of long term plants and parent stock plants that might act as reservoirs for thrips and/or the virus.

Management (IDM)

Are you a commercial grower or home gardener? Management guides are available for some viruses (Persley et al 2008).

1. **Obtain/prepare a plan** that incorporates information from the National Strategy for Management of **WFT** and **TSWV** and/or State/Territory brochures.
2. **Crop, region,** season, life cycle. Be aware of all these and the **extensive** host range.
3. **Identification** may be difficult and complicated. Expert help may be needed so consult a diagnostic service (page xiv).
4. **Monitor. Know when, where, what and how to monitor**, early detection is vital.
   - Check sticky traps for signs of **thrips**.
   - **Symptoms** of abnormal leaves and growing points.
   - Flag **indicator plants**, eg petunias, with blue or yellow non-sticky cards to attract thrips.
5. **Threshold.** There may be a **nil** threshold in some commercial crops and the **vector** may be a targeted pest in **WFT-free** zones. Growers may have to set their own economic threshold on some crops.
6. **Action/control** depends on thresholds and includes weed control, etc. Home gardeners may rogue affected plants and not use infected plants for propagation, they should **not** attempt to control thrips by spraying.
7. **Evaluation.** Review program and recommend improvements if required. Continue to monitor thrips in the crop and surrounding areas.

Control methods

There is **no cure** for infected plants in the field. **Minimize** losses from **TSWV** by eliminating **TSWV**-infected plants and controlling thrips vectors.

Cultural methods.

- Do not grow tomatoes near flowers crops or weeds which act as alternative hosts for vectors.
- Early plantings of tomato are affected more seriously than later plantings.
- Avoid overlapping or sequential planting of susceptible crops.
- Use a fallow break or plant a crop that is not **TSWV**-susceptible between regular crops.
- Home gardeners can plant excess tomato seedlings to allow for losses due to **TSWV**.

Sanitation.

- Rogue or spray and destroy **TSWV-infected** crops as soon as observed, especially if young crops are growing nearby. Symptomless hosts cannot be rogued and so act as a source of virus.
- Dispose by burning or burying (maybe spray first to ensure that any thrips infected are killed).
- Destroy infected stock plants.
- Destroy **weeds** harbouring thrips and **TSWV** around crops (at least a 10-25m strip), eg sowthistle. Most weeds are symptomless.
- Plant new susceptible crops as far away from a source of infection as possible.
- Keep property free of crop residues and volunteer crop plants, eg corms, tubers, bulbs.
- Clean and sterilize greenhouses between crops. Place sticky traps in the empty greenhouse to detect any remaining adults.

Biological control.

Thrips vectors have many natural controls including a predatory mite (*Typhlodromis montdorensis*) and lacewings (*Mallada* spp.) which are general predators. (page 139). List of suppliers www.**goodbugs**.org.au

Resistant varieties.

- Use **TSWV**-resistant varieties when possible, these may be available for tomato and capsicum.
- If possible avoid planting varieties of crops that are most likely to carryover **TSWV**.
- Most **tomato varieties** are susceptible to **TSWV**. Resistant varieties are being bred.
- Resistance to **thrips** may assist.

Plant quarantine.

- **WFT**, a vector of **TSWV**, is a targeted pest in some districts, eg the Toolangi Plant Protection District.
- Check **all** incoming plants, eg cut flowers for thrips and **TSWV**, quarantine in an insect-proof area to determine thrips and **TSWV** status.

Disease-tested planting material.

- **TSWV** is not seedborne, seed from diseased crops can be saved (except broad bean). You can grow your own seedlings which will remain free if kept away from thrips with access to infected plants.
- Plant only certified virus-tested planting material (seed, propagation material) if available.
- Only propagate from disease-tested stock plants.
- Keep stock plants separate from crop plants.
- If buying check that plants are free of thrips.

Physical & mechanical methods.

- Exclude thrips from greenhouse crops by screening with a fine thrips-proof mesh (may reduce air-flow).

Viricides, insecticides.

- **There are no registered pesticides which will cure a plant of virus infection in the field**.
- Use sticky traps to measure vector activity and apply insecticide when populations are above the recognized action threshold (page 140).
- Because **TSWV** is more serious in young plants, it may be worthwhile spraying commercial seed or cutting beds to control thrips.
- Regular insecticide applications to field crops and surrounding crops and weeds to control thrips during periods of thrips activity (as determined by monitoring), will reduce numbers of infected plants.
- Anti-transpirants and spray oils may repel thrips.
- Follow Insecticide Resistance Management Strategies on labels (page 140).

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Tomato big bud (greening)

An example of a phytoplasma disease

Also called greening, rosette or virescence

Cause

Candidatus Phytoplasma aurantifolia.
Note that although phytoplasmas are more closely related to bacteria, they are dealt with here because they behave more like viruses.

Host range

Very wide. Species affected include:
Ornamentals, eg aster, chrysanthemum, dahlia, geranium, larkspur, marigold, petunia, phlox, snapdragon, shasta daisy, zinnia.
Vegetables, eg tomato, potato, eggplant, capsicum, lettuce.
Field crops, eg clovers, lucerne, tobacco.
Weeds, eg crowsfoot, dock, lamb's tongue, nightshade, spear thistle, sowthistle, thornapple.

Symptoms

Different symptoms develop on different hosts. Phytoplasmas infect plants systemically.

Vegetables.

Tomato Symptoms may not develop for 6 weeks or longer after infection. **Stems** become thick and the plant has a stiff upright appearance (Fig. 146). Plants branch prolifically to produce many stiff shoots, with shortened internodes, giving the plant a bushy appearance. **Root initials** may develop high on the stem and splitting may occur. **Flower buds** are greatly enlarged and imperfectly developed. The sepals often fail to separate and the whole bud is green. Abnormal flowers do not set fruit. **Fruit,** immature at the time of infection, becomes distorted with a large woody core. Fruit production is greatly reduced. Slightly raised white surface areas may develop in an irregular pattern.

Potato (purple top wilt). A rolling and pigmentation of **upper leaves** and erect **leaf stalks**. **Leaves** of white flowered varieties turn yellow, leaves of pigmented varieties turn red or purplish depending on the variety. Leaf pigmentation intensifies and stems also become pigmented. Crops grown under high moisture develop a bunched appearance. **Stems** eventually yellow and collapse, the lower stems showing internal browning. **Flowers.** There is no greening. **Tubers** may be flabby and may show discoloration at the stem end. Tubers from infected plants may form spindly shoots.

Ornamentals, other hosts.
Some or all the petals are green instead of their usual colour, hence the name 'virescence' which is often used (Figs. 146, 147). There may be a proliferation of shoots, plants look bushy. There is no bud enlargement. Plants may be stunted.

Diagnostics.
- Where tomato big bud is suspected commercial growers can submit samples to a diagnostic service for confirmation (page xiv).
- The greening symptoms and bushiness may be mistaken for herbicide injury or genetic causes.
- 'Greening' usually only infects herbaceous plants.
- A few species of flowers are **naturally green**, eg green rose (*Rosa chinensis viridiflora*, Bells of Ireland (*Molucella* sp.).
- Some **senescing flowers** are greenish, eg hydrangea, arum lily (*Zantedeschia* sp.).
- Some diseases called 'greening' are not necessarily caused by virus diseases, eg citrus greening is a bacterial disease.
- Other phytoplasmas produce different symptoms, eg witches broom, aster yellows.


Stiff upright stems.


Split stems.


Small, distorted green woody fruit.

Fig. 146. Tomato big bud - symptoms on tomato. Photo©CIT, Canberra (P.W.Unger).

‘Overwintering’

In infected host plants, eg weeds, perennial ornamentals and field crops. It is not seed-borne and does not survive in soil.

Spread

- **By the common brown leafhopper** (*Orosius argentatus*) which is brown speckled and about **3 mm** long. It breeds on weeds which can be infected with tomato big bud. Overseas other leafhopper species may also transmit it. **Tomato big bud** is transmitted in a persistent manner. **Leafhoppers** acquire tomato big bud after feeding on infected hosts for several hours or days but cannot transmit big bud immediately. During this latent period the phytoplasma multiplies and circulates within the vector finally accumulating in the salivary glands. Leafhoppers are infective for the rest of their lives, through several moults but tomato big bud is not passed from adults to eggs.
- **By vegetative propagation** from infected plants.
- **Not** seedborne.

Conditions favoring

- Crops surrounded by weeds where leafhoppers breed.
- Plants which are vegetatively propagated.
- Leafhoppers build up rapidly at temperatures > 16°C.
- At certain times of the year, particularly after hot and dry weather, leafhoppers migrate from drying weeds where they breed, to ornamental plants, vegetables and other herbaceous plants. Migration most commonly occurs in Oct/Nov.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that suits your situation.
2. **Crop, region.** Know the variations, wide host range and vector.
3. **Identification**. This must be accurate, so consult a diagnostic service (page xiv) to ensure correct diagnosis and correct control measures are used, ie that the problem really is caused by tomato big bud and not herbicides, etc.
4. **Monitor** crops regularly for diseased plants and vectors and record your findings. **Know when, where, what and how to monitor**.
5. **Threshold.** Nil thresholds for some commercial crops. Home gardeners tolerate some diseased plants.
6. **Action/control** involves roguing infected plants, not propagating from infected plants. Home gardeners should not attempt to control the vector by spraying.
7. **Evaluation.** Review the success of your plan. Recommend any necessary improvements. Continue regular crop inspections.

Control methods

Control is difficult. To minimize losses:

Sanitation.

- There is no cure for infected plants so they should be removed and destroyed.
- Weeds known to harbour the leafhopper vector should be destroyed.

Resistant varieties.

- No tomato varieties are resistant to big bud, the resistance of different varieties of ornamental plants is not known.

Disease-tested planting material.

- Seed can be saved from infected plants (disease is not seed-borne).
- Do not propagate vegetatively from infected plants.

Insecticides.

- **There are currently no registered pesticides which will cure a plant of phytoplasma infection in the field**.
- Where tomato big bud is a problem in commercial seedbeds, surrounding vegetation which may harbour leafhoppers, may be sprayed with an appropriate insecticide to control the leafhoppers.
- Regular insecticide applications to field crops in spring and early summer will, at the most, only reduce the number of infected plants.
- Home gardeners should **not** attempt to control the insect vector.

Fig. 147. Tomato big bud (greening).
Above: Gazania. ***Left:*** Greening of floral parts. ***Right:*** Healthy plant.
Right: Parsnip. ***Left:*** Healthy plant. ***Right:*** Greening of floral parts.
Photo©CIT, Canberra (P.W.Unger).

VIRUS DISEASES OF ROSES

Rose 'mosaic'

Cause

A **number of viruses** have been associated with roses in Australia including Apple mosaic virus, Potato Y virus, *Prunus* necrotic ringspot virus, Strawberry latent ringspot virus. About 40 viruses and virus-like diseases affect roses worldwide including aster yellows phytoplasma.

Host range

The host range of each virus is different. Apple mosaic virus and *Prunus* necrotic ringspot virus, the commonest viruses which affect roses, are mainly confined to Rosaceae, eg apple, *Prunus*, rose, strawberry.

Symptoms

The disease is characterized by yellow patterns on many or only a few leaves (Fig. 148). These detract from the overall appearance.

Leaves. Symptoms are **variable**, eg

- **Chlorotic mottling.** A yellow mottle involving the minor veins of the leaflet which may gradually spread to a general chlorosis.
- **Line patterns.** Many lines or broad bands of pale green or creamy tissue, 'oak leaf' patterns.
- **Veinbanding.** A narrow band of yellow along the entire vein network of the leaflet, an isolated area of the leaflet or only around the margins.

Flowers usually appear normal.

General. Although it has long been thought that 'mosaic' has no general deleterious effect on rose plants, recent work has shown that infection can lead to a reduction in vigour and flowering.

Diagnostics. Different symptoms associated with rose mosaic, and can often be mistaken for:

- **Herbicides** injury, the chlorophyll has been destroyed.
- **Nutrient deficiencies or toxicities**, eg iron deficiency on new leaves or magnesium deficiency on old leaves (page 275, Table 54).

'Overwintering'

In the canes, buds and roots of infected rose and other host plants.

Spread

- **All viruses are spread by propagation** (budding and grafting) from infected plants or by the use of infected rootstocks.
- **Apple mosaic virus** is also spread by contact between plants and possibly by pollen, its spread in nature is not known.
- ***Prunus* necrotic ringspot virus** is also spread by pollen to seed and by pollen to the pollinated plant, and may be by seed in some species, but **not** by contact between plants.
- **Not** by insects.

Conditions favoring

- Vegetative propagation from infected plants.
- Symptoms are often more pronounced during spring and may disappear during summer.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. Rose mosaic is not considered a serious disease and is usually introduced to a plant during grafting by the use of infected rootstock, budding or grafting material.
2. **Crop, region.** Control measures will vary depending on the crop, region or situation.
3. **Identification**, if there is any doubt, must be confirmed by diagnostic tests in a laboratory (page xiv).
4. **Monitor**. Inspect crops regularly for diseased plants.
5. **Threshold.** There is a **nil** threshold for commercial propagators and growers. Home gardeners generally accept the disease.
6. **Action/Control.** Commercial growers should **r**emove infected rose bushes and plan to only use disease-tested propagation material.
7. **Evaluation.** Review your program to see how well it worked and recommend improvements if needed. Continue regular crop inspections.

Control methods

To minimize losses in commercial plantings:

Cultural methods.

- Plant virus-tested and healthy plants some distance away from older infected bushes to reduce likelihood of virus infection via pollen.

Sanitation.

- Commercial rose propagators, growers and nurseries should remove infected rose bushes.

Disease-tested planting material.

- Only use virus-tested budwood and rootstock for propagation, purchase virus-tested nursery stock.
- Do not use virus-infected plants as a source of budwood or rootstock.

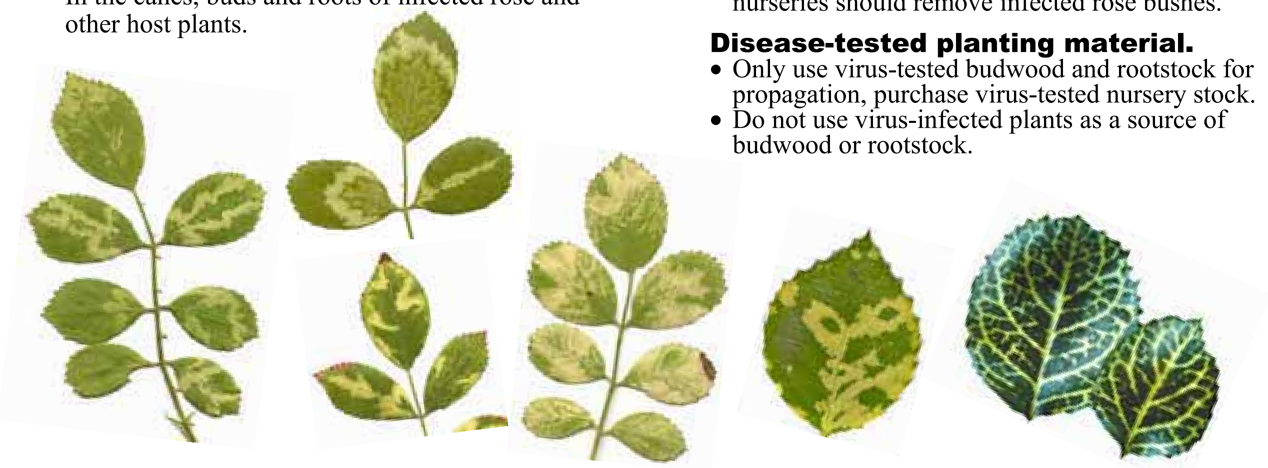


Fig. 148. Rose 'mosaic' – symptoms on rose.
Left: Line patterns. ***Centre:*** Chlorotic mottles. ***Right:*** Veinbanding. Photo©David Olsen

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List the **distinctive features** of viroids, viruses and phytoplasmas and describe the features they have in **common** as well as those that are **different**.
2. Explain how viruses are **named**.
3. Describe **symptoms** on **leaves, flowers, fruit and stems** produced by local virus and virus-like diseases. Name 1 example of each.
4. Describe how viruses **infect** host plants and are **distributed** within a plant.
5. **Explain** the following terms: Name 1 example of each.
   Chlorosis — Latent virus
   Mosaic — Masked virus
6. **Recognize by sight**, local virus & virus-like diseases.
7. **Distinguish between leaf symptoms** caused by virus and virus-like diseases from symptoms caused by other agents on selected plants, including:

Insect attack	**Non-parasitic agents**
Greenhouse whitefly	Deficiencies
Lace bugs	Genetic variegation
Leafhoppers	Pesticide injury
Thrips	Senescence
Twospotted mite	

8. Describe the following procedures used to determine the **presence of virus** in a plant:
   Electron microscopy — ELISA
   Indexing — DNA
9. Describe 4 ways by which viruses '**overwinter**'. Name 1 example of each.
10. Describe 4 ways by which viruses **spread**. Name 1 example of each.
11. Explain the importance of **insects** in spreading virus diseases.
12. Why should one **not** smoke when **handling** young tomato plants?
13. **Pesticides** have limited use in the control of some virus and virus-like diseases. Explain.
14. Describe **conditions which favour** some virus diseases. Name 1 example of each.
15. Describe State/Territory/Commonwealth **legislation** which provides for the control of virus & virus-like diseases.
16. List **control methods** for virus & virus-like disease. Describe 1 example of each.
17. Explain the term **'disease-tested'**.
18. **Provide the following information** for tomato spotted wilt virus, virus diseases of roses and other local virus diseases:
    Common name — 'Overwintering'
    Cause — Spread
    Host range — Conditions favouring
    Symptoms — **IDM** & Control
    Disease cycle
19. Describe how viruses may be used to **control insect pests**. Name 1 example.
20. Prepare/access an **IDM** program for a virus or virus-like disease at your work or in your region.
21. Locate **resource material** and know where to obtain advice on the identification and control of virus and virus-like diseases.

SELECTED REFERENCES

The Australasian Plant Pathology Society (APPSnet) includes the Plant Virology Working Group www.**australasianplantpathologysociety**.org.au/
The American Phytopathology Society (APSnet) www.**apsnet**.org/
Nepoviruses and Their Diagnosis in Plants - www.daff.gov.au/ba/publications/**nepoviruses**
Qld DPIF 2007.*Thrips and Tospovirus: A Management Guide*. avail online
Plant Virus Newsletter, Export controls for pathogens

Fact Sheets by State/Territory Depts of Primary Industries are available online, eg
Virus Diseases of Carnations
Virus Diseases of Daphne

Quarantine
Commonwealth quarantine www.daff.gov.au/**aqis**
PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.**padil**.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. www.**daff**.gov.au and search for target lists
State websites have information of viruses and quarantine restrictions in their states

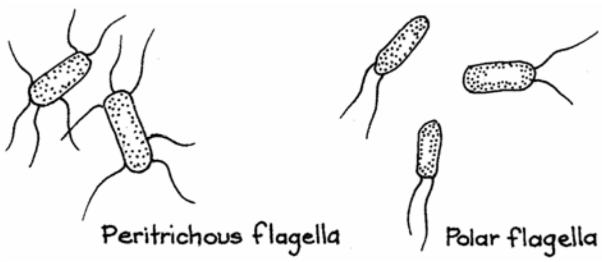
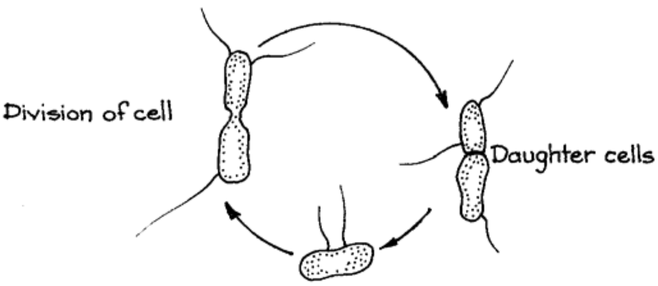
General
Agrios, G. N. 2005. *Plant Pathology*. 4th edn. Academic Press, NY. also 4th edn 1997.
American Phytopathological Society (APS) Press, St. Paul, Minnesota produces compendiums on diseases and pests of particular plants. www.**shopapspress**.org
Barnett, O. W. and Sherwood, J. L. 2009. (eds). *Virus Diseases of Plants : Image Database Collection CD*. APS Press www.shopapspress.org
Brown, J. F. and Ogle, H. J. (eds). 1997. *Plant Pathogens and Plant Diseases*. Rockvale Pub., Armidale, NSW.
Brunt, A. A., Crabtree, K., Dallwitz, M. J. and Gibbs, A. J. 1996. *Viruses of Plants*. CABI, UK.
Buchen-Osmond, C., Crabtree, K., Gibbs, A. and McLean, G. (eds). 1988. *Viruses of Plants in Australia*. RSBS, ANU, Canberra.
Buczacki, S. and Harris, K. 2005. *Pests, Diseases & Disorders of Garden Plants*. 3rd edn. HarperCollins, London.
Cooke, T., Persley, D and House, S. (eds). 2009. *Diseases of Fruit Crops in Australia*. CSIRO Pub.
Cooper, J. I. 1994. *Virus Diseases of Trees and Shrubs*. Chapman & Hall, NY.
Hadidi etc al. 2002. *Viroids*. USDA. CSIRO Pub.
Horst, R. K. (ed.). 2008. *Westcott's Plant Disease Handbook*. 7th edn. eReference, originally published by Springer, NY.
Hull, R. 2002. *Matthews' Plant Virology*. Academic Press, NY.
McMaugh, J. 1994. *What Garden Pest or Disease is That?* Lansdowne Press, Sydney.
Persley, D. M.,Sharman, M.Thomas, T., Kay, I. Heisswolf, S. and McMichael, L. 2008. *Thrips and Tospovirus: A Management Guide*. Qld DPI, Brisbane. avail online
Persley, D., Cooke, T. and House, S. 2010. *Diseases of Vegetable Crops in Australia*. CSIRO Pub.
Streton, C. and Gibb, K. 2006. *Phytoplasma Diseases in Sub-tropical and Tropical Australia*. Australasian Plant Pathology 35, 129-146.

Bacterial Diseases

Bacterial gall of oleander.
Galls may develop on all aboveground parts of the plant, including the flowers.

BIOLOGY & IDENTIFICATION

Bacterial diseases

NO. DISEASES IN AUSTRALIA	Bacteria are the most numerous living organisms on earth. For about 2 billion years bacteria were the only life on earth. More than 100 species of bacteria cause plant diseases. There are always some bacteria on the surfaces of plants, but some of these never harm these plants. About 400 species live in our intestines. Others cause tuberculosis, pneumonia, typhoid fever; anthrax in humans and animals. The Australasian Plant Pathology Society (APPSnet) *Pathogen of the Month* www.**australasianplantpathologysociety**.org.au/ The American Phytopathology Society (APSnet) www.**apsnet**.org/
SOME DISTINCTIVE FEATURES	Bacteria are very simple organisms. Phytoplasmas which are closely related to bacteria but have been included with virus diseases as they generally are more virus-like than bacterial-like in their behaviour. **SINGLE-CELLED** Bacteria are small single-celled organisms which can only be seen under high magnification (x 1,000). Some are thread-like in form. The bacteria which cause diseases of plants are mostly short, rod-shaped organisms with one or more flagella which enable them to move through a film of water. Some exceptions, eg *Streptomyces* which is filamentaous.  **CELL WALL** They have a cell wall surrounding the cytoplasm but do not have the nucleus found in higher plants. **CHLOROPHYLL** They have no chlorophyll and therefore cannot manufacture their own food like green plants and so must obtain it from external sources.
LIFE CYCLE ;	Multiplication is by **simple fission**. Under favorable conditions, it can take as little as 20 minutes so that the rate of increase can be tremendous! Potentially millions of bacteria within 24 hours.  Bacteria, parasitic on plants, generally do **not** form spores but they can **remain viable** for long periods of time even under dry conditions. This property enables some of them to **remain alive for years** on plants, in stored seed and other plant products and in the soil.

CLASSIFICATION

BACTERIA ARE CLASSIFIED BY VARIOUS FEATURES including colony characteristics, pigments, stain reactions and morphology, eg shape of cells, motility, flagellation and a range of chemical tests (Fahy and Persley 1983, Agrios 2005). Bacteria causing diseases of plants include:

Agrobacterium	*Erwinia*	*Ralstonia*	*Streptomyces*
Clavibacter	*Pseudomonas*	*Xanthomonas*	*Xylella*

- **Phytoplasmas** are classified with bacteria but in this book are studied with virus diseases because of similarities in symptoms, methods of spread, etc.
- Some organisms with mycelium-like forms, eg *Streptomyces scabies* (common scab of potatoes), are **classified with bacteria** rather than with fungi.

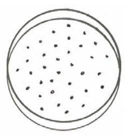
IDENTIFICATION

Symptoms

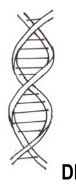
SYMPTOMS EXHIBITED BY THE HOST PLANT

- **For those without access to specialized facilities** this is often the main method of identification but **considerable expertise** is needed.
- **Other disease organisms**, environmental extremes and chemical toxicities may cause similar symptoms. Bacterial leaf spots may be confused with fungal leaf spots, bacterial wilts with fungal wilts, senescence, other agents.
- **Secondary bacterial infections** may be associated with above conditions.
- **Bacterial ooze** may be observed using a high-powered compound microscope when suspect stems or leaf lesions are cut transversely with a razor blade and placed on a microscope slide in water. Similarly when kept in a moist chamber, creamy bacterial ooze may ooze from the vascular system, eg bacterial wilt of tomato. However, this does not identify the bacterial species.

Bacteria are identified by what they do rather than what they look like, (Brown & Ogle 1997)



ELISA Testing Service



DNA

DETECTION AND IDENTIFICATION BY EXPERTS

Experts test for the presence of bacteria in seeds, food supplies and in parent stock and certification schemes, eg strawberry, cut flowers, potato, grape.

- **Microscopic** morphology is of little value in identifying bacteria.
- **Pure bacterial cultures** can be isolated on **selective media** and identified. Continuous culture-indexing includes regular checks of plant material for bacterial infection over a 2-year period. Pathogenicity tests can be carried out.
- **Biochemical tests and molecular techniques** are precise, species and subspecies can be identified. Some test kits have been developed.
  - **ELISA** tests are relatively low cost, give a quick specific answer (a color change indicates a positive test result) but are not as sensitive as some other methods. An **ELISA** test is available for **bacterial leaf & stem rot** of pelargonium (*X. campestris* pv. *pelargonii*) and is useful when scouting in **IDM** programs.
  - **Other techniques** include gram staining reaction, substances used by bacteria for food, the fatty acid composition of cells. Serological tests which produce a colour change can be used for quick and fairly accurate identification of bacteria.
- Sensitive **DNA tests**, eg **PCR** (polymerase chain reaction) enable researchers to distinguish one bacteriium from another by comparing segments of **DNA**.
- For **some bacterial organisms** on **some hosts** there are specific tests.

SYMPTOMS

Many bacterial diseases produce more than 1 symptom, eg **crown gall** may cause dieback, galls and wilting

Symptoms caused by bacterial diseases may be confused with those caused by **fungal** and **non-parasitic diseases and other causes**

DIRECT DAMAGE

LEAVES	**Blights**, eg bacterial blight (cotton, pea, stock, walnut, etc) **Defoliation**, eg bacterial canker (stone fruit) **Galls**, eg bacterial gall of oleander **Leaf spots**, eg bacterial leaf spots (begonia, hibiscus), bacterial canker (stone fruit), bacterial blight (mulberry)
BUDS, FLOWERS	**Blights**, eg bacterial canker of stone fruit
FRUIT	**Sunken black areas**, eg bacterial blight (walnut) **Rots**, eg bacterial soft rot (stored fruit and vegetables)
STEMS, TRUNKS	**Cankers**, eg bacterial canker (stone fruit) **Dieback**, eg bacterial canker (stone fruit), bacterial blight (walnut) **Gumming**, eg bacterial canker (stone fruit) **Rots**, eg bacterial leaf and stem rot (pelargonium) **Wilts**, eg bacterial wilt (tomatoes, internal staining of vascular tissue)
CROWNS, TUBERS, ROOTS	**Galls**, eg crown gall **Rots,** eg soft rots **Scabs**, eg leaf spot/corm scab (gladiolus), common scab (potato)

INDIRECT DAMAGE

- **Secondary** bacterial infections may be associated with injury caused by other disease organisms, environmental effects, injuries and toxicities.
- **Nematode-bacterial disease complexes** may occur (page 253).
- Bacteria may clog screens in pumps and reticulation systems.

Fig. 149. Symptoms of bacterial diseases ***(examples only)***

Blight. A disease which produces a general and rapid killing of leaves, flowers and stems; may be caused by bacteria, eg bacterial blight of peas. Also caused by insects, fungal diseases, and many non-parasitic problems, eg frost. **Canker.** A dead or discoloured area/spot on a stem, branch, or twig of a plant, eg bacterial canker of stone fruit. Also caused by fungal diseases. **Defoliation.** Leaves fall off prematurely, eg bacterial canker of stone fruit. Also caused by many fungal diseases, twospotted mites, senescence. **Dieback.** Progressive death of shoots, branches, and roots generally starting at the tip, eg bacterial canker of stone fruit. Also caused by fungi, eg *Phytophthora*, borers, drought, etc.	**Galls.** Bacteria stimulate plant cells to multiply and enlarge abnormally causing lumps to appear on plant parts, eg crown gall. Also caused by nitrogen-fixing bacteria (see below), fungal diseases, eg gall rust on wattles, insects, eg gall wasps. **Gumming/gummosis.** Production of gum by, or in plant tissue, eg bacterial canker of stone fruit (gummosis). Also caused by fungal diseases, eg shot hole, injury, eg apricots. **Leaf spots.** A self-limiting lesion on a leaf, eg bacterial leaf spot of mulberry (see below). Also caused by fungi and other agents.	**Scab.** A roughened cracked diseased area on the surface of plant tissues, eg bacterial scab of gladiolus (below). Also caused by fungal diseases, eg apple scab, non-parasitic problems, eg oedema. **Soft rot.** The material holding plant cells together is destroyed by the disease organism so that plant cells collapse causing tubers and bulbs to rot. May have an unpleasant smell, eg bacterial soft rot of potatoes. May also be caused by some fungal diseases. **Wilts.** Disease organisms multiply in and block water-conducting cells causing wilting of plant parts above the blockage, eg bacterial wilt of tomato; bacterial cells spread quickly and may end up in **fruits** and **seeds**. If these are used to produce a new crop, the bacteria will quickly produce diseased seedlings which will probably die. Also caused by fungal diseases, eg *Fusarium* wilt of tomatoes.

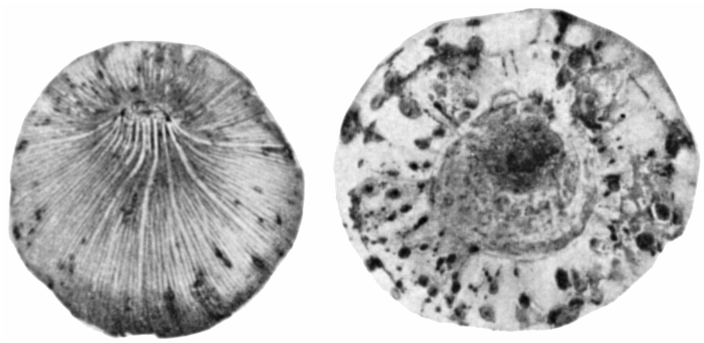


Fig. 150. Bacterial leaf and corm scab of gladiolus (*Pseudomonas gladioli* pv. *gladioli*). Scab lesions occur on corms, leaf bases may rot. Photo©NSW Dept. of Industry and Investment.

Fig. 151. Nitrogen-fixing nodules on legumes, eg clovers. On legumes do not confuse with root knot nematode galls (*Meloidogyne* spp.).

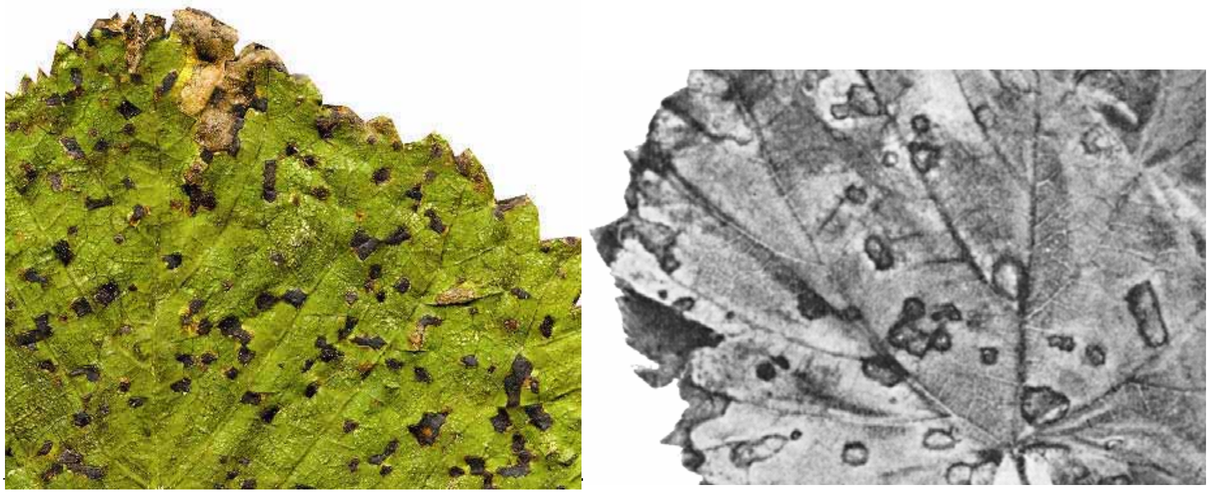


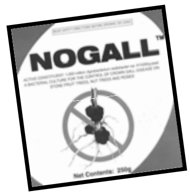
Fig. 152. Mulberry leaves. ***Left:*** **Bacterial leaf spots (bacterial blight) of mulberry** (*Pseudomonas syringae* subsp. *mori*) with small, black, angular spots. Photo©CIT, Canberra (P.W.Unger).
Right: **Fungal leaf spots of mulberry** with larger round spots with dark margins and light-centres. Photo©NSW Dept. of Industry and Investment.

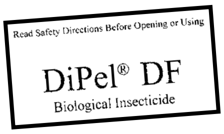
LIST OF SOME BACTERIAL DISEASES

	COMMON NAME	SCIENTIFIC NAME (alphabetical order)	HOST RANGE (not exhaustive)
	Crown gall	*Agrobacterium* spp. (used to transfer genes into plants, insects etc)	Wide range especially stone fruits, roses. Not all strains infect all hosts
	Bacterial canker	*Clavibacter michiganense* subsp. *michiganense*	Tomato, capsicum, blackberry nightshade
Synonym *Pectobacterium carotovorum* subsp. *carotorum*	Bacterial soft rot	*Ewinia carotovora* pv. *carotovora*	Field and postharvest rots of carrot, potato, iris
	Bacterial soft rot	*E. carotovora* pv. *atroseptica*	As above but mostly restricted to potato
Not known in Australia	Fireblight (in NZ)	*Erwinia amylovora*	Apple, pear, related plants, eg hawthorn, pyracantha, *Sorbus*, quince, loquat, cotoneaster
Rots may also be caused by fungi and environmental agents	Soft rot	*Erwinia chrysanthemi* and Foz (*Fusarium oxysporum* f.sp. *zingiberi*)	Ginger seed after planting. Many soil diseases may involve one or several agents.
	Bacterial wilts (S*), moko, bugtok and blood disease	*Ralstonia solanacearum* complex	Asteraceae, Solanaceae (tomato, potato), Fabaceae (legumes), Musaceae (**bananas**)
	Leaf spots, streaks	*Pseudomonas andropogonis*	Carnation, clover, vetch, others
	Soft rot of onion	*P. gladioli* pv. *alliicola*	Onion
	Leaf spot & corm scab of gladioli	*P. gladioli* pv. *gladioli*	Gladiolus, freesia, crocus, other Iridaceae
	Seedling blight of snapdragon	*P. syringae* pv. *antirrhini*	Snapdragon
	Black spot of delphinium	*P. syringae* pv. *delphinii*	Delphinium
	Bud rot of loquat	*P. syringae* pv. *eriobotryae*	Loquat
	Bacterial leaf spot of sunflower	*P. syringae* pv. *helianthi*	Sunflower
	Angular leaf spot of cucurbits (S)	*P. syringae* pv. *lachrymans*	Cucurbits
	Peppery leaf of crucifers (S)	*P. syringae* pv. *maculicola*	Cucurbits
	Bacterial blight of mulberry	*P. syringae* pv. *mori*	Mulberry
	Grease-spot of passionfruit	*P. syringae* pv. *passiflorae*	Passionfruit
	Halo blight of bean (S)	*P syringae* pv. *phaseolicola*	Bean, other *Phaseolus* spp., related legumes
	Bacterial blight of pea (S)	*P. syringae* pv. *pisi*	Field and garden peas
	Bacterial leaf spot of primula, polyanthus (S)	*P. syringae* pv. *primulae*	*Primula* spp.
	Bacterial canker of stone fruit, gummosis	*P. syringae* pv. *syringae*	Wide range, eg stone fruits, citrus, hibiscus
	Bacterial canker of stone fruit, gummosis	*P. syringae* pv. *morsprunorum*	Cherry, plum
	Bacterial gall of oleander	*P. savastanoi* pv. *nerii*	Oleander
	Olive knot	*P. savastanoi pv.savastonoi*	Olives, possibly plants in the same family
	Common scab	*Streptomyces scabies*	Potato
Not known in Australia	Citrus greening, huanglongbing, yellow dragon	*Candidatus Liberobacter* spp	All citrus. **Spread** by a psyllid (not in Australia), budding, grafting
Eradicated from Australia	Citrus canker	*Xanthomonas axonopodis pv. citri*	**Citrus**, other Rutaceae. **Spread** by rain, wind, people, plant parts
Not known in Australia	Citrus variegated chlorosis **(CVC)**	*Xylella bacterium*	Citrus, other woody plants
Not known in Australia	Pierce's disease	*X. fastidiosa*	Grapes, fruit and ornamental trees and shrubs, etc. **Spread** by glassy-winged sharpshooter

(S) Indicates that the disease is seedborne

LIST OF SOME BACTERIAL DISEASES *(contd)*	COMMON NAME	SCIENTIFIC NAME (alphabetical order)	HOST RANGE (not exhaustive)
	Bacterial wilt and leaf spot of begonia	*Xanthomonas campestris* pv. *begoniae*	Begonia
	Black rot of crucifers (S*)	*X. campestris* pv. *campestris*	Crucifers
	Bacterial blight of stock (S)	*X. campestris* pv. *incanae*	Stock
	Bacterial blight of walnut	*X. campestris* pv. *juglandis*	Walnut
	Bacterial leaf & stem rot of pelargonium	*X. campestris* pv. *pelargonii*	Pelargonium.
	Common blight of bean (S)	*X. campestris* pv. *phaseoli*	French bean, navy bean, some other beans
	Bacterial spot of stone fruit	*X. campestris* pv. *pruni*	*Prunus* spp. especially plum
	Bacterial leaf spot of zinnia (S)	*X. campestris* pv. *zinniae*	*Zinnia elegans*
	Angular leaf spot of strawberry	*X. fragariae*	Strawberry
Nematode-disease complexes	**Annual ryegrass toxicity (ARGT)** (nematodes page 253)		





	BENEFICIAL BACTERIA		
	Nogall	*Agrobacterium* sp.	Crown gall bacteria
	Formulations of *Bacillus thuringiensis* ***(Bt)*** are available to control some species of leafeating caterpillars. The caterpillars eat the bacterial spores which contain a toxin that causes septicaemia and death. Caterpillars with a **high gut pH** are susceptible.		
	Novodor®	*Bacillus thuringiensis* **(Bt)** var. *tenebrionis*	Chrysomelid and tenebrionid beetles in eucalypt plantations
	Cybate®, Vectobac®	***Bt*** var. *israelensis*	Mosquitoes
	Dipel®	***Bt*** var. *kurstaki*	Some leafeating caterpillars, mosquitoes
	XenTari®	***Bt*** var. *aizawai*	Caterpillars, eg corn earworm, diamondback moth
	Cybate®, Vectobac®	***Bt*** var. *israelensis*	Mosquitoes
	Bt crops, eg cotton	Cotton	*Helicoverpa* caterpillars
	Bt *bringai India*	Brinjai (eggplant)	Fruit and shoot borer in India
	Being researched in Australia to control dengue fever	Wolbachia bacteria	Kills the dengue fever mosquito (*Aedes aegypti*) before it can pass the dengue fever virus to humans
Free-living nitrogen-fixing bacteria include endophytes, plant growth promoting Rhizobacteria and saprophytes. They find their own energy source to convert into nitrogen	**Nitrogen-fixing bacteria** Researchers aim to transfer the same traits to cereals, eg International Rice Nodulation Group	*Rhizobia* spp.	Legumes convert **N** in the air (not accessible to plants) into a form (ammonia) that plants can use to make proteins
	Endophytic bacteria Some strains can fix large quantities of **N** in a crop cycle	*Azospirillum* spp., in wheat roots, turf	Live in the intracellular spaces in plant vascular systems and take dissolved gas from the sap flow and covert it into amines and ammonium nitrogen for plant use
	Plant Growth Promoting Rhizobacteria (PGPR) Promote root growth, enabling greater nutrient uptake, superior plant growth and higher yields, and in legumes, optimal **N** fixation	*Azobacter* spp. *Pseudomonas* spp *Bacillus subtilis* (various strains have been studied for use as bio-control agents)	Live on the surface of plant roots in the soil, consuming sugary exudates from the plant; they use this energy source to fuel the conversion of **N** gas into plant available **N**.
	Bio-Stacked® Companion. Soil inoculant in horticulture and agriculture	*Bacillus subtilis* (various strains), may be formulated with fungi, eg *Trichoderma*	Suppresses *Fusarium, Pythum, Phytophthora, Rhizoctonia,* in protected environments
	Saprophytic bacteria	Bacteria (also fungi, nematodes, flies, etc)	Breakdown plant residues, stubble, organic matter, compost
Nemacur biodegradation.	Biodegradation, bioremediation	Naturally-occurring bacteria (various species)	Break down pesticides, eg Nemacur® (fenamiphos), sulfur, pollutants, nutrient residues
These bacteria also impact on the winter survival of certain insects and on weather systems	Epiphytic bacteria on the foliage of plants reduce frost damage. May increase growth and disease resistance	Various bacteria, eg strains of *Pseudomonas fluorescens*	Bacteria lower the temperature at which ice forms by several degrees, does not provide against a dramatic drop in temperature.
	BACTERIA THAT CAN AFFECT HUMANS		
Do not confuse with ***L. pneumophila*** associated with inhalation of water droplets from contaminated cooling towers	Legionella, Legionnaire's disease	*Legionella longbeachae*	Pneumonia in humans, potting mixes, water fogging systems
	Salmonella	*Escherichia coli*	Food spoilage, food poisoning
	Whooping cough	*Bordetella pertussis*	Highly contagious

(S) Indicates that the disease is seedborne

NUTRITION AND PARASITISM

Most bacteria parasitic on plants develop on host plants as parasites on the plant surface, especially on buds as epiphytes and partly in plant debris or in the soil as saprophytes (Agrios 2005). Under suitable conditions, they can become parasitic. Most plant pathogens are facultative saprophytes and can be grown artificially on nutrient media (page 324).

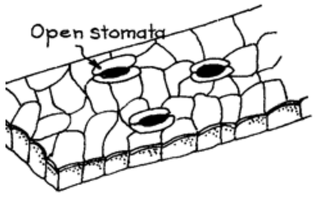
HOW BACTERIA INFECT HOST PLANTS

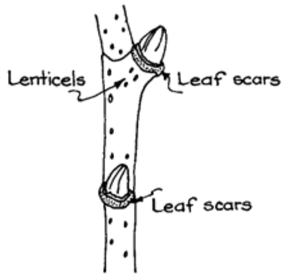
Bacteria **cannot** physically penetrate protective barriers of plants

Bacteria that cause **leaf spots** randomly on the leaf surface are likely to have invaded leaves through stomates

NATURAL OPENINGS

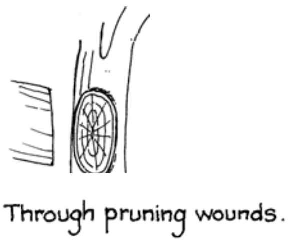
There are always some bacteria on plant surfaces. Some never harm the plant; others which cause disease can infect the plant through natural openings (leaf stomates, leaf scars, lenticels, small pores at the margins of leaves (hydathodes), or through relatively fresh wounds (hail, pruning wounds, etc).





WOUNDS

Damaging the intact surface of a plant can facilitate the entry of bacteria.



DISTRIBUTION WITHIN A PLANT

- Some bacteria destroy the material holding **plant cells together**, plant cells collapse causing sunken areas on stems, tubers or bulbs, eg soft rots which may be accompanied by unpleasant smells, eg soft rot of potato.
- Some remain mostly **on the surface of plant tissue**, eg galls, and tend to decrease in numbers as they invade the gall tissue, eg crown gall bacteria.
- Bacterial cells may invade **water and food-conducting** tubes of plants:
  - Spreading quickly to **fruits and seeds**. If these are used to produce a new crop, bacteria will quickly produce diseased seedlings which may die.
  - Bacteria also multiply in, and block, water-conducting cells causing **wilting** of plants parts above the blockage (page 296, Fig. 149).

DISEASE CYCLE

Many bacteria parasitic on plants develop partly on the host as parasites and partly in the soil, or on plant debris in the soil, as saprophytes.

HOST ONLY

These diseases produce their populations on the host plant. If the bacteria do reach the soil, eg via fallen leaves or fruit, their populations rapidly decline and they do not play a part in the spread of the disease, eg bacterial blight of walnut, bacterial canker of stone fruit. These bacteria have developed sustained plant to plant infection cycles.

HOST, HOST DEBRIS AND SOIL

These diseases build up large populations on the host. If the bacteria reach the soil, through decaying parts of the plant, they can remain there for many years, populations only gradually declining over years. Susceptible plants in contaminated soil will soon become infected, eg crown gall.

HOST, HOST DEBRIS, BUT MAINLY SOIL

These diseases produce most of their populations by growing on **plant matter** in the soil. They only attack plants incidentally. Plants are not essential for their continued existence, eg bacterial soft rot of iris or potato.

OVERWINTERING, OVERSUMMERING

BACTERIAL DISEASES MAY 'OVERWINTER' IN SEVERAL WAYS

Crown gall may overwinter on the host, in soil or in or on seed.

HOST

Parasitic bacteria which attack trees or shrubs overwinter in bacterial lesions, galls or cankers on the host plant, eg bacterial gall of oleander. They may also exist on the surface of a plant or plant organ without causing infection.

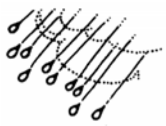
SOIL

Some parasitic bacteria can accumulate and survive in the soil on or in debris from infected plants, seeds or insects. Remaining alive for varying periods of time they are then able to infect a future susceptible crop, eg crown gall. Some like those causing bacterial soft rot can live in the soil indefinitely while others will decrease in numbers unless plants they are able to attack are grown.

SEED

Many bacterial diseases are seedborne, which means that the bacteria are present either in, on or in association with the seed. Plants produced from such infected seed will automatically produce infected plants, eg bacterial blight (black rot) of Brassicas (stock, cabbage, cauliflower), bacterial blight and halo blight of beans.

SPREAD



WATER, WATER SPLASH

- Flagella enable bacteria to move only very short distances on their own.
- Rain and irrigation water can wash bacteria from one part of a plant to another, from plant to plant and from soil to the lower leaves of plants.
- Wind may assist spread of rain and irrigation water.
- Drainage water or any other running water, in or on soil, can wash bacteria downhill to where susceptible plants are growing.
- Pruning or other activities within a wet crop can assist spread.

WIND, AIR CURRENTS

Airborne dispersal of bacteria may occur in tomato and pepper transplant fields.

SEED

Many bacterial diseases are seedborne, eg bacterial wilt of tomato. Bacteria can therefore be spread by any of the agents which aid seed dispersal.
Bacterial cells which get into the **water and food-conducting** tubes of plants spread quickly to fruits and seeds. If these are used to produce a new crop, the bacteria will quickly produce diseased seedlings which will probably die.

VEGETATIVE PROPAGATION MATERIAL

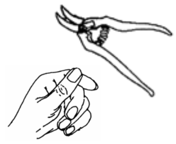
Bacterial diseases can be transferred to new plants on or in buds, cuttings, cormlets and similar vegetative propagation material, eg bacterial canker of stone fruit is spread in infected budwood.

INSECTS MITES

INSECTS

Insects and mites do not commonly spread bacterial diseases but they may:
- Carry bacteria from one part of a plant to another or to other plants.
- Inoculate plants with bacteria during feeding, eg the walnut blister mite is thought to **aid in the spread** of bacterial blight of walnut.

HUMAN ACTIVITIES AND ANIMALS



- **Pruning activities.** Bacteria can be carried on pruning tools and cause infection through pruning cuts, especially during cool wet conditions, eg bacterial canker of stone fruit.
- **Handling plants.** Bacteria can be spread on hands, shoes etc.
- **Bird and other animals** may carry bacteria on their bodies when moving among plants.
- **Movement of soil.** Bacteria may be spread in soil on machinery and vehicles, in containers and in soil deliveries when these are moved from one place to another.
- **Movement of plant material.** Bacterial diseases can be transferred in infected plants, nursery stock, bulbs, seed, cuttings and other vegetative propagation material.

CONDITIONS FAVORING	Conditions favoring development of bacterial diseases may be complex, eg **WEATHER REQUIREMENTS** Different bacterial diseases require different conditions for host plant infection and disease development, eg bacterial canker infection of stone fruit is favoured by cool, wet and windy weather. Bacteria thrive in moist conditions and can build up into larger populations in a short time. **SOIL CONDITIONS** • Soil temperatures, moisture and alkalinity may affect the development of soilborne bacterial diseases. • High soil moisture and temperatures favour bacterial wilt of tomato and capsicum. • Poor drainage may favour some bacterial diseases. • Planting susceptible crops in soil containing infected plant residues. **VENTILATION** Crowded, shady plantings increase disease levels due to poor air circulation around plants. **PLANT INJURY** Injury to plants by hail, wind-driven rain, irrigation, pruning or pesticide applications will favour infection. Avoid pruning trees during wet weather. • It is recommended that stone fruit trees be pruned during spring or autumn to allow pruning cuts to heal rapidly and so lessen the chance of infection by bacterial canker. **NUTRITION OF HOST** Host nutrition will also affect the development of disease, eg bacteria may more easily infect and cause damage to succulent shoots. **CONTINUOUS CROPPING** Soilborne bacterial diseases build up in soils if susceptible corps are grown continually.

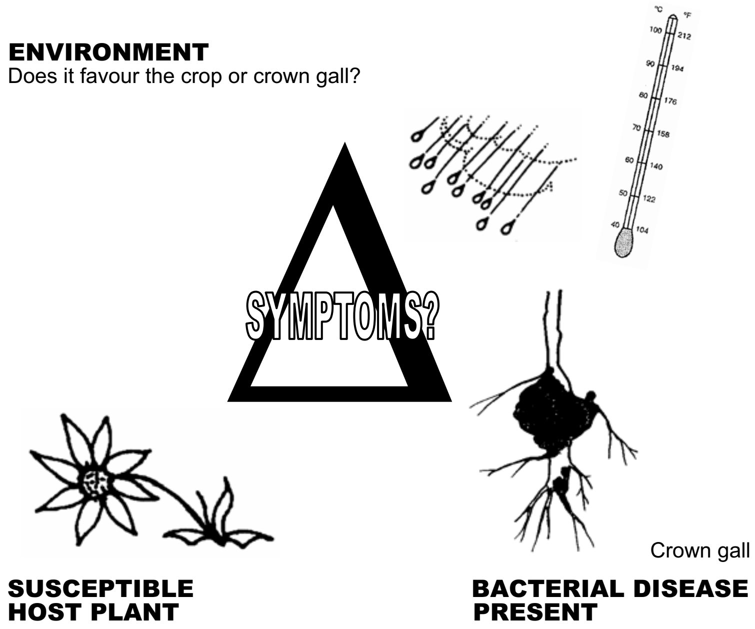


Fig. 153. Bacterial disease triangle.

INTEGRATED DISEASE MANAGEMENT (IDM)

MAIN STEPS

1. **Plan** well in advance to use an **IDM** program that fits your situation. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides.
2. **Crop/region**. **IDM** programs are available for some bacterial diseases on a range of crops in particular regions.
3. **Identification** of disease must be confirmed, consult a diagnostic service if necessary (page xiv). Have an understanding of the life cycle and of conditions favouring the disease. Obtain a Fact Sheet on the bacterial disease.
4. **Monitoring. Know when, where, what and how to monitor**. Early detection, together with appropriate control measures, can halt spread of disease. Monitoring can also indicate the effectiveness of earlier control measures.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? There is a nil threshold for some diseases under an eradication program, eg citrus canker.
6. **Action/Control** may include rogueing, strategic spraying, etc. and should be carried out at the right time. Institute **preventative** controls, eg sanitation, disease-tested planting material. There may be legal requirements. There are contingency plans etc for some diseases on some commercial crops, eg citrus canker.
7. **Evaluation.** Review your program to see how well it worked. Recommend improvements if necessary, eg use of disease-tested seed.

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Disease-tested material
Physical/mechanical
Pesticides
Organic, BMP, etc

CONTROL METHODS

Once established **bacterial diseases are usually difficult to manage**.

LEGISLATION

Relevant legislation includes Plant Quarantine Acts, Seed Acts, Certification and Accreditation Schemes, etc.

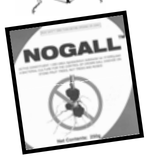
CULTURAL METHODS

- **Rotate crops** if the disease has a limited host range, eg bacterial blight of bean.
- **Space plants** to allow good air circulation to reduce disease levels.
- **Do not wet foliage unnecessarily**. Avoid overhead irrigation and working in wet crops if practical. Water with as little splashing as possible.
- **Adjust** cultural practices, eg fertilizing and watering, to **avoid** lush growth.
- Ensure seedbeds are **well drained**.
- **Avoid windy sites** or protect plants from wind to reduce plant injury and minimize bacterial aerosol formation.
- **Monitor and adjust environment** around crops to reduce disease pressure. Lower humidity in **greenhouses** and optimize soil pH and moisture levels consistent with **plant** needs, **not** those of the disease organism.

Sanitation is especially important if plants cannot be treated effectively with chemicals, eg **bacterial blight of pelargonium** (*Xanthomonas campestris pv. pelargonii*)

SANITATION

- Sanitation practices reduce the inoculum in the field and in greenhouses.
- **Rogue** infected crops, dispose of diseased plants and those immediately adjacent before disease spreads throughout the crop. It may be necessary to discard all plants belonging to one cultivar especially if it appears that only that cultivar is susceptible. Dispose of infected crop residues.
- **Prune** out and destroy infected **plant parts** as soon as observed, if practical, to assist control on woody plants, eg bacterial gall of oleander.
- **Sterilize** pruning tools before each cut and/or between plants to prevent the transfer of bacteria on secateurs, eg bacterial canker of stone fruit.
- **Disinfect** benches, used containers.
- **Clean trash from machinery** before disinfecting it **after** working in diseased crops and **before** working in disease-free crops.
- **Sanitize soil** or media, water and soil.
- **Do not handle diseased material** before handling healthy seed or moving through the crop. **Avoid movement** of machinery and workers from infected to disease-free crops especially when crops are **wet**.



BIOLOGICAL CONTROL

- **Soil bacteria.**
  - **Crown gall** is controlled in commercial plantings by the 'bio-pesticide', *Agrobacterium* sp. (Nogall®). The bacteria grow on the outside of susceptible nursery stock, cuttings or seed and are antagonistic to crown gall bacteria.
  - **Beneficial bacteria** are incorporated into soil and seed treatments (page 298).
- **Bacteriophages** are viruses that attack bacteria. They are being researched as a means of controlling bacterial diseases such as bacterial leaf and stem rot of pelargonium (*Xanthomonas campestris* pv. *pelargonii*).

CONTROL METHODS *(contd)*

RESISTANT, TOLERANT VARIETIES

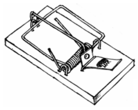
Use disease-resistant or tolerant cultivars suited to local conditions if available. Some walnut varieties show some resistance to bacterial blight (*X. campestris* pv. *juglandis*).

PLANT QUARANTINE

- **Australian Quarantine & Inspection Service (AQIS).** Some exotic bacterial diseases which have entered Australia have been eradicated, eg **ryegrass bacterial wilt** (*Xanthomonas translucent* pv. *graminis*) from Victoria and **citrus canker** (*Ralstonia solanacearum*) from Qld. There are many bacterial diseases overseas which are not as yet in Australia, eg
  - **Bacterial wilt** (*Ralstonia solanacearum* race 1) of *Eucalyptus*.
  - **Moko disease** (*R. solanacearum* race 2 biovar 1) of bananas.
  - **Fire blight** (*Erwinia amylovora*) of apples and pears which occurs in NZ.
  - **Sumatra disease** (*Pseudomonas syzygii*) of eucalypts, syzygiums
  - *Target list of diseases which might enter Australia* www.daff.gov.au/aqis/**quarantine**/naqs/**target-lists** *Padil - Pests and Diseases Image Library* www.**padil**.gov,au
- **Interstate and Regional Plant Quarantine**. Some bacterial diseases occur only in certain regions, eg halo blight of beans. Check state websites.
- **Local quarantine**. Bacterial diseases may be introduced into nurseries and gardens by the purchase of infected plants, eg bacterial diseases of carnation, bacterial gall of oleander.

DISEASE-TESTED PLANTING MATERIAL

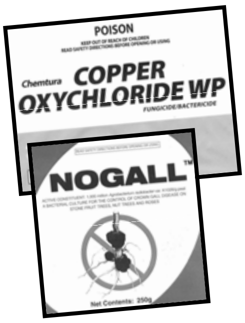
- **Seed. Many bacterial diseases are seedborne**.
  - Bacterial cells which get into the **water and food-conducting tubes** of plants spread quickly to fruits and seeds.
  - **Certified** bean seed guaranteed free from halo blight and certain other specified diseases is available for beans and other crops. Certified seed of some crops does not necessarily mean it is 100% free from a specified disease, a designated amount may be tolerated.
  - Do not save seed from infected crops unless it is treated with hot water, aerated steam or fumigated. Seek advice.
- **Vegetative propagation.** Do not propagate from infected plants. For some crops disease-tested planting material is available which is guaranteed free from certain bacterial diseases.
- **Only plant** disease-tested planting material in disease-free seedbeds, or in soil which does not contain infected plant residues.



PHYSICAL & MECHANICAL METHODS

- **Seeds** may be treated with hot water **(HW)** or aerated steam to kill **internal** bacteria. Prescribed **HW** treatment can penetrate seeds sufficiently to eradicate bacterial infections **inside** some of the seed only. Careful temperature regulation is required but some seeds, eg fleshy seeds such as beans and peas, cannot be treated with aerated steam or **HW**.
- **Soil pasteurization** (60^{o}C for 30 minutes) kills disease-causing bacteria in soil (page 330). Practical only for raising seedlings in greenhouses and frames.
- **Irradiation** destroys microorganisms, eg bacteria, fungi, and insects). Some non-edible items are irradiated in Australia (page 330).
- **Pulsed UV light** kills bacterial and fungi on the skin of many kinds of fruit, also improves fruit quality and extends shelf life up to 80 days.

Note - many biocontrol agents are registered as pesticides



BACTERICIDES

- **The use of chemicals** to control bacterial diseases has **not** been very successful. In Australia only a few fungicides, eg copper and mancozeb, are registered as foliar sprays. These are **non-systemic** and only prevent infection; they have no effect on established infections **inside** seeds or other plant parts, so that control is often unsatisfactory. Copper is used when conditions favour infection, development and spread; mancozeb may be used on young plants which may be damaged by copper. Formulations of copper are now available which are 'flowable' and easier to apply (pages 341). Note that copper fungicides have a **'POISON'** signal heading.
- **There is a low risk** that bacteria will develop a **resistance** to **copper** (page 341). Excess copper can harm plant growth, persist in the environment over a long time, may accumulate in some soils and be toxic to earthworms and some soil microbes.
- **Disinfectants** such as sodium hypochlorite also do **not** reach inside seed.
- Overseas **systemic antibiotics** such as streptomycin are available, but resistance may develop and they are not allowed on edible plant produce.
- **Biological pesticides** such as *Agrobacterium* sp. (Nogall®) are used to control crown gall (pages 302, 306).
- Pre-plant soil treatments with fumigants (or pasteurization) are suitable only for treating **small quantities** of infested soil, eg cutting beds. Only plant disease-tested seeds, cuttings and bare-rooted nursery stock into treated soil.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

EXAMPLES OF BACTERIAL DISEASES

Crown gall

This disease is serious on nursery stock but occurs sporadically. The same piece of ground may yield badly infected plants one year and completely healthy plants the following year.

Scientific name

Common soilborne bacteria (*Agrobacterium* spp., tumor state). Not all strains can infect all hosts. *Agrobacterium* sp. is considered to be a **natural genetic engineer**. The gall-inducing genes causing crown gall can be removed, but the infective ability retained to transfer genes, so that **DNA** is inserted into another plant cell.

Host range

Wide host range, mainly Rosaceous plants but other plants as well. Economic damage is largely confined to *Prunus* spp., rose and beetroot.
Ornamentals, eg chrysanthemum, *Prunus* spp., rose, also dahlia, geranium.
Fruit & nuts, eg pome and stone fruits (especially peach), bush fruits, grapevine, rhubarb, walnut.
Vegetables, eg beetroot.
Agrobacterium rhizogenes and *A. tumefaciens* (less frequently) affect Rosaceae plants such as stone fruit and roses. *A. vitis* infects grapevines and lives systemically in the vascular tissue of the host.

Symptoms

Below ground/crowns. Galls ranging in size from a pea to the size of a football develop at ground level or on the roots (Fig. 154). Galls often arise from root lenticels and are irregular in shape and their texture depends on the host species. Galls are the result of bacteria multiplying inside the host, producing hormones which stimulate the host to increase cell division and cell size resulting in the formation of galls. The vascular system is damaged, plants grow poorly and wilt readily. Galls may also develop on side roots but they probably do not do much damage. Other strains cause excessive root proliferation.

Above ground. Aerial galls have been recorded more than 100cm from the ground on grapevines and on the branches of trees overseas. There is some evidence that in these hosts, the bacteria can move through the vascular system and that gall formation may be associated with frost damage.

General. The effect of the disease is variable. Infected plants may lack vigour, become stunted and produce few flowers, however. **Young plants** which are infected when planting out or which become infected soon afterwards usually make unthrifty growth and may eventually die. **Older plants** which become infected may remain vigorous for many years. It is not uncommon to find established vigorous plants with large galls on roots and crowns showing no apparent reduction in vigour or other effects. Crown gall usually only affects the vigour of older plants in the field if they suffer moisture stress. Affected plants may die.

Grapevine. *A. vitis* unlike the gall-forming species, lives systemically in the vascular tissue of its host. Galls may develop where frost damage to canes and trunks has occurred or at the bases of cuttings used for propagation, or to major graft wounds in warmer areas.

Diagnostics. Do not confuse crown gall with:
- Natural adventitious 'burr' knots on *Prunus* sp. which occur at the base of the trunk in some species (page 397, Fig. 243).
- With natural lignotubers on eucalypts.
- Beneficial mycorrhizal roots on trees, eg alder.
- With forked roots in crops such as carrots which may be due to over-fertilization, unsuitable soil structure, transplanting seedlings, etc.
- With root knot nematode infections.
- With clubroot disease in brassicas.
- **Expert diagnosis is necessary**. As it is difficult to isolate bacteria from galls, **DNA** fingerprinting identifies strains on grapes.
- Remember galls are often only seen when roots or plants are dug up.

Fig. 154. Crown gall (*Agrobacterium* sp.).
Left: A large gall on rhubarb. ***Right:*** Galls on loganberry canes. Photo©CIT, Canberra (P.W.Unger).

Disease cycle

The disease cycle is quite simple (see Fig. 155 below). Susceptible healthy plants become infected when planted into infested soil.

'Overwintering'

- In galls on host plants (especially nursery stock) and in soil.
- The bacteria can live as saprophytes in the soil for years, but in the absence of hosts, the population gradually declines. *A. vitis* can be detected in plant debris in soil for at least 2 years.
- Main source of infection is planting material.
- If healthy vines are planted in old vineyard soils containing contaminated debris the new plants will be become infected.

Spread

- By movement of infested soil on machinery, in soil deliveries and containers, infected plants and contaminated soil water.
- By propagating from infected plants.
- On pruning, budding and grafting tools. Nursery plants may become infected through budding and grafting scars.

Conditions favoring

- Wounding of roots, crowns, stems or seeds by cultivation, insects or animals. On grapevines and *Rubus* spp. aerial galls are formed, thought to be associated with frost damage to the stems and canes.
- The repeated planting of susceptible species into infested soil.

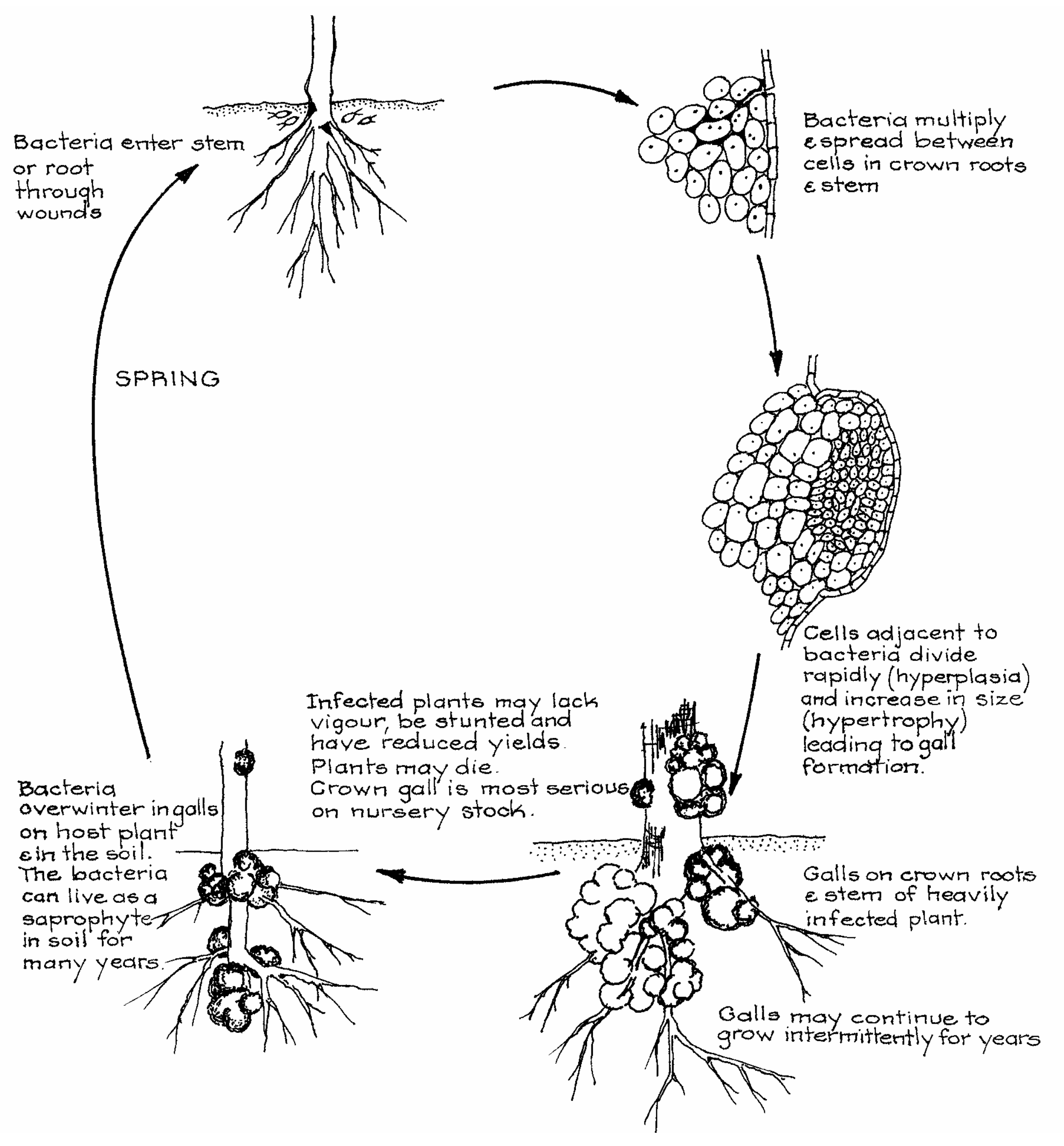


Fig. 155. Disease cycle of crown gall (*Agrobacterium* sp.) (adapted from Agrios, 1997).

Management (IDM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region.** Recognize variations.
3. **Identification** of disease must be confirmed. Consult a diagnostic service if needed (page xiv).
4. **Monitor** disease and/or damage and record results as recommended. Check sources of all planting material and inspect all new stock. Remember **know when, where, what and how to monitor**.
5. **Threshold.** How much damage can you accept? Do you need to calculate a threshold for your particular crop? This will depend on whether you are a commercial grower or a home gardener.
6. **Action.** Take action when any threshold is reached. Remember crown gall is a sporadic disease and is mainly a serious problem on **nursery stock**. If the disease is a regular problem commercial growers should treat susceptible planting material (Table 55).
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required. Monitor treated nursery stock, etc for the next few years after treatment where practical.

Control methods

Once a plant is infected with crown gall there is **no** reliable effective eradication treatment.

Cultural methods.

- **Avoid** wounding roots of trees and nursery stock when planting and during subsequent cultivation, crown gall enters only via relatively fresh wounds.
- Make sure graft union is **above** ground level. There is a greater incidence of crown gall on grafted nursery stock rather than on bud unions.
- Do **not** unnecessarily lime soil or add wood ash.
- Avoid repeatedly planting susceptible crops into infested soil unless roots, etc are treated with Nogall™. Some crops, eg corn or other grain crops, are resistant and would reduce the amount of inoculum in the soil.

Sanitation.

- **Destroy young plants** with galls at the graft union or near soil level. Remember older plants may tolerate infection.
- **Infected plants** should be dug up and burnt, and if practical, eg in a home garden, also dig up surrounding soil and burn, sterilize or replace.
- **Contaminated containers**, seed boxes and benches must be disinfected so that treated soil or healthy seed, cuttings and other nursery stock do not become infected.
- **Budding and grafting tools** must be disinfected to stop bacteria from spreading via budding and grafting (page 309).

Biological control.

- **Nogall®.** Where crown gall is a recurring problem, protect new plantings from attack by dipping planting material (seeds, cuttings or roots of young plants) in Nogall®. This a **non**-pathogenic strain of *Agrobacterium* sp. which produces an **antibiotic**, that **inhibits** the growth of the gall-forming strain of *Agrobacterium*. The non-pathogenic bacteria grow on wound sites produced during striking, root pruning, repotting, digging, planting, weeding, and frost. Susceptible plants are protected during their initial growth stage when they are likely to suffer severe damage if infected with crown gall.
- **Very occasionally**, strains of crown gall, eg those that infect grapevines, are not controlled by this method. Research is under way to use non-pathogenic strain of *A. vitis*.

Resistant varieties.

Within the known host groups there are no known resistant cultivars. Overseas research is attempting to develop resistant rootstock.

Plant quarantine. Avoid introducing crown gall to disease-free areas by purchasing from reliable suppliers of disease-tested planting material and avoiding introductions of infested soil. Make an effort to keep crown gall out of nurseries and gardens by inspecting all new stock and rejecting infected plants.

Disease-tested planting material.

- Main source of infection is **planting material**.
- Do not propagate from infected plant material. unless treated with a biological pesticide.
- Treated planting material **must** be planted in disease-free soil.
- **Disease-free soil** must only be planted up with **disease-tested planting material**, eg disease-tested nursery stock. Growers should purchase and plant only crown gall-free trees.

Physical & mechanical methods.

- Where crown gall is a problem in small areas such as seedbeds and cutting beds, soil can be pasteurized (60°C for 30 minutes).

Bactericides.

- There are **no non-fumigants** that will kill crown gall bacteria in soil.
- **Gall paints** have been researched for decades to eradicate gall from established woody plants. The usual method is to remove the gall and then apply paint to the raw surface. **Gallex®** (2,4-xylenol plus meta-cresol) is still being researched for the eradication of crown gall in established roses in the USA (Anyango and Odhiambo 2000).
- Controlling root chewing insect on grapevine stems in nurseries reduce wounds which are entry points for crown gall.

Table. 55. Crown gall – Biocontrol agent.

What to use?	When and how to apply?
PRE-PLANT DIPS **Seeds, roots of seedlings and cuttings** Nogall™ (*Agrobacterium radiobacter* var. *radiobacter* strain K102.) ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE	On stone fruit, almonds, pecans, walnuts, roses... Seeds, cuttings, bare plant roots may be **dipped** in a prepared suspension prior to planting in contaminated soil. Trim damaged roots before dipping. • Used to protect propagation material before planting. • Very effective on Rosaceous plants but not as useful on other plants such as chrysanthemum and grapevines. • Treatment is ineffective once infection has occurred.

Bacterial canker of stone fruit

Gummosis, Blast

This is a **serious disease** of ornamental and fruiting stone fruits. Infection of young trees is particularly severe often killing them.

Scientific name

A bacterium (*Pseudomonas syringae* pv. *syringae*). *P. syringae* pv. *morsprunorum* may also occur on cherry and plum in some areas.

Host range

Wide range of plants including:
Fruit & ornamentals, eg all fruiting and ornamental stone fruit, especially apricot, sweet cherry; also citrus, rose, lilac, poplar.
Vegetables, eg beans and peas.
A particular strain of bacteria may be **restricted** to a particular **host or group** of related hosts, so that the organism causing citrus blast may not be able to attack cherry and vice versa.

Symptoms

The disease is most serious on **young trees**.

Buds. Dormant buds may be blighted, resulting in the death of the bud and the formation of small cankers at the base. **Flowers.** Blossom blight may develop in favourable weather and this may develop into twig blight. **Leaves.** Water soaked spots develop which rapidly become brown and drop out giving a 'shot-hole' effect. Infection may result in thin yellow leaves which may be rolled. In moist conditions, young sappy shoots may wilt as a result of infection. There may be prolific defoliation in spring. **Fruit** of apricot and cherry trees develop sunken black lesions with underlying gum pockets. However, **lesions on fruit are variable**. Severe fruit infection is **most common** in cherry.

Branches and trunks. The most destructive damage is caused by the development of cankers on branches and trunks. Cankers extend more rapidly along a branch than round it, and may be more than 100 cm long before the branch is girdled and killed. Stem infection of young trees is usually fatal. There are 2 types of canker:
- **Gummosis canker.** Water soluble gum exudes from elongated dead areas of bark. The underlying wood shows extensive browning.
- **Soursap canker.** First noticed as a slightly sunken zone but if the bark is cut away dead tissue is found underneath. Later the bark is brown, moist or gummy and sour smelling, little or no gum is exuded. These cankers may not be noticed until spring when growth begins and limbs and even whole trees may collapse and die. Where a branch has been killed by girdling there is often prolific new growth below the canker.

Roots are seldom attacked.

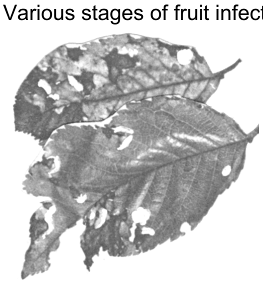
General. Infection of **young** trees is particularly severe and often results in their death.

Diagnostics. On stone fruit.
- State Fact Sheets are available online.
- Do not confuse bacterial canker with:
  - Bacterial spot of stone fruit (*Xanthomonas arboricola* pv. *pruni*.
  - Phytophthora trunk, collar and root rots (*Phytophthora* spp.).
  - Fireblight (if established in Australia).
- Seek expert advice from a diagnostic service.


Gumming on stem


Bark removed, brown dead tissue beneath


Various stages of fruit infection


Cherry leaves with brown spots and shot holes


Dieback of leaders and bud failure due to leaf scar infections

Fig. 156. Bacterial canker of stone fruit (*Pseudomonas syringae* pv. *syringae*).
Left: Photo©CIT, Canberra (P.W.Unger). ***Centre and Right:*** Photo©NSW Dept. of Industry and Investment...

Disease cycle

See Fig. 157 below.

'Overwintering'

- *P. syringae* bacteria are always present on leaves of all stone fruits (healthy and diseased).
- Bacteria can also overwinter as actively growing bacteria in cankers, in infected buds on stone fruit and other deciduous hosts, and in lesions on other hosts. Systemically in some hosts.
- The disease is **not** soilborne.

Spread

- Movement of infected nursery stock.
- By water splash, wind-blown leaves, irrigation water, insects and pruning tools. Bacteria are spread from cankers, infected buds, leaf spots and other lesions on the host to healthy parts.

Conditions favoring

- Cankers are first noticed in **early spring** when gum is produced in most cankers.
- Woody tissue of **actively** growing trees is generally **resistant** to canker infection, and that of **dormant** trees, **susceptible**.
- Autumn, winter and early spring are the danger periods for infection.
- Wounds, eg pruning scars, hail damage, leaf scars, stomates and other natural openings during wet windy conditions in autumn just before and during leaf fall. Frost injury.

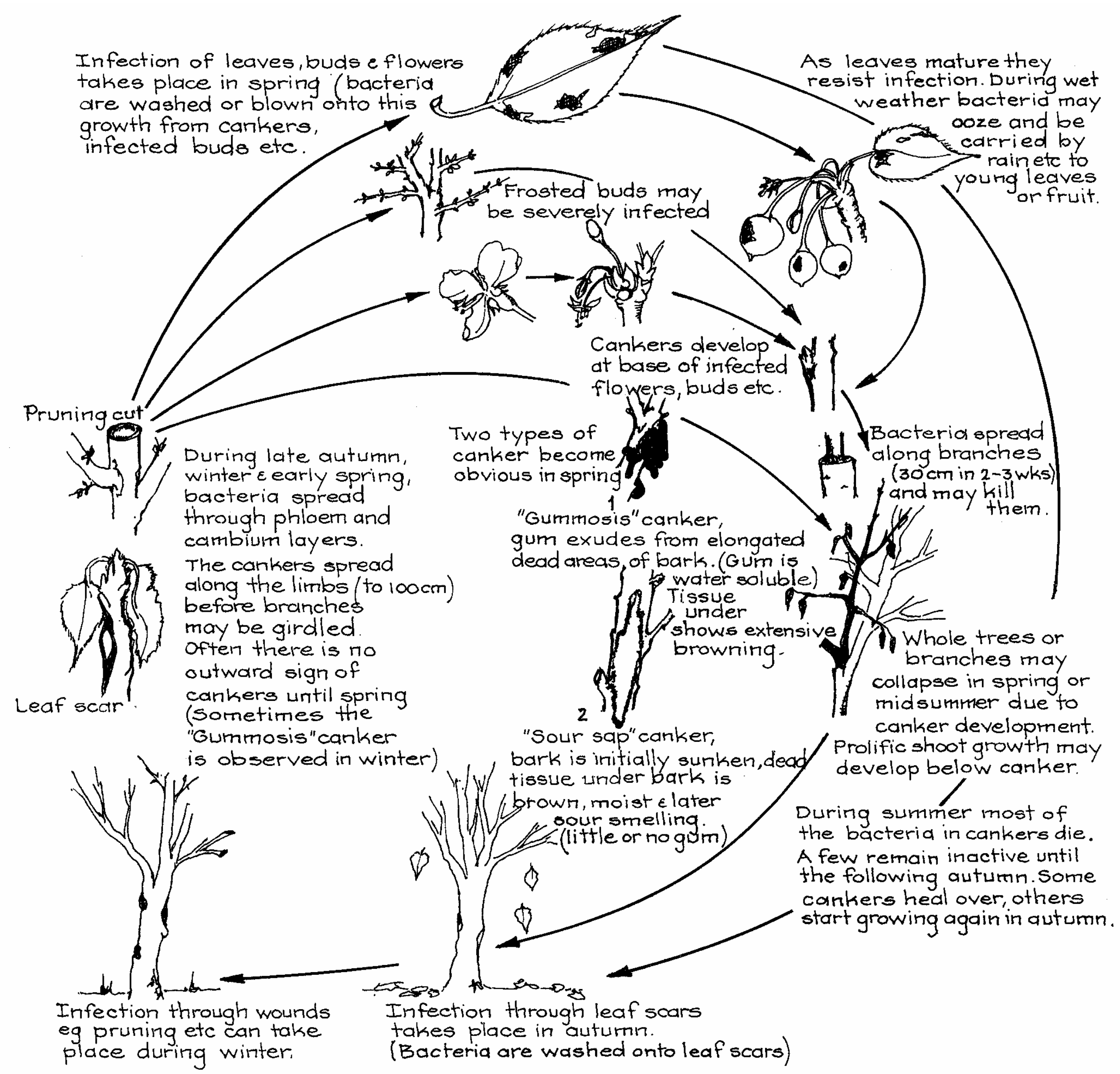


Fig. 157. Disease cycle of bacterial canker of stone fruit
(*Pseudomonas syringae* pv. *syringae*) (adapted from Agrios, 1997).

Management (IDM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. There are management programs for this disease in commercial growing areas, otherwise seek advice for this disease on your crop in your region.
2. **Crop, region.** Recognize variations.
3. **Identification** of disease must be confirmed, by a diagnostic service (page xiv).
4. **Monitor** symptoms. Seek advice on **when, where, what and how to monitor**. Record results.
5. **Threshold**. How much damage can you accept? Do you need to calculate your own threshold for a particular **crop** and **region**?
6. **Action**. Take appropriate action when any predetermined threshold is reached.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required.

Control methods

Generally young trees are affected more seriously than older trees. Once bacteria are established in bark or leaf tissue there is little chance of killing them so control measures aim to protect leaf scars, pruning and other wounds from infection.

Cultural methods.

- **There is evidence** that bacterial canker infections in young trees can be reduced by orchard practices which discourage vigorous growth.
- **Do not locate** susceptible orchards in areas where trees are subject to frost damage, waterlogged soils or prolonged drought.
- **Prevention of frost damage** before bud movement is also important in stopping entry through frosted buds.
- **Pruning generally** should be completed as soon as possible **after** leaf fall. Pruning cuts are one of the main points of entry and a large proportion of infection occurs through winter pruning cuts.
- **Prune** susceptible varieties of **young non-bearing trees** after bud burst when they are actively growing, **older trees** just before leaf fall. **Prune apricots** in late summer or autumn when warm and dry, or even when leaves are still on the tree, wounds heal and seal quickly.
- **Any pruning of cherry trees** required should be done **before** early autumn.
- **Trees should be protected** from wind driven rain and overhead irrigation. Irrigate when leaf surfaces can dry quickly.

Sanitation. .

- **Remove and destroy infected young trees** less than 4 years old. Sites can be replanted.
- **Sterilize pruning tools** between cuts and between trees, eg either by dipping in 70% methylated spirit or wiping with a rag moistened with methylated spirit.
- **In older trees**, cut out diseased wood. Scrape away large cankers, burn scrapings. Paint area with Bordeaux or similar paint. Alternatively large cankers may be cauterized with a blow lamp in spring and if necessary, again 2-3 weeks later. Neither treatments are guaranteed 100%.

Resistant varieties. While all stone fruits may become infected; apricot and cherry are **more susceptible** than others. **For cherries**:

- **Highly susceptible** - Florence, Napoleon, St. Margaret.
- **More tolerant** - Merton, Ron's Seedlings, Williams Favourite. Other imported resistant cherry cultivars are undergoing testing.
- **Susceptible varieties** should be propagated on rootstocks resistant to bacterial canker and should be grafted as high as possible.

Plant quarantine. Bacterial canker of stone fruit may be introduced into an area by the purchase of infected nursery stock and possibly by the use of contaminated secateurs.

Disease-tested planting material.

- Only purchase trees from reliable suppliers.
- New trees which are 'suspect' should not be planted but destroyed.
- Propagate only from trees with no symptoms. Only healthy budwood and rootstocks should be used for propagation.

Physical & mechanical methods.
Cankers on trunks and large branches can be controlled by cauterization with a handheld propane burner (Agrios 2005) in early to mid-spring. If considered necessary it can be repeated 3 weeks later.

Bactericides. Copper fungicides which are non-systemic and protectant only, are the main products currently available for controlling bacterial canker. Overseas streptomycin, which is systemic, is available for use.

Table 56. Bacterial canker of stone fruit – Some fungicides.

What to use?	When and how to use?
NON-SYSTEMIC PROTECTANTS **Group M1**, eg various® (copper oxychloride) **Group M1/M3**, eg Mankocide® (cupric hydroxide/mancozeb) CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE	Copper sprays can only be used as dormant sprays on stone fruit otherwise leaf and fruit burn may occur. Keep accurate records of spray programs from year to year. The number of sprays and timing of sprays will depend on: • The particular species of stone fruit, eg cherry, etc. • The region of Australia. • Whether the disease is of minor importance, moderately severe or severe. • Whether the trees are nursery stock, non-bearing, or bearing.

Bacterial leaf spots

Scientific name

Almost all bacterial spots and blights of leaves, stems and fruits are caused by bacteria in the genera *Pseudomonas* and *Xanthomonas* (see also page 297).

Host range

Wide range of plants, eg
Ornamentals, eg begonia, carnation, chrysanthemum, ferns, geraniums, gladiolus, hibiscus, poinsettia, *Prunus*, statice, stock, zinnia.
Fruit & nuts, eg mulberry, strawberry, walnut.
Vegetables, eg.cucurbits, lettuce.
Field crops, eg lucerne. Although some species of bacterial leaf spots can infect several species of plants, specific strains may be restricted to one host, or group of related hosts, eg one species may attacks lettuce another geranium and so on.

Symptoms

Spots (and blights) are the most common type of bacterial disease. Symptoms vary depending on the host and the specific disease organism.

Leaves.

- **Leaf spots** usually start as small lesions 1 mm in diameter on the leaf surfaces. The brownish spots enlarge to 2-10 mm across, have irregular borders and translucent or yellow halos.
  - Shape is usually affected by the leaf veins which may make the spots more angular.
  - On some hosts the center of the leaf spot falls out giving the leaf a **shot hole** appearance.
  - Fungal structures are absent.
- **Blight infections.** Spots can begin on leaf edges leaf dieback or the spots can join together killing the leaf.
  - Tissue is water soaked and slimy when newly rotted but dries out with age becoming brown and papery.
- **Systemic infection.** Bacteria may extend along leaf veins and establish in the vascular system which is blocked inhibiting the flow of water and nutrients to the foliage.
  - Young foliage or whole plants may wilt and die.
  - Older leaves may turn yellow and eventually die.
  - Discolored vascular bundles are visible when stems and petioles are cut.

Fruit. Leaf spot bacteria may also attack fruit, eg bacterial leaf spot of cucurbits

Stems. Black section may develop on stems.

Diagnostics.

- Do not confuse with fungal leaf spots, chemical toxicities, environmental problems, etc.
- Bacterial leaf spots are generally **angular** with a yellow halo. Fungal leaf spots are generally **round** with fungal structures present (often can only be seen with a hand lens or microscope).
- Sometimes bacteria invade already damaged plant tissue, ie they are secondary infections.
- Can test for bacterial ooze (page 295).
- Need an expert to confirm diagnosis (page 295).

Disease cycle

The disease cycle varies with the particular leaf spot disease.

'Overwintering'

Bacteria exist at very low levels:

- In or on plant parts and seed.
- Infected crop debris in soil.
- On contaminated tools, containers, or in the soil.

Spread

- Water splashed from infected to healthy plants.
- Recycled and untreated irrigation water, surface water. Wind blown rain, direct contact with host, insects such as flies, bees and ants, handling of plants, tools.
- Infected propagation material, eg cuttings, seed.
- Contaminated tools during pruning and cultivation.
- Clothes when brushed against diseased foliage, especially during wet weather.
- Infected soil in pots, on vehicles and footwear.

Fig. 158. Bacterial leaf and stem rot of pelargonium (*Xanthomonas campestris* pv. *pelargonii*). ***Upper:*** Leaf spots on ivy-leafed geranium appear sunken and water-soaked. ***Lower left:*** Stem rot, the brown withering and rotting progresses from the stem tips downwards. Photo©NSW Dept. of Industry and Investment. ***Lower right:*** Black sections on stems.

Conditions favoring

- Bacterial leaf spots are **more common** in warm, wet or humid climates, rather than dry, hot or cold climates. However, some bacterial diseases are common in wet cool winter, eg bacterial leaf spot of lettuce.
- Bacteria require free water for spread and infection.
- Plants can be infected through wounds.
- Generally lush growth favours leaf spots but on some hosts high fertilizer rates may reduce them.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare plan** that fits your situation.
2. **Crop, region.** Recognize variations in management plans depending on the region.
3. **Identification.** Accurate and early detection is essential for control and prevention of spread. Check leaves and suspect spots carefully for bacterial ooze to avoid confusion with other causes (page 310). If unsure consult a diagnostic service (page xiv).
4. **Monitor.** Find out if a monitoring system is available for your particular disease and crop. Remember **know when, where, what and how to monitor**.
5. **Threshold.** How much damage can you accept? Do you need to calculate your own threshold, eg damage threshold for your particular **crop** and **region** or are there prescribed threshold?
6. **Action.** Take appropriate action when required, including reduced irrigation, sanitation, etc.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required.

Control methods

Disease outbreaks can be extremely destructive and **difficult to control**.

Cultural methods.

- Avoid wounding.
- Avoid excessive nitrogenous fertilizer.
- Practice crop rotation as bacteria can survive on plant debris in the soil.
- Provide adequate ventilation between plants, avoid overcrowding nursery stock. Avoid overwatering. Increased spacings between plants may lower humidity.
- Keep foliage dry. Control the growing environment to reduce leaf wetness.
- Avoid walking through, or working in, susceptible crops while foliage is wet due to irrigation or wet weather.

Sanitation.

- Remove and destroy infected plants or leaves as soon as they are observed.
- Prune off affected branches at least 30-40 mm below the damaged area and destroy.
- If base of **main stem** is rotted remove and destroy the whole plant as soon as detected. Destroy systemically-infected plants.
- Destroy self-sown plants.
- Implement strict hygiene when growing highly susceptible crops.
- Staff must be trained in hygienic practices such as washing hands after handling diseased plants or soil, sterilization of tools, and wearing clean uniforms.
- Disinfect tools frequently when pruning.
- Sterilize benches used for preparing cuttings between batches to avoid chance contamination.
- All debris must be removed between crops to eliminate the risk of contamination.

Resistant varieties.

- Grow if available and practical, varieties with some resistance to bacterial leaf spots.
- Grow highly susceptible crops in greenhouses which keep out rain.

Plant quarantine.

- If new planting material is suspected of being infected grow separately from disease-free areas.
- **Keep stock plants separate**.
- Introduction of even **one** diseased cutting can result in rapid spread if conditions are favorable.

Disease-tested planting material.

- **Only plant disease-tested** seed, cuttings, nursery stock.
- Obtain planting material from a reputable source.
- Do not take cuttings or save seeds from infected plants.

Bactericides.

Copper-based fungicides are moderately effective in reducing some bacterial diseases. However they may be phytotoxic to some plants.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 57. Bacterial leaf spots – Some bactericides.

What to use?	When and how to use?
NON-SYSTEMIC PROTECTANTS **Group M1**, eg copper oxychloride; cupric hydroxide; cuprous oxide; Liquicop® (copper ammonium acetate); Tri-base Blue (tribasic copper sulphate) (page 341) - copper fungicides are non-systemic **Group M1/M3**, eg Mankocide™ (cupric hydroxide/mancozeb) - both are non-systemic	• Copper-based and mancozeb fungicide sprays can suppress bacteria on surfaces but will not eradicate established infections or prevent re-infection if conditions are favorable.

REVIEW QUESTIONS AND ANSWERS

By the end of this topic, you should be able to do the following:

1. List the **distinctive features** of bacteria.
2. Explain how bacteria **reproduce** and **infect host plants**.
3. Describe **symptoms** on leaves, flowers, fruit, seed, seedlings, branches, trunks, crowns, roots, bulbs, corms and tubers produced by local bacterial diseases. Name 1 example of each.
4. **Recognize by sight**, crown gall, bacterial soft rot and other **local** bacterial diseases.
5. **Distinguish between galls** caused by crown gall from those caused by other agents:

Root knot nematodes	Nitrogen-fixing nodules
Lignotubers	Burr knots
Gall wasps	Rust fungi

6. Distinguish between **bacterial and fungal leaf spots**.
7. Describe State/Territory/Commonwealth **legislation** which provides for the control of bacterial diseases.
8. List **control methods** for bacterial diseases. Describe 1 example of each.
9. Describe how bacteria may be used to **control insect pests of plants**.
10. Describe bacterial diseases for which it is important to **sterilize pruning tools** between each cut during pruning operations.
11. Explain how bacterial **seedborne diseases** may be controlled.
12. Provide the active constituent, some trade names and some uses for **1 bactericide**.
13. **Provide the following information** for crown gall and other local bacterial diseases:

Common name	'Overwintering'
Cause	Spread
Host range	Conditions favouring
Symptoms	**IDM** & control methods
Disease cycle	

14. Prepare/access an **IDM** program for a bacterial disease at your work or in your region.
15. Locate **reference material** and know where to obtain advice on the identification and control of bacterial diseases.

SELECTED REFERENCES

The Australasian Plant Pathology Society (APPSnet) www.australasianplantpathologysociety.org.au/
The American Phytopathology Society (APSnet) www.apsnet.org/
Royal Botanic Gardens Sydney www.rbgsyd.nsw.gov.au/

Fact Sheets by State/Territory Depts of Primary Industries are available online, eg
Crown gall
Bacterial Canker of Stone fruit
Bacterial Spot of Stone fruit

Organic standards

AS 6000—2009. *Standards Australia Organic and Biodynamic Products*. Standards Australia.
Organic Federation of Australia www.ofa.org.au
For organic certifiers, products etc

Quarantine

Commonwealth quarantine www.daff.gov.au/aqis
PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.padil.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. www.daff.gov.au and search for target lists
State websites have information of certain bacterial diseases and quarantine restrictions in their states

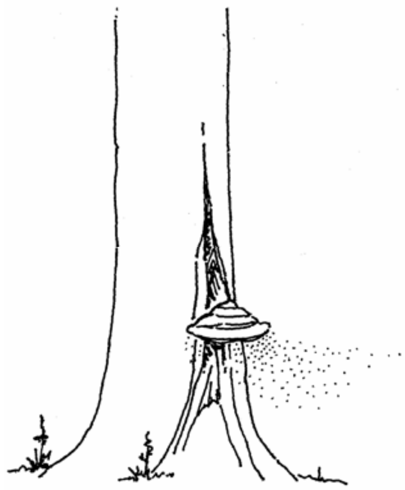
Bactericides

Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
Croplife Australia www.cropelifeaustralia.org.au/
MSDS www.msds.com.au/
Company websites make labels and MSDSs available
Regional Orchard Pest & Disease Handbooks

General

Agrios, G. N. 2005. *Plant Pathology*. 5th edn. Academic Press, NY. also 4th edn 1997.
American Phytopathological Society (APS) Press, St. Paul, Minnesota produces compendiums on diseases and pests of particular plants. www.shopapspress.org
Anyango, J. J. and Odhiambo, B. O. 2000. *Eradicating Crown Gall in Rosa hybrida Cultivars.* American Nurseryman May 15.
Bodman, K., Carson, C., Forsberg, L., Gough, N., Hughes, I., Parker, R., Ramsey, M. and Whitehouse, M. 1996. *Ornamental Plants : Pests, Diseases & Disorders.* Q196001. Qld DPI, Brisbane.
Brown, J. F. and Ogle, H. J. (eds). 1997. *Plant Pathogens and Plant Diseases.* Rockvale Pubs., Armidale, NSW.
Cooke, T., Persley, D and House, S. (eds) 2009. *Diseases of Fruit Crops in Australia*. CSIRO Pub., Melbourne.
Fahy, P. C. and Persley, G. J. 1983. *Plant Bacterial Diseases : A Diagnostic Guide.* Academic Press, North Ryde, NSW.
Goodwin, S., Steiner, M., Parker, R., Tesoriero, L., et al. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* Agrilink. QAL0004, NSW Agric. Sydney.
Goodwin, S. and Steiner, M. (eds). 2000. *The Pests, Diseases, Disorders and Beneficials in Ornamentals – Field Identification Guide.* DPI. Will be available as an electronic device for use in the field.
Horst, R. K. (ed.). 2008. *Westcott's Plant Disease Handbook*. 7th edn. eReference, originally published by Springer, NY.
Janse, J. D. 2005. *Phytobacteriology: Principles and Practice*. CABI Pub., Wallingford.
Jones, D. L. and Elliot, W. R. 1986. *Pests, Diseases & Ailments of Australian Plants.* Lothian Pub., Melbourne.
McMaugh, J. 1994. *What Garden Pest or Disease is that?* Lansdowne Press, Sydney.
Persley, D., Cooke, T. and House, S. 2010. *Diseases of Vegetable Crops in Australia.* CSIRO Pub., Melbourne.
Ryder, M. H., Stephens, P., Bowen, G. D. (eds). 1994. *Improving Plant Production with Rhizosphere Bacteria.* CSIRO, Melbourne.
Stephens, R. (ed.). 2001. *Water Fogging and Misting Systems : Are they a Risk to Human Health.* The Nursery Papers 2001/5, Melbourne.
Streton, C. and Gibb, K. 2006. *Phytoplasma Diseases in Sub-tropical and Tropical Australia.* Australasian Plant Pathology 35, 129-146.
Vadakattu, G. and Paterson, J. 2006. *Free-living Bacteria Lift Soil Nitrogen Supply*. Farming Ahead, Feb.
Walker, G. 2006. *Biocontrol Organisms and Human Health*. Australasian Nematology Newsletter, Vol.7,1.

Fungal Diseases



Wood rot fungus, spores are spread by wind.

BIOLOGY, IDENTIFICATION AND CLASSIFICATION

Fungal diseases

NO. DISEASES IN AUSTRALIA

Several thousand species of fungi can cause diseases of plants in Australia. Some fungal diseases are considered to have altered the course of history, eg the devastating effect of coffee rust in Ceylon in the 19th century is given as the main reason for the British being now mainly tea drinkers.

Fungimap www.rbg.vic.gov.au/**fungimap** /fungi_down_under
The Australasian Plant Pathology Society (APPSnet) *Pathogen of the Month* www.**australasianplantpathologysociety**.org.au/
The American Phytopathology Society (APSnet) www.**apsnet**.org/
Australasian Mycological Society www.australasianmycology.com/

SOME DISTINCTIVE FEATURES

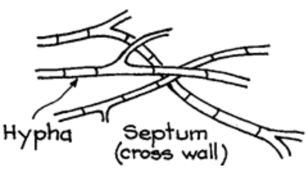
Hyphae produce enzymes which change the plant tissues into substances the fungus can use for nourishment

Fungi were originally considered to be very simple members of the plant kingdom but are now in a separate kingdom of their own:

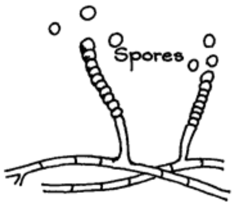
MYCELIUM Fungi have a **very simple plant body** called a mycelium which is made up of thread-like filaments called **hyphae** which usually can only be seen under a microscope (x 100). Hyphae obtain food from the host which makes them similar to plant roots, sometimes forming structures which help the fungus survive and spread.

CHLOROPHYLL They contain **no chlorophyll** and so **cannot** manufacture their own food.

REPRODUCTION They **reproduce by spores** which are important in the **spread** and '**overwintering'** of disease.



Mycelium (x 100)



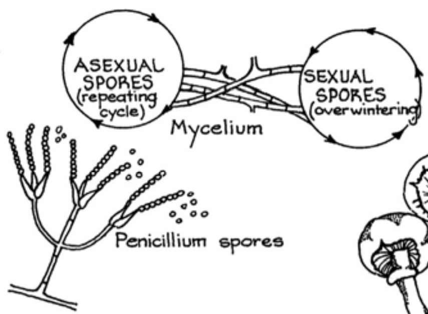
Mycelium and spores of powdery mildew (x 100)

LIFE CYCLE

THE MAIN METHOD OF REPRODUCTION IS BY SPORES.

- Spores may be **single-celled** or **multi-celled**.
- Although single spores can be seen **only** with the aid of a **microscope**, larger masses of spores **can** be seen with the naked eye, eg the fine blue or green powder on a mouldy orange or lemon is in fact, billions of tiny spores.
- **Generally 2 types of spores are produced**, ie **asexual repeating** spores produced during the growing season and **sexual 'overwintering'** spores.
- Spores are produced near the **outside of the plant or on the soil surface** so they can be easily spread by wind, etc.
- Spores **may or may not be produced in fruiting bodies** which may be as large as mushrooms. However, the fruiting bodies of fungi that attack plants are usually much smaller and may appear as pinhead-size black dots on an area of damaged leaf eg *Septoria*.
- Fungi obviously produce **millions of spores**. While most spores never reach a site suitable for their germination, those that do only germinate and successfully cause infection if some moisture is present.

At germination fungal spores produce a small tube which begins to elongate and branch forming hyphae



Spores not in fruiting bodies (x 100)

Spores in fruiting bodies

SYMPTOMS, DAMAGE

Many fungal diseases cause several symptoms to develop, eg **Shothole of stone fruit** may cause **shotholes** on leaves, **cankers, gumming and dieback** of stems; **gumming and scabs** may develop on fruit

DIRECT SYMPTOMS/DAMAGE

LEAVES
- **Anthracnose***, eg anthracnose of rose
- **Defoliation**, eg black spot of rose
- **Galls**, eg azalea leaf gall
- **Leaf curls**, eg peach leaf curl
- **Leaf rolls**, eg powdery mildew of rose, apple
- **Leaf spots**, eg leaf spot of celery
- **Pigmentation**, eg leaf spot of azalea
- **Spores present**, eg
  - Red, orange or black, eg **rust**
  - White (on upper & lower surface), eg **powdery mildew**
  - White (on under surface only), eg **downy mildew**
- **Scabs**, eg apple scab, shothole of stone fruit
- **Witches' broom***, eg shothole of apricot
- **Wilt**, eg *Verticillium* wilt of chrysanthemum

FLOWERS
- **Blights*,** eg blossom blight of azalea
- **Grey spores**, eg blossom blight (*Botrytis* sp.), brown rot of stone fruits, some powdery mildews look grey
- **Pink spots**, eg early stages of blossom blight (*Botrytis* sp.) on white flowered varieties

FRUIT
- **Freckle***, eg freckle of stone fruit
- **Gumming**, eg shothole of almond
- **Rots**, eg storage rots of fruit and vegetables
- **Russet***, eg powdery mildew of apple
- **Scabs**, eg apple scab, citrus scab
- **Spots**, eg black spot of grape
- **Spores present**, eg blue mould of citrus, brown rot of peach

STEMS, TRUNK
- **Cankers***, eg shothole of stone fruit
- **Dieback**, eg *Phytophthora* root rot of eucalypts
- **Galls**, eg gall rust of wattle
- **Gumming**, eg shothole
- **Rot**, eg wood rot, basal stem rots

SEEDS
- **Ergots**, eg rye ergot, paspalum ergot
- **Smuts**, eg loose smut

SEEDLINGS
- **Damping-off***, eg seedlings, cuttings

BULBS, CORMS
- **Rots**, eg *Fusarium* rots
- **Scabs, warts**, eg powdery scab of potato

CROWNS
- **Rot**, eg *Rhizoctonia* stem rot, *Sclerotium* stem rot

ROOTS
- **Galls**, eg clubroot of crucifers
- **Rot**, eg *Phytophthora* root rot

INDIRECT DAMAGE

- **Nematode-fungal disease complexes** are described on page 253.
- **Aflatoxins.** *Aspergillus flavus* produces aflatoxin when growing on certain crops eg peanuts. As it is poisonous to animals and humans in minute concentrations, there is a legal maximum permitted concentration of aflatoxin in peanuts in Australia.
- **Mushroom poisonings.**
  - **Yellow stainer** (*Agaricus xanthodermus*) mushroom causes most mushroom poisonings in southern Australia (looks similar to field mushrooms).
  - **Death cap** (*Amanita phalloides*) has a mycorrhizal relationship with exotic oak trees and came from its native Europe on one of the first oak seedlings to arrive in Australia. Extending root systems of older trees in Australia means that fruiting bodies could be found up to 200 metres away from any given oak tree. Mycologists are now concerned that it could naturalize onto eucalypts and spread into native forest reserves and suburban backyards around Australia.
- **Allergic responses, breathing difficulties and hay fever** may be caused by the spores of some fungi.
- **Diseases of animals and humans**, eg ringworm, tinia; also thrush (*Candida albicans*) and Sauna-taker's disease (*Aurobasidium pallulans*). **Cryptococcisus** (*Cryptococcus neoformans* var. *gatti*) occurs in the tropics and sub-tropics in association with some eucalypt species, eg *Corymbia camaldulensis*, causing a range of diseases in susceptible individuals. **Sporotrichosis** (*Sporothrix schenckii*) occurs worldwide in tropical and temperate regions and is commonly found in soil and decaying vegetation and is well known to infect humans and animals.

* Terms marked with an asterisk have a special meaning and are described in the glossary.

Symptoms on leaves

Fig. 159. Shothole (*Stigmina carpophila*) of cherry. Leaf spots break away from the leaf tissue. Photo©CIT, Canberra (P.W.Unger).

Fig. 160. Fungal leaf spot of strawberry. Photo©CIT, Canberra (P.W.Unger).

Fig. 161. Powdery mildew (*Oidium* sp.) of euonymus. Photo©CIT, Canberra (P.W.Unger).

Fig. 162. Rust (*Puccinia anthirrhini*) of snapdragon. Raised pustules containing spores develop on leaves and stems. Photo©CIT, Canberra (P.W.Unger).

Symptoms on flowers

Fig. 163. ***Left:*** **Petal blight, grey mould** (*Botrytis cinerea*) on rose petals. ***Left:*** White spots on pink petals. ***Centre:*** Pink spots on white petals. ***Right:*** Brownish spots on white petals.Photo©CIT, Canberra (P.W.Unger).

Fig. 164. Azalea petal blight (*Ovulinia azaleae*) disfiguring petals on azalea in wet weather. Photo©NSW Dept of Industry and Investment.

Symptoms on seeds, seedlings, cuttings

Fig. 165. Loose smut (*Ustilago avenae*) of oats. Photo©NSW Dept of Industry and Investment (M.S.Senior).

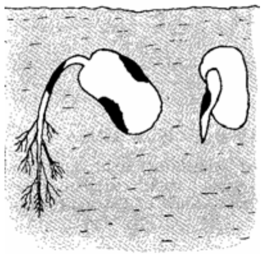


Fig. 166. Damping-off symptoms on seeds before they germinate, caused by various fungi and bacteria. Photo©NSW Dept of Industry and Investment.

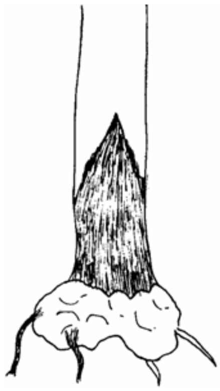


Fig. 167. Damping-off symptoms on cuttings caused by various fungi. Photo©NSW Dept of Industry and Investment.

Symptoms on fruit

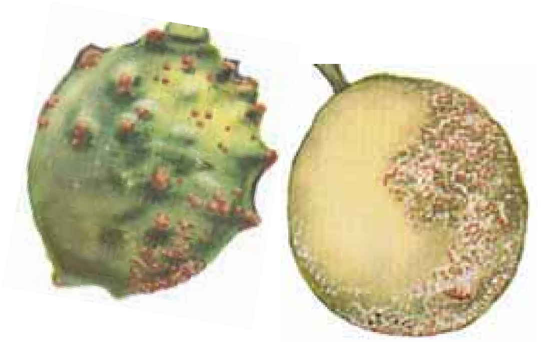


Fig. 168. **Lemon scab** (*Sphaceloma fawcettii* var. *scabiosa*). ***Left:*** On rough lemon. ***Right:*** On Eureka lemon. Photos© NSW Dept of Industry and Investment (M.S.Senior).

Fig. 169. **Black spot** (*Elsinoe ampelina*) on grape berries. Photo©NSW Dept of Industry and Investment (M.S.Senior).

Fig. 170. Brown rot (*Monilinia fructicola*) infection of peach fruit causing fruit rots and twig blight. Photo©NSW Dept of Industry and Investment (M.S.Senior).

Fig. 171. Freckle (*Cladosporium carpophilum*) on nectarine fruit. Photo© NSW Dept of Industry and Investment (M.S.Senior).

Symptoms on crowns, stems, roots

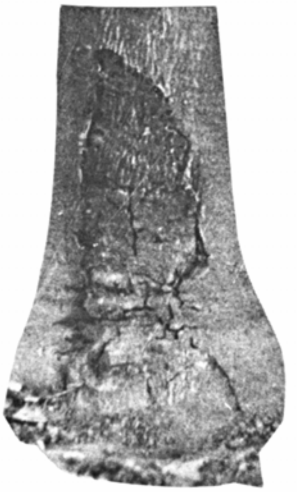


Fig. 172. Collar rot (*Phytophthora* sp.) on citrus. Photo©NSW Dept of Industry and Investment.

Fig. 173. Red wood rot fungus (*Pycnoporus coccineus*). Brackets at the base of the main leader of a peach tree. Photo©NSW Dept of Industry and Investment (M.S.Senior).

Fig. 174. Stem canker (*Coniothyrium fuckelii*) on rose canes. Photo©NSW Dept of Industry and Investment.

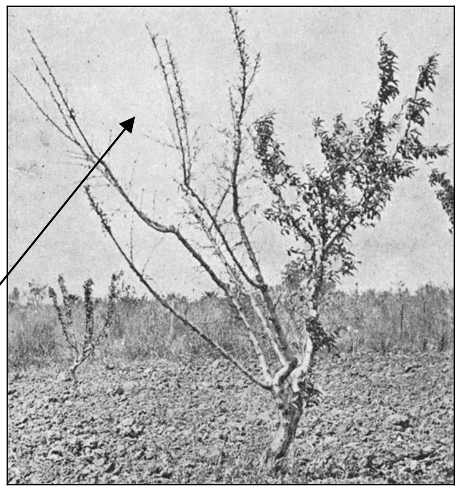
Fig. 175. Phytophthora root rot (*Phytophthora citrophthora*) on a 2-year old rough lemon showing the absence of root hairs. Photo©NSW Dept of Industry and Investment.

Fig. 176. Rhizoctonia stem rot (*Rhizoctonia solani*) on beans. Photo© NSW Dept of Industry and Investment (M.S.Senior).

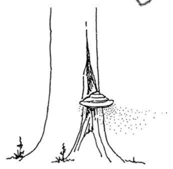
Fig. 177. **Damping off** (various fungi) causes bare patches in seedling trays. Photo©CIT, Canberra (P.W.Unger).

Non-specific symptoms

Fig. 178. Peach leaf curl (*Taphrina deformans*). Severe defoliation of a peach tree affected by peach leaf curl causing smaller crops and seriously weakening the tree. Photo©NSW Dept of Industry and Investment.

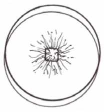


IDENTIFICATION



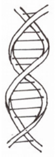
Fruiting body of a wood rot fungus, a "conk"

Powdery mildew



Culture

ALERT TESTING KIT



DNA

SYMPTOMS EXHIBITED BY THE HOST PLANT

Foliage fungal diseases are possibly easier to diagnose in the field than other diseases but can still be difficult, expert help is often needed and nearly always needed for soil diseases. The presence of signs and symptoms may be sufficient for a preliminary diagnosis of some fungal diseases, eg **signs** of grey powdery coating on leaves (powdery mildew) or **symptoms**, eg leaf spots.

DETECTION AND IDENTIFICATION BY EXPERTS

- **Microscopy** detects and identifies some diseases which cannot be cultured, eg powdery mildew, or when fungicides have been previously applied. Examine affected tissue directly, under a low powered (dissecting) or high powered (compound) microscope for mycelium, fruiting structures and spores which may be sufficient for a useful diagnosis. If spores are lacking, diseased tissue can be kept in a high humidity chamber for a few days or cultured to promote spore development. Spores of some species of *Phytophthora*, *Pythium* and *Cylindrocladium,* or the characteristic hyphae of *Rhizoctonia*, can be identified this way. Lucid keys www.**lucidcentral.org/**
  Interactive Key to the Fungi of Australia
  Key to Common Microscopic Fungi (for schools)
  Fungi of Australia
  Key to 101 Forest Fungi of Eastern Australia
- **Isolation and culture** from infected material obtains pure cultures of fungi which can be identified from the spores produced. Suspect plant tissue or seeds are placed on agar media and the organisms that grow from it identified. Others need to be incubated under certain temperature, aeration or light conditions to produce spores. **Baiting** for disease organisms, eg *Phytophthora, Pythium*, *Rhizoctonia,* involves floating plant material (carrot, lupin baits) on the surface of a representative sample of soil, media or water and observing the baits for signs of fungal invasion and rotting.
- **Biochemical tests** are used for accreditation schemes. Commercial growers use Alert Fungal Disease Kits to detect soil fungi, eg *Phytophthora, Pythium, Rhizoctonia.*
- **ELISA** tests are quick, efficient and mostly laboratory-based, some can be used on-site. The fungus reacts with chemical reagents to cause a detectable color change.
- **DNA** techniques are used to identify fungi, eg *Phytophthora*, black sigatoka smut of banana. The *Phytophthora* – IDENTIKIT™ has been marketed. An in-field clubroot diagnostic test is in the process of development.
- **Wide range of soil pests and diseases** can be identified from a single soil sample.

CLASSIFICATION

Knowledge of classification helps in in understanding the biology of fungi and their control

CLASSIFICATION is mainly according to types of **mycelium** (with or without cross walls, etc) and **sexual spores** produced and can be complicated (Agrios 2005). Fungi and fungal-like organisms are grouped into various **Phyla**, eg

- **Fungal-like organisms** (various Kingdoms) which include the following phyla:
  - **Myxomycota** (slime moulds) on lowlying plants (not parasitic on plants).
  - **Plasmodiophoromycota** (endoparasitic slime moulds), eg powdery scab of potato tubers.
  - **Oomycota** (water moulds), eg *Pythium, Phytophthora*, downy mildews.
- **True fungi** belong to the Kingdom Fungi which include the following phyla:
  - **Chytridiomycota** (zoospores), eg *Olpidium* (can transmit virus diseases).
  - **Zygomycota** (spores in sporangia), eg bread moulds (*Rhizopus, Mucor*).
  - **Ascomycota** (ascospores in a sac), eg powdery mildews, peach leaf curl, yeast.
    Imperfect Fungi produce asexual spores, not known to produce sexual spores, eg some powdery mildews (*Oidium* sp.).
  - **Basidiomycota** (basidiospores in a club), eg mushrooms, wood rots, rusts, smuts.
    Sterile Fungi are not known to produce any kind of spores, eg *Rhizoctonia.*

WHAT IS IT'S PROPER NAME?

When the sexual state of an Imperfect or Sterile Fungus **is** found, it is usually given the name of the sexual stage. However, if the name of the asexual or sterile stage is common and well known, it may continue to be used in preference to the new name.

Powdery mildew of pea	**Rhizoctonia root rot**
Imperfect Fungi - *Oidium* sp. Ascomycota - *Erisyphe pisi*	Sterile Fungi - *Rhizoctonia solani* Basidiomycota - *Thanatephorus cucumeris*

WHY IS KNOWLEDGE OF THE FUNGAL GROUP IMPORTANT?

Most fungicides are selective, ie they are effective against one group of fungi but not another. Fungicides belonging to the **same chemical groups** tend to be effective against **similar groups of fungi**. There are exceptions and some of the newer fungicides are effective against **both** downy and powdery mildews.

LIST OF SOME FUNGAL DISEASES	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)


Plasmodium


Thick-walled Spores


Motile zoospores

PHYLUM MYXOMYCOTA (slime moulds)

1. **No mycelium**. Body is a **plasmodium** (naked slimy mass of protoplasm) which grows on low-lying parts of plants, does **not** infect them. Various colours, gray to yellow.
2. **Sexual spores** are thick-walled resting spores, which may survive for years in soil.
3. **Asexual spores** are thin-walled zoospores with flagella, which can swim in water.

Common name	Scientific name	Host range
Slime moulds	*Fuligo*, *Physarum*, *Diachea*	Non-parasitic, grows on turf, onions, mulch material

PHYLUM PLASMODIOPHOROMYCOTA (endoparasitic slime moulds)

1. The body is a plasmodium **within** the cells of root and stems of plants.
2. Asexual spores are thin-walled zoospores.

Common name	Scientific name	Host range
Clubroot	*Plasmodiophora brassicae*	Brassicas, eg cabbage, stock
Powdery scab	*Spongospora subterranea*	Potato

PHYLUM OOMYCOTA (algal fungi, water moulds)


Hyphae


Thick-walled spores

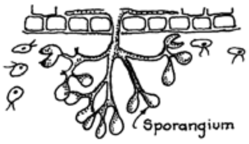
1. Mycelium present, hyphae well developed with few cross walls.
2. **Sexual spores** are thick walled resting spores called **oospores**.
3. **Asexual spores** may be:
   - Thin-walled zoospores with flagella which can swim in water and are produced in sporangia. In some species conidia are produced.
   - Thick walled resting chlamydospores adapted to withstand adverse conditions.

ROOT ROTS

	Common name	Scientific name	Host range
	Crown and collar rots, root rots	*Phytophthora* spp.	Some have a wide host range, others are host specific
	Damping-off	*Pythium* spp. *Phytophthora* spp.	Seedlings. Other fungi can also cause damping-off
	Phytophthora root rot	*Phytophthora cinnamomi*	Wide range of plants
Not known in Australia	Sudden oak death	*P. ramorum*	Oak, over 40 plant genera

DOWNY MILDEWS

Common name	Scientific name	Host range
Downy mildews	Many genera, eg	Usually **host specific**, eg
	Bremia lactucae	Lettuce
	Peronospora destructor	Onion
	P. parasitica	Brassicas, eg stock
	P. sparsa	Rose
	P. violae	Pansy
	Pseudoperonospora cubensis	Cucurbits, eg pumpkin
	Plasmopara viticola	Grape



Zoospores released from sporangia downy mildew

MISCELLANEOUS DISEASES

Common name	Scientific name	Host range
Late blight, Irish blight	*Phytophthora infestans*	Potato, tomato, Solanaceae
Soft rot	*Rhizopus* spp.	Stored fruit & vegetables
White blister	*Albugo candida*	Brassicas
Anthracnose	*Colletotrichum fragariae*	Strawberry
Celery leaf curl	*C. acutatum.*	Celery

PHYLUM CHYTRIDIOMYCOTA (water moulds)

Common name	Scientific name	Host range
Water moulds	*Olpidium* spp.	Can transmit virus diseases

PHYLUM ZYGOMYCOTA (bread moulds)


Zygospore

1. **Sexual** thick-walled resting **zygospores**.
2. **Non-motile asexual spores** in sporangia, no motile zoospores.

Common name	Scientific name	Host range
Bread moulds	*Mucor, Rhizopus*	Stored fruit, vegetables

PHYLUM ASCOMYCOTA, IMPERFECT FUNGI


Hyphae


Cleistothecium

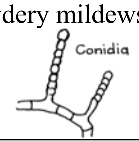
1. Mycelium present, well developed **with** cross walls.
2. **Sexual spores**:
   - **Ascospores** produced in groups of 8 in a sac-like **ascus** directly on the surface of plant material or in special fruiting bodies, eg cleistothecia, perithecia, apothecia.
3. **Asexual spores**:
   - Thin-walled **conidia** which may be produced on the surface of the host or in fruiting bodies eg pycnidia, acervuli, etc
   - Thick walled chlamydospores adapted to withstand adverse conditions.

ANTHRACNOSE DISEASES

Common name	Scientific name	Host range
Anthracnose	*Sphaceloma rosarum*	Rose
Anthracnose	*Gnomonia errabunda*	Plane trees

BLIGHTS

Common name	Scientific name	Host range
Blossom, flower, petal blights, grey mould	*Botrytis cinerea*	Wide range, eg flowers, fruit geraniums, roses
Petal blight	*Ovulinia azaleae*	Azalea
Early blight of tomato	*Alternaria solani*	Potato, tomato, related weeds

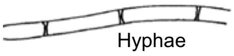
LIST OF SOME FUNGAL DISEASES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	PHYLUM ASCOMYCOTA, IMPERFECT FUNGI		*(contd)*
	CANKERS		
	Botryosphaeria canker, bunch rot, etc	*Botryosphaeria* spp.	Many trees, grapevines, stone and pome fruits
	Cypress canker	*Seiridium* spp.	Chamaecyparis, Cupressus
	LEAF CURLS		
	Leaf blister	*Taphrina aurea*	Poplar
	Peach leaf curl	*T. deformans*	Stone fruit
	LEAF SPOTS		
 Conidia in an acervulus	Leaf spots	Many species, eg *Cercospora beticola* *C. handelii* *Mycosphaerella fragariae* *Mycosphaerella* (> 60 spp.) *M. pinodes* *Septoria apiicola*	Usually host specific, eg Beet Azalea Strawberry Eucalypts Pea Celery
	Black spot	*Marssonina rosae*	Rose
	Black spot	*Elsinoe ampelina*	Grapevine
	Black spot (scab)	*Venturia inaequalis*	Apple
	Black spot (scab)	*V. pyrina*	Pear
	POWDERY MILDEWS		
 Powdery mildew mycelium sending haustoria into cells of	Powdery mildews 	Many genera, eg *Erisyphe graminis* *E. pisi* *Podosphaera leucotricha* *Sphaerotheca pannosa* *Erisyphe necator*	Usually **host specific**, eg Cereals, grasses Pea Apple Rose Grapevines
	FRUIT/ POSTHARVEST DISEASES		
 Powdery mildew, spores in perithecium	Bitter rot, stem canker	*Glomerella cingulata*	Apple, other trees and shrubs
	Brown rot	*Monilinia fructicola*	Stone fruit
	Fleck	*Diplocarpon mespli*	Quince, pear, hawthorn
	Freckle	*Cladosporium carpophilum*	Stone fruit
	Storage rots	*Aspergillus, Botrytis, Mucor, Penicillium, Alternaria*, etc	Stored fruit, vegetables
	ROOT ROTS		
	Fusarium root/stem rot	*Fusarium solani*	Vegetables
	Brown patch	*Bipolaris*, *Drechslera,* etc	Turf grasses
	Corm rot	*Penicillium gladioli*	Gladiolus
	Sclerotinia rot	*Sclerotinia* spp.	Wide host range
	Spring dead spot	*Leptosphaeria spp.*	Intensively managed couch
	Black root rot	*Thievaliopsis basicola*	Damping off, vegetables, etc, cotton, other hosts
	Ashy stem blight, charcoal rot	*Macrophomina phaseolina*	Beans, peas, other plants
	Aphanomyces root rot	*Aphanomyces cochlioides*	Young plants, eg beet
	Take-all	*Gaeumannomyces graminis* var. *avenae*	Cereals, various grasses
	SCABS		
	Apple scab	*Venturia inaequalis*	Apple
	Pear scab	*V. pyrina*	Pear
	Citrus scab	*Sphaceloma fawcetti* var. *scabiosa*	Citrus
	WILTS		
	Fusarium wilt	*Fusarium* spp.	Wide host range (strains)
	Verticillium wilt	*Verticillium dahliae* *V. albo-atrum*	Wide host range Potato
Not known in Australia	Dutch elm disease (DED)	*Ophiostoma ulmi*	Elms
	MISCELLANEOUS DISEASES		
	Dollar spot	*Sclerotinia homeocarpa*	Turf grasses
	Ergot	*Claviceps* spp.	Paspalum, rye, cereals, grasses
	Eutypa dieback, dying arm	*Eutypa lata* = *E. armeniacea*	Apricot, grapevine, other woody plants
	Ink spot	Several species	Kangaroo paw
	Shothole	*Stigmina carpophila*	Stone fruit
	Sooty mould **(non-parasitic)**	*Capnodium* spp.	Grows on honeydew secreted by aphids, lerp, mealybugs, soft scales, whiteflies
	Yeast sugar rot	*Geotrichum candida*	Gerbera, others

LIST OF SOME FUNGAL DISEASES *(contd)*

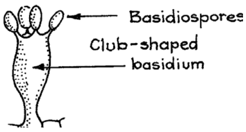
COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)

PHYLUM BASIDIOMYCOTA (Basidiomycetes)

1. Mycelium is well developed, hyphae with cross walls.
2. **Sexual spores** are thin walled **basidiospores** produced externally on club-like, 1-4 celled **basidium**., eg azalea leaf gall or in special fruiting bodies, eg mushrooms, or in a variety of other ways, eg rusts and smuts. Some produce additional sexual spores, eg rusts.
3. **Asexual spores** (conidia and oidia) **similar to the Ascomycota** are sometimes produced. The rusts produce a variety of additional asexual spores, eg urediniospores.



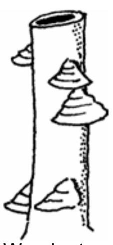
Hyphae



Basidiospores are produced over the surface of gills.

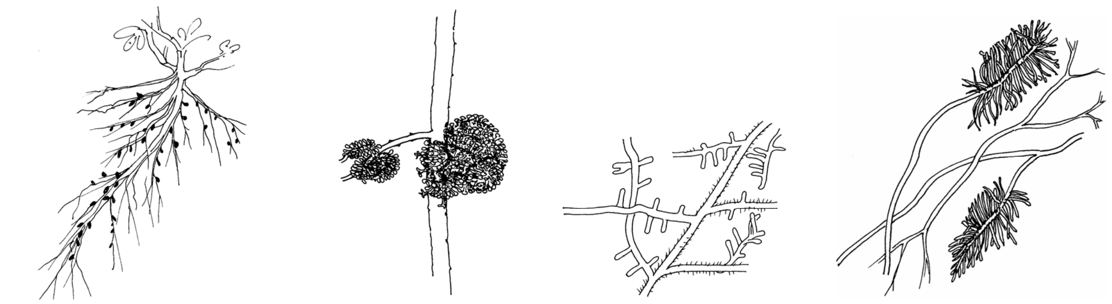
Basidiospores are produced on internal surface of pores

	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	COLLAR, ROOT AND STEM ROTS		
	Armillaria root rot	*Armillaria* spp.	Wide range of trees and shrubs
	Rhizoctonia rot, **damping off**	*Rhizoctonia solani* = *Thanatephorus*	Wide range of weeds, vegetables, ornamentals
	Sclerotium stem rot, **damping off**	*Sclerotium rolfsii* = *Athelia*	Wide range of weeds, vegetables, ornamentals
	GALLS		
	Azalea leaf gall	*Exobasidium japonicum*	Azalea
	Camellia leaf gall	*E. gracile*	*Camellia sasanqua*
	RUSTS		
		Many genera, eg	Usually **host specific**
		Phragmidium mucronatum	Rose
		Puccinia antirrhini	Antirrhinum
		P. chrysanthemi	Chrysanthemum
		P. horiana (white rust)	Chrysanthemum
		P. malvacearum	Hollyhock, other Malvaceae
		P. haemodori	Kangaroo paw, *Conostylis*, *Haemodorum*, *Macropidia*
	Sunflower rust	*P. helianthi*	Sunflower
	Wheat stem rust	*P. graminis* f. sp. *tritici*	Wheat
Not known in Australia	Guava rust	*P. psidii* (threat to Australian environment and economy)	Myrtaceae, eg guava, eucalypt, *Callistemon, Melaleuca, Syzygium,* etc; Heteropyxideae eg *Heteropyxis*
	Myrtle rust	*Uredo rangelii)*	Myrtaceae, eg *Agonis flexuosa, Syncarpia, Callistemon*
	Prune rust	*Tranzschelia discolor, P. pruni*	Stone fruits, especially prunes
Not known in Australia	Coffee rust	*Hemileia vastatrix*	Coffee
	Bean rust	*Uromyces appendiculatus*	Beans
	Gall rusts	*Uromycladium* spp.	*Acacia* spp.
Not known in Australia	Western gall rust	*Endocronartium harknessii*	5-needle pines, eg radiata pine (*Pinus radiata)*
Not known in Australia	White pine blister rust	*Cronartium ribicola*	3-needle pines, eg eastern white pine (*P. strobus)*
	SAPROPHYTIC FUNGI		
	Cultivated mushroom	*Agaricus bisporus*	Non-parasitic, grows on soil organic matter, compost.
Other moulds (white, yellow green or orange) may also grow on surface of potting mixes containing sawdust or bark; the fungus may grow into the mix	Mushrooms/toadstools	Various species	Potting mixes, the fungus grow on sawdust or bark.
	Fairy rings	*Marasmius oreades* Many other genera	Grow on organic matter in the soil in turf, pasture
	SMUTS		
		Many genera	Usually **host specific**
	Anther smut	*Ustilago violacea*	Carnation 'Mandy'
	Boil smut	*U. zeae*	Corn, maize
	Covered smut	*U. segentum* var. *hordei*	Oats
	Loose smut	*U. avenae*	Oats
	Smut	*U. cynodontis*	Couch
	Onion smut	*Urocystis cepulae*	Onions
	White smut	*Entyloma dahliae*	Dahlia
	WOOD ROTS		
	Heart rot	*Schizophyllum commune*	Most have a wide host range
	Yellowish wood rot	*Trametes versicolor*	
	Pink limb blight	*Corticium salmonicolor*	
	Red wood rot	*Pycnoporus coccineus*	
	Many other species,	*Fomes, Phellinus, Poria, Ganoderma, Peniophora*	



Wood rot fruiting bodies

LIST OF SOME FUNGAL DISEASES *(contd)*	COMMON NAME	SCIENTIFIC NAME	HOST RANGE (not exhaustive)
	BENEFICIAL FUNGI		
	FOOD		
	French black truffle	*Tuber melanosporum*	Truffles grow on roots of hazel and oak trees in Tas in a mycorrhizal symbiosis
	Cultivated mushrooms	*Agaricus bisporus*	Grow on organic matter
	PHARMACEUTICAL DRUGS		
	Pencillin antibiotics	*Penicillium* spp.	Bacterial diseases in humans and animals
	MYCORRHIZAS		
	Beneficial association between fungi from all groups and the roots of most plants.		
	Symbiosis	*Boletus* spp., *Endogone* spp. *Glomus* spp. Many more species	Make certain nutrients more available to the plant, see also truffles above
	ENDOPHYTES		
	An endophyte is a fungus or bacterium that grows within a plant in a mutually beneficial relationship; it may protect the plant from insects, disease, heat or drought.		
	Endophyte fungi	*Acremonium lolii* in perennial ryegrass	Protects perennial ryegrass from Argentine stem weevil
	BIO-CONTROL OF INSECTS		
	Greenguard®	*Metarhizium* spp.	Australian plague locust
	BioCane®	*Metarhizium* spp.	Greyback canegrub
	Other fungi	*Beauvaria bassiana*	Thrips, aphids, whiteflies, mealybugs, etc
		Entomophthora spp.	Various insects
		Verticillium lecanii	Green peach aphid
	BI0-CONTROL OF SOIL FUNGI		
	Trich-A-Soil®	*Trichoderma* spp.	Suppresses soilborne fungal diseases, eg *Phytophthora, Pythium, Fusarium, Rhizoctonia;* in NZ possibly *Botrytis* on kiwi fruit
Many more biocontrol products available overseas (Agrios 2005)	Nutri-Life TrichoShield™	Fungi (*Trichoderma* spp., *Gliocladium)* and a bacterium *(Bacillus subtilis)*	Disease suppressant for seeds, seedlings, transplants, bulbs, cuttings, grafts and established crops
	Others (possibility of commercialization)	*Clonostachys rosea* *Coniothyrium mintans*	Seed and soilborne diseases *Sclerotinia sclerotiorum*
Mycoherbicides	**BIO-CONTROL OF WEEDS**		
Potential	Mycoherbicide	*Alternaria zinniae*	Noogoora burr complex
Possibility	Mycoherbicide (NZ)	*Sclerotinia sclerotiorum*	*Ranunculus acris* in pastures
Rusts	Blackberry rust	*Phragmidium violacearum*	Blackberry
	Rust	*Puccinia myrsiphylli* *Prospodium tuberculatum*	Bridal creeper Lantana
	OTHERS		
	Kombuchea fungus	A yeast fungus	Kombacha is a symbiotic relationship of a number of bacterial and yeast cultures
	Saprophytic fungi (decomposers)	Fungi (also bacteria, nematodes, insects, mites, etc)	Plant residues, releasing nutrients for plants, etc



Nitrogen-fixing nodules (bacteria) on legumes, eg clovers

Actinorhizae (bacteria) on *Alnus*.

Mycorrhizal roots (fungus roots).

Proteoid roots form on most Proteaceae, eg banksia, grevillea.

Fig. 179. Beneficial structures on roots of plants greatly improve plant growth by increasing the absorbing surface of the root system. Mycorrhizal and proteoid roots exploit nutrients especially in soils low in phosphorus.

NUTRITION AND PARASITISM

Fungi and bacteria are **alike in one respect**, they have no chlorophyll. Fungi obtain their food either by:

- Infecting living organisms such as plants as **parasites**, or
- Attacking dead organic matter as **saprophytes**.

OBLIGATE PARASITES

Fungi which can only attack and complete their life cycle in nature on living host plants as **parasites**, eg downy mildews, powdery mildews, rusts (few exceptions). Host specificity in some cases is extreme.

FACULTATIVE PARASITES

Fungi which can live for an indefinite period on dead organic matter as **saprophytes.** When host plants are available and environmental conditions are favourable, they become **parasites**, eg damping-off fungi, ***Phytophthora*** root rot, ***Botrytis***, ***Verticillium***. Some fungi can grow actively **only** on debris from the host plant. Others can live for long periods by obtaining nourishment from dead leaves and other plant material, only attacking living plants when they are available.

OBLIGATE SAPROPHYTES

Fungi which can live and complete their life cycle only on dead organic matter as **saprophytes**,eg mushrooms, wood rot fungi. Wood rot fungi attack the dead parts of a tree.

FACULTATIVE SAPROPHYTES

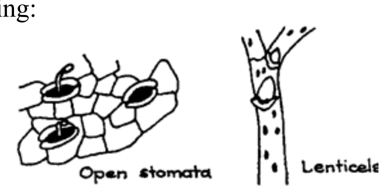
Fungi which spend most of their life cycle on living plants as **parasites** and may survive as **saprophytes** for short periods of their life cycle, eg smuts.

HOW FUNGI INFECT HOST PLANTS

Fungi enter host plants by several means including:

NATURAL OPENINGS

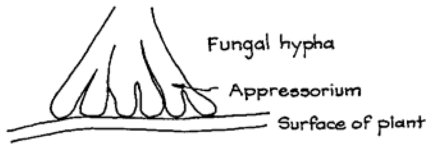
The germ tubes of some fungi, eg downy mildews, usually only penetrate host plants through natural openings such as stomates and lenticels.



Germ tubes grow through open stomates and lenticels

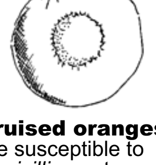
MECHANICAL PRESSURE

The hyphae of some fungi, eg storage moulds and root rots, penetrate host plants by using mechanical pressure.

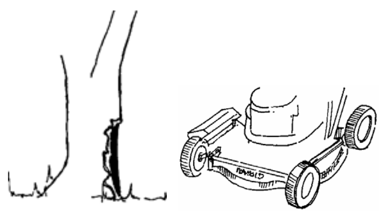


WOUNDS

Some fungi can enter plants through damaged surfaces.



Bruised oranges are susceptible to *Penicillium* rots.



Damage to trees by lawn mowers facilitates infection by wood rotting fungi.

DISTRIBUTION WITHIN HOST PLANTS

Hyphae produce enzymes which change plant tissue into a food source

HYPHAE

- **Hyphae of some fungi**, eg **powdery mildews**, grow **on the plant surface**, sending haustoria into surface cells to obtain nourishment. The furry or powdery growth on the surface of plants is composed of hyphae and spores.
- **Hyphae of other fungi** grow **inside plants**, eg *Fusarium* wilts grow inside xylem vessels of infected plants. Some **downy mildews** grow systemically within plants. **Endophytic fungi** also grow systemically within plants but cause no disease symptoms; they may improve resistance to certain pests, diseases, drought and heat.
- **Regardless where mycelium grows in the host**, spores are produced at or near the **surface of the host** ensuring their prompt dispersal. Many mycorrhizal fungi produce their spores underground and rely on fungal-feeding animals, eg marsupials and insects ('earth boring' beetles) for their spread.

DISEASE CYCLE



ALMOST ALL FUNGI WHICH INFECT PLANTS spend part of their lives on host plants and part in the soil, or in or on plant debris in the soil.

HOST ONLY

These fungi spend all their vegetative life cycle on the host plant. Spores may land on soil or plant debris where they remain until carried to a host where they can germinate, grow and complete their life cycle, eg powdery mildews.

HOST AND HOST DEBRIS

These fungi grow parasitically on their hosts and continue to grow on the dead tissues of their hosts as **saprophytes** to complete their life cycle. They can **only grow** on the organic matter of **their host**, eg apple and pear scab.

HOST, HOST DEBRIS, OTHER DEBRIS AND SOIL

These fungi grow parasitically on their hosts but continue to grow on the dead tissues of the host after it has died. These fungi also grow out of the host plant into the soil or other decaying plant material, where they can grow and multiply as a **saprophyte**, eg *Sclerotinia, Sclerotium.*

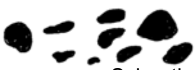
WHY IS KNOWLEDGE OF THE DISEASE CYCLE IMPORTANT?

Knowledge of the disease cycle is **essential** for the implementation of effective control measures, including:

- Timing of pesticide applications.
- Application of **preventative protectant** treatments.
- Whether leaves should be gathered and destroyed.
- Whether seed from diseased plants should be used.

OVERWINTERING, OVERSUMMERING


Resistant spore


Sclerotia


Rhizomorphs

CARRYING OVER THE FUNGUS FROM ONE SEASON TO THE NEXT

- **Fungal structures**. Hyphae may grow into different structures which ensure **survival and spread** of the fungus but which make control difficult. Dormant stages are stimulated into growth when the roots of a susceptible host plant is in close proximity and conditions are favourable, eg
  - **Thick-walled spores**, eg chlamydospores, oospores of *Phytophthora*.
  - **Sclerotia** consist of a mass of hyphae bunched together formed by some fungi, eg *Rhizoctonia*, *Sclerotium*, *Sclerotinia*. Sclerotia are pale at first but they darken as the hyphae on the outside dry out forming a hard skin that protects the hyphae inside, enabling them to start growing again sometimes years later when conditions are favourable. They are formed either inside or on outside of plants.
  - **Rhizomorphs** are bundles of parallel hyphae (about the thickness of a shoelace) formed by some fungi, eg *Armillaria*, that can grow through the soil to new hosts. However, Armillaria does not appear to readily form rhizomorphs in Australia.

ON OR IN THE HOST PLANT

- Bud scales - Peach leaf curl of stone fruit
- Twigs, branches - Brown rot of stone fruit, powdery mildews
- Trunks - Wood rots
- Roots - *Phytophthora* root rot, *Rhizoctonia* stem rot

ON OR IN PLANT DEBRIS

- Leaves - Apple scab
- Fruit - Brown rot of stone fruit
- Trunks - Wood rot
- Roots - *Phytophthora* root rot

SOIL

As mycelium, sclerotia or thick walled resting spores, eg *Phytophthora, Rhizoctonia, Fusarium* and *Verticillium*.

SEED

Many fungal diseases are seedborne. They are either within or on the surface seed, eg rust spores adhere to the outside of seed of infected plants.

'OVERWINTERING' IN SEVERAL WAYS

Some fungi can overwinter in several ways, eg

- *Phytophthora* root rot on host plants, in plant debris, soil and as thick-walled spores.
- *Botrytis* blight as spores on leaves of rooted cuttings, discarded plant debris, etc.

SPREAD


Air has many fungal spores floating in it

WIND

Fungal spores are produced at or near the surface of the host ensuring prompt spread by wind and air currents. Spores of **wheat rust** can be carried 500 km. Some even further, **poplar rust** is thought to have spread by wind to NZ.

H_2O

WATER

Rain and irrigation water splash spores from leaf to leaf and from plant to plant, eg black spot of rose. Drainage water washes spores and other fungal bodies of soilborne fungi downhill, eg *Sclerotium* stem rot, *Phytophthora*. *Phytophthora* zoospores have flagella and can 'swim' a few mm or cm.

SOIL, POTTING MIXES, DUST

Soilborne fungi may be transported in dust, soil eroded by water, mud on implements, vehicles, footwear, soil in deliveries and containers, eg *Fusarium*.

SEED

If a fungal disease is seed-borne, then any agency that spreads seeds of infected plants, eg humans, wind, water, will also spread the fungal disease.

INFECTED PLANTS, NURSERY STOCK

Infected susceptible plants, plant parts, nursery stock, eg peach leaf curl, shothole of stone fruits, *Phytophthora* root rot.

OTHER METHODS

- **Insects** are not a common method of spread. Driedfruit beetles and caterpillars of the oriental fruit moth spread brown rot in stone fruits. Fungus gnat larvae spread *Pythium*. Overseas, Dutch elm disease is spread by the European elm bark beetle.
- **Birds** and other animals are not an important method of spread.
- **Pruning wounds**, eg *Eutypa* dieback of apricots and grapevines.
- **Hyphal growth**, eg during postharvest storage of fruit.
- **Infected germplasm**. In SE Asia, leaf blight and stem cankers (*Kirramyces* spp.) of eucalypts may have spread around the region on infected germplasm.

CONDITIONS FAVOURING

EACH DISEASE IS DIFFERENT

- **Each fungal disease** has its own optimum environmental needs for spore formation and germination, host plant infection, disease development, eg
  - **Moisture**. Downy mildew spores germinate in a thin film of rain or dew on the plant surface, powdery mildew spores on a dry surface in humid conditions.
  - **Temperature**. Most fungal spores germinate at 15-30°C. Free mycelium survive from -5°C to 45°C when in contact with moist surfaces, inside or outside the host. Most spores can survive broader ranges of temperature.
  - **Weather monitoring**. Knowledge of temperature, rain, humidity, etc necessary for spore germination, host plant infection and disease development, means that epidemics can be forecast with fewer but more effective pesticide applications.
  - Others, eg poor light; deficiencies or toxicities can increase disease risk.
- **Stage of crop development** affects seriousness of disease outbreaks, eg leaf disease at the end of harvest of a tomato crop is not serious – unless the disease can spread to new plantings.
- **Lack of crop rotation**. A **mature** susceptible crop may withstand a disease but a following planting of the same susceptible crop in the same ground will certainly develop a damaging infection **while still young**.
- **Injury to produce** during harvesting favours infection by disease organisms causing postharvest rots.
- **Vegetatively propagated plants** have greater uniformity. The severity of a disease outbreak is greatest when the uniformity of the host is increased.
- **Lush new growth** favours certain diseases, eg powdery mildews.

Weather monitoring

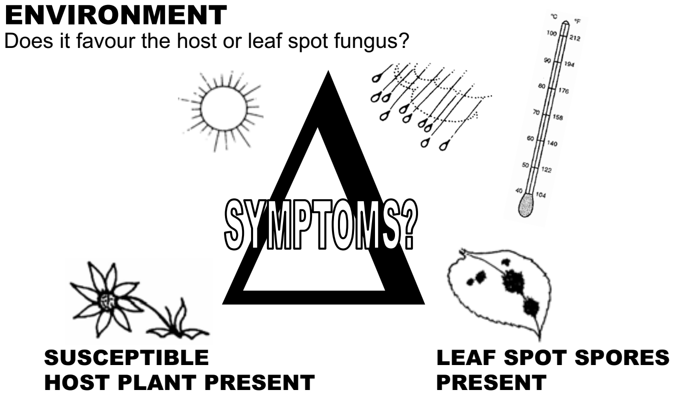


Fig. 180. Disease triangle.

INTEGRATED DISEASE MANAGEMENT (IDM)

MAIN STEPS

IDM is not a specific set of rules, there is no central program for everyone

IDM attempts to manage diseases systematically. The crop is managed as a whole and the management of diseases is part of producing the crop. **IDM maximizes** the use of **non-chemical** controls and **optimizes/minimizes** the use of chemical methods while taking into account all environmental factors, economics, etc, for long term control. May control diseases more slowly. Training programs are available.

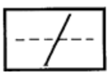
PLAN
PLAN
PLAN

1. **Plan** well in advance to use an **IDM** program that fits your situation. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides.

2. **Crop, region**. List the problems which occur in your crop/region. Check if an **IDM** program is available for your crop, eg
   - Soilborne diseases, eg for **clubroot**
   - Crops such as roses, citrus, grapes, vegetables.
   - The Nursery Industry Accreditation Scheme, Australia (**NIASA**).
3. **Identification.** Early detection and accurate diagnosis ensure effective control measures. This may be difficult and professional advice is often necessary (page xiv). A good knowledge of the host range, life cycles, types of spores produced, spread and conditions favouring the disease is necessary. **Obtain** a fact sheet for each problem affecting your crop.

1234
5678

4. **Monitor** early to minimize disease spread, facilitate control by early detection and determine the effectiveness of earlier control measures. Record findings.
   - Know **when** to monitor, eg before sowing, before flowering. **Weather warning systems** indicate when some diseases may develop on some crops, eg brown rot of stone fruits, apple scab, downy and powdery mildews and *Botrytis* of grapevines, rust on prunes, eg Prune Rust Infection Prediction **(PRIP)**.
   - Check **where** to look, eg leaves, flowers.
   - Decide **what** has to be monitored, eg symptoms, presence of spores, soil tests.
   - Know **how** to monitor, eg **preplant soil tests** using a **DNA** extraction process can quantify a range of fungal and nematode pathogens from a single soil sample and predict the likely extent of the losses well before the crop is planted, eg *Fusarium, Rhizoctonia.* Results have to be interpreted accurately. Methods include counting leaf spots, walking the crop in a predetermined pattern, **GPS** systems.



5. **Threshold**. Damage thresholds vary with the particular **crop** and **region** and may be determined by legislation. There may be a nil threshold. Otherwise, how much damage can you accept? Have any thresholds been established?

?

6. **Action/Control**. Take **preventative** measures when possible, eg planting resistant varieties, appropriate culture. Take appropriate action at the correct time when a prescribed threshold is reached. There may be **legal** or **organic** requirements. Disease figures may not indicate enough potential damage to warrant action.
   - **For diseases not yet in Australia or in certain states**, entry can be prevented by quarantine measures.
   - **For new arrivals** Response Programs control specified disease outbreaks. Noxious pest/disease legislation and other regulations are most effective during early stages of invasion. Available disease control methods do not eradicate pests unless they have been selected for a national or state eradication program.
   - **Most established diseases** in Australia can only be contained using appropriate control methods at the correct time, they cannot be eradicated. **Use non-chemical controls** if and when effective. Avoid broad spectrum chemicals.

✓x

7. **Evaluation**. Compare current results with those of previous seasons. Make improvements if necessary, eg planting disease-tested planting material or resistant varieties. Monitoring or application methods may need to be improved.

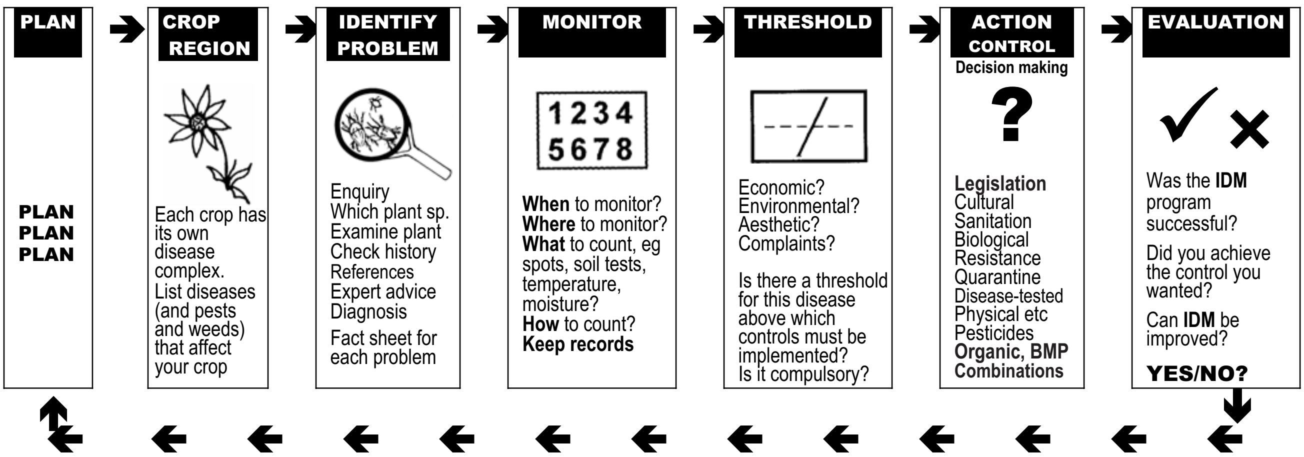


Fig. 181. Steps in IDM.

CONTROL METHODS

Fungal diseases are probably easier to control than any other group of diseases, but they are still costly and losses can be great. Most fungal diseases require an integrated approach, no one method is sufficient.

LEGISLATION

Relevant Acts regulating the control of fungal diseases include Seed Acts, Plant Quarantine Acts and Pesticides Acts. Food Acts regulate food, eg the maximum amount of aflatoxin permitted in peanuts (produced when peanuts are infected with particular species of fungi).

CULTURAL METHODS

Provide optimum conditions for crop growth and unfavourable conditions for disease. Generally a healthy plant withstands diseases better

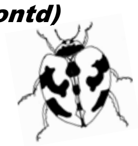
- **Favourable conditions for plant growth**.
  - **Choose a geographic location** suited to the crop.
  - **Crop rotation** is only useful for fungal diseases that do **not** survive for long in the soil or in plant residues. **Brassica rotation crops**, eg mustard, canola, release volatile gases toxic to many organisms, eg take-all fungus on wheat (page 321). Check whether diseases may be carried over when continuously cropping.
  - **Planting site**. Do not plant susceptible crops in soils known to be infested with diseases, eg *Sclerotium* stem rot, or in poorly drained, eg *Phytophthora* spp. Parsnip planted in alkaline soils encourages *Rhizoctonia* scab.
  - **Sowing/planting dates.** Keep up-to-date with new research, eg short season sunflower crops sown into in soil infested with *Sclerotinia minor* before mid-November in north Victoria yielded more than later sown crops.
  - **Maintain recommended** day and night temperatures, humidity and light for optimum crop growth.
  - **Maintain recommended** fertilizer programs. High nitrogen levels which lead to excessive growth of vines make them susceptible to certain foliar diseases, eg powdery mildews.
- **Unfavourable conditions for disease**.
  - **Most spores of fungi** that cause leaf, flower and stem diseases need **water** to germinate. Space plants and use drippers rather than misters, to reduce humidity and discourage spore production and germination. **Sprinkler irrigation** increase *Sclerotinia* and *Pythium* on peanuts.
  - **Fruit trees and vines** can be trellised and pruned appropriately to provide aeration.
  - **Keep plant surfaces dry** in greenhouses. Minimize duration of leaf wetness.
  - **Adjust temperature and humidity** in greenhouses to minimize risk of grey mould (*Botrytis cinerea*). The use of exhaust fans to circulate air in greenhouses reduces dependence on fungicide sprays.
  - **Handle** fruit and flowers gently during harvesting and packing to prevent bruising which provide entry points for post harvest fungal diseases.

SANITATION

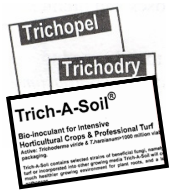
Sanitation includes **all activities** aimed at reducing or eliminating the amount of inoculum present on a plant, in a nursery, glasshouse or other situation to prevent the spread of disease to healthy plants.

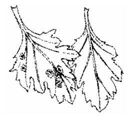
- **Destruction of diseased plant material.**
  - Many fungi overwinter on the shoots of host plants, pruning out infected parts is essential for control, eg powdery mildew of apple.
  - Damping-off fungi grow on **dead seedlings** and **cuttings** in propagation areas, remove such materials promptly.
  - Some fungi, eg brown rot of stone fruit, **overwinter on fallen fruit**; one of the recommended sanitation procedures for the control of brown rot is to destroy all fallen fruit as soon as possible.
  - Tree surgery techniques are used to assist in control of wood rotting fungi.
  - Produce rejected during harvest and packing should be removed and destroyed each day to prevent the spread of spores by wind and water splash.
- **Cleaning and disinfecting surfaces in nurseries** is important in the control of soilborne and other diseases.
  - **Remove all dirt** and organic matter (roots, sap, etc), from floors, benches, tools, equipment, trays, pots, etc.
  - **Then thoroughly wash** them all.
  - **Treat surfaces** with a disinfectant at the concentration and for the recommended time. Check that the disinfectant you want to use is effective against the problem you have, eg *Phytophthora*. Use only **freshly prepared** disinfectant (used disinfectant solutions may not work).and whether the surfaces are steel or plastic.
  - **Keep all all treated surfaces/objects in a clean area** away from dirt and other contamination until required.
- **Remember to treat water and media/potting mixes** as necessary.

CONTROL METHODS *(contd)*



Biocontrol agents can be affected by fungicides and environmental factors such as moisture and temperature





Vegetatively propagated plants have greater uniformity. Severity of disease outbreaks increase as genetic uniformity of the host crop increases.

Blights/Cankers
In SE Asia, leaf blight (*Kirramyces destructans*) and stem cankers (*K. zuluensis*) causes diseases of eucalypts and may have spread around the region on infected germplasm. These diseases could threaten Australia's endemic eucalypts and the productivity of commercial plantations

BIOLOGICAL CONTROL

- **Antagonistic fungi and bacteria** are naturally present in crop soils and exert some control over fungal disease organisms. They do this by either by parasitizing disease organisms, competing for food or producing antibiotic or volatile substances such as ethylene. Some have been commercialized (page 344, Table 60).
  - **In suppressive soils**, antagonistic microorganisms (mostly bacterial, fungi and actinomycetes) suppress soilborne diseases. **Most beneficial effects of compost** are due to the activities of antagonistic microorganisms.
  - **Trichopel**®, **others** (*Trichoderma* spp.) suppress soilborne fungal diseases including *Fusarium, Phytophthora, Pythium* and *Rhizoctonia*.
  - **Companion**® (*Bacillus subtilis*) as a soil drench suppresses *Fusarium, Pythum, Phytophthora, Rhizoctonia,* in protected environments. **Fulzyme Plus** (*B. subtilis + amino acids*) **may** suppress *Phytophthora* and *Pythium* in certain situations.
  - **Nutri-Life TrichoShield™** (*B. subtilis*, *Trichoderma* spp., *Gliocladium virens*) for seed, seedlings, transplants, bulbs, cuttings, grafts and established crops.
- **Mycorrhizal fungi** belong to all fungal groups and are essential for establishment and growth of many plant species. Plants with mycorrhizal roots can exploit a much greater volume of soil than non-mycorrhizal plants. **Mycorrhiza activators**, eg Mycorrcin, boost indigenous mycorrhizal populations increasing root colonization.
- **Endophytes** (fungi or bacteria growing systemically in living plants), cause few or no symptoms, but protects them from diseases and pests, while improving growth and drought tolerance. The best known are probably the grass endophytes.
- **Hyperparasites**. A fungus (*Ampelomyces quisqualis*) is a hyperasite of powdery mildew (natural control).
- **Fungal-feeding insects and mites**. Mites, springtails, protozoans, free-living nematodes and earthworms in soil feed on parasitic fungi and may assist their suppression. Up to 150 fungal-feeding mites can be found on some leaves. **Some beneficial ladybirds** may eat powdery mildew fungi.
- **Others**, eg a **plant protein** (finotin) has been extracted from the tropical forage legume *Clitoria ternatea* and found to have broad bio-pesticide properties against insect pests, a range of fungi and some bacterial disease organisms. A **bio-fungicide** extracted from *Swinglea glutinosa* against powdery mildew on beans and roses is currently marketed to flower growers overseas.

RESISTANT, TOLERANT VARIETIES

For many fungal diseases, eg rusts, this is the only practical method of control.

- **Provenances** of *Eucalyptus nitens* vary in resistance to *Mycosphaerella* leaf spot (*Mycosphaerella nubilosa*).
- **Rootstocks**. Susceptible tomato scions are grafted onto tomato rootstocks with some resistance to *Verticillium* and *Fusarium* wilt diseases.
- **Traditional cross-breeding** has been successful for centuries in producing hybrids with a mix of characteristics. Interspecific crosses can be used to transfer genes from one species to another closely related species.
- **Genetic engineering (GE)** allows for **quick transfer** of individual genes or combination of genes for resistance into susceptible crop varieties, reducing the time required to develop new resistant varieties. Rust resistant genes in flax and maize may be transferred into wheat.
- **Cross protection** (mild strain protection). **Dutch elm disease (DED)** (*Ophiostoma ulmi*) is carried from tree to tree overseas by the elm bark beetle (*Scolytus multistriatus*). Trees possibly could be protected from **DED** by inoculating them every year with a mild strain of **DED**.
- **Systemic acquired resistance (SAR). Plant activators** stimulate the natural **SAR** response mechanisms found in most plant species, to certain virus, bacterial and fungal diseases and increase crop yield. They have no direct effect against the target pathogens. Downy and powdery mildews, postharvest diseases and bacterial leaf spots of certain vegetables are being researched. **Bion**® **Plant Activator Seed Treatment** (acibenzolar-s-methyl) suppresses *Fusarium* wilt and black root rot of cotton in **IDM** programs.

PLANT QUARANTINE

Quarantine treatments can prevent introduction or establishment of a disease into an area, eg fumigation, hot water, fungicides, seed fungicidal dust, etc.

- **Australian Quarantine & Inspection Service.** Many fungal diseases are not as yet in Australia, eg many rust diseases, strains of brown rot of stone fruits.

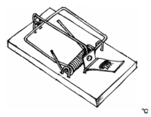
  Target list of diseases www.daff.gov.au/aqis/**quarantine**/naqs/**target-lists**
  PaDIL - Pests and Diseases Image Library www.**padil**.gov,au
- **Interstate and Regional Plant Quarantine.** Many fungal diseases already in Australia have a restricted distribution, eg **black spot** of apple does not occur in WA. **Area/property freedom certification** certifies that an area or property is free from a specified disease, eg WA will accept gladioli from an area in Qld which is certified to be free from gladiolus rust (*Uromyces transversalis*).
- **Local quarantine.** Protocols have been developed for production nurseries to **prevent** contaminated seed, plants and soil being **brought into** a nursery and to prevent contaminated plants, soil, etc **being supplied to** growers, landscapers, fruit growers, vegetable growers, cut flower producers, etc (**BioSecure *HACCP***).

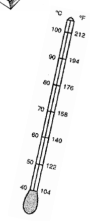
CONTROL METHODS *(contd)*

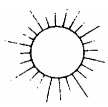
DISEASE-TESTED PLANTING MATERIAL

- **Seed**. Many fungal diseases are carried on, in, or in association with, seed. Using disease-tested seed is an effective way of controlling these diseases, eg loose smut of cereals, various seedborne diseases of annuals and vegetables.
- **Vegetative propagation material** eg bulbs, corms, cuttings, rootstocks, may carry fungal diseases from the parent plant and are often treated with heat or chemicals to free them from disease. Special techniques are used to obtain disease-freedom, eg
  - **Tip cuttings** from chrysanthemums infected with *Verticillium* wilt, often escape carrying the disease.
  - **Continuous culture-indexing** includes regular checks of plant material for fungal infection, eg *Verticillium* (and other diseases) over a 2-year period. Accurate records mean that contaminated plant lines can be destroyed.
- **Certification Schemes** provide the grower with seed or vegetative propagation material, which is "guaranteed free" from the diseases for which it has been **tested and found to be free from**. The planting material conforms to certain standards and certain tolerances for a disease. Zero tolerances may apply to a disease (or pest) that if detected on a property, would result in severe quarantine restrictions.

PHYSICAL & MECHANICAL METHODS







- **Temperature**
  - **Hot water treatment (HWT)** of **rootstocks**, rootlings and cuttings. **Surface treatments**, eg 55°C for 5 minutes, eliminate root rotting fungi, bacteria, phylloxera and nematodes from grapevine propagation material.
  - **Aerated steam** is used to rid **seeds** of fungal and other diseases. Soil pasteurization (60°C for 30 minutes) will kill *Thielaviopsis* (*Chalara*) in soil.
  - **Composting**, properly carried out (60°C for 30 minutes or longer will kill most soil disease organisms, while leaving some beneficial ones.
  - **Sterilizing recycled water by heat**.
    10 seconds at 95°C - Kill 100% disease organisms
    30 seconds at 95°C - Kills nearly everything
    Lower temperatures may be used for longer periods.
  - **Solarization** prior to planting traps energy from the **sun** under clear plastic sheeting laid on soil beds for at least 4-6 weeks when there is adequate sun. Soil may be heated to a depth of 30-25cm and summer soil temperatures can rise to 60°C which may assist control of some soil fungal diseases; acts a bit like pasteurization with steam. Water beds before solarization to improve control. Home gardeners can put media in plastic bags and leave in sun for 2-3 weeks. Solarization is not possible in mixed or perennial plantings, difficult in large areas and depth of treatment is limited (pages 373, 438).
  - **Flame burners** can be used to burn crop stubble after harvest, eg wheat. But this causes loss of nutrients and increased wind erosion (page 438).
  - **Cooling and freezing** is used extensively to control bacterial and fungal diseases of fruit, vegetables, cheese, milk and other food products.
  - **Pasteurization of soil/media** can be used to treat potting and propagation media in nurseries to kill most plant disease organisms that cause damping off, leaving some beneficial microflora (aerated steam at 60°C for 30 minutes). Prevent infested soil from re-contaminating pots, potting mixes, cuttings, germinating seeds and seedlings on benches. Because soilless mixes are used today, pasteurization has mostly been abandoned or used for treating pots and trays. Principal substitutes are bark and sawdust which when composted provides conditions for a huge growth of microorganisms several of which suppress plant disease organisms.

Select the right disinfestation system for your situation

  - **'Smart films'** either block or allow through different wavelengths of light which biologically affect the plants, pests and diseases growing beneath them. They have been used overseas to eliminate bacteria, fungi and viruses. **Flora-Fresh** is a protective packaging film which absorbs ethylene to minimize moisture loss and damage in transportation and optimizes shelf-life and natural colour of each bunch.
- **Irradiation** destroys microorganisms, eg bacteria and fungi, and insects, eg weevil, fruit flies, and therefore can reduce the incidence of food-borne diseases and extend the refrigerated shelf life of foodstuffs. Some non-edible items are irradiated in Australia.
- **Microwaves** can be used to disinfest small quantities of media or soil.
- **Pulsed UV light** kills bacteria and fungi on the skin of many kinds of fruit improving fruit quality and extends shelf life. Also effective in hydroponic units against *Pythium*, *Fusarium* and *Thielaviopsis*.
- **Heat treatment** and **UV light** are currently the most popular methods of disinfecting recirculating nutrient solutions in the Netherlands. UV light is well-known in nursery circles for its ability to eradicate water-borne micro-organisms, eg *Phytophthora, Pythium, Fusarium* (Rolfe et al 2002).
- **Filters** are used to remove disease organisms from water.
  - **Membranous filters** remove the disease organisms which are causing the problem. Correct filters must be used.
  - **Slow sand filtration (SSF)** is used to disinfest recycled water or irrigation water from on-site dams to eliminate disease organisms, eg *Phytophthora* and *Pythium*. **SSF** is only partially effective at filtering *Fusarium*, viruses and nematodes.
  - **Biofilters** are used to treat run-off, rain and industrial waste water overseas. They consist of a medium of heavy scoria and a rotation system. Bacteria are added and multiply on the scoria grains and eliminate all fine organic matter including *Fusarium, Phytophthora, Pythium* and tomato mosaic virus. Non-harmful flora is retained.

CONTROL METHODS *(contd)*

AS 6000—2009. **Organic and Biodynamic Products** (Standards Australia) outlines the minimum requirements to be met by growers and manufacturers wishing to label their products organic or biodynamic

FUNGICIDES

LEGISLATION

- **Commonwealth legislation** provides for a national system of pesticide **registration** up to the point of sale. Registration is the responsibility of the Australian Pesticides and Veterinary Medicines Authority (**APVMA**).

> **APVMA** www.**apvma**.gov.au/ and search **PUBCRIS** for registered chemicals
> or purchase **Infopest** www.dpi.qld.gov.au/**infopest**
>
> To check for products **permitted in organic systems**
> **AS 6000—2009. Organic and Biodynamic Products** www.**standards**.org.au/
> Organic Federation of Australia (OFA) www.**ofa**.org.au/
> Biological Farmers of Australia www.**bfa**.com.au/
> National Association for Sustainable Agriculture, Australia **(NASAA)** www.**nasaa**.com.au/
> Organic Growers of Australia (OGA) www.**organicgrowers**.org.au/

- **State/Territory/Regional legislation** currently regulates the **use** of pesticides. However, it is intended that there be a national system. All persons using pesticides **commercially** must undergo **training** in the safe handling and use of pesticides.

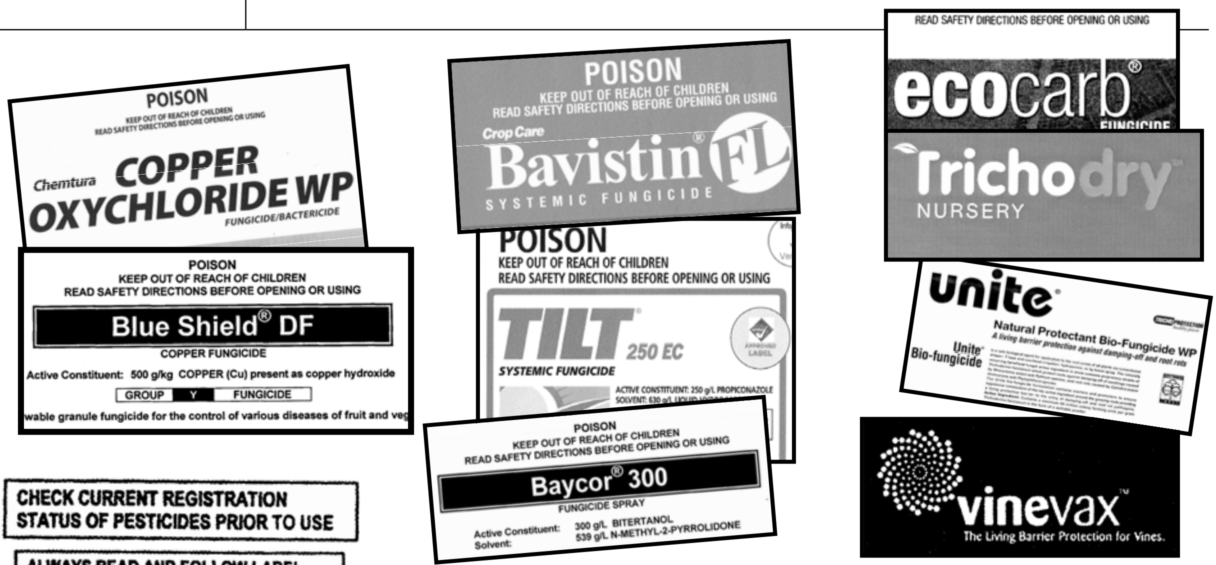
FUNGICIDE APPLICATIONS

Fungal diseases are generally **more difficult** to **control/suppress** with fungicides than insects, other animal pests and weeds, this is because the fungus itself is a very simple plant living in close quarters with another plant. Root, crown and stem rots and wilt diseases, are also more difficult to control with fungicides than foliage diseases, eg powdery mildews. Fungicides often just suppress root diseases; they do **not** eradicate them.

Repeated application of fungicides may kill some beneficial microorganisms and so change the composition flora on leaves and soil to some extent. Some such as *Trichoderma* spp. are considered to have some tolerance to a variety of fungicides

- **Fungicide applications** (page 332).
- **Non-systemic & systemic fungicides** (movement plants, page 333).
- **Summary and examples** (page 335).
- **Non-selective & selective fungicides** (page 336).
- **When** should fungicides be **applied?** (page 336).
- **Resistance** (page337).
- **Fungicide Activity Groups** (page 338, Table 58).
- **Disinfectants** (page 340 (Table 58) and page 343 (Table 59).
- **Bio-fungicides, soaps, bicarbonates, milk, etc** (page 344, Table 60).
- Fumigants (page 267).

> Contact **CropLife Australia** for updates of **Fungicide Activity Groups**
> www.**cropelifeaustralia**.org.au/



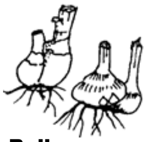
CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Fig. 182. Some fungicide labels.

FUNGICIDE APPLICATIONS.

WHAT ARE FUNGICIDES USED TO TREAT?


Bulbs, corns

ALL PLANT PARTS, eg

- Foliage
- Stems, trunks, limbs, branches
- Flowers, fruit and seed
- Roots, bulbs, corms, tubers
- Seedlings, cuttings
- Stored fruit, vegetables, grain
- Soil, potting mixes
- Tools, benches
- Water


Seeds


Cuttings


Nursery stock

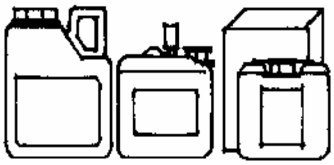
FORMULATIONS

LIQUIDS, eg

- Emulsifiable concentrates
- Suspension concentrates
- Aqueous concentrates
- Liquid concentrate
- Liquid

SOLIDS, eg

- Dust
- Granules
- Soluble powder
- Wettable powder


The formulation is the product purchased

OTHERS, eg

- Aerosol
- Fumigant
- Fungicide amended fertilizers
- Wetting agents, eg powdery mildews.

APPLICATION EQUIPMENT*

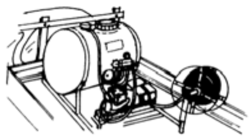

Knapsack

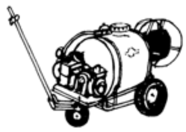

Trolleypak

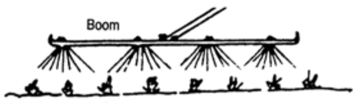
Application equipment ranges from expensive large units to small ready-to-use convenient container-applicators.

SPRAY EQUIPMENT, eg

- Hydraulic sprayers, eg knapsacks, trolleypaks, trailer sprayers, booms
- Air blast sprayers
- Mist blowers
- Rotary atomizers
- Electrostatic sprayers
- Fog generators
- Aircraft


Truck sprayer

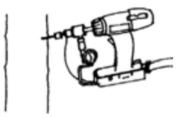

Trailer sprayer



Boom sprayer

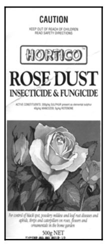
OTHER EQUIPMENT, eg

- Dusters
- Granule dispensers/spreaders
- Tree injection, tree implants
- Soil injectors
- Vaporizers


Tree injection

SELF-DISPENSING APPLICATORS, eg

- Dusters
- Guns
- Aerosols



Duster

Gun

Aerosol

NON-SYSTEMIC & SYSTEMIC FUNGICIDES
Protectant & eradicant fungicides - Movement in plants

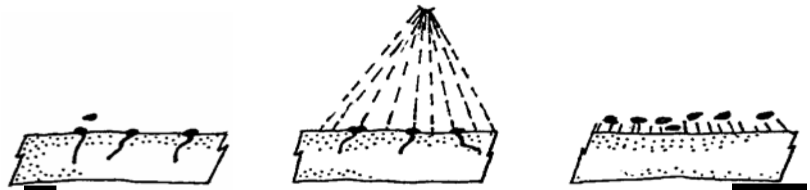
NON-SYSTEMIC FUNGICIDES

Protectant fungicides

PROTECTANTS

- **Non-systemic fungicides are not absorbed by plant tissue and are only active at the site of application** (contact between the fungicide and the fungus). They are often called **protectant fungicides** because they protect the host plant from initial infection and further infections.
- **Most fungal spores** infect the host during wet weather, the wet surface of the plant providing a suitable 'seed-bed' in which spores can germinate. When the plant is coated with a fungicide, some of the chemical will dissolve in the water on the surface of the host and the spores are killed **before** they can enter the host. Coverage must be thorough, make sure there is time for it to dry on the foliage.
- **Because protectant fungicides are non-systemic**, they **only** kill fungi on the **outside** of the host, they will **not kill** the fungus once it is inside the host plant! The fungicide must be applied **before** the spores land on leaves!

Cross section of leaf



No spray. Spores germinate and germ tubes penetrate leaf

Spray applied after spores have germinated. Germ tubes and mycelium already within the leaf are not killed

Spray applied before spores land on leaf. Spores are killed on the outside before germ tubes penetrate leaf.

NON-SYSTEMIC - FOLAGE, eg	**NON-SYSTEMIC - SOIL**, eg
copper hydroxide copper oxychloride mancozeb sulphur	Previcur®, various (propamocarb) Terrazole® (etridiazole) TMTD®, various (thiram)
	

- **Advantages of non-systemic fungicides** include:
  - Often cheaper than systemic fungicides.
  - Less toxic (there are some exceptions).
  - Limited fungicide resistance.
  - Usually affect a number of metabolic pathways in the fungus, and tend to have a broad spectrum of activity.
- **Disadvantages of non-systemic fungicides** include:
  - They must be applied **before** the arrival of the disease organisms, before symptoms are apparent or when the first symptoms appear. It must be applied before the fungus has actually been found but where it is expected.
  - All the foliage must be treated.
  - Rain or very windy weather may prevent fungicides being applied at the right time, so control may be difficult to achieve even with an effective fungicide.
  - The fungicide remains on the outside of the plant and so may be toxic to beneficial or other harmless organisms.
  - Regular applications may be necessary when plants are growing actively to protect new growth and because rain may wash protectant fungicides off the plant or they may deteriorate due to heat, light and rain.

NON-SYSTEMIC & SYSTEMIC FUNGICIDES *(contd)*
Protectant & eradicant fungicides - Movement in plants

SYSTEMIC FUNGICIDES

Eradicant fungicides

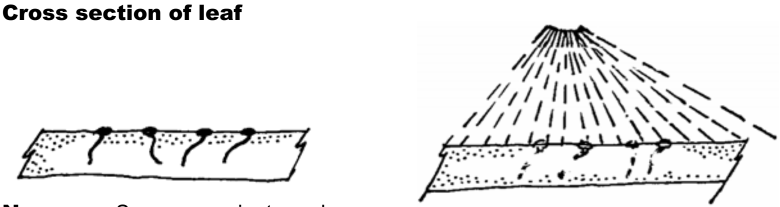
Curative fungicides

Translocated fungicides

ERADICANTS, CHEMO-THERAPEUTANTS

- Systemic fungicides enter a plant and are active at sites remote from where they are applied; they are carried through the sap stream. They are often called **eradicants** or **chemo-therapeutants** because they not only protect the host from infection while they are on the outside, some may suppress or kill fungal organisms after they are **within** the host.

Cross section of leaf

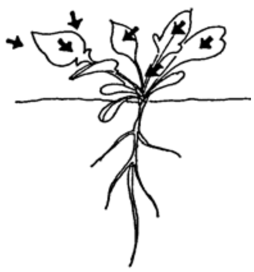


No spray. Spores germinate and germ tubes penetrate leaf.

Spray applied after germ tubes and mycelium are inside the host. Mycelium already inside the leaf is killed.

SYSTEMIC - FOLIAGE, eg

Baycor® (bitertanol)
Bayleton®, various (triadimefon)
Saprol®, various (triforine)
Tilt®, various (propiconazole)



Systemic **fungicides** and applied to the **foliage** do **not** generally move downwards into the roots. Their distribution within the above ground parts of the plant is variable.

SYSTEMIC – SOIL, eg

Fongarid® (furalaxyl)
Ridomil®, various (metalaxyl)

Systemic **fungicides** applied to the **roots** do **not** generally move upwards to control foliage diseases, there are exceptions. **When applied to the soil**, they dissolve in soil water and are taken up by the roots and **translocated upwards** to varying degrees within the plant. The soil must be kept moist for continued uptake

Narrow spectrum of activity. Some new systemic have a very narrow spectrum of activity but they work better than the older ones

Translaminar movement. Some fungicides, eg Stroby (kresoxim-methyl), are non-systemic but can move into, and may to a limited extent move within the leaf blade.

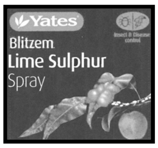
Excessive residues may still occur unless withholding periods are observed. Washing the outside does not remove internal residues.

- **Advantages of systemic fungicides** include:
  – They can reach diseases already in the host, eradicate established infections. They can be applied **after** any infection period determined by environmental monitoring stations.
  – Timing is not so critical. New developing foliage may be protected without further applications being necessary immediately.
  – The whole plant surface need not be treated, eg systemic pesticides may be applied as foliage, root and soil or tree injection treatments.
  – After the fungicide has been absorbed by the plant, it is not washed off by rain.
  – Surface residues disappear rapidly which minimizes risk to non-target organisms.
  – Some also have quite good protectant qualities.
  – Can be used to target periods when conditions are favourable for disease.
- **Disadvantages of systemic fungicides** include:
  – Many are selective fungicides, not broad spectrum, and are usually only effective against a particular group of fungi. There are exceptions.
  – Fungal diseases may develop **resistance** to systemic fungicides and their overuse is the most common way for resistant strains to be generated.
  – Some systemic fungicides are not evenly distributed inside a plant but remain in the general area of entry to the plant. Penetration into certain tissues such as fruit and stems can be very limited. The degree of systemic activity varies but most are absorbed by the leaves or roots and transported upwards through the xylem (water-conducting system) and phloem. Thorough coverage is often still necessary for control.
  – They may control the disease, pest or weed more slowly than contact non-systemic pesticides.

SUMMARY & EXAMPLES

Fig. 183. FUNGICIDES & BACTERICIDES (page 338)

- **Foliage**
  - **NON-SYSTEMIC Protectant**: **Captan®** (captan), copper, **Daconil®** (chlorothalonil), **Dithane®** (mancozeb), sulphur
  - **SYSTEMIC Eradicant**: **Antirot®, Phospot®, Aus-phoz®** (phosphorous acid), **Amistar®** (azoxyztrobin), **Baycor®** (bitertanol), **Bayleton®** (triadimefon), **Rovral®** (iprodione), **Saprol®** (triiforine), **Stroby®** (kresoxim-methyl)
- **Soil Roots**
  - **NON-SYSTEMIC Protectant**: **Terrazole®** (etridiazole), **Thiram®**
  - **SYSTEMIC Eradicant**: **Aliette®** (fosetyl), **Banol®, Previcur®** (promamocarb), **Fongarid®** (furalaxyl), **Ridomil®** (metalaxyl), thiophanate-methyl
- **Trees**: copper lime sulphur, phosphorous acid
- **Seed dressing**: copper, **Thiram®**, **Rovral®** (iprodione)
- **Cuttings, seedlings Bulb dip**: **Tecto®** (thiabendazole)
- **Fruit dip** Postharvest: **Bavistin®** (carbendazim)



MIXTURES

Fig. 184. DISINFECTANTS (page 343)

- **Secateurs**: methylated spirit
- **Containers**: Biogram Bleach (sodium hypochlorite)
- **Benches, floors, mats**: Biogram Phytoclean (benzalkonium chloride)
- **Cuttings, seed**: calcium hypochlorite
- **Hands**: various
- **Respirators**: Manufacturer's recommendation

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

NON-SELECTIVE & SELECTIVE FUNGICIDES
Broad & narrow spectrum fungicides

NON-SELECTIVE FUNGICIDES
Broad spectrum

WIDE RANGE OF ACTIVITY

- Many fungicides have some activity against a wide range of fungal diseases, eg
  - Copper and sulphur
  - Mancozeb®, Thiram® and Zineb®
  - Zyban® (mancozeb/thiophanate-methyl)

SELECTIVE FUNGICIDES
Narrow spectrum

Many fungicides, especially the new systemic ones, may only be effective against **particular groups of fungi** (some exceptions).

- **Phycomycota fungi only**. These fungicides are **only** effective against Phycomycota, eg
  - Fongarid® (furalaxyl) - *Phytophthora*, *Pythium*
  - Ridomil® (metalaxyl) - *Phytophthora*, *Pythium*

- **Not Phycomycota fungi.** Some fungicides are **not** effective against Phycomycota fungal diseases but are affective against powdery mildews, leaf spots, rusts and some soil diseases, eg
  - Bavistin® (carbendazim) - Powdery mildews, leaf spots
  - Bayleton® (triadimefon) - Powdery mildews, rusts
  - Tilt® (propiconazole) - Powdery mildews, leaf spots, rusts
  - Saprol® (triforine) - Powdery mildews, leaf spots, rusts, brown rot

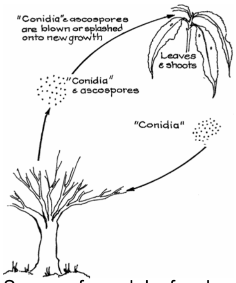
WHEN SHOULD FUNGICIDES BE APPLIED?

GROWTH STAGE OF HOST

Depending on the disease and fungicide type, fungicides can be applied to different parts of the host plant. Some diseases only affect new foliage, eg peach leaf curl.

Foliage Flowers Dormant Seeds, cuttings Bulbs, corms Roots, soil

SUSCEPTIBLE STAGE IN FUNGUS LIFE CYCLE



Spores of peach leaf curl 'overwinter' on buds

Choose a susceptible stage in the life cycle of the fungus, eg peach leaf curl spores '**overwinter' in the buds** and infect new leaves in spring (page 359).

- **Timing**. The disease cycle determines **where and when** a fungicide is applied.
  - **Peach leaf curl** can be controlled with a single application to dormant buds before new leaves are infected.
  - **Some disease**s may be controlled by starting applications **at the very first sign of disease**, eg powdery mildews.
- **Early warning systems**. Once conditions favouring a particular disease are known, weather can be monitored and spore germination and infection predicted with some certainty.
  - **Early warning systems** are available for many crops, including downy mildew of grapes, prune rust.
  - **Sometimes it is difficult** to apply fungicides at the correct time, eg weather is unsuitable for application. Inability to recognize the problem.

NUMBER AND INTERVAL BETWEEN APPLICATIONS

PEACH LEAF CURL (an example)

- **Follow resistance strategies** on fungicide labels.
- **Correct number of applications** is necessary to obtain satisfactory control of many diseases. There are exceptions, eg peach leaf curl of stone fruit may be controlled by only **one preventative application** of copper to susceptible trees at **early** budswell and **no** later than **mid-budswell** or control will be unsatisfactory and new leaves may be damaged. Weather may prevent this.
- **Correct interval between applications.** For some diseases applications may need to be made at **regular** intervals, which may vary according to weather, the particular fungus and persistence of the fungicide, eg black spot of rose. Warning systems may indicate when applications are necessary.
- **Preventative applications** may be necessary for 'key' diseases that occur every year, eg seeds, cuttings and soil are frequently treated with fungicides to provide some control of damping off diseases.

RESISTANCE

WHAT IS RESISTANCE?

Resistance is the ability of disease organisms to survive doses of fungicide that would normally provide control. Resistance is so extensive it is difficult to find effective fungicides. Fungi which produce large numbers of spores with many infection cycles per season, eg powdery mildews, grey mould, brown rot, develop resistance more quickly. **Continuous use** of systemic fungicides with only one mode of action can lead to resistance problems after less than 20 applications due to the continual selection of resistant spores.

- **Reduced yields**. Prolonged use of some systemic fungicides has led to reduced yields due to increased disease in some fruit crops.
- **In Australia**, fungal diseases of ornamentals, turf, fruit and vegetables which have developed resistance to a range of chemicals include:
  - Downy and powdery mildews
  - Grey mould (*Botrytis*) and other postharvest diseases of fruit
  - Brown rot of stone fruit, apple and pear scab
  - Late and early blights of potato and tomato

RESISTANCE MANAGEMENT STRATEGIES

The application of fungicides must be part of an **IDM** program which include non-chemical control methods to preserve beneficial fungi and other micro-organisms and delay resistance development. **IDM** strategies should be in place **before** resistance becomes a problem.

- **Fungicide Resistance Management Strategies.**
  - **CropLife Australia** has classified fungicides into **Fungicide Activity Groups** which indicate how the fungicide **kills or suppresses the fungus** (page 338, Table 58). Some disinfectants and biological fungicides are **not** classified by **CropLife Australia** (page 343, Table 59, page 344, Table 60). Contact **Croplife Australia** for updates on classification and click on **Resistance Management**:
    www.**croplifeaustralia**.org.au/
  - **To minimize the development of resistance** and prolong the life of existing fungicides, observe **1 2 3…. groups** on **commercial fungicide labels**. Follow resistance warnings. Rotate fungicides between different groups as recommended. Remember, persons using commercial fungicides must undergo training. **Home garden products available from garden centres are not required to have fungicide activity groups on their labels**.
  - **CropLife Australia** has prepared management strategies for some diseases on some crops, to minimize the development of resistance.
    - ❑ **Crop-Disease** Resistance Management Strategies have been developed, eg **grey mould** (*Botrytis*) on grapevine, lettuce, ornamentals, pulse crops, strawberry; **powdery mildew** of cucurbits, grapevine, strawberry; **downy mildew** on cucurbits, grapevine, lettuce, onion, poppies.
- **Follow label instructions and warnings**, which include resistance strategies. Application of some fungicides for control of some diseases is **restricted** in order to prevent or delay the likelihood of resistance developing. Do not exceed recommended rates of application if a specific fungicide is no longer giving control of a disease. **"Example"** and **"Company"** are used in the following general instructions to avoid using specific insecticide or company names.

> Classification by Croplife Australia is according to **how the pesticides kill the insect, fungi and weeds** and is used for resistance management
>
> It does **not indicate toxicity,** it is true that some groups are more toxic than others as indicated by the signal headings on their labels (see page 237).

FUNCTIONAL RESISTANCE WARNING

FUNGICIDE RESISTANCE WARNING

GROUP **3** FUNGICIDE

Example is a member of the DMI froup of fungicides. For fungicide resistance management, **Example** is a Group 3 fungicide. Some naturally occurring individual fungi resistant to **Example** and other Group 3 fungicides may exist through normal genetic variability in any fungal population. The resistant individuals can eventually dominate the fungal population if these fungicides are used repeatedly. **Example** and other Group 3 fungicides will not control these resistant fungi, thus resulting in a reduction in efficacy and possible yield loss. Since occurrence of resistant individuals is difficult to detect prior to use. **Company** accepts no liability for any losses that may result from the failure of **Example** to control resistant fungi.

Some labels may include: Refer to specific Croplife Resistance Management Strategies on the label

> **Applications may fail for reasons other than resistance**, eg
> - Incorrect identification of the disease.
> - Wrong fungicide may have been used. Many fungicides control only 1 or 2 types of fungal diseases.
> - Equipment not calibrated properly.
> - Applied at wrong time
> - Weather unsuitable for application.

FUNGICIDE ACTIVITY GROUPS

- Fungicides are classified by **Croplife Australia** into fungicide activity groups which assist in **resistance management**.
- The following tables are a summary guide only, and not a substitute for reading a currently registered label, the MSDS and obtaining up-to-date advice.
- They also provide an overall picture of the types of fungicides available for crop protection.
- **Mark fungicides you use at work.**

Contact **Croplife Australia** for a full list of fungicides, updates of the classification and further information: www.**croplifeaustralia**.org.au

Check **Pubcris** for current **registration** status: www.**apvma**.gov.au/

Infopest can be purchased www.dpi.**qld**.gov.au/

Table 58. Fungicide Activity Groups (2009) *some examples*

ACTIVITY GROUP		THE PRODUCT		SOME USES Read label, obtain advice from company	
ACTIVITY GROUP CODE Activity group	**CHEMICAL FAMILY**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**DISEASES CONTROLLED, SUPPRESSED**
1 **Methyl Benzimidazole Carbamates**	**Benzimidazole**	**BAVISTIN, VARIOUS** carbendazim	**Eradicant** (systemic) also post-harvest dips, seed pieces (sugar cane, ginger)	Certain ornamentals, fruit, vegetables & field crops, turf	**Broad spectrum** *Botrytis*, brown rot, leaf spot, powdery mildew, *Rhizoctonia, others, **not*** Oomycota
	Thiophanates	**BANROT** thiophanate-methyl + etridiazole **(Grp 14)**	**Eradicant** (systemic) **Protectant** **thiophanate-methyl** – *Phytophthora, Pythium* **etridiazole** – *Rhizoctonia, Thielvaliopsis (Chalara)*	Ornamentals	**Broad spectrum** Damping off, root & stem rots caused by *Phytophthora, Pythium, Rhizoctonia, Thielvaliopsis (Chalara)*
2 **Dicarboximide**	**Dicarboximide**	**ROVRAL, VARIOUS** iprodione	**Mainly protectant** **Contact action** Also seed treatments	Certain vegetables, ornamentals and fruit, turf	**Broad spectrum** *Botrytis*, brown rot, *Sclerotinia, Sclerotium,* turf diseases, but ***not*** Oomycota
		FORTRESS, VARIOUS procymidone DANGEROUS POISON	**Eradicant** (systemic) **Protectant**	Potatoes, onions	**Narrow spectrum** target spot (potato), white rot (onion)
3 **DMIs** (often called sterol inhibitors)	**Imidazole**	**FUNGAFLOR, VARIOUS** imazalil	**Eradicant** (systemic) **Protectant**	Apples, pears, citrus, also stored potato tubers	**Narrow spectrum** Postharvest diseases & storage diseases
		PROTAK, VARIOUS prochloraz	**Protectant** **Eradicant** (systemic)	Certain fruits, turf	**Broad spectrum** postharvest diseases, dollar spot, ***not*** Oomycota
	Piperazine	**SAPROL, VARIOUS** triforine	**Protectant** **Eradicant** (systemic)	Rose, chrysanthemum, stonefruit, apples	**Broad spectrum** black spot, powdery mildew, rust, brown rot, post harvest diseases; ***not*** Oomycota
	Pyrimidine	**RUBIGAN** fenarimol	**Protectant** **Eradicant** (systemic)	Certain fruit, ornamentals, vegetables	**Broad spectrum** powdery mildews, black spot, ***not*** Oomycota
There are currently 17 triazole products (2009) registered; many are seed dressings for wheat, barley, oats, stored grain	**Triazole**	**BAYCOR, VARIOUS** bitertanol	**Protectant** **Eradicant** (systemic)	Ornamentals, turf	**Broad spectrum** powdery mildews, rusts, black spot of rose, turf diseases,; ***not*** Oomycota
		NUSTAR, CANE STRIKE flusilazole	**Protectant** **Eradicant** (systemic)	Apple, pear, grapevine; dip for sugarcane setts for pineapple disease	**Broad spectrum** black spot of apple & pear, powdery mildew of apple & grapevine, etc ***not*** Oomycota
		BANNER, TILT, THROTTLE, VARIOUS propiconazole may be formulated with azoxystrobin (**Grp 11**)	**Protectant** **Eradicant** (systemic)	Certain fruit, field crops, turf, boronia, sugarcane	**Broad spectrum** powdery mildews, rusts, leaf spots, brown rot, turf diseases, ***not*** Oomycota
		BAYLETON, VARIOUS triadimefon	**Eradicant** (systemic)	Azalea, cucurbits, grapevines, peas, sugarcane, barley, wheat, turf	**Broad spectrum** powdery mildews, rusts, azalea petal blight, turf diseases
		BAYFIDAN, VARIOUS triadimenol often formulated with an insecticide for seed dressings	**Eradicant** (systemic) taken up through roots and foliage	Brassicas, papaws grapevines, turf	**Broad spectrum** powdery mildews, ringspot, sugarcane (pineapple disease)

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 58. Fungicide Activity Groups. (2009) ***some examples (contd)***

ACTIVITY GROUP		THE PRODUCT		SOME USES Read label, obtain advice from company	
ACTIVITY GROUP CODE Activity group	**CHEMICAL FAMILY**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**DISEASES CONTROLLED, SUPPRESSED**
4 **Phenylamide**	**Acylalanine**	**FONGARID** furalaxyl	**Eradicant** (systemic)	Ornamentals, seed & cutting beds, shrubs, glasshouse beds, soil for potted plants	**Narrow spectrum** damping of & root rot diseases (*Pythium, Phytophthora*), Oomycota fungi
		RIDOMIL, VARIOUS metalaxyl often formulated with other fungicides	**Protectant** **Eradicant** (systemic) also seed treatments for downy mildews, damping off, *Phytophthora*	Certain fruit and vegetables	**Narrow spectrum** root & trunk rots (*Phytophthora,* damping off, Oomycota fungi
	Oxazoli dinone (only avail in combination)	**REBOUND** oxadixyl + propineb (group M3)	**Eradicant** - oxadixyl **Protectant** - propineb	Cucurbits, grapes, lettuce, onions	**Fungicide** downy mildews; gummy stem blight and anthracnose on cucurbits only
5 **Amines (Morpholines)**	**Spiroketal-amine**	**PROSPER** spiroxamine	**Eradicant** (systemic)	Grapevines	**Narrow spectrum** powdery mildew
7 **Carboxamides**	**Oxathiin carboxamides**	**VITAVAX, VARIOUS** carboxin often formulated with other fungicides or insecticides	**Eradicant** (systemic) Seed treatments	Barley, oats, wheat, triticale	**Narrow spectrum** smut diseases **Insecticide** stored grain pests
		PLANTVAX oxycarboxin	**Eradicant** (systemic) absorbed by foliage & roots	Ornamentals, green beans	**Narrow spectrum** rusts
	Phenyl benxamides	**MONCUT** flutolanil	**Protectant** mainly	Potato	**Narrow spectrum** black scurf
	Pyridine carboxamides	**FILAN** boscalid may formulated with other fungicides	**Protectant** and translaminar activity in individual leaves	Grapevines, inhibits spore germination and germ tube elongation	**Narrow spectrum** bunch rot, grey mould (*Botrytis cinerea*)
8 **Hydroxy- (2-amino-) pyramidine**	**Hydroxy- (2-amino-) pyramidine**	**NIMROD** bupirimate Inhibits appressoria formation and so prevents infections	**Protectant** **Eradicant** (systemic)	Apples, melons (except watermelons), some ornamentals	**Narrow spectrum** powdery mildews
9 **Anilino pyrimidine**	**Anilino pyrimidine**	**CHORUS** cyprodinil may formulated with other fungicides, eg Switch (cyprodinil + fludioxonil)	**Eradicant** (systemic)	Apple, pear, apricot, peach, plum, nectarine	**Narrow spectrum** scab of apple, pear, blossom blight & brown rot of apricot, peach, plum, nectarine
		PYRUS, SCALA, SIGANEX pyrimethanil may be formulated with other fungicides	**Protectant** some **eradicant** properties, penetrates developing fruitlets	Grapevines, strawberries & tolerant ornamentals	**Narrow spectrum** bunch rot (*Botrytis cinerea*) including fungal strains resistant to dicarboximides and benzimidazoles
11 **Quinone outside Inhibitor (QoIs)** Strobilurin fungicides originated from small mushrooms (*Strobilurus* sp.) in pine forests in Europe	**Methoxy acrylate**	**AMISTAR, HERITAGE MAXX** azoxystrobin may be formulated with other fungicides, eg Amistar Xtra (azoxystrobin + cyproconazole	**Eradicant** (systemic) It is absorbed through the roots and translocated in the xylem to the stems and leaves, or	Certain fruit, vegetables, poppies, turf	**Broad spectrum** **both** downy mildew & powdery mildew, suppresses bunch rot (*Botrytis)* & other specified diseases, some turf diseases
	Oximino acetates	**STROBY** kresoxim-methyl	**Protectant** (non-systemic) **trans-laminar** activity	Apple, pear	**Narrow spectrum** black spot and powdery mildew in apples, scab in pears
	Methoxy carbamate	**CABRIO** pyraclostrobin	**Protectant** **p**rovide some locally **systemic** movement in plant tissue	Grapevine, banana	**Narrow spectrum** downy & powdery mildews of grape-vines, leaf spot & leaf speckle of banana
12 **Phenylpyrroles**	**Phenyl pyrroles**	**MAXIM** fludioxonil may be formulated with other fungicides	**Protectant** Seed treatment **non-systemic** in the plant system. However, its penetrative	Maize, sweetcorn, potato	**Broad spectrum** damping off (*Fusarium, Penicillium*); also black scurf, silver surf & common scab
13 **Quinolines**	**Quinolines**	**LEGEND** quinoxyfen	**Protectant** (non-systemic)	Grapevines	**Narrow spectrum** powdery mildew

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Table 58. **Fungicide Activity Groups** (2009) *some examples (contd)*

ACTIVITY GROUP		THE PRODUCT		SOME USES Read label, obtain advice from company	
ACTIVITY GROUP CODE Activity group	CHEMICAL FAMILY	Trade name Active constituent	Mode of action	CROPS, SITES TREATED	DISEASES CONTROLLED, SUPPRESSED
14 **Aromatic hydrocarbons (chlorophenyls nitroanilines)**	**Aromatic hydrocarbons**	**TERRACLOR, VARIOUS** quintozene **APVMA has suspended the supply or use of material/ products containing quintozene until 12 April 2011**	**Protectant** (non-systemic) Soil treatment Seed treatment for rhizoctinia in cotton	Ornamentals, vegetables, peanuts, turf, cotton	**Narrow spectrum** soilborne diseases, eg *Rhizoctonia, Sclerotium rofsii* (**not** *Fusarium. Phytophthora, Pythium, Verticillium)*
		RIZOLEX, VARIOUS tolclofos-methyl Different formulations for different crops	**Protectant** (non-systemic) seed & seed tuber treatments	Cotton, potatoes.	**Narrow spectrum** *Rhizoctonia* *(not Pythium,*
Hetero aromatics	**1,2,4-thiadiazole**	**TERRAZOLE** etridiazole may be formulated with other fungicides, eg **Banrot** (etridiazole/ thiophanate)	**Protectant** (slightly systemic) Soil fungicide	Ornamentals, turf	**Narrow spectrum** *Phytophthora, Pythium*
17 **Hydroxyanilide**	**Hydroxyanilide**	**TELDOR** fenhexamid	**Protectant** non-systemic) **Locosystemic**	Grapevines, strawberries	**Narrow spectrm** bunch rot, gray mould *(Botrytis)*
20 **Phenylureas**	**Phenylureas**	**MONCEREN** pencycuron	**Protectant** (non-systemic)	Potato (at planting) Seed tuber at planting	**Fungicide** Seedborne black scurf (*Rhizoctonia*)
28 **Carbamate**	**Carbamate**	**PREVICUR, BANOL, PROPLANT** propamocarb	**Eradicant** (systemic) Residual qualities	Ornamentals, recreational turf	**Narrow spectrum** damping-off (*Pythium* spp.)
29 **Unspecified**	**2,6-dinitro-anilines**	**SHIRLAN, GEM** fluazinam	**Protectant** (non-systemic) Little systemic activity, good residual effect	Brassicas, grapevines, apple Some miticide acitivity	**Broad spectrum** club root, white root rot (*Rosellinia necatrix*) on apple; suppression of *Phomopsis* blight (grapevines)
33 **Phosphanates** (stimulate defense mechanisms in the host plant (**phytoalexins**) and so increase host resistance)	**Ethyl phosphonate**	**ALIETTE, SIGNATURE** fosetyl (as the-aluminum salt)	**Eradicant** (systemic) long persistent control	Apple, avocado, ornamentals, peach, turf, pineapple	**Narrow spectrum** some *Phytophthora* rots, *Pythium* spp.
		ANTI ROT, PHOSPOT, VARIOUS phosphorous acid **apply as tree injection or foliar spray (check label)**	**Protectant** **Eradicant** (systemic) moves in phloem and xylem, moves up & down in plants Foliar sprays may cause leaf burn esp. to new growth	Avocado, citrus, ornamentals, pineapple, subterranean clover	**Narrow spectrum** *Phytophthora* rots; downy mildews of grapes, poppies & cucurbits
40 **Carboxylic acid amides**	**Cinnamic acid derivative**	**ACROBAT** dimethomorph	**Eradicant** (systemic)	Certain vegetables (lettuce, cucurbits, onion, potatoes), grapes, oil seed poppies	**Fungicides** downy mildews, late & early blights of potatoes
M **Multi-site activity**	**Inorganic**	**VIBREX HORTICARE SANITISER, VARIOUS** chlorine dioxide	**Sanitizer**	Mushroom growing facilities, fruit & vegetable rinses	**Sanitizer** bacteria
Group M fungicides have an inherently low risk of fungicid resistance developing		**PERATEC, TSUNAMI, VARIOUS** hydrogen peroxide + peroxyacetic acid See **TerraClean Broad Spectrum Fungicide** below*	**Sanitizes** and kills all aerobic bacteria, anaerobic bacteria & their spores, and fungi & their spores	Process water for post-harvest processing fruit & vegetables, eg bunch rot on grapes. Cleans hard non-porous surfaces on vegetable and other farms	**Disinfectant** bacteria, viruses; also suppresses grey mould (bunch rot) *Botrytis cinerea*) close to harvest
More disinfectants are listed on pages 343, 284		**BIOMAXA IODINE GRANULE POST-HARVEST SANITISER** Iodine used with the **Isan system**: **Iodoclean™ system**	**Sanitizer**. Aids in preventing spread of citrus canker Ioteq www.**ioteq**.com	Agriculture, horticulture, nurseries, hydroponics, fruit & vegetables	**Sanitizer** *Pythium, Phytophthora, Fusarium, Rhizoconia, Chalara* & certain bacteria
		SHIRTAN mercury present as methoxy ethyl mercuric chloride	**Fungicidal dip** for sugarcane setts **DANGEROUS POISON**	Sugar cane setts	**Fungicide** pineapple disease (*Ceratocystis paradoxa*)
		OSKU-VID GRAPE GUARDS sodium metabisulphite anhydrous	**Fumigant action**	Grape guard pads applied to packaged grapes emit sulphur dioxide gas	**Fungicide** *Botrytis* rots during cool storage
	Hydroxy quinoline	**STAEHLER GRAFTING WAX** hydroxyquinoline		Grapevines	**Fungicide** improved healing of grapevine grafts

* **TerraClean Broad Spectrum Fungicide** (activated peroxygen liquid concentrate) overseas, eliminates serious root and stem diseases including *Phytophthora, Pythium, Fusarium, Rhizoctonia, Verticillium, Thielaviopsis (Chalara* www.**biosafesystems**.com.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 58. Fungicide Activity Groups. (2009) ***some examples (contd)***

ACTIVITY GROUP		THE PRODUCT		SOME USES Read label, obtain advice from company	
ACTIVITY GROUP CODE Activity group	**CHEMICAL FAMILY**	**Trade name** **Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**DISEASES CONTROLLED, SUPPRESSED**
M1 **Multi-site activity *(contd)***	**Inorganic (copper compounds)** **Bordeaux mixture** refers to the freshly made up mixture of mixture of copper sulphate, hydrated lime and water. This mixture is no longer a registered treatment and has been replaced by other copper products.	**NORSHIELD, VARIOUS** cuprous oxide	**Protectant** (non-systemic) **Preventative**	Various diseases of stone & pome fruit trees, other fruits, vegetables	**Fungicide** peach leaf curl, shothole, freckle, scab, melanose, leaf spots, downy mildew (***not*** powdery mildew), **Bactericide** bacterial cankers, leaf spots, etc
Group M fungicides have an inherently low risk of fungicid resistance developing		**BLUE SHIELD, KOCIDE, VARIOUS** cupric hydroxide may be formulated with mancozeb (ManKocide) **Group M fungicides** have an inherently low risk of fungicide resistance developing	**Protectant** (non-systemic) **Preventative** copper stops roots growing outside containers. May help to reduce root diseases	Various diseases of stone & pome fruits, other fruits, vegetables, ornamentals	**Fungicide** as for copper oxychloride, also *Phytophthopra* **Bactericide** bacterial cankers, leaf spots **Root pruning** has been used for treating containers for growing trees and shrubs
Copper is residual in soil for decades, and can be toxic to earthworms and other organisms, including fungi and plants		**BRYCOP, OXYDUL, VARIOUS** copper oxychloride may be formulated with metalaxyl (Axiom® Plus)	**Protectant** (non-systemic) **Preventative**	Stone & pome fruits, other fruits, grapevines, vegetables, roses, ornamentals	**Fungicide** peach leaf curl, shothole, leaf spots, downy mildews, *Phytophthora* trunk canker & root rot **Bactericide** bacterial canker, spots
Bluestone (copper sulphate) controls algae on paths and in ponds, and corrects copper deficiency in fruit trees and vegetables		**LIQUICOP, VARIOUS** copper ammonium acetate copper ammonium complex	**Protectant** (non-systemic) **Preventative**	Fruit & vegetables	**Fungicide** peach leaf curl, shothole, leaf spots, scab, *Phyophthora* stem rot, cankers, downy mildews, powdery mildew (grapevines) **Bactericide** bacterial soft rots, leaf pots, bacterial canker
		TRI-BASE BLUE, BORDEAX, CUPROFIX, VARIOUS tribasic copper sulpate may be formulated with mancozeb (Cuprofix Plus)	**Protectant** (non-systemic) **Preventative**	Fruit, nuts, vegetables & ornamentals	**Fungicide** peach leaf curl, freckle, shothole, spot diseases, melanose, downy mildew **Bactericide** bacterial canker, bacterial spot diseases
		TRICOP copper octanoate	**Protectant** (non-systemic) **Preventative**	Nectarine, peaches, vines, vegatables	**Fungicide** peach leaf curl, downy & powdery mildew, leaf spots etc.
M2 **Multi-site activity**	**Inorganic**	**DUSTING SULPHUR** sulphur	**Protectant** (non-systemic)	Citrus, grapes, pawpaws, pumpkins, marrows	**Fungicide** powdery mildews **Miticide** citrus rust mite
Sulphur can be toxic to many organisms and may kill some parasites and predators		**KUMULUS, THIOVIT JET, WETTABLE SULPHUR, VARIOUS** wettable or dispersible sulphur	**Protectant** (non-systemic)	Some fruit and vegetables, ornamentals, eg roses. Causes less plant injury than lime sulphur	**Fungicide** black spot, rust, powdery mildew **Insecticide** scales **Miticide** twospotted mite
		LIME SULFUR sulphur (S) as polysulphide sulphur Disagreeable to handle, do not apply if air temperature is > 32°C, if freezing weather is predicted or within 2 weeks of oil sprays unless label indicates otherwise	**Protectant** (non-systemic) **Contact, some fumigant action**	Apples, pears, stone fruit, grapes, citrus, tomato & ornamentals may stain trellises, often used as dormant spray	**Insecticide.** scales **Miticide.** blister mites, others **Fungicide** powdery mildews, black spot, peach leaf curl, rust
Eco-fungicide is a BFA CERTIFIED PRODUCT FOR ORGANIC GARDENS		**ECO-FUNGICIDE, ECO-ROSE, ECO-CARB** potassium bicarbonate (page 344)	**Contact fungicide** (non-systemic)	Roses, grapevines, strawberries, vegetables (tomato, capsicum, cucumber, zucchini)	**Fungicide** powdery mildews, also black spot of rose. Mix with Eco-oil for increased effectiveness

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 58. Fungicide Activity Groups (2009) ***some examples (contd)***

ManKocide (cupric hydroxide + mancozeb) both Group Y

ACTIVITY GROUP		THE PRODUCT		SOME USES Read label, obtain advice from company	
ACTIVITY GROUP CODE Activity group	CHEMICAL FAMILY	Trade name Active constituent	Mode of action	CROPS, SITES TREATED	DISEASES, CONTROLLED, SUPPRESSED
M3 Multi-site activity	Dithio carbamate	**MANCOZEB, DITHANE, PENNCOZEB, VARIOUS** mancozeb may be formulated with other fungicides, eg with cupric hydroxide (**Mankocide®DF®** with sulphur **(Mancozeb Plus)**	**Protectant** (non-systemic)	Ornamentals, vegetables, fruit, turf, field crops	**Broad spectrum** leaf spots, rusts, brown rot, turf diseases, *Botrytis*, downy mildews, ***not*** powdery mildews
		THIRAM, VARIOUS thiram maye be formulated with carboxin (Vitavax)	**Protectant** (non-systemic) Seed treatments, soil drenches	Ornamentals, fruit, flowers, vegetable, turf, seeds	**Broad spectrum** damping off, turf diseases, leaf spots,
		ZINEB zineb may be formulated with other fungicides.	**Protectant** (non-systemic)	Ornamentals, fruit trees, vegetables, turf	**Broad spectrum** downy mildews, leaf spots, rusts, damping off, etc
M4 Multi-site activity	Phthalimide	**CAPTAN, VARIOUS** captan may be formulated with other fungacides.	**Protectant** (non-systemic), very slight systemic activity,	Ornamentals, grape, turf, pome & stone fruits, strawberries, peanuts	**Broad spectrum** black spot, grey mould (*Botrytis*), fruit rots, brown patch, damping off (*Pythium*),downy mildew, blossom blight/brown rot; seedling blight (*Rhizopus, Aspergillus*) of peanuts
M5 Multi-site activity	Chloronitriles	**BRAVO, DACONIL, VARIOUS** chlorothalonil	**Protectant** (non-systemic), long residual activity	Ornamentals, turf, fruit, vegetables, crops	**Broad spectrum** *Botrytis*, leaf spots, brown patch, dollar spot, rusts, downy mildews
M6 Multi-site activity	Sulfamide	**EUPAREN MULTI** tolylfluanid	**Protectant** (non-systemic)	Strawberry	**Broad spectrum** black spot, grey mould (*Botrytis*); suppresses powdery mildew
M7 Multi-site activity	Quanidine	**SYLLIT** dodine	**Protectant** (non-systemic) local systemic activity	Pome fruit, stone fruit	**Broad spectrum** black spot in apples, pears; peach leaf curl & blossom blight
		PANOCTINE, ZANOCTINE guazatine	**Protectant** (non-systemic)	Citrus, tomatoes, rockmelons	**Broad spectrum** postharvest diseases
M9 Multi-site activity	Quinone (anthraquinone)	**DELAN, VARIOUS** dithianon	**Protectant** (non-systemic)	Some pome and stone fruits, vines	**Broad spectrum** black spot, bitter rot, shothole, brown rot, freckle downy mildew

Fumigants (page 267)

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 59. Disinfectants, *some examples*

- The term **'disinfectant'** commonly refers to chemicals used to **surface-sterilize** inanimate objects, some are used to surface-sterilize plant surfaces. The term **'disinfection'** is used to describe using a chemical or other agent to kill or inactivate disease-producing microorganisms **inside** seeds or other plant parts.
- There is **no general disinfectant** which will **eradicate all disease organisms**. So that **identification** of the disease problem is essential, followed by careful selection of a disinfectant/fungicide/bactericide that will be effective. **Permits may be required.** Heat is still one of the most effective disinfectants.
- **Certain situations may specifiy particular disinfectants and rates**, eg viruses, quarantine (pages 340, 284). Seek advice for your particular situation.
- Some disinfectants are **not registered as pesticides** but are included here for convenience.
- Some disinfectants may **damage plants** and some may **contaminate the environment.**
- **Prior to treating tools, benches and other items, remove all dirt or soil**.
- **Sodium hypochlorite** is the most common form of chlorine used in horticulture and is often used as a disinfectant. Its effectiveness is influenced by concentration, exposure time, light and temperature, etc.
- **Common treatments for contaminated water** include chlorination or a combination of chlorination and filtration. **Chlorination is hazardous**, improper use of chemicals and higher than recommended concentrations may corrode the irrigation system, damage soil and plants.
- Some disinfectants are **hazardous to the operator**, eg they may cause skin and bronchial irritation. Consult the Material Safety Data Sheet (**MSDS**), available standards, wear recommended personal protective equipment **(PPE).**

CHEMICAL TYPE		THE PRODUCT		SOME USES Read label, obtain advice from company	
		Trade name **Active constituent**		**CROPS, PLANTS, SITES TREATED**	**DISEASES, PESTS, WEEDS CONTROLLED**
See page 340 for more disinfectants	**Alcohols**	**ETHANOL, METHYLATED SPIRITS** ethyl alcohol	Solution of 70% in cold water, at this concentration it evaporates less quickly and is less flammable	Secateurs, personal use **CAUTION** **Australia Standard** **Refer AS 2508 3.017**	**Disinfectant** ethanol plus flaming **does not** adequately inactivate viruses
	Halogens	**BLEACH** sodium hypochlorite calcium hypochlorite (use calcium hypochlorite for disinfecting plant material)	Recommended concentration and dip time must be adhered to, can damage clothing, degrades rapidly in light	Cuttings, floors, benches, containers. Do not contaminate food, inactivated by organic matter	**Disinfectant** household, dairy, food processing areas, containers, plant material
		PYTHOFF chlorine compounds	Nonsystemic	Hydroponic nutrient conditioner	**Disinfectant** used from seed to harvest
	Phenols & substituted phenols	**BIOGRAM** ethanol o-Phenylphenol Clorofene		Container dip, floors, benches, floor pad entrance to glass-houses, tools, tyres, machinery, items in contact with soil	**Disinfectant** broad spectrum disinfectant, *Botrytis, Fusarium, Phytophthora, Pythium*
		KENDOCIDE dichlorophen		Floors & benches in green houses, pots, paths, brickwork; lawns, turf.	**Algae, mosses, liverworts**
	Quaternary ammonium compounds (quats)	**VARIOUS** quaternary ammonium compound	Recommended dip times must be adhered to	Tools, hands, foot baths, seed trays, cuttings, growing media, etc Containers, used for blue metal under containers. May damage some plants	**Disinfectant** broad spectrum bactericide, algacide and fungicide especially *Phytophthora*, *Pythium*, *Sclerotium*
		VARIOUS, PHYTOCLEAN CANE KNIFE STERILIZER benzalkonium chloride **140 products registered, eg Zero Moss & Algae Gun**	Fast acting, with a moderately long duration of action. Inactivated by organic matter	Footwear, tools, tyres, machinery washdown, vehicles and other items in contact with soil, vehicle, glasshouses, work areas, walls, pots, tools, cane knives, packing sheds. Paths, roofs, hard surfaces, greens & lawns	**Disinfectant** Only some bacteria, viruses, protozoa; fungi (*Phytophthora*) **Algae, mosses, lichens, liverworts**
	Others	**FLORALIFE** **Food** - sugar **Biocide** - to inhibit growth of bacteria & fungi **Acidifier** - to lower pH		Extend the life of cut flowers	**Disinfectant** bacteria & fungi
		DETTOL chloroxylenol (phenol or cresol compd)			**General antiseptic**
		MICROKILL citrus pulp + herbs to buffer and stabilize shelf life	Nonsystemic	Seedlings, plants	**Disinfectant**
		COOLACIDE poly(oxyethylene) (dimethyliminio) ethylene (dimethylyliminio) ethylene dichloride)		Recirculating waters, cooling towers etc. Footwear, tools, tyres, machinery and other items in contact with soil	**Disinfectant** algae, bacteria and fungi

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 60. Bio-fungicides, soaps, bicarbonates, milk, etc (agricultural biological products)

THE PRODUCT	SOME USES Read label, obtain advice from company
BIO-FUNGICIDES, BIO-INOCULANT MICROBIAL AGENTS Mostly for soilborne diseases **Trich-A-Soil®** **Trichodry™** **Trichoflow™** **Trichospray™** **TrichoShield™** **Trichodex™** **Vinevax™**	***Trichoderma harzianum*** is naturally occurring fungus which has been developed as a bio-fungicide for **soilborne diseases and foliar pathogens**. In soil, it colonises the root zone, establishing a strong beneficial population which stimulates root initiation, promoting vigorous root growth and utilization of micro-nutrients giving plants a faster start with more resistance to adverse conditions. The environment is less favourable for soil disease organisms, suppressing some damping off and root rot diseases, eg *Fusarium, Phytophthora, Pythium* and *Rhizoctonia*. Used in **IDM** programs. It is marketed in different formulations depending on the situation, eg glasshouses, organic media, hydroponics, field crops, seed plantings, seed plugs, ornamental plantings, orchards, vineyards, turf. **May be formulated with other organisms, eg mycorrhiza**. **Trich-A-Soil®, Trichodry Nursery, Trichoflow Nursery, Trichospray Nursery, Unite Natural Protectant Bio-Fungicide WP** (*T. harzianum*). **Trichodex™ Bio-fungicide** (*T. harzianum*) for the control of grey mould (*Botrytis cinerea*) on grapevines. **Sentinel® Bio-fungicide** protects against grey mould (*Botrytis cinerea* on grapes and tomatoes (not available in Australia) as yet. **Vinevax™ Biological Wound Dressing, Vinevax™ Biological Fungicide Bio-implants, Vinevax™ Bio-injection Biological Fungicide** (*T. harzianum*) may assist control of *Eutypa* dieback in grapevines. Has potential for development as a pruning wound protectant against *Botryosphaeria* in grapevines.
Companion **Fulzyme-Plus™**	***Bacillus subtilis*** is a naturally occurring bacterium which has been developed as a bio-fungicide. It colonizes soil, attaches to the plant's root hairs, crowding out disease organisms, preventing them from becoming further established, aids in decomposing organic matter. Solubizes various nutrient elements, so they are readily available to roots. Used in **IDM** programs to suppress *Pythium, Fusarium, Rhizoctonia, Phytophthora*. **Companion**, **Fulzyme Plus™** (*Bacillus subtilis*) used in **IDM** in disease management of *Phytophthora* and *Pythium*.
	Mixtures eg **Nutri-Life TrichoShield™** (*Trichoderma* spp., *Gliocladium virens, Bacillus subtilis*) for treatments of seeds, seedlings, transplants, cuttings, bulbs, grafts, established crops. Improves balance between desired & undesirable micro-organisms on leaves & in soil. **Noculate Liquid** (*Bacillus*, *Trichoderma*, vitamins, humic acid, kelp) for use on professionally maintained turf.
	Other possible bio-fungicides being researched or under development **AQ10** *(Ampelomyces quisqualis)* may provide some control of **powdery mildews**. **Mycostop** (*Streptomyces griseoviridis*). Seed treatment, dip, soil spray or drench to minimize root diseases, eg ***Fusarium, Alternaria, Pythium, Phytophthora, Rhizoctonia***. **Streptomycin** (*Streptomyces* sp.) is a systemic bactericide used for foliage, & seed treatments, eg bacterial blight of walnut, bacterial canker of stone fruit, seed treatment for halo blight of bean. May cause yellowing on some crops. **Soilgard™** *(Gliocladium virens)* is a soil-applied fungus used pre-plant as a media additive to control ***Rhizoctonia, Pythium*** *of* greenhouse ornamentals & food crops. **Other fungi** include ***Conostachys rosea, Coniothyrium minitans***. Anti-fungal proteins isolated from Australian flora inhibit a range of fungal pathogens.
MYCORRHIZA	**Mycorrhizal fungi** can be purchased for use in nurseries to inoculate a range of plants including conifer seedlings for reforestation outplanting. Mycorrhizal **activators** are being researched.
PLANT ACTIVATORS	**Bion®** (acibenzolar-S-methyl) **induces host resistance** in cotton to suppress *Fusarium* wilt and black root rot.
SPRAY OILS	**Some petroleum oils** are registered for powdery mildew on pome fruit, greenhouse roses and some other fungal diseases of banana, citrus & passion fruit (page 61). **Some paraffinic oils** are registered for powdery mildew of pome fruit & some other diseases of banana & citrus (page 61).
MILK 	**Milk** must be full cream - the cream causes the milk to stick. Powdered full-cream milk is particularly effective because it is not homogenized and helps retard black spot on roses. Spray once per week in bad seasons when mildew is constant or when you see it. It is not a preventative as it works directly on the spores causing the fine hairs of the fungi to shrivel up within hours of the milk application (page 347).
SOAPS	**Soaps** are usually used as insecticides, but can suppress certain foliar diseases such as **powdery mildews** under some conditions. Note that soap sprays marketed through garden centres are only registered for the control of certain insect pests.
BICARBONATES 	**Eco-fungicide, Eco-carb, Eco-rose** (potassium bicarbonate) are registered for powdery mildew, also black spot of rose (page 341); They are contact fungicides. Potassium bicarbonate is more effective than sodium bicarbonate (Moore 1996). **Sodium bicarbonate** (baking soda) combined with horticultural oil (a surfactant) provides some control of **powdery mildew** & some other diseases of ornamentals, vegetables & fruit crops. The oil allows the bicarbonate to better adhere and spread evenly over the target leaf area.
FUMAFERT	**Fumafert®** (mustard seed meal (*Brassica juncea*) plus neem kernel (*Azadirachtin indica*) has soil bio-fumigant properties which aid in the control of some **soil, insects, diseases** & **nematodes** (page 267).
OTHERS	**Acti-dione** (cycloheximide) overseas controls **powdery mildews** & **rusts** on ornamentals and turf. May cause leaf injury to roses. Highly toxic to fish & wildlife. **Anti-transpirants,** eg Envy® can provide some protection against fungal diseases, eg rusts, powdery mildews by forming a physical barrier to disease organisms.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

EXAMPLES OF FUNGAL DISEASES

Powdery mildews

Powdery mildews are considered to cause more financial losses worldwide than any other plant disease. Historically the most famous powdery mildew disease is the one that devastated the vine crops in Europe during the 19th century and is still costly to the wine industry. It was the same fungus which led to the discovery of **lime sulphur** - sheer necessity! This fungicide is still used today for powdery mildews and to a lesser extent rusts, other fungal diseases and mites.

Scientific name

Powdery mildews (Order Erysiphales, Phylum Ascomycota). However, when the sexual stages (cleistothecia) of powdery mildews are not known, they are placed in the Imperfect Fungi and called *Oidium* spp. Common powdery mildews include:

Phylum Ascomycota, Order Erysiphales

Blumeria graminis	Cereals, grasses
Podosphaeria leucotricha	Apple
Sphaerotheca fuligina	Cucurbits
S. pannosa	Rose
Uncinula necator	Grapevines

Imperfect Fungi (sexual stage not known, when found the fungus is given a genus and species). *Oidium* spp. – Aster, azalea, begonia, calendula, chrysanthemum, dahlia, euonymus, eucalypt, oak, pansy, plane tree, primula, other plants.
See also page 321.

Host range

Ornamentals, azalea, begonia, hebe, eucalypt, wisteria, hardenbergia, oak, rose.
Fruit, eg apple, grape, papaya, strawberry.
Vegetables, eg cucurbits, pea, tomato.
Field crops, eg cereals, clover, lupins.
Turf, eg grasses, clover.
Parasitic plants, eg mistletoe. **Weeds**.
Although all powdery mildews look the same, usually a particular species is restricted to one host, or group of related hosts, eg one species attacks roses another azaleas and so on.

Fig. 185. Powdery mildew of euonymus (*Oidium* spp.). Photo©CIT, Canberra (P.W.Unger).

Symptoms

Leaves, stems, buds, petals. The first sign of disease is usually small white circular patches on the surface of leaves or stems. These increase in size, often running together to cover large areas of **both** upper and lower leaf surfaces, becoming powdery due to the production of masses of conidia.

- **Young leaves** on some species seem to be very susceptible and may yellow, shrivel and curl, eventually they may die, eg apple. However, in most cases, younger leaves of bedding plants do not show infection.
- **Petals and buds** may also become distorted. Flowers are downgraded.
- **Infected leaves** on some hosts redden in colour on the uppersurface opposite a powdery mildew colony on the undersurface and may be confused with chemical toxicity. Leaves may wither and fall. Infected soft leaves of some hosts, eg roses, may "bubble" with spores developing on the deformed areas.
- **Old powdery mildew infections** on some leaves, eg *Photinia*, hebe, may appear grayish.
- **Dormant shoots** of apple are covered with dense white mycelium. Infected shoots on perennials may die back. Dormant rose and grapevine shoots may turn reddish so it is easy to see where the infected shoots from last season are.
- **Small fruiting bodies** (cleistothecia) may develop on plant tissues killed by powdery mildew. They look like small black specks.

Fruit. **Mango** fruit develops purplish brown blotches and immature fruit may fall. **Apples** may russet and be downgraded. **Grape bunches** with as little as 5% disease may be rejected by wineries as they cause 'off flavor' in wine. Table grapes are unmarketable if berries or stalks are infected.

General. Important seedling disease in nurseries. Plants may be stunted and crops lost. Can be a late season, end-of-crop disease.

Diagnostics.

- Fresh powdery mildews are generally **easy** to identify, exceptions include hebe, hydrangea.
- **Do not confuse** with down mildews (page 348).
- **A few hosts** may become infected with **both** powdery mildew and downy mildew, eg rose, grape, hebe, cucurbits.
- **Microscopic examination** - a x10 eyepiece and x10 objective (student compound microscope) is needed to see spores in **'chains'** (page 346, Fig.186) rather than **'trees'** (page 349, Fig.189). Expert advice may be needed to confirm the exact species although very few plants host more than one species of powdery mildew.
- **Active infections** appear powdery and fluffy, while **inactive infections** appear flattened and may be brownish.
- **The purplish discolorations** of some powdery mildews may be confused with chemical toxicity.
- **On some hosts**, eg cucurbits, spots may appear first on leaf **undersurfaces** but later cover **both** surfaces and growers may not be aware of disease until it is well established and difficult to control.

Disease cycle

Powdery mildew of rose is one example (Fig. 186). Powdery mildews are **obligate parasites** and can only multiply on living plants. The fungus grows almost entirely externally on the surface and tiny suckers called haustoria penetrate the outer cells of the leaf to obtain food. Small black spots (cleistothecia) form with cool weather in autumn.

'Overwintering'

- As mycelium and spores on buds, twigs, canes, fruit and other plant parts, especially on perennials such as roses and apples.
- As active infections on host plants (in warm climates and glasshouses). Infection of annuals probably originates from out-of-season plants, held over stock, etc. Infected volunteer plants.
- Spores in fruiting bodies on infected crop debris.
- Seedborne on some hosts, eg pea.

Spread

- Spores spread by wind, air currents water splash.
- By movement of infected plant material, seed.

'Conditions favoring'

- **Night temperatures** of about 15^{o}C and relative humidity of 90-95% and **day temperatures** of above 26^{o}C and relative humidity of 40-70%.
- Epidemics are prompted by high humidity.
- Most severe in spring and autumn during hot humid weather. Many powdery mildews flourish in **hot dry conditions**, dews at night provide sufficient moisture for spore germination. Unlike downy mildews, powdery mildews can flourish in fairly dry weather.
- Spores germinate and infect hosts without free water and will not germinate in rainy weather.
- **Late crops** may be severely affected, eg pea, gerbera, days are warm and dry and nights cool enough for dew to form and spores to germinate.
- Shade, high plant densities and luxurious plant growth due to high nitrogen levels provide plenty green young tissue for powdery establishment.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Access/prepare a plan** in advance.
2. **Crop, region**. Know if your crop is susceptible to powdery mildew. Management programs are available, eg AUSVEG, Ausvit, Cropwatch (Vic), Rose Growers Assoc.
3. **Identification**. List the diseases the crop is susceptible to. On some crops you may need expert advice to confirm that it is powdery mildew and not downy mildew as the fungicides used to control them are often quite different. Consult a diagnostic service if necessary (page xiv).
4. **Monitor & detect** disease especially in low light sites, record results (page 327). You may need a x10 magnifying lens. Remember you need to **know when, where, what and how to monitor**.
   - Monitor **apple trees** during winter and growing seasons for small areas of white powdery growth.
   - Weekly inspections of **glasshouses** (1 plant in 30) where mildew has **not** been found. If detected, scout 1 plant in 10 every week until plants are disease-free for at least 3 weeks then go back to 1 plant in 30.
   - **Disease warning services** may be available.
   - Roses planted along the edge of vineyards in France served as an early warning system for powdery mildew of grapevines.
5. **Threshold**. How much damage is acceptable? Have any thresholds been established? If so, what are they, eg economic, aesthetic, environmental?
6. **Action/Control**. Take appropriate action when any threshold is reached, eg cultural improvement, sprays.
7. **Evaluation.** Review program. Within a few days of spraying check whether powdery mildew colonies are active. Recommend improvements if required.

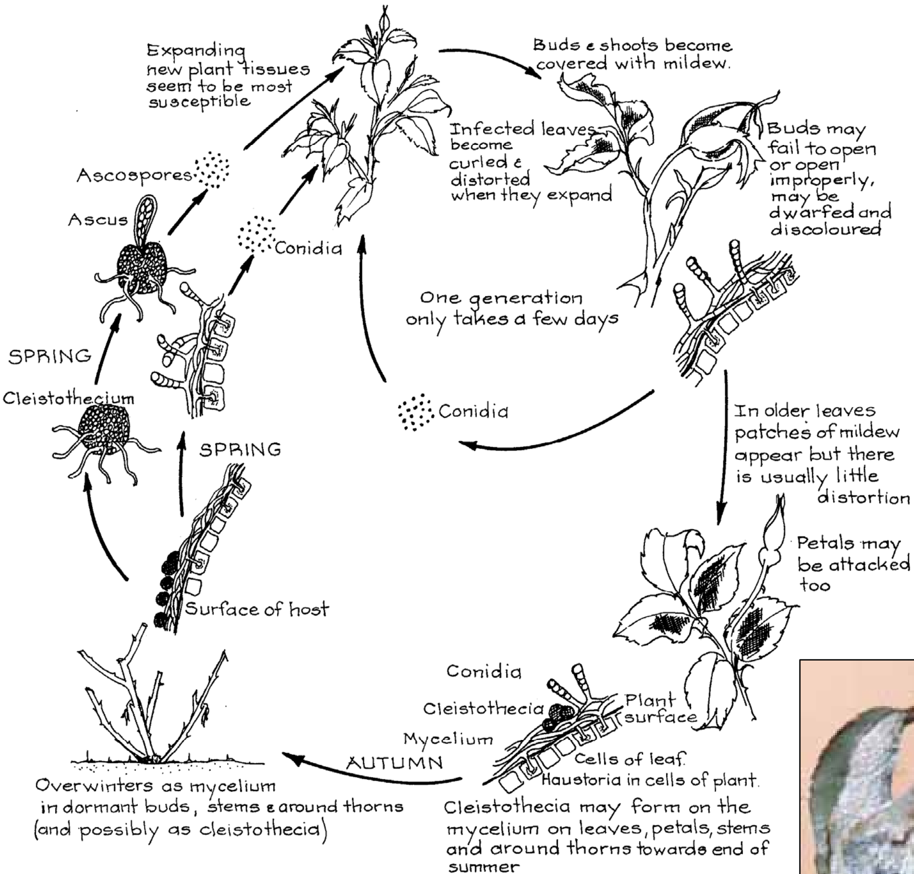


Fig. 186. Disease cycle of powdery mildew of rose (*Podosphaera pannosa*) (adapted from Agrios, 1997).

Control methods

Cultural methods.

- Keep relative humidity low at < 85%. Avoid overhead irrigation to assist control. Use drippers.
- Space/trellis/prune plants to allow good air circulation and penetration of sunlight.
- Avoid heavy nitrogen applications since young succulent tissue is more susceptible to infection.
- Ventilate and or heat glasshouses in the evening to reduce humidity levels by removing moist air which builds up during the day. Prevent condensation of moisture on leaf surfaces.
- Hosing down plants over 2-3 days in the morning may limit spread but favour *Botrytis*.
- Avoid clipping hedges of susceptible varieties of *Photinia* or *Euonymus* if disease is a problem.
- **Rotate crops** every 3-4 years to reduce incidence and severity in subsequent crops.

Sanitation.

- Destroy diseased crop residues, prunings and infected held over plants, volunteer plants.
- Prune out and destroy during winter all infected shoots on woody hosts, eg roses, apples. On apple, also prune off and destroy mildewed shoots as they appear during the growing season.
- Pick off and destroy first infected leaves regularly and immediately seal in a bag. Could delay an epidemic. Do not compost.
- Discard heavily infected transplants before they reach the main greenhouse.

Biological control.

Not very practical, but natural controls include:

- **Fungi**, eg *Sporothrix flocculosa*, *Ampelomyces quisqualis* (BC AQ10) and *Tilletiopsis* spp., provide some control of powdery mildew of roses overseas under certain conditions.
- **Fungus-eating ladybirds/larvae** (*Illeis galbula*) feed on powdery mildew of cucurbits. Some *Stethorus* beetles feed on fungal spores. **Tydeid mites**, living in tiny hair-like structures on undersides of wild grape leaves, feed on powdery mildew.

Resistant varieties.

If possible, grow varieties with some resistance, eg

- **Photinia**. Varieties with some resistance include *P. glabra robusta*. Very susceptible species include *P. serrulata*.
- **Apple**. Varieties with some resistance include Granny Smith and Delicious. Very susceptible varieties include Jonathon and Rome Beauty.
- **Grapevines**. Most susceptible **wine varieties** include Cabernet Sauvignon, Chardonnay, Chenin Blanc, Muller Thurgau, Muscadelle, Riesling, Semillon. Most susceptible **table varieties** include Cardinal, Flame Seedless, Red Globe.
- **Defense-activating compounds** are being researched.

Plant quarantine. **AQIS** periodically may reassess the quarantine status of some powdery mildews to see if treatment is still required.

Disease-tested planting material.

Only plant disease-tested seed, or treat seed.

Fungicides.

- Fungicides which control powdery mildew, often do not control many other diseases. Exceptions.
- In some vineyards, powdery mildew may be controlled mainly by regular applications of sulfur and synthetic fungicides and in organic agriculture by sulfur and botanical and mineral oils. Milk, whey and mixtures of botanical oil plus bicarbonate are potential replacements for synthetic fungicides and sulfur for powdery mildew.
- Apply at the first signs of disease as infection spreads rapidly. On **susceptible varieties** you may need to spray regularly at intervals depending on weather. Thoroughly cover **both** leaf surfaces.
- Powdery mildew mycelium is 'hard-to-wet', a wetting agent may be necessary. Use a fine mist.
- **Treating seed** of some crops, eg barley, delays onset and reduces severity of disease.
- **Risk of resistance.** Powdery mildew of cucurbit is accepted as having a **high** risk of developing resistance to fungicides, while powdery mildews of apple and grapevine have a **medium** risk. Resistance management strategies are available for some crops and powdery mildews on the CropLife Australia website www.**croplifeaustralia**.org.au/
- Check label **Resistance Management Strategies.**

Table 61. Powdery mildews – Some fungicides.

What to use?	When and how to apply?
BIO-FUNGICIDES (non-systemic) The following reduce the severity of powdery mildews: **Group M2**, eg Eco-fungicide®, Eco-carb®, Eco-rose® (potassium bicarbonate) Whey (waste cheese), dilute to one-third of normal strength Full cream milk - dilute to one tenth of normal strength Milk products may not be permitted on some crops as lactose intolerant consumers may have an allergic reaction to plants sprayed with milk products. Products being researched include azaradachtin (neem), jojoba oil, garlic extracts	• Some bio-fungicides may cause leaf spotting on some cultivars if applied at higher than recommended rates, too often, or at high temperatures. Must be good coverage. • Mix Eco-fungicide® with Eco-oil® to increase effectiveness. • Bicarbonate, oil, milk and whey are not preventative as they work directly on the spores and mycelium, causing them to shrivel up (they are contact fungicides). They often have to be applied at 7-14 day intervals. Too much milk encourages sooty mould.
NON SYSTEMIC FUNGICIDES (protectant) **Group 13**, eg Legend® (quinoxyfen) **Group M1**, eg copper compounds (limited use if disease pressure is high (residual) **Group M2**, eg Sulphur Dust® (elemental sulphur); Wettable Sulphur® (dispersible sulphur); Lime Sulphur® (polysulphides) **Group M3/M2**, eg Mancozeb® Plus (mancozeb + sulphur) **Summer spray oils**, eg D-C-Tron® Plus (petroleum oil)	• Sulphur may damage some plants > 30°C, especially flower petals of some ornamentals. Can be volatilized from hot plates in greenhouses. May leave unacceptable residues on foliage. • Sulphur can also kill of beneficial insects and mites. • Lime sulphur may be applied during dormancy **after** pruning • Products purchased by **home gardeners** often include sulphur, eg rose or vegetable sprays and dusts. • See spray oils page 61.
SYSTEMIC FUNGICIDES (eradicant) **Wide range of systemic fungicides but only a few are registered for use on any particular crop**. **Group 1**, eg Bavistin®, Spin® (carbendazim) **Group 3**, eg Anvil® (hexaconazole); Baycor® (bitertanol); Nustar® (flusilazole); Tilt® (propiconazole); Saprol® (triforine); Systhane® (myclobutanil) **Group 5**, eg Prosper® (spiroxamine) **Group 11**, eg Amistar® (azoxystrobin); Flint® (trifloxystrobin)	• Follow **Croplife Australia Resistance Management Strategies** and any label instructions. • At **harvest** when most protection is needed it is preferable to rely on the newest and most effective systemic fungicide. Keep other fungicides for less risky stages. • Amistar® (azoxystrobin) is effective against **both** powdery and downy mildews. • Some fungicides only registered for use **on only one crop**, eg Domark® (tetraconazole) for powdery mildew on grapevines.
SEED DRESSINGS Fungicides to control powdery mildew on some crops, eg cereals, may be formulated with insecticides.	See also page 374.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Downy mildews

The most famous downy mildew disease is that caused by a fungus (*Plasmopara viticola*) on grape vines which devastated French vineyards in the l890s. The trouble started when, to control a gall aphid, the grape phylloxera (*Daktulosphaira vitifolii*); resistant rootstocks were imported from North America. Downy mildew was apparently introduced on these, and although this disease was not destructive in North America, it was on the varieties grown in France. The disease was not without some compensation, for it led to the development of Bordeaux Mixture, arguably one of the most important fungicides of all time. Check current registration status in your State/Territory.

Scientific name

Downy mildews (Order Peronosporales, Phylum Oomycota). Common downy mildews include:

Bremia lactucae	Lettuce
Hyaloperonospora parasitica (formerly *Peronospora parasitica*)	Brassicas, eg cabbage, stock
Peronospora antirrhini	Antirrhinum
P. destructor	Onion
P. sparsa	Rose
P. tabacina	Tobacco (blue mould)
Plasmopara viticola	Grape
Pseudoperonospora cubensis	Cucurbits
Sclerophthora macrospora	Grasses, cereals
See also page 320.	

Host range

Ornamentals, eg bedding plants, eg stock, sweet pea, poppy, ranunculus, roses, etc. **Fruit**, eg grape. **Vegetables**, eg cucurbits, lettuce. **Field crops**, eg wheat. **Weeds**. Generally a particular species of downy mildew is restricted to one host, or group of related hosts, eg one species attacks roses and another cucurbits, and so on. Strains of some downy mildews exist and new strains may be continually evolving so that new resistant varieties and fungicides may be continually required. Races of *Peronospora parasitica* f.sp. *matthiola* will only infect **stock** and not other *Brassica* spp.

Symptoms

Leaves, stems, petals, flower stalks, buds, fruit and pods may be attacked. **Seedlings** may be killed.

Leaves, shoots. Most obvious symptoms appear on leaves but vary with the host. Leaves may fall. As lesions dry out during dry weather, they shrivel and die and entire plants may be killed if attacked early in the season. **Systemic infection** may occur in some hosts, eg antirrhinum, cereals, rose, causing yellowing of growing tissues, distortion, leaf russetting and stunting (impatiens).

- **Upper surface**. Pale green to yellow irregular shaped areas/spots, usually delineated by veins develop on the leaf upper surface, they may enlarge, coalesce and cover large areas of the leaf. Depending on the host, these spots vary from light green to red to brown dead areas, eg on roses purple areas are evident while on stock and pansies, yellow areas are prominent.
- **Lower surface**. Under high humidity a typical white or gray downy/fluffy fungal growth may form on the underside of infected tissue. Sometimes there is insufficient fungal mass to be seen even with a magnifying glass, eg pansies (spores mauve), snapdragon, Brassicas (spores white).
- **Roses** develop red-black spots on leaves, petals and stems in advance of obvious mildew. Purple areas on leaves turn pale brown. Leaves may fall, even when other symptoms are not obvious.
- **Infection of young apical shoots** causes distortion, stunting and stem cracking.

Fruit. Downy mildew spores may develop on fruit, eg grapes which later shrivel.

Secondary infections. Downy mildews are less common than powdery mildews, but secondary infections may follow, eg *Botrytis*, bacterial slime and rotting (lettuce).

General. Downy mildew can be common and destructive in favourable conditions leading to total crop loss. Some downy mildews are more aggressive than others, eg downy mildew on snapdragon seems to spread faster than on pansy. Nursery seedlings can be seriously affected.

Fig. 187. Downy mildew of lettuce (*Bremia lactucae*). White angular patches of fluffy fungal growth on **undersurface** of leaf. Photo© NSW Dept of Industry and Investment.

Fig. 188. Downy mildew of grapes (*Plasmopara viticola*). ***Left:*** Fungal spores on **undersurface** of leaf. ***Right:*** Lesions on **uppersurface** of leaf and on fruit. Photo© NSW Dept of Industry and Investment (M.Senior).

Diagnostics

- Symptoms on Impatiens are easily confused with nutritional deficiencies or mite damage
- Many hosts are not susceptible to downy mildews.
- With a hand lens check for the characteristic downy growth usually on **underside** of leaves, it may escape notice until spores form. See page 345 for comparison with powdery mildews.
- If still unsure incubate suspect tissue in moist chambers for about 48 hrs to encourage development of downy growth on leaf undersides.
- **Microscopic examination** by experts will identify characteristic tree-like spore structures (which varies for each species of downy mildew) and distinguish it from powdery mildew and gray mould.
- **Systemic infection** characterized by discolouration and stunting of growing points.
- **DNA** is not commonly used to identify downy mildews.

Disease cycle

For downy mildew of grape (see Fig. 189). Short-lived zoospores are produced at night and released the following morning as air dries out. Spores germinate within 4 hours in water and can produce more spores in 3 days. Many downy mildews can only reproduce on living plants.

'Overwintering'

- As **systemic** infections in some plants, eg roses.
- Infections on perennial crops, eg grape, roses infected buds and stems. Infected regrowth.
- Fallen leaves, etc in soil, growing media, compost, crop debris. Some spores remain viable for years (oospores), others (zoospores) for only a few days.
- Alternate or weed hosts, volunteer plants.
- Old infected seedlings in nurseries, stock plants.
- Contaminated seed, propagation material, cuttings.

Spread

- 'Overwintering' spores may wash from infected plant debris into soil. Short-lived zoospores spread by wind, water, sprinkler or rain splash.
- By movement of infected plants, seeds, cuttings, bulbs, etc. before symptoms are apparent.
- Infected crop debris returned to soil and distributed with irrigation or flood water.
- There is some evidence that downy mildew could be seedborne on some hosts.

Conditions favoring

- Leaves wet for long periods. Spores require free moisture on the leaf surface to establish infection.
- Cool nights, wet warm days, extended periods of cool, wet weather during spring and autumn.
- Can be devastating on seedlings in crowded seed-beds during cool, moist, dull weather in unheated, poorly ventilated glasshouses. Only checked when weather becomes hot and dry.
- Temperature requirements vary with the species, eg Brassicas 8-24°C, pansies 13-18°C.
- Weather warning systems predict when outbreaks may occur, eg downy mildew of grapevine.

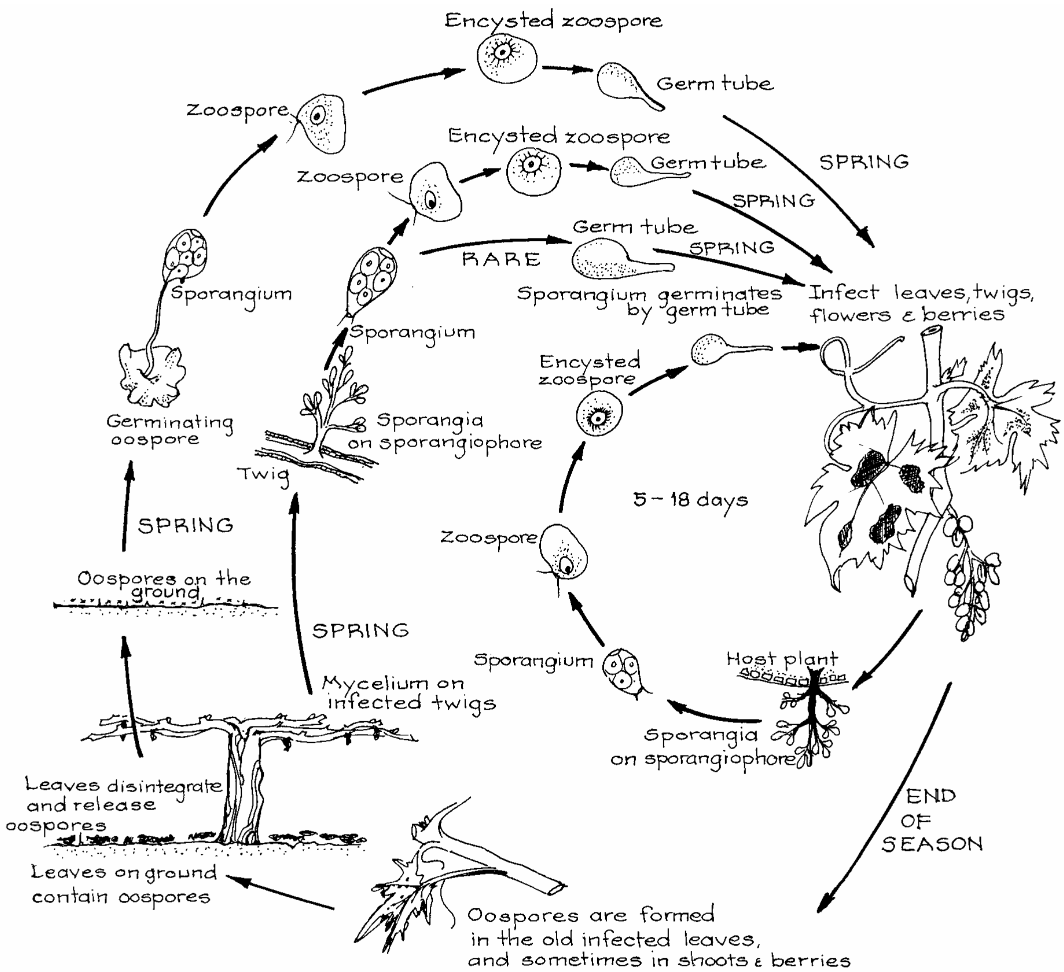


Fig. 189. Disease cycle of downy mildew of grapes (*Plasmopara viticola*) (adapted from Agrios, 1997).

Management (IDM)

Are you a commercial grower or home gardener?

1. **Access/prepare a plan** that fits your situation. **IDM** programs are available for downy mildews of many crops, eg lettuce via **AUSVEG**. Also check Ausvit, Cropwatch, State Depts. of Primary Industry.
2. **Crop, region**. Recognize variations.
3. **Identification** can be difficult without a microscope. Consult a diagnostic service (page xiv).
4. **Monitor and detect** disease and/or damage on susceptible species/ varieties from spring onwards, record results (page 327). Do you **know when, where, what and how to monitor** for your situation.
   - **Inspect** upper and lower surfaces of new leaves at least once per week for spotting or discolouration of the most susceptible cultivars. Will need a magnifying glass. Also check fruit if necessary.
   - **Warning services/Disease predictive models** are available for some crops, eg onions, grapes, lettuce, nursery seedlings. As each downy mildew species has specific weather requirements for successful sporulation and infection, eg leaf wetness, temperature and rainfall, disease forecasts can be made reducing fungicide use. Some also provide management advice.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic or aesthetic? Do you need to calculate your own threshold for your **crop** in your **region**?
6. **Action**. For some crops, property freedom and prescribed treatments may apply. Check your situation.
7. **Evaluation.** Review your program compare current records with earlier ones. If required, put improvements in place, eg using resistant varieties, different fungicides.

Control methods

Downy mildews can be difficult to control.

Cultural methods can reduce the incidence by 80-100%. In glasshouses regulate temperature and humidity to reduce night-time humidity by ventilation, heating, air movement.

- **Irrigation**. Keep crop as dry as possible. Spores need water to germinate on the leaf surfaces to infect plants. Do not overwater and avoid overhead irrigation. Irrigate late in afternoon allowing time for leaves to dry before dew forms on leaves. Do not water seedlings in morning when spores are released and infect plants. Consider capillary watering which does not wet foliage.
- **Maintain good ventilation** to lower humidity, minimize spore production on infected plants and spore germination on new plants. Space and plant rows along direction of prevailing winds to reduce infection. Space seedling trays to improve ventilation and dry the leaf surfaces quickly.
- Maintain even temperatures.
- **Nutrition**. Adequate potash (K) reduces seedling susceptibility to downy mildew, eg on cauliflowers. Controlled mostly in production with balanced nutrients.
- **Use a crop rotation** of 2-3 years for susceptible field crops where practical. Rotate propagation areas.

Sanitation.

- **Rogue and burn/deep bury** diseased seedlings to eliminate sources of infection. Remove heaviliy infested seedling trays, old seedlings, weeds.
- Plough in field crop debris immediately after harvest.
- **Before planting new crops** remove crop debris, destroy self-sown volunteer plants and regrowth of annuals and weeds from previous crops and bury or incinerate it. Disinfect propagation areas and equipment with a short persistent disinfectant. Keep production areas clean. Fallow glasshouses.
- Prune out/destroy diseased branches on woody hosts.

Resistant varieties.

- If downy mildew is a problem select varieties with some resistance to new strains of downy mildews, eg lettuce.

Plant quarantine.

- Property freedom, prescribed treatments.
- Isolate stock plants especially when first introduced into the nursery, eg petunia.

Disease-tested planting material.

- Do not propagate from infected perennial plants.
- Only purchase and plant disease-tested seeds or select seed only from healthy plants or treat seed, disease-free seedlings or bare-rooted nursery stock.

Physical & mechanical methods.

- Pasteurization of soil in seedbeds is recommended but is not economical for larger areas.
- Research indicates that blue wave lengths of light can help in reduction of downy mildew of cucurbits

Fungicides.

- **Fungicide-resistant strains** of downy mildews are present in many districts, eg downy mildew of peas has developed resistance to metalaxyl.
- **Risk of resistance.** The downy mildews of grapes and cucurbits are accepted as having a **high** risk of development of resistance to fungicides, while the downy mildews of lettuce and certain other plants have a **medium** risk. Resistance management strategies are available for control of downy mildew of cucurbits, grape, lettuce and onion on the **CropLife Australia** website www.**croplifeaustralia**.org.au/
- **Spray programs** for the control of downy mildew of grape vines is also available for commercial growers from Cropwatch in Riverland, Hort Hotline in Sunraysia.
- Check **label Resistance Management Strategies.**
- **Use Disease Prediction Services** which allow fungicide applications to be better timed, reducing fungicide use in low risk seasons.
- Thoroughly spray **lower** and upper leaf surfaces.
- **Soil fumigation** for production areas of potting soil will eliminate soilborne infection which could be significant where the same crop is grown repeatedly.
- **Some plants**, eg lettuce, are difficult to spray effectively.

Table 62. Downy mildews – Some fungicides ***(check on particular DM***

What to use?	When and how to apply?
NON-SYSTEMIC FUNGICIDES (protectants) **Group M1**, eg copper hydroxide; copper oxychloride; copper ammonium acetate **Group M3**, eg zineb; mancozeb (often formulated with systemic fungicides); Phytan®, Banvel® Polyram® (metiram) **Group M5**, eg Alert®, Bravo®, various (chlorothalonil)	• Apply **before** infection occurs for best results. • Make sure **undersurfaces** of leaves are wetted. • **M3 and M5** fungicides are often used on seedlings which might be damaged by copper sprays. • Adjuvants such as Synetrol, Codacide, Agridex or DCTron can provide strong activity.
SYSTEMIC FUNGICIDES (eradicants) **Group 4**, eg Fongarid® (furalaxyl); Ridomil® (metalaxyl) **Group 11**, eg Amistar® (azoxystrobin) (**controls both downy and powdery mildews**) **Group 40**, eg Acrobat® (dimethomorph) - **locally systemic** **Group 33**, eg Alliette® (fosetyl-al); Fol-R-Fos®, Phospot®, various (phosphorous acid)	• Follow **Resistance Management Strategies** on labels. • Keep systemic fungicides for conditions that are particularly favourable for disease. • Systemic and contact fungicides may be combined. • Many new products being developed
SEED DRESSINGS **Group 4**, eg Fongarid® (furalaxyl); Rampart®, Mantle® (metalaxyl); Apron® (metalaxyl-M)	Many new seed treatments are being developed (page 374).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Rusts

Rust diseases derive their name from the orange-brown spore masses which many rust fungi produce on their hosts. The **cereal rusts** occur universally wherever susceptible hosts grow. The Romans considered the cereal rusts so important that they believed that the Gods Robigo and the Robigus were responsible for them and planned annual festivals to please them. **GRDC Rustlinks** is the main online source of information for **cereals rusts**. www.grdc.com.au/rustlinks

Scientific name

Rusts (Order Uredinales, Phylum Basidiomycota) are a specialized group of fungi which produce a range of spore states (Table 63).

Host range

Ornamentals, fruit, vegetables, field crops and weeds may be attacked. Generally a particular species of rust can attack only certain host species or only certain varieties. Rust fungi that are morphologically identical but attack different host genera or species are called form species (f.sp.), eg *Puccinia graminis* f.sp. *tritici*. Native rust fungi are continually being detected.

Rose rust (*Phragmidium mucronatum*)
Sunflower rust (*Puccinia helianthi*)
Stripe rust (*P. striiformis*)
Wheat leaf rust (*P. recondita* f.sp. *tritici*)
Rust (*P.grevilleae*) on Proteaceae
See also page 322.

Symptoms

Leaves, stems and fruit may be attacked. Sepals, and occasionally other flower parts, glumes in cereals and grasses. After infection it may be some time before symptoms appear – plants can be dispatched infected but without symptoms.

Leaves, stems

- The leaf **upper surface** becomes speckled due to a yellow zone which forms around infection zones. The small yellow patches may run together.
- On leaf **under surface**, corresponding **yellow**, **orange** or **rusty-brown** spores masses (urediniospores) develop. Later in the season, **dark or black** spores may form in pustules (teliospores). White rust of chrysanthemum produces pinkish-white waxy pustules. Some rusts produce spores on both leaf surfaces.
- **When infection is heavy**, premature and repeated leaf fall seriously weakens the plant. If stem infections are heavy, stems may be ring-barked causing dieback of the upper portion.
  – **Wattles.** Rust galls (*Uromycladium* spp.) develop on flowers, stems and foliage (Fig. 192).
  – Young **poplar trees** in **nurseries** may die.
  – **French bean** (*Phaseolaris vulgaris*). Spore masses on leaves may be black rather than red.

Fruit
Lesions may develop on peach fruit, bean pods, etc.

Diagnostics. Presence of rust spores

- **The powdery rust spores** can be **removed** by running the thumbnail across **mature** lesions, this indicates the presence of characteristic rust spores.
- May be confused on **leaves** with various leaf spotting diseases on some hosts.
- Rust on **fruit** and **twigs** can be difficult to recognize without microscopic examination and experience.
- **Microscopic examination** of spores by an expert may be required to confirm identification (se page xiv). Observation of the intricate structure of the spores is often needed to enable accurate identification.
- In the early stages of infection only pin point spots may be present on leaf under sides. Experience is needed to detect the early stages of infection.
- For some rusts, there are keys and **DNA** tests.

Fig. 190. Geranium rust (*Puccinia pelargonii-zonalis*). Rust pustules on leaf undersurfaces. Photo©NSW Dept of Industry and Investment..

Fig. 191. Bean rust (*Uromyces appendiculatus*). **Under surface** of bean leaflet with reddish-brown pustules surrounded by a pale border. Photo©NSW Dept of Industry and Investment.

Fig. 192. Gall rust (*Uromycladium* spp.) on wattle stems. Photo©CIT, Canberra (P.W.Unger).

Fig. 193. Rose rust (*Phragmidium mucronatum*). ***Left:*** Upper surface of leaf with yellow areas. ***Right:*** Undersurface of leaf showing orange urediniospores and black teliospores. Photo©CIT, Canberra (P.W.Unger).

Table 63. Some rust diseases, types of life cycles and spore state numbers.

SOME RUST DISEASES	**HOST RANGE**	**RUST LIFE CYCLE.** **Autoecious** All spore states on one host **Heteroecious** Life cycle split between two unrelated hosts with 0,1 spore states on one host and 11,111 on the other **May not be known if rust is autoecious or heteroecious**	**KEY - SPORE STATE NUMBERS.** (in brackets are those not yet found in Australia) 0 **Pycnium** (pl. pycnia) produce pycniospores, spermogonium (pl. spermogonia) produce spermatia 1 **Aecium** (pl. aecia) producing aeciospores 11 **Uredinium** (pl. uredinia) producing urediniospores, this is the **REPEATING STAGE**. 111 **Telium** (pl. telia) producing teliospores 1V **Basidium** (pl. basidia) producing basdiospores, spore state **1V** occurs in **all** rusts
Melampsora medusae *M. epitea* *M. coleosporioides*	Poplar Pussy willow Weeping willow	Heteroecious Heteroecious Heteroecious	(0,1 on larch) **11,111 on poplar** (0,1 on several hosts) **11,111 on pussy willow** (0,1 unknown),**11,111 on weeping willow**
Phragmidium mucronatum	Rose	Autoecious	**0,1,11,111 on rose**
Puccinia graminis f.sp. triticii (wheat stem rust) *P. horiana* (white rust) *P. lagenophorae* *P. malvacearum*	Wheat, barley, oats, rye Chrysanthemum **Asteraceae**, ie **natives** eg Senecio; **exotics**, eg calendula; **weeds** eg groundsel **Malvaceae**, eg mallow, hollyhock	Heteroecious Autoecious Autoecious Autoecious	(0,1 on barberry), **11,111**, **1V grasses, cereals** **111 on chrysanthemum** **0,1,111 on Asteraceae** **111 on Malvaceae**
Uromycladium spp.	Wattle	Autoecious	**0,1,11,111 on wattle**
Not known in Australia *Puccinia psidii* (eucalypt rust, guava rust)	**Myrtaceae**, eg eucalypts, melaleuca, callistemon, guava **Heteropyxidaceae,** eg lavender tree (*Heteropyxis natalensis*)	Autoecious	0,**11,111,1V on eucalypt, gauva etc**
Beneficial rusts *Phragmidium violaceum*	European blackberry	Autoecious	**0,1,11,111,1V on blackberry correct**

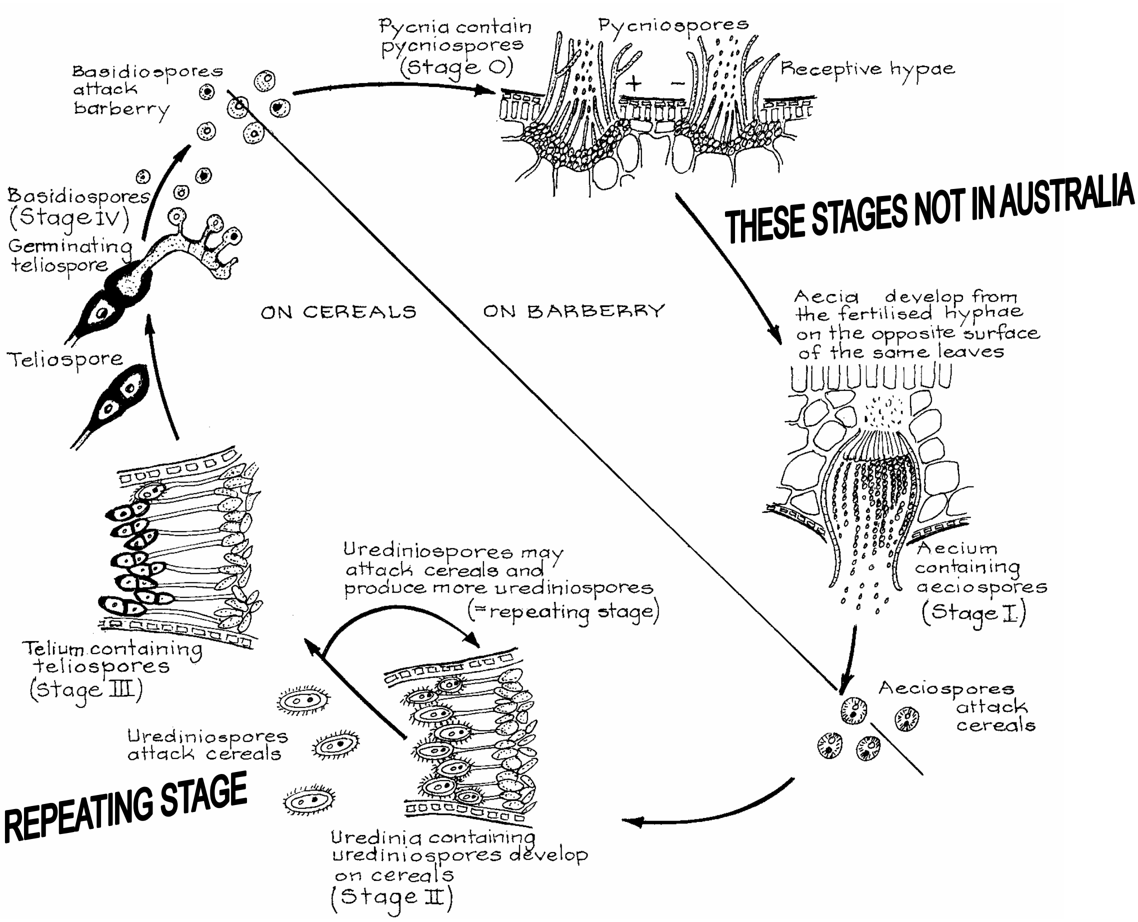


Fig. 194. Disease cycle of wheat rust (*Puccinia graminis*) (adapted from Agrios, 1997).

Disease cycle

In Australia, many rust diseases appear to produce only urediniospores (stage 11 - asexual repeating stage), eg chrysanthemum rust (*Puccinia chrysanthemi*) (Fig.195 below).

'Overwintering'

- **As infections on perennial hosts**, old diseased crops left standing after harvest.
- **As thick walled spores** (urediniospores and teliospores) on **infected crop debris**, in the **soil** and on **seed** and crop regrowth volunteers.
- **Many heteroecious rusts** can survive from season to season in countries with mild winters, such as most parts of Australia, in the repeating stage (**urediniospores**), which can lodge in bark crevices, on buds or on plant debris until the following season when the wind will blow them onto new host leaves and other plant parts. Poplar rust, stone fruit rust and the cereal rusts are examples of heteroecious rusts which can successfully 'overwinter' by this means.
- **In heteroecious rusts**, the fungus can be going through further spore stages on the alternate host. In Australia these rusts seem to be able to 'overwinter' as urediniopsores.
- **Oversummers on volunteer plants**.

Spread

- Spores are spread by wind and water splash from infected host plants and infected host plant debris to other susceptible host plants.
- Spores may adhere to the surface of seed from infected host plants and infected leaves. The inoculum can survive in the soil and is often spread via splashing water.
- Overseas, barley stripe rust on susceptible varieties may spread via unwashed clothes or shoes worn in infected crops.
- Movement of infected host plants.

Conditions favoring

- **Most problems occur in field** plantings.
- **A film of water on leaves** for a period of about 4-5 hrs is necessary for downy mildew spores to germinate and infect a plant but symptoms may not develop until much later so that plants which appear healthy and are dispatched can subsequently develop rust.
- **For each species of rust** or even each race there is a particular regime of temperature and humidity which determines infection, it is not possible to generalize, eg
  - **Poplar rust** – High humidity. high temperatures.
  - **Stem rust (cereals)** - High humidity and moderate temperatures.
  - **Bean rust** - Cool, damp weather, fogs, mists.
  - **Sorghum rust** - Warm humid weather favours leaf infection, disease development, spore production.

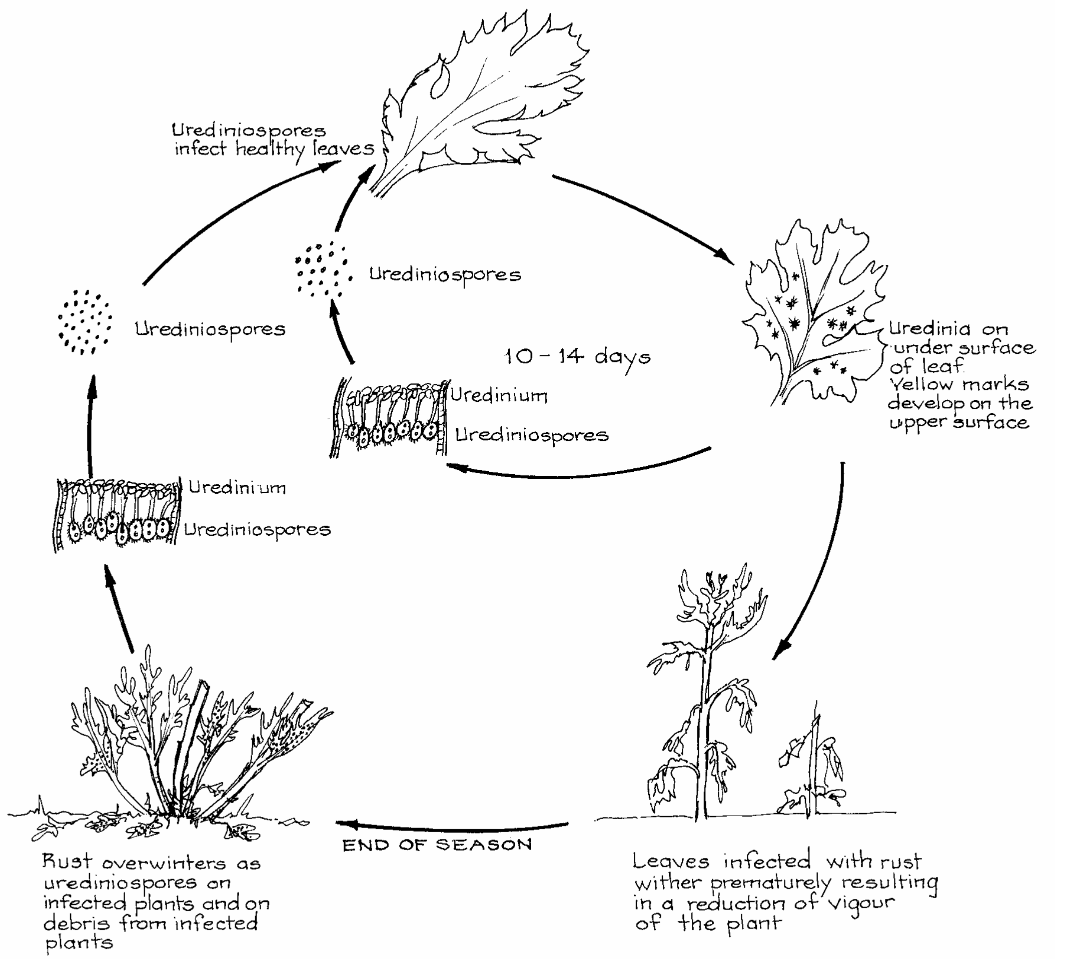


Fig. 195. Disease cycle of chrysanthemum rust (*Puccinia chrysanthemi*).

Management (IDM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** in advance for your crop.
2. **Crop, region**. Recognize variations. Rusts may be more severe in some areas than others.
3. **Identification** of disease must be confirmed. If necessary consult a diagnostic service (page xiv).
4. **Monitor and detect disease** on the **most susceptible varieties**, seedlings, earliest sown crops and sentinel crops along certain walking patterns as they are most likely to develop early rust. Inspect leaf undersurfaces for pinpoint spots but experience is needed to detect this early stage of infection, also look for spores. Record findings. **Early warning systems** are available for some rusts, eg Prune Rust Infection Predictors, Stripe Rust Alert Services.
5. **Threshold**. Quarantine regulations may require a nil threshold in some crops. How much damage can you accept? What is your threshold, eg economic, aesthetic, environmental?
6. **Action/control**. Take appropriate action when any threshold is reached. This may involve removing/ destroying affected plant parts, spraying it may be following some prescribed control measures.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required, eg planting more resistant cultivars, rust-tested seed.

Control methods

Cultural methods.

- Avoid high rust hazard zones.
- Avoid planting seed or cutting beds too thickly.
- Keep foliage as dry as possible. Avoid overhead irrigation, or water early in the day to allow crop to dry. Sub-irrigation helps prevent rust outbreaks.
- Provide adequate ventilation, reduce humidity, maintain even temperature to reduce infection.
- Where rust causes severe losses and no resistant varieties are available it may be possible to plant early in the season so that plants can make good growth before development of an epidemic.

Sanitation.

- Remove and destroy severely infected plants, fallen leaves, crop regrowth, volunteer seedlings, crop debris and prunings as soon as practical to reduce the amount of inoculum available for next season.
- Remove infected leaves or whole plants in cutting or seedbeds, as soon as they are observed.
- Susceptible tree species generally should not be removed, rust may be minimal during dry seasons and trees may survive for years despite rust.
- With rust diseases which produce galls, infected branches can be pruned out and burnt.
- Susceptible weeds should be controlled.
- Do not plant susceptible crops near older diseased crops. Plough in crops immediately after harvest.

Biological control.

- Some fungi are parasitic on rusts but provide no economic control, eg *Verticillium lecanii* on coffee rust, *Cladosporium* sp. on poplar rust.

Resistant varieties.

- **Use of resistant varieties** is the most common, effective method of rust control www.**grdc**.com.au/
- **The National Wheat Rust Control Program** screens wheat lines for resistance. As rust fungi regularly develop new virulent strains, ongoing screening and selection is necessary to maintain resistant varieties for wheat growers. Rust genes from plants other than wheat could potentially be transferred to wheat. 'Designer' genes providing more durable resistance could be developed.
- **Combining** two or more resistance genes in sunflowers is expected to produce robust protection.
- **Even cultivars** with **partial resistance** to rust are useful because they reduce the amount of fungicide used, eg antirrhinum and carnation rust.

Plant quarantine.

- New rusts enter Australia all the time; recent arrivals include grape leaf rust (*Phakopsora euvitis*). A National Grapevine Eradication Program was put in place and the disease has since been eradicated. Although eradication of other recent entries may not really be possible, eg myrtle rust (*Uredo rangelii*), chrysanthemum white rust (*Puccinia horiana*), daylily rust (*P. hemerocallidis*) and its alternate hosts, eg *Hosta, Patrinia*, they are subject to regulations and local protocols. Check.
- An Asian-Pacific Strategy manages the threat of *Eucalytpus* Rust (*Puccinia psidii*).

Disease-tested planting material.

- Avoid propagating vegetatively from infected plants.
- Do not save seed from infected plants, if such seed is to be used it must be treated.

Fungicides.

- Rusts are **suppressed** by fungicides, not eradicated.
- **Some rusts occur in crops** such as wheat which cannot be economically sprayed or on plants such as poplars which are too tall to spray.
- Foliage sprays and dusts are only practical for **small areas**, eg orchards, nurseries, gardens. Begin treatment at an early stage of infection as advanced rust outbreaks are difficult to control. And thoroughly spray all plant surfaces.
- **Risk of resistance.** The rusts of wheat and barley are accepted as having a **medium** risk of developing resistance to fungicides. Follow Resistance management strategies available for some crops and rusts on the CropLife Australia website www.**croplifeaustralia**.org.au/
- Follow label Resistance Management Strategies.
- Overseas soil drenches and tree injection are used to control rust diseases with systemic fungicides.

Table 64. Rusts – Some fungicides.

What to use?	When and how to apply?
NON-SYSTEMIC FUNGICIDES (protectants) **Group M1**, eg copper hydroxide; copper oxychloride **Group M2**, eg Dusting Sulphur; Kumulus®, Lansul®, Sulfine® (dispersible sulphur); Lime Sulphur® (polysulphides) **Groul M3**, eg mancozeb	• Sulphur has long been a specific remedy for rust. • Sulphur may scorch some species at > 30°C, eg begonia, soft-foliaged plants. Flower petals may be very susceptible • Sulphur is often included in all-purpose garden sprays or dusts, eg rose or vegetable sprays and dusts. • Mancozeb is probably the most widely used fungicide for rust diseases.
SYSTEMIC FUNGICIDES (eradicants) **Group 3**, eg Baycor® (bitertanol); Saprol® (triforine); Tilt® (propiconazole) Impact® (flutriafol) may be applied as a foliar sprays or as in furrow as a fertilizer treatment **Group 7**, eg Plantvax® (oxycarboxin)	• Apply systemic fungicides at the first sign of rust. • Frequency of further applications depends on weather. • Generally if you can see the rust pustules then systemic fungicides are usually required. • If disease is well established do not try to spray, remove/ destroy severely affected plants and self-sown seedlings.
SEED DRESSINGS Wide range of seed dressing are available See also page 374	• Most rust diseases are **seedborne**. • Sulphur is used occasionally as a dust or dip to kill the rust spores which adhere to the **outside** of seed.
BIO-FUNGICIDES (non-systemic) Some products are being researched.	

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Black spot of rose

Example of a fungal leaf spot

The most common and serious disease of roses.

Scientific name

Black spot (*Marssonina rosae,* Imperfect Fungi = *Diplocarpon rosa,* Phylum Ascomycota).

Host range

Roses. Some cultivars are more susceptible than others. Most fungal leaf spots are host specific – see page 321 for more species

Symptoms

Leaves.

- More or less circular black spots with fringed margins up to **12 mm** across develop usually on leaf **uppersurfaces** (Fig. 196).
- Leaf spots vary in number from 1-20 per leaf and may coalesce to produce large, irregular black areas.
- During damp weather, examination of the feathery spots with a hand lens shows small black blisters (fruiting bodies or **acervuli**) which contain spores (**conidia**).
- In susceptible varieties, the appearance of black spots is soon followed by a yellowing of portion or the entire leaflet and then by defoliation. The leaf tissue around the lesions turns yellow and often entire leaves become yellow and fall prematurely.
- Sometimes new leaves are produced which also become infected.

Flowers. Continual defoliation results in a reduction in the size and number of flowers.

Young canes of susceptible varieties may also develop spots. Lesions are indistinct black areas, slightly blistered **without** fringed margins and as raised, purple-red blotches on immature wood of 1st year canes. There will be a reduction in size and number of flowers as well as dieback of stems.

General. Repeated defoliation weakens the plant and may lead to dieback of stems and reduction in size and number of flowers. If the plant is continually defoliated in this way dieback and death may follow.

Diagnostics.

- Do not confuse the feathery black spots on roses with anthracnose (*Sphaceloma rosarum*) or other **minor** leaf spotting fungi, eg *Mycosphaerella* which have smooth margins.
- Small dark fruiting bodies can be seen with a hand lens or under a compound microscope.
- Some fungal leaf spotting fungi can be identified by **DNA** analysis, eg *Mycosphaerella nubiloa* on *Eucalyptus globulus*.

Fig. 196. Black spot (*Marssonina rosae*) on rose. Rose leaves showing typical symptoms of black spot. The large black spots have a feathery margin. Severely affected leaves yellow and fall prematurely. Photo©CIT, Canberra (P.W.Unger).

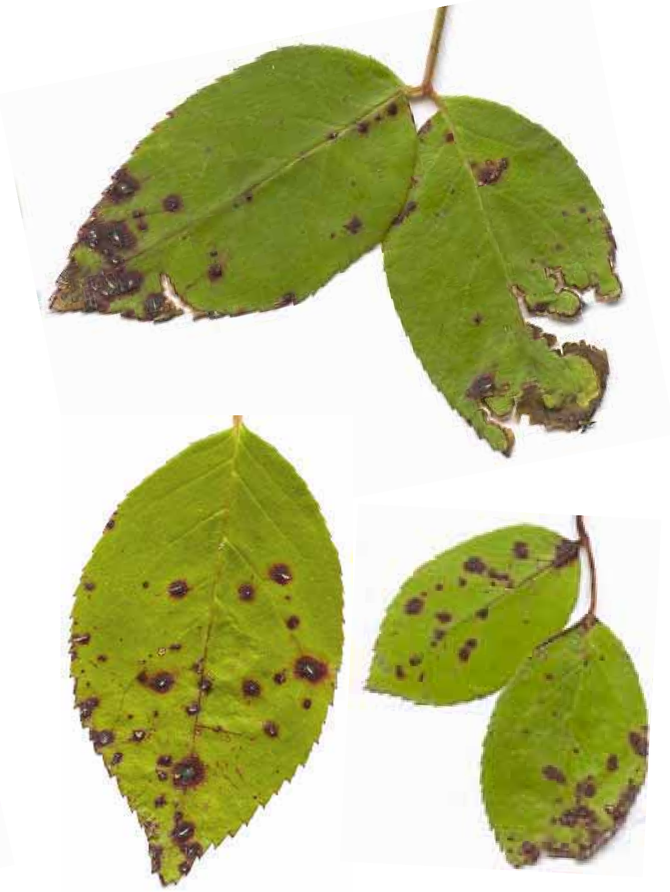


Fig. 197. Anthracnose (*Sphaceloma rosarum*) on rose. Rose leaves showing typical symptoms of anthracnose. Spots are ash-gray with well defined margins. Leaves may become tattered at the tips. Defoliation does not occur to the same extent as with black spot. Photo©CIT, Canberra (P.W.Unger).

Disease cycle

The sexual Ascomycota state, ie apothecia and ascospores, has not yet been found in Australia and only rarely overseas. Spore germ tubes penetrate and infect leaves in spring, the fungus grows in the mesophyll and within 2 weeks forms more spores on upper leaf surfaces. Conidia are produced throughout the growing season and cause repeated infections during warm, wet weather.

'Overwintering'

In susceptible varieties, in lesions on canes, fallen leaves, and prunings from infected plants.

Spread

- Spores (conidia) are spread by wind, rain or water splash from infected plants and fallen leaves and prunings from infected plants.
- Over long distances, by movement of infected plants. By the introduction of infected plants

Conditions favoring

Warm (13-24^{O}C), wet weather especially in spring.

Management (IDM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region**. Recognize variations, some varieties are more susceptible than others.
3. **Identification** may be difficult to confirm. Consult a diagnostic service if necessary (page xiv). Do not confuse with anthracnose.
4. **Monitor** leaves of susceptible rose varieties during damp weather in more shaded areas for the first signs of leaf spots (page 327). Record results as recommended. Defoliation caused by leaf diseases of eucalypts in plantations is monitored. Remember **know when, where, what and how to monitor**.
5. **Threshold**. How much damage can you accept? Reduction in flower size and numbers may be an economic issue for commercial growers. Is your threshold economic or aesthetic?
6. **Action**. Take appropriate action when any threshold is reached, eg reduce overhead irrigation, remove affected leaves, and spray only if a need has been demonstrated.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required, eg change irrigation practices, replace some very susceptible varieties.

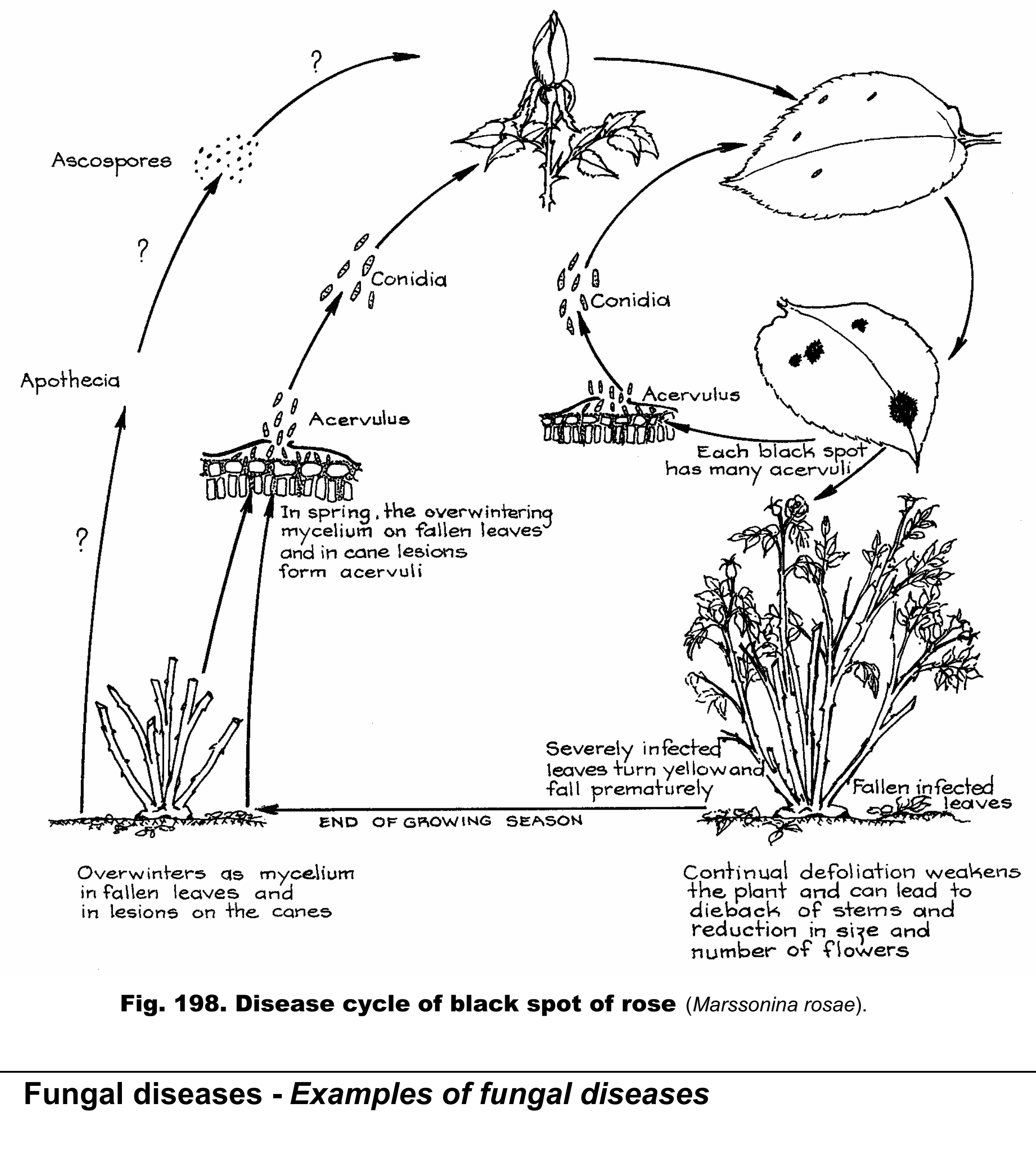


Fig. 198. Disease cycle of black spot of rose (*Marssonina rosae*).

Control methods

Cultural methods.

- Cultural practices will not control black spot entirely but may reduce its incidence. They may be only practical in greenhouses.
- **Keep humidity low**
  - By not planting bushes too close together.
  - Avoid growing smaller plants such as flowering annuals underneath rose bushes.
  - Do not plant roses in shady situations or very sheltered areas where air circulation is minimal.
  - Do not water plants late in the day so that leaves remain wet for a long period of time.
- **Avoid overhead irrigation**, eg use drip or hydroponic systems. If overhead irrigating, do so early in the day so foliage is dry before evening.
- **Avoid overfertilizing** which causes soft growth which is very susceptible to black spot.
- **Mulching** early in spring can serve as a mechanical barrier between the spores formed on old leaves on the ground and the developing leaves overhead. However, in susceptible varieties the fungus may overwinter on canes.
- **Other fungal leaf spots**, eg *Mycosphaerella cryptica* in *Eucalyptus globulus*, have been shown to be more severe when phosphorus levels were low.

Sanitation.

- **Fallen leaves**. Although the fungus grows as a saprophyte on fallen leaves and prunings, the importance of collecting them has probably been over-stressed. Also it is impossible to collect **all** fallen leaves and in susceptible varieties, the fungus may overwinter on the canes.
- **Prune out** infected canes during winter pruning, and destroy fallen leaves and prunings. Prune so that the center of the bush is not overgrown.
- **In gardens**, first infected leaves in spring can be removed by hand providing foliage is dry.
- **Remove and destroy infected leaves**, cutting back canes of diseased rose plants. Pick up and burn diseased fallen leaves.

Biological control.

- In the USA, Rose Flora™ (*Bacillus laterosporus*) has been found to inhibit the growth of the black spot fungus and a number of soilborne fungi including *Rhizoctonia, Verticillium, Phytophthora* and *Pythium* in the laboratory.
- To make it more effective it can be mixed with an anti-transpirant foliar spray.

Resistant varieties.

- **Varieties vary in their susceptibility**. Discard very susceptible varieties if practical.
- **Varieties with some resistance** include:
  - **Hybrid teas**, eg 'Electron', 'First Prize', 'Peace', 'Tiffany'.
  - **Grandifloras and floribundas**, eg 'Angel Face', 'Carousel', 'First Edition', 'Gene Boerner', 'Queen Elizabeth', Sonia'.

Fungicides.

- **Fungicides may be applied** to susceptible varieties when warm, humid conditions start.
- **Make sure that both leaf surfaces** are wetted with fungicide.
- **Fungicides that control black spot** will also control anthracnose.
- **Excess copper applications** may cause leaf yellowing.
- **If predatory mites** are used to control twospotted mite then only fungicides non-toxic to the predators should be selected.
- **Risk of resistance.** Leaf spotting fungi of some other crops, eg wheat, are accepted as having a **medium** risk of development of resistance to fungicides. Resistance management strategies are available for some crops and leaf spots on the CropLife Australia website www.croplifeaustralia.org.au/
- **Check label resistance Management Strategies.**

Table 65. Black spot – Some fungicides.

What to use?	When and how to apply?
Nearly all garden sprays and dusts for roses contain a fungicide which will control black spot on roses.	On susceptible varieties, the more humid the weather, the more often it is likely that spraying will be necessary.
POTASSIUM BICARBONATE & OILS (non-systemic) Eco-Rose (potassium bicarbonate) Baking soda + horticultural oil Spray oils, eg petroleum oils	These sprays have little residual effect
NON-SYSTEMIC FUNGICIDES (protectant) Group M fungicides carry an inherently low risk of fungicide resistance developing **Group M1**, eg copper compounds, eg copper hydroxide, oxychloride **Group M3**, eg mancozeb; thiram; zineb, **Group M4**, eg Captan®, Merpan® (captan) **Group M5**, eg Bravo® (chlorothanonil)	• Some of these fungicides also control rust on roses. • As soon as humid weather commences in spring **susceptible** varieties may be sprayed with a suitable fungicide at various intervals depending on the weather, eg after each rain. • Ensure both upper and lower leaf surfaces are covered with the fungicide.
SYSTEMIC FUNGICIDES (eradicant) **Group 1**, eg Various (carbendazim) **Group 3**, eg Baycor® (bitertanol), Saprol® (triforine) CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE	• Follow **Resistance Management Strategies**. • Some of these fungicides also control powdery mildew and/or rust on roses. • Fungicide applications may begin in spring at the first appearance of black spot on the foliage of **susceptible** varieties. Repeat applications may be required after rain (check label).

Peach leaf curl

Curly leaf, leaf curl

Scientific name

Peach leaf curl (*Taphrina deformans*, Phylum Ascomycota).

Host range

Ornamental and flowering stone fruits. Mainly peaches and nectarines, but almonds, apricots and plum may also be attacked.

Symptoms

Leaves.

- **In spring, spores germinate** and the spore tubes penetrate directly through the cuticle or stomata of leaves. The mycelium then grows between the cells and invades tissue increasing cell enlargement and cell division causing abnormal growth and distortion of leaves.
- **Leaves infected throughout** lose most of their green colour and become very thick and pale. **Partially infected** leaves become distorted because growth is more rapid in the infected parts than in the healthy sections.
- **Affected leaf areas are pale green** initially but develop a deep pink or purplish colour. Later a white bloom appears on the surface and leaves shrivel, brown, die and fall.
- **Severe attack** can completely defoliate a tree.
- **Trees usually produce new leaves** that remain healthy as the season advances. However, if cool, wet weather persists during spring, infections may continue to appear on new leaves for several months.

Shoots.

- **Infected peach shoots** are less obvious than infected leaves. Shoots become swollen, stunted, pale green to yellow, gum may ooze from them.
- **In apricot trees a witches' broom** develops (densely bunched curled growth). Infected shoots usually die. This is the common symptom of peach leaf curl on apricot trees; it is rare to find an isolated infected leaf.

Flowers and fruit.

- **Infected flowers** usually fall from the tree.
- **Partial or complete defoliation** after leaf infection usually results in heavy shedding of developing fruit.
- **Infected peach fruits** show raised, irregularly-shaped areas which may develop a pinkish or reddish color long before normal fruit show any colour change.
- **Small infected fruits** usually die and fall.

General.

- Defoliation in consecutive seasons seriously weakens tree growth.
- Nursery stock which has suffered severe defoliation rarely develops satisfactorily after such a setback.

Diagnostics.

- Do not confuse symptoms of peach leaf curl, with those caused by **green peach aphids** (page 152). This can be a common mistake.
- Peaches and some other stone fruits may be affected by **both** peach leaf curl and green peach aphid injury at the same time.

Fig. 199. Peach leaf curl (*Taphrina deformans*). Affected parts of the fruit are blistered. Photo©CIT, Canberra (P.W.Unger).

Fig. 200. Peach leaf curl (*Taphrina deformans*). Affected parts of leaves are thickened distorted and covered with a white bloom of spores. Photo©NSW Dept of Industry and Investment (M.Senior).

Disease cycle

The 'conidia' produced are not really conidia but bud spores produced when previous ascospores proliferate by budding (Fig. 201 below) and the fungus survives summer as ascospores. These germinate in autumn rains and form yeast-like spores that can 'overwinter' in bud scales and on twigs. These spores infect the newly developing leaves in spring if the following weather is warm and humid during early blossoming. It appears that the expanding leaves are only susceptible when they are **young**; they become resistant to infection as they age.

'Overwintering'

Spores ('conidia' and ascospores) of the fungus mainly 'overwinter' on bud scales.

Spread

Spores are spread by **wind** and **water splash** onto emerging leaves. As nearly **all** susceptible varieties are infected, peach leaf curl is spread by the movement of infected nursery stock.

Conditions favoring

- Cold, wet weather during leaf emergence in spring followed by warm, humid weather during early blossoming in spring.
- Disease ceases with high summer temperatures. However, if weather again becomes favourable further disease may develop on new leaves.
- Tissue is only susceptible when young. Tissue becomes resistant to infection as it ages.

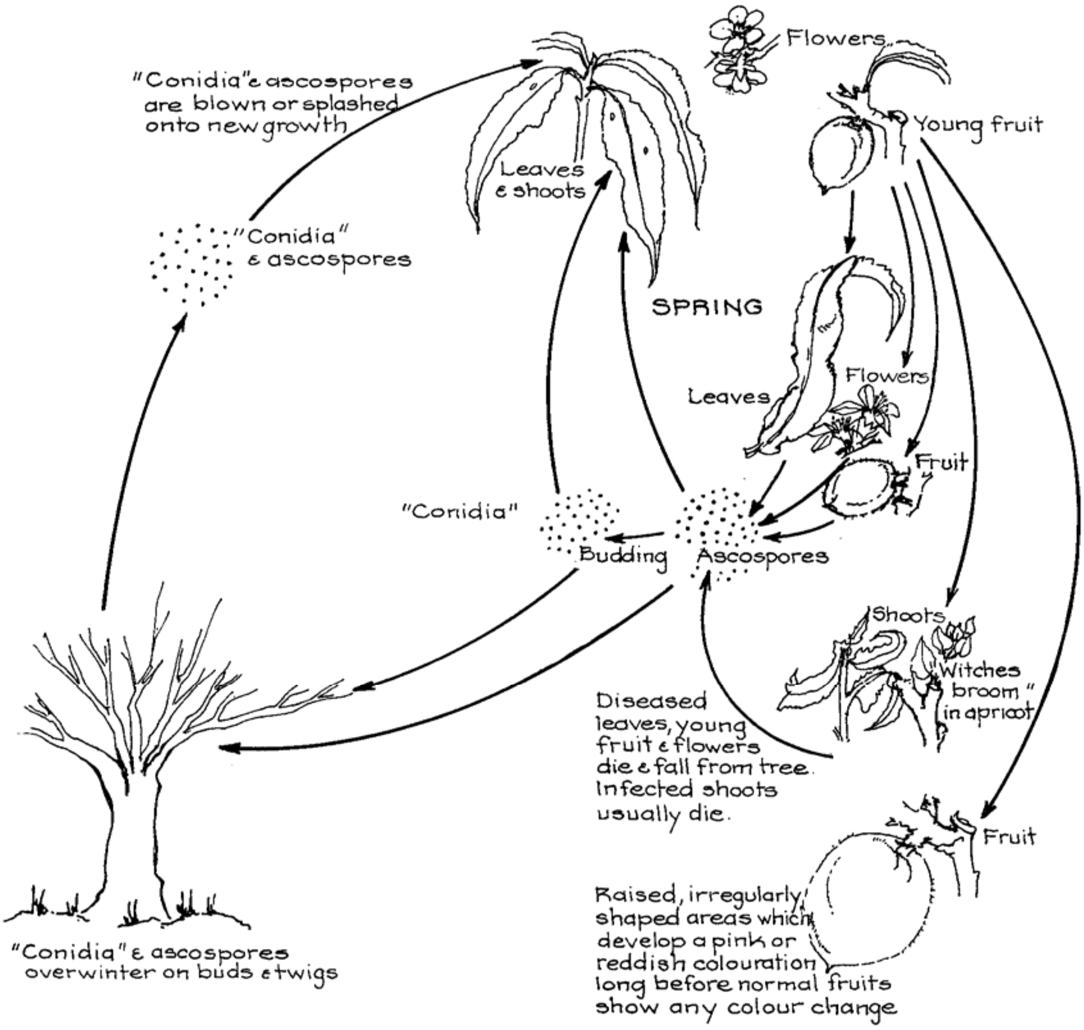


Fig. 201. Disease cycle of peach leaf curl (*Taphrina deformans*).

Management (IDM)

1. **Prepare a plan** that fits your situation, as a commercial orchardist or home gardener.
2. **Crop, region**. Obtain local information sheets on peach leaf curl.
3. **Identification** of disease must be confirmed. Do not confuse with aphid injury. Consult a diagnostic service if symptoms are confusing (page xiv).
4. **Monitor** disease and/or damage during spring to determine which trees/varieties will require treatment **the following spring** and to determine the effectiveness of any treatments already carried out. Mark affected varieties if necessary. Record results.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? If so, what are they, eg economic, aesthetic, environmental? Do you need to calculate your own threshold? Remember **know when, where, what and how to monitor**.
6. **Action**. Take appropriate action when any threshold is reached. During the growing season, fertilize severely affected trees, etc.
7. **Evaluation.** Review **IDM** program to see how well it worked. Recommend improvements if required, eg replacing susceptible varieties. Note: An **occasional curly leaf** on an otherwise healthy tree is not important.

Control methods

Peach leaf curl may be controlled more efficiently and more easily than any other major disease of stone fruits.

Cultural methods.

If trees have been severely defoliated by the disease through failure to spray at the correct time, a light application of a quickly-acting fertilizer such as sulphate of ammonia, may help them to produce new foliage.

Sanitation.

Prune out all infected shoots at pruning time to reduce infection sources for the following season. Infected shoots can be difficult to see.

Resistant varieties.

Some varieties of peaches are very susceptible, eg Elberta and Blackburn.

Fungicides.

Peach leaf curl can be controlled satisfactorily with a single spray of a registered fungicide just before budswell. Some fungicides are not suitable for some stone fruits, eg peach or apricots. Follow label instructions.

Table 66. Peach leaf curl – Some fungicides.

What to use?	When and how to apply?
NON-SYSTEMIC FUNGICIDES (protectants) Group M fungicides carry an inherently low risk of fungicide resistance developing. **Group M1**, **Copper compounds**, eg copper hydroxide, copper oxychloride, cupric hydroxide, cuprous oxide, copper ammonium acetate, tribasic copper sulphate, copper octanoate, buffered copper complex **Group M2**, **Sulphur compounds**, eg Kumulus®, Lansul®, Sulfine®, Wettable sulphur (dispersible sulphur); Lime Sulphur® (polysulphide sulfur) **Group M3**, eg Ziram® (ziram) **Group M1/M3**, eg Mankozeb® DF (cupric hydroxide/ mancozeb) **Group M5**, eg Bravo®, Rover®, various (chlorothalonil) **Group M7**, eg, Syllit® (dodine) **Group M9**, eg Delan® (dithianon) CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE	• **Correct timing is critical for effective control**. For effective control spray when buds are swelling but before they have opened. It is not possible to satisfactorily control peach leaf curl once the fungus has entered the leaf. • **As initial infection** occurs during a **short period** when leaves are emerging from buds, **1 application** of a copper fungicide (or lime sulphur) just before buds start to swell (when buds are beginning to get plumper) in spring may give satisfactory control. • **To ensure correct timing** and complete coverage, sometimes 2 sprays, the 1st at the very first sign of bud movement and a 2nd spray a week later are applied. It is better to apply the 1st spray too early rather than too late. Do not apply after mid-budswell or control will be unsatisfactory and sprays may **burn** young leaves. • **Where disease has been difficult to control** in previous seasons the following 3 sprays is suggested: 1st spray in autumn at leaf fall. 2nd spray immediately before budswell. 3rd spray about 1 week later at budswell. • **Failure to control peach leaf curl adequately** with 1-2 copper sprays is usually due to incorrect timing, usually too late due to difficulty in recognizing the 1st sign of budswell or wet weather (spraying impossible). In a planting containing peach and nectarine cultivars, sprays must be timed for the cultivar which shows the earliest movement of buds. • **Copper fungicides** are more effective than sulphur when conditions favour disease. Whichever spray is used, the whole tree must be **thoroughly sprayed**, taking care not to miss limb and twig extremities. • **After budswell**. Some protectant fungicides are registered for use just after budswell, these can be useful where the disease has been a problem in previous seasons. • Some of these fungicides will also control other diseases of stone fruits.

Wood rots

Scientific name

Several orders of the Phylum Basidiomycota, eg

Heart rot (*Schizophyllum commune*) Pink limb blight (*Corticium salmonicolor*) Red wood rot (*Pycnoporus coccineus)* Yellowish wood rot (*Trametes versicolor*) Many other species, eg *Fomes, Phellinus, Poria, Ganoderma, Peniophora, Lenzites* Keane et al (2000) described comprehensively wood, stem and butt rots of eucalypts.

Host range

Most have a wide host range and can attack ageing ornamental, native, forest and fruit trees, sometimes found on younger trees. Many can also attack and reproduce on dead branches, fallen logs.

Symptoms/Damage

General. Infected trees may live for many years but eventually they die or **blow over** during storms and temperature extremes due to internal rotting wood which structurally weakens the tree. Check that the tree will not cause any physical damage if it falls.

Trunks.
Older decaying trees may drop branches, break or shatter without warning in gales or storms endangering life and property. Inspection may indicate wood rot.

- **External symptoms** include:
  - **Die-back** of twigs, branches or the whole tree. defoliation, lack of vigour (which could also be caused by root rot, insect attack or mismanagement).
  - **Fungal fruiting bodies** may develop on outside of affected limbs and trunks, usually during autumn or winter, one to many years after infection. They may be the only indication that there is a well established wood rot infection (Fig. 202). They vary in colour and size depending on the species. Common names of wood rot fungi often describe the type and colour of fruiting body (or rot) produced, eg white rot, pink limb blight. Fruiting bodies may be annual or perennial and 'mushrooms' or 'toadstools'.

Some fruiting bodies

Internal decay

White yellowish wood rot (*Polyporus versicolor*)

Fig. 202. Fruiting bodies and internal decay of some wood rotting fungi.

- **Internal symptoms. Soft wood**, **no structural strength, when dry is extremely light in weight**.
  - **Rotted wood** when dry is soft and very light in weight. Any exposed woody tissue is readily attacked by wood rot fungi and, once infection becomes established, a tree has no protective mechanism to stop the rot. Wood decay generally spreads longitudinally within the trunk mainly because this is the way of 'least resistance'. The extent and exact location of the decay within a trunk depends on the species of wood rot fungus and the species of tree attacked.
  - **Some wood rotting fungi**, eg *Schizophyllum*, are weak pathogens and are usually only important in older neglected trees.
  - **In living trees** most wood rots are confined to older central dead wood **(heartwood)**. Depending on the part of the tree attacked, wood rots are also called **root, butt** or **stem rots**.
  - **Brown rots** decompose cellulose causing a brown rot with a cubical pattern of cracking and crumbly texture. They preferably attack softwoods, eg conifers. **White rots** decompose cellulose and lignin, reducing wood to a pale spongy mass. They preferably attack hardwoods normally resistant to brown rot fungi.
  - **Termite damage** often follows fungal decay on old living trees (page 178). There are exceptions.

Potting mixes/lawns.

- Wood rot fungi may grow on improperly **composted** material in potting mixes (page 391, Fig. 212). The fungi are **not** parasitic on the plants in the pots.
- Similarly fungi growing on chips and bark used for mulches, feed on organic matter in the soil and are **not** parasitic on plants.

Diagnostics.

- **All assessments of large trees** should be carried out by a professional arborist to avoid confusion with possible borer or termite damage (page 178, Table 35). As a generalization an arborist can get some indication of the health of a tree from external symptoms and 'sounding' the tree, eg
  - **External signs** of decay may include dieback and fruiting bodies which may be easier to see during winter on deciduous trees.
  - A **composite hammer** is used to **'sound'** trees as this can indicate if there is a hollow and some idea of how big the hollow is.
  - As a generalization, if a problem **cannot** be **seen** or **sounded** then it is not an important factor in tree failure. If it **can be seen or sounded** then the principle of Visual Tree Assessment (VTA) must be engaged to see if hollows are likely to cause failure.
- **Visual Tree Assessment** (VTA) is the method of evaluating structural defects and stability in trees including the detection and extent of decay in older trees (Matheny et al. 1994).
- **Many tools** are available to assist with tree assessment in certain situations, eg
  - **Internal diagnosis of decay. Resistographs** are **invasive** and involve drilling a small hole into the trunk. The drill hole may pass through both sound and decayed wood. The small drill holes with remaining sawdust create a highway for spread of fungal decay. Older types of drilling equipment were better because the holes were large and not full of sawdust. Not commonly used to diagnose internal diagnosis of decay. Some arborists refuse to use it on trees that are not definitely being removed.
  - **Picus sonic tomography** is **non-invasive** and measures the structural integrity of trees and extent of fungal invasion. Variations in the velocity of sound in the tree's wood measure density and elasticity.
  - **Electronic fracture meters** can conduct accurate wood strength testing of trees on site.
  - **Ground penetrating radar technology** scans tree roots 3-5m deep in soil which can used in saving trees on construction sites by locating roots before design.
  - **Chlorophyll Fluorescence Analyzers** are suitable for large scale screening of trees in the field for diagnostic research and teaching applications.
  - **GPS and GIS** computer equipment can map assets.

Enspec www.**enspec**.com/

Disease cycle

See Fig. 203 below.

'Overwintering'

As mycelium in diseased or dead trees, logs and stumps, and sometimes as perennial fruiting bodies. Infected trees, plant debris, stumps.

Spread

- Fruiting bodies release **spores** (basidiospores) during or soon after rain and are spread by **wind, rain, animals, pruning and harvesting tools** to other trees. Spores lodge on crevices in dead bark, borer damage, pruning and natural wounds, germinate, invade the plant and the mycelium grows slowly through the woody tissue. A tree has no protective mechanism to stop infection progressing.
- Some wood rotting fungi, eg *Fomes* can also enter through **roots**, others, eg *Rigidoporus muroporus*, important in some tropical and subtropical areas, spread as mycelium in the soil.

Conditions favoring

Any exposed woody tissue is readily attacked by wood rotting fungi. Wood rot fungi commonly infect trees through wounds and large dead or dying branches.

- **Wounds**, eg
  - Mechanical injury, wind, stress fractures due to drought. broken branches in storms, heavy winter pruning, dead projecting stubs (poor pruning techniques), re-worked trees, root damage, lawn mower or whipper-snipper injury.
  - Borer damage.
  - Butt and stem rots may be associated with termite tunnels in eucalypts.
  - Excavations causing tree root damage, change in soil moisture.
- **Environment**, eg
  - **Frost or spray injury** may kill twigs.
  - **Hail** may damage limbs.
  - **Sunburn** scalds exposed surfaces, bark is killed and is an entry point for wood rot fungi. Small trunks and branches facing west may be scalded by heat reflection from chip bark. Larger limbs and butts especially are at risk if they are exposed to the sun by premature leaf fall following diseases or pests, drought or unsuitable pruning.
- **Stress** due to drought, poor nutrition and ventilation, overcropping, waterlogging. Some wood rot fungi will only attack trees weakened by root injury or drought.
- **Ageing trees**, eg *Ganoderma* is mainly a problem on ageing trees.

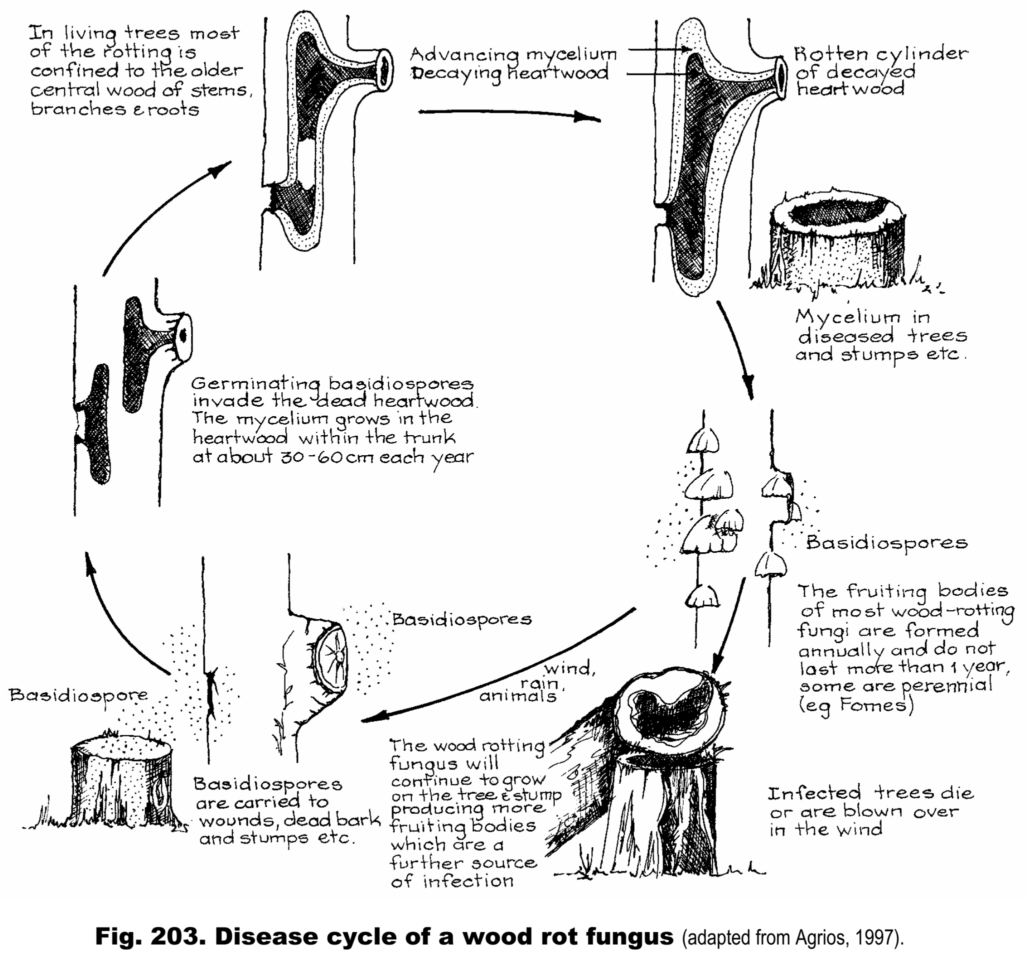


Fig. 203. Disease cycle of a wood rot fungus (adapted from Agrios, 1997).

Management (IDM)

Are you a commercial grower or home gardener?

1. **Access/prepare a plan** that fits your situation. If large or protected trees are involved, check environmental legislation, tree preservation orders, health and safety regulations, etc. Obtain advice from a qualified arborist as trees may fall over and there may be public and personal safety issues.
2. **Crop, region**. Recognize variations.
3. **Identification** of wood rot and its extent must be confirmed. In the absence of obvious fruiting bodies, consult an arborist or diagnostic service (page xiv).
4. **Monitor** or have a **qualified arborist** monitor all suspect trees **regularly** trees for fruiting bodies, evidence of canker diseases, insect borers, termite damage, pruning wounds, especially after stormy weather or prolonged drought. Keep accurate records of soft dry wood in fallen branches, etc.
5. **Threshold**. For large trees where there is a risk that they may fall, there is a **nil** threshold. What is you threshold, eg economic, aesthetic, environmental?
6. **Action**. Follow recommended safety regulations for trees at risk. For other trees perform recommended cultural and sanitation measures. All trees should receive regular maintenance.
7. **Evaluation.** Review **your** program to see how well it worked. Compare records from year to year; make improvements or seeking advice when necessary.

Control methods

Control in **living trees** can be difficult. Seek advice for your particular tree. Wood rot takes a large annual toll of trees, much of which could be prevented.

Legislation

- **Safety**. If the tree is large and the trunk decayed to the extent that the tree may possibly blow over and damage personnel or property, or fruiting bodies are present on the trunk, it should be removed.
- **If there is any doubt**, **about a tree's safety, seek advice from a professional arborist**.
- If the tree is small (less than 3 metres tall) and the trunk has **extensive** decay, eg *Prunus* spp., fruit trees, wattles, it is often not possible to save them and they can be removed.
- Control of wood rot is often **impractical** except if identified at an early stage, badly infected trees are best removed before it infects others.

Cultural methods. The best treatment for all tree problems is to ensure that the trees are as healthy as possible (Alan Mann, Canopy Tree Experts, ACT).

- **Maintain/improve tree vigour** to reduce stress by mulching, fertilizing and watering. Avoid stress and ensure trees are established properly.
  - After tree surgery **fertilizing and watering** will assist new bark to quickly cover the wound.
  - Aerate compacted soil around trees by digging lightly with a fork. protect root zone from compaction.
  - Avoid parking underneath trees, dripping oil, etc
  - Avoid injury to trunks and roots and mulching around trunk bases.
  - Correctly space of groups of trees in amenity plantings. In forestry stocking density is used to manipulate branch size; minimize wounding during forestry operations. Forestry operations can be timed to coincide with low levels of inoculum.
- **Minimize sunburn** injury to trunks/branches by:
  - Avoiding reflective mulches.
  - Pruning appropriately to shade limbs and trunk.
  - Controlling diseases and pests (if applicable) to prevent leaf fall in summer.
  - Applying flat white plastic paint reflects the sun.
- **Have a plan to replace ageing trees** because like us they do not live forever.

Sanitation

- **Remove old tree stumps and roots** before replanting a site or orchards in bushland.
- **Avoid wounding** bark with lawn mowers and whipper-snippers.
- **Decayed trees near houses** should be pruned or cut down. Remove sick or dying trees and dead stumps to reduce food sources.

- **Pruning**.
  - **Prune** when weather is to be **dry** for more than 24 hours, avoiding periods of rapid vegetative growth. For **silver leaf** prune in late summer or early autumn as trees are less susceptible at this time.
  - **Avoid leaving long pruning stubs** without buds.
  - Prune deciduous plants while dormant.
  - **Prune storm-damaged trees** to remove badly damaged branches. **Branch pruning** removes stress on the root system of trees and shrubs on poor sites and favours rehabilitation.
  - **Cut off and burn** all dead wood and rotted limbs to prevent wood rot fungi growing on dead wood.
  - **Trim all wounds including pruning wounds** carefully using a clean sharp implement. Cut wound cleanly at an angle to encourage bud development and favour healing.
  - **Prune trees carefully at collars** and shape young trees carefully to avoid large pruning cuts.

- **Limbs**. Cut off affected branches well below the decay, preferably just beyond the ridges or shoulder of bark where the branch meets the trunk or another large branch, leaving as small a scar as possible, so that callus tissue will grow quickly over the exposed wood.

- **Trunk**. Attempts to save severely affected trees can be made by careful **tree surgery**, eg
  - **Chisel back** to healthy wood and bark and burn excavated material. Clean wounds by cutting off torn bark so there is a neat smooth surface for callusing. **Avoid** large pruning cuts if possible.
  - **Drain hollows** in stems which hold water.

Biological control

Overseas, Rotstop® (*Phlebia gigantea*) targets *Heterobasidion annosum* in trees and BINAB® T (*Trichoderma harzianum* and *T. polysporum*) targets wood decay fungi (Agrios 2005).

Resistant varieties.

Species vary in susceptibility. Match species to site. Avoid using susceptible trees as windbreaks.

Plant quarantine.

Many wood rot fungi occur overseas, eg inocutis stem rot (*Inocutis* spp.) which attacks many species including grapevines, eucalypts and wattles.

Physical & mechanical methods.

Use only properly composted potting mixes from reputable sources for potted plants. The fruiting bodies in potting mixes will disappear when all food sources in the mix has been used by the fungus.

Fungicides

- **Disinfect tools** when moving from plant to plant.
- **Wound treatments.** Tar-based pruning paints are available but not commonly used as water may collect underneath the painted surface. However, where wood rot is prevalent on susceptible trees in commercial orchards, cuts larger than a 50c piece, prescribed wound treatments within hours of pruning, may reduce incidence in some species, eg
  - **Garrison Pruning Wound Dressing Fungicide** (cyproconazole + iodocarb) for the prevention of silverleaf fungus (*Chondrostereum purpureum*) on pruning wounds and wind damaged limbs of apples, apricots, peaches, plums and ornamentals.
  - **Seek advice** regarding wound treatments for your situation.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

‘Phytophthora’ root rot

An example of a soilborne fungal disease

***Phytophthora*, one of the world’s most damaging disease organisms** affects a broad range of plant species costing millions of dollars each year in Australia. This introduced soilborne fungus became important initially because of its occurrence in the jarrah forest in WA (Keane et al. 2000, Shearer et al 2009) and the seriousness of the disease on many ornamental plants and fruit crops. Threatened species may be at high risk of extinction. Many *Phytophthora* species and other root rotting fungi cause major yield losses in Australia annually. Many investigative and information groups have been formed, eg

Dieback Information Group www.**dieback**.org.au/
Centre for Phytophthora Science and Management www.**cpsm.murdoch**.edu.au/
Biological Crop Protection www.**biolcrop**.com.au/
Soilborne Diseases Symposia held regularly by the Australasian Plant Pathology Society www.**apps**.net.au/
Phytophthora Online Course: Training for Nursery Growers (Oregon State University, currently. available at http://oregonstate.edu/instruct/dce/**phytophthora**/

Scientific name

Phytophthora root rot (*Phytophthora cinnamomi* (***Pc***), Phylum Oomycota) is often called ‘dieback’ but do not confuse ‘*Phytophthora* root rot’ caused by ***Pc*** with dieback caused by other agents, eg *Armillaria* root rot, Christmas beetles and other foliage-feeding insects, drought, etc. Additionally, diseases called ‘*Phytophthora* root rot’ may be caused by species of *Phytophthora* other than *P. cinnamomi*, eg *Phytophthora* root rot of lucerne is caused by *P. megasperma*. There are more than 60 described species of *Phytophthora*, many of which have been imported into Australia.

Host range

Wide host range, including **ornamentals**, eg azalea, **native plants**, eg Proteaceae, Epacridcaeae, Myrtaceae especially eucalypts (jarrah), susceptible commercial floriculture taxa include waxflower, banksia, boronia, crowea, rice flower, waratah, thryptomene; **fruit**, eg apple, avocado. peas, orange, grape, **vegetables**, **field crops** and **weeds**. Most states have host ranges for their state, eg Reid (2006) has provided a list of the main species of importance to horticulture in WA.

Phytophthora spp.	Many species cause damping-off of seeds, seedlings, cuttings, also root, collar and trunk rots of a wide range of plants, nursery plants. A few species attack fruit, leaves, etc. Nursery plants.
P. cinnamomi	Wide range of plants (native, exotic)
P. cactorum	Apples, pears, certain native plants
P. citricola	Citrus, some genera of native plants
P. citrophthora	Citrus, causing collar, crown, stem, root and fruit rots, also some other fruits, some vegetables, etc
P. cryptogea	Apples, some genera of native plants, gerbera
P. drechsleri	Proteaceae, many genera of native plants, nursery plants
P. megasperma	Wide range of plants, eg lucerne, Brassicas and other vegetables, etc
P. nicotianae	Many genera native plants, stone fruit, strawberry, tomato, nursery plants
P. palmivora	Wide range of exotic species, durian,
P. infestans	Late blight (Irish blight) of potatoes, tomatoes and other Solanaceae occurs in some states and some strains are still a serious disease in some parts of the world. **Not discussed in this text.**

Symptoms and impacts

Soil diseases affecting roots and crowns are often unnoticed for years. In addition to attacking mature plants, this fungus can attack seeds and seedlings (page 371).

Above ground symptoms (on shrubs, trees).

- **Leaves** may develop brown tips and margins. Generally a wilting, yellowing or dying back of foliage and a general unthrifty appearance prior to death of the plant, may be present on only one side of the plant. Damage to roots and water conducting vessels prevent plants from taking up enough water from the soil. Many of these symptoms may be caused or exacerbated by other soil diseases, nutrient deficiencies or toxicities and a range of environmental stresses, which may be operating at the same time.
- Plant may die during the dry summer months as diseased root systems cannot supply adequate water for plant survival.
- **Large trees** may take years to die.
- **Collar rots and stem cankers**. If the bark is removed at ground level or from stem cankers, underlying tissues are often brownish due to the fungus attacking these areas.

Below ground symptoms.

- On removing plants from soil, affected roots are black or brown, rotted and outer areas may come away leaving a thread-like vascular system.
- Root system is reduced preventing uptake of water and nutrients. Tip out pots to assess root health, examine the collar region, wash roots from potting medium and examine under a dissecting microscope against a white background.

Impacts.

Phytophthora has been listed as a key threatening process to native vegetation in parts of Australia, whole ecosystems being affected. Many crops are seriously affected.

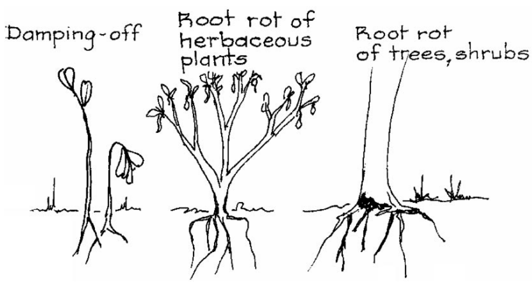


Fig. 204. Some of the many symptoms and diseases caused by *Phytophthora* spp.

Combinations of causes:

- *Fusarium oxysporum* f.sp. *zingiberi (Foz)* and soft rot bacterium (*Erwinia chrysanthemi*) have played a part in the poor crop establishment of ginger in Qld.
- *Macrophomina phaseolina* and root knot nematode *(Meloidogyne incognita*) play a part in root disease of chick pea.
- Root colonization by arbuscular mycorrhiza fungi also increases in the presence of *Pseudomosas putida*.

Fig. 205. Fungal root, crown, collar rots.

MOST ROOT DISEASES ARE DIFFICULT TO RECOGNIZE FROM SYMPTOMS

But there are a few that are relatively easy. Get to know which root diseases **your crop** is susceptible to.

EASY TO IDENTIFY?

Those fungi that produce readily identifiable structures are relatively easy to identify, eg

Sclerotium stem rot
Sclerotinia rot
Armillaria root rot
Gray mould (*Botrytis* spp.)

However in many situations, eg nurseries, these are not usually the commonest root rot fungi.

ARE SOME MORE DIFFICULT TO IDENTIFY?

Unless you have some experience with the diseases which affect your crop you will probably need to have the disease isolated and identified by an expert. Potting mixes, irrigation water and in-ground mixes may also have to be tested.

Some kits are available for growers, but they are not commonly used and can be expensive.

The diagnostic service will tell you how to send samples to the laboratory to prevent cross contamination of samples and spread of disease. They will identify the disease or confirm diagnosis and assist with control measures (see pages xiv, G 53). Examples of difficult to identify fungi include:

Aphanomyces black root rot (*Aphanomyces* sp.)
Ashy stem blight, charcoal rot (*Macrophomina phaseolina*)
Chalara black root rot (*Chalara* sp. = *Thielaviopsis* sp.)
Cylindrocladium root rots (*Cylindrocladium* spp.)
Fusarium root rots (*Fusarium* spp.)
Phytophthora root/collar rots (*Phytophthora* spp.)
Pythium rots (*Pythium* spp.)
Rhizoctonia stem rot (*Rhizoctonia solani*)
Summer decline (associated with *Pythium, Rhizoctonia, Drechslera, Curvularia* and *Fusarium*) in turf
Take-all (*Gaeumannomyces graminis* var. *avenae*)
Vascular wilts, eg Fusarium wilts (*Fusarium oxysporum*), Verticillium wilt (*Verticillium* sp.)
Other root diseases include those caused by nematodes, bacteria, and nematode-disease complexes (page 253).

SYMPTOMS CAUSED BY OTHER AGENTS?

Above ground, eg **foliage**

Too little/too much water
Salinity
Environmental
Bacterial vascular wilts
Etc

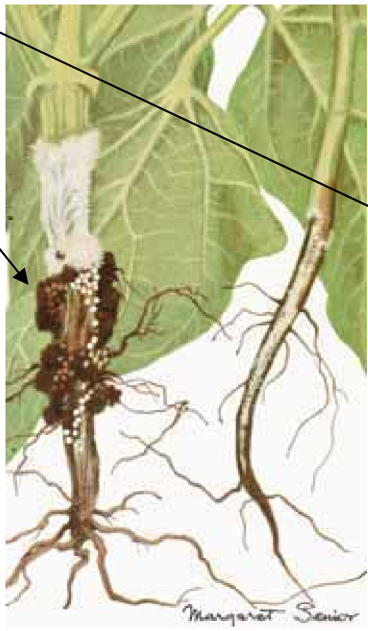
Below ground, eg **roots**.

Lack of oxygen, eg due to too much water, poor drainage.
Soil disturbance
Etc

Fruiting bodies

Rhizomorphs

Armillaria root rot (*Armillaria* spp.). ***Top:*** Clusters of **mushrooms** on rotting wood at base of tree trunks. Do not confuse with fruiting bodies of other fungi. ***Lower:*** Dark **rhizomorphs** (like shoelaces bundles of parallel hyphae) on roots of infected trees are produced by some *Armillaria* spp.

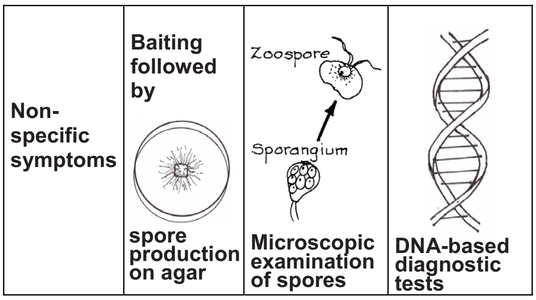


Sclerotium stem rot (*Sclerotium rolfsii*). ***Left:*** Tiny brown resting bodies (sclerotia) about **2-3 mm** in diameter (the size of cabbage seed) on French bean. Photo©NSW Dept of Industry and Investment (M.S.Senior).

Sclerotinia stem rot (*Sclerotinia sclerotiorum*). ***Left:*** Irregularly-shaped black sclerotia up to **12 cm long** on the outside of a carrot. ***Right:*** Sclerotia formed inside infected stems. Photo©NSW Dept of Industry and Investment.

Diagnostics. Current focus is on detection and diagnostics of soilborne diseases (nematodes, bacteria, fungi, etc) **before** planting the crop. Pscheidt (2009) provides a good summary of the *Diagnosis and Control of Phytophthora Diseases* (avail online).

- **Symptoms**. *Phytophthora* infection may be present but not observed because root replacement may keep up with the rate of root death.
  - ***Pc*** cannot be easily distinguished by growers from symptoms alone and the disease is often misdiagnosed. Laboratory analysis necessary. However, growers of crops which ***Pc*** commonly infects and which produce reliable visible symptoms, eg azalea, jarrah, avocado, quickly become familiar with symptoms of disease.
  - **Other soilborne disease** on some plants, eg *Pythium, Fusarium, Cylindrocladium, Rhizoctonia* and *Thielaviopsis* (*Chalara*) are difficult to distinguish from ***Pc*** as the cause of root rot on initial examination.
  - **Diseases and pests of the upper part** of the plant, eg trunks, etc, can be difficult to determine.
  - **Non-pathogenic causes** such as anaerobic conditions in the root zone caused by excessive watering, poor quality potting mix, or herbicide injury can cause similar breakdown of roots.
  - **Indicator species**, eg grass trees (*Xanthorrhoea*) found dead or dying indicate that ***Pc*** is in the area.
  - **Identification** of unknown fungi in the soil can be difficult if there are insufficient fungal hyphae for proper identification.
- **The detection and identification** of *Phytophthora*, and other root rots in plants, soils, potting mix, sand and other materials is a major part of the work of laboratories diagnosing plant diseases. However, no one piece of information is enough to conclusively diagnose a *Phytophthora* disease, the presence of the fungus may only be part of a broader or deeper problem or not related at all. Evidence from the field, sick plants and identification in a laboratory must all indicate the same problem.
- **Consult a diagnostic service** to confirm or reject a preliminary diagnosis. Association of a fungus with symptoms does not prove that it is the **primary** cause of the symptoms, it may be a **secondary** invader of tissue damaged by one or several other agent. Several diagnostic tests have developed to diagnose ***PC.***
  - **Soil. Baiting** for disease organisms, eg ***Pc***, involves placing a soil sample in a container, flooding it with water and adding susceptible plant parts as bait, eg lupin roots, cotyledons of *Eucalyptus sieberi*). If zoospores are present they will infect the bait which is then placed onto agar, spores are produced and identified by either microscopic examination or more recently by DNA tests. A negative result from baiting indicates freedom from ***Pc***. Sometimes this may be a false negative when populations of ***Pc*** are low.
  - **Roots** of infected plants may be directly placed onto selective agars, spores produced similarly identified.
  - **Microscopic examination** to distinguish spore structures in infected tissue, on agar cultures or baits. Taxonomic keys identify species. If spores are lacking, diseased tissue can be kept in a high humidity chamber for a few days or cultured to promote spore formation. Spores of some species of *Phytophthora*, *Pythium* and *Cylindrocladium,* or the characteristic hyphae of *Rhizoctonia*, can be identified this way.
  - **Non-DNA test kits for some soilborne diseases. Alert Fungal Disease Detection Kits** have been used by commercial growers to detect some soil fungi including ***Pc***, *Pythium* and *Rhizoctonia.* These kits allow early detection and confirmation of disease avoiding unnecessary chemical applications while maintaining good crop quality. Test kits can be expensive. **ELISA** tests are quick and efficient and mostly laboratory-based, some can be used on-site. The fungus reacts with chemical reagents to cause a detectable color change.
  - **DNA-based tests. Phytophthora IDENTIKIT™** is a **DNA**-based diagnostic test that accurately and identifies the pathogen from infected plant material, baited soils and water. It overcomes the limitations of the traditional baiting method in that failed negatives are eliminated and large numbers of samples can be processed in a short time. Such tests will benefit management of eucalypt dieback.
- **A single soil sample**, using a **DNA** extraction process, can now identify and quantify a range of fungal and nematode disease organisms and predict the likely extent of the losses well **before** a crop is even planted, eg *Fusarium, Rhizoctonia, Mycospherella, Guaeumannomyces graminis*, *Phoma*, nematodes, etc. Results have to be interpreted accurately at field level. Growers can change cultivars, crops, modify cropping programs where risk of crop loss is high.



Some methods used to diagnose *Phytophthora* spp.

Disease cycle

See Fig. 206, page 367.

‘Overwintering’

- ***Pc*** as spores (up to 9-10 years) and/or mycelium in the soil or media up to 20 years.
- ***Pc*** can be recovered from tap roots 1-2 m deep.
- As spores and/or mycelium in infected plants, on root and stem debris from infected plants.
- Other soilborne fungi can 'overwinter' as sclerotia, etc.

Spread

- **Water.** Zoospores spread in surface drainage water from contaminated areas, in recycled irrigation water and from infected to healthy plants in running or splashing water. Run off and subsoil seepage may carry spores onto a site. Rate of spread in bushland downhill may be 0.7-3.6 m/yr but more after fires etc.
- **Aerial spread**. Contaminated wind-blown dust may contaminate stored media. Other species, eg *P. infestans*, may be spread by irrigation splash and wind blown driven rain.
- **In soil** in containers, on tools, machinery, vehicles, bicycles, boots, other equipment; re-using infected soil as a potting mix; in gravel from surrounding forest areas. ***Pc*** readily contaminates pots and potting mixes allowed to contact soil, and in the past has been detected in some brands of imported peat.
- **Plants.** Movement of infected nursery plants, plant material, tube stock, seedlings. *P. ramorum* was spread widely in the USA through the shipping of infected stock from nurseries.
- **Infected propagation material**, eg tube stock, tubers, plugs, seeds. Cuttings can be a source of infection if taken too close to ground level.
- **Possibly by soil animals.** Fungus gnats present in moist organic matter may spread *Chalara.*
- **Bush regenerators** may unwittingly contribute to the spread of disease through soil disturbance and planting stock from infected nurseries.
- **Vertebrate pests**, eg feral pigs, horses.
- Many plants become infected in garden or bush via a nursery (like weeds) and then may spread in water run off into neighbouring bushland and through dumping plants in the bush.
- **Pod-boring beetles** overseas are attracted to disease lesions and rapidly generate and spread secondary inoculum in epidemics of pod rot.

Conditions favoring

- **Continuous cropping** of susceptible crops.
- **Fire.** Jarrah dieback (***Pc***) in WA appears to be related to a change from hot uncontrolled bush fires to less hot controlled burning programs. This has led to a change from an *Acacia* understory to one of *Banksias* which is very susceptible to ***Pc*** relative to *Acacia*, providing much inoculum that can infect jarrah.
- **Each soilborne disease** is favoured by different conditions.
- **Stress.** Rate of disease development increases as stress increases, eg avocado plants stressed by **root pruning** develop cankers more readily than non-stressed plants.
- **Water management**.
  – **Prolonged periods of rain** or excessive irrigation over a long period of time.
  – **Poorly drained**, waterlogged soils and **drought** will stress plants. Tensiometers measure soil moisture and improve irrigation management by accurately determining when water should be applied to a crop to maintain optimum growth and how much water should be applied to avoid over-irrigating.
  – **Warm, wet winters followed** by dry summers stress plants. In WA areas with rainfall above 400mm are most affected. Symptoms appear more rapidly when plants are stressed by periodic drought, fluctuating water tables and higher temperatures associated with wet conditions.
  – **Warm moist aerated soils** at >12°C (optimum 25-27°C) with temporary flooding.
  – **Wet soil conditions** and **slow infiltration** favour many root pathogens, ie temporary flooding and prolonged period of saturation that can occur following heavy rainfall or overhead irrigation in soils with structural decline.
  – **Planting azaleas with 'balled' roots** in soil different to the one into which it has been growing favours *Phytophthora* root rot. Where 2 soil types meet there is a natural water course, new roots growing into it are readily infected with ***Pc***.
- **Soils low in organic matter** and micro-organisms.
- **Poor soil structure**, chemical and physical properties.
- **Nutrients deficiencies & toxicities**. Highly soluble salts can kill rootlets providing sites for infection with ***Pc.*** The level of calcium carbonate in soil can increase the level of *Rhizoctonia* disease. Phosphorous and zinc deficiencies can be an issue in some soils. **Salinity** will exacerbate *Phytophthora.*
- **Other infections**, eg **root-knot nematode** damage to roots allows the entry of *Phytophthora* spp., and other fungal diseases of rice flower. These diseases, along with other common problems such as stem or root damage due to wind, root congestion and longicorn borer damage, contribute to the early decline and death of rice flower plantings.
- **Herbicides** may have some affect but the situation is unclear. Glyphosate is a broad spectrum inhibitor and potent inhibitor of EPSPS, a key enzyme in the synthesis of amino acids present in plants, fungi and bacteria. So fungi and bacteria with glyphosate-sensitive EPSPS may be susceptible to the action of glyphosate. Laboratory and field reports indicate that glyphosate can cause **temporary** increases in *Pythium* and other damping-off fungi in the soil but decreases in *Sclerotium* and *Fusarium*.

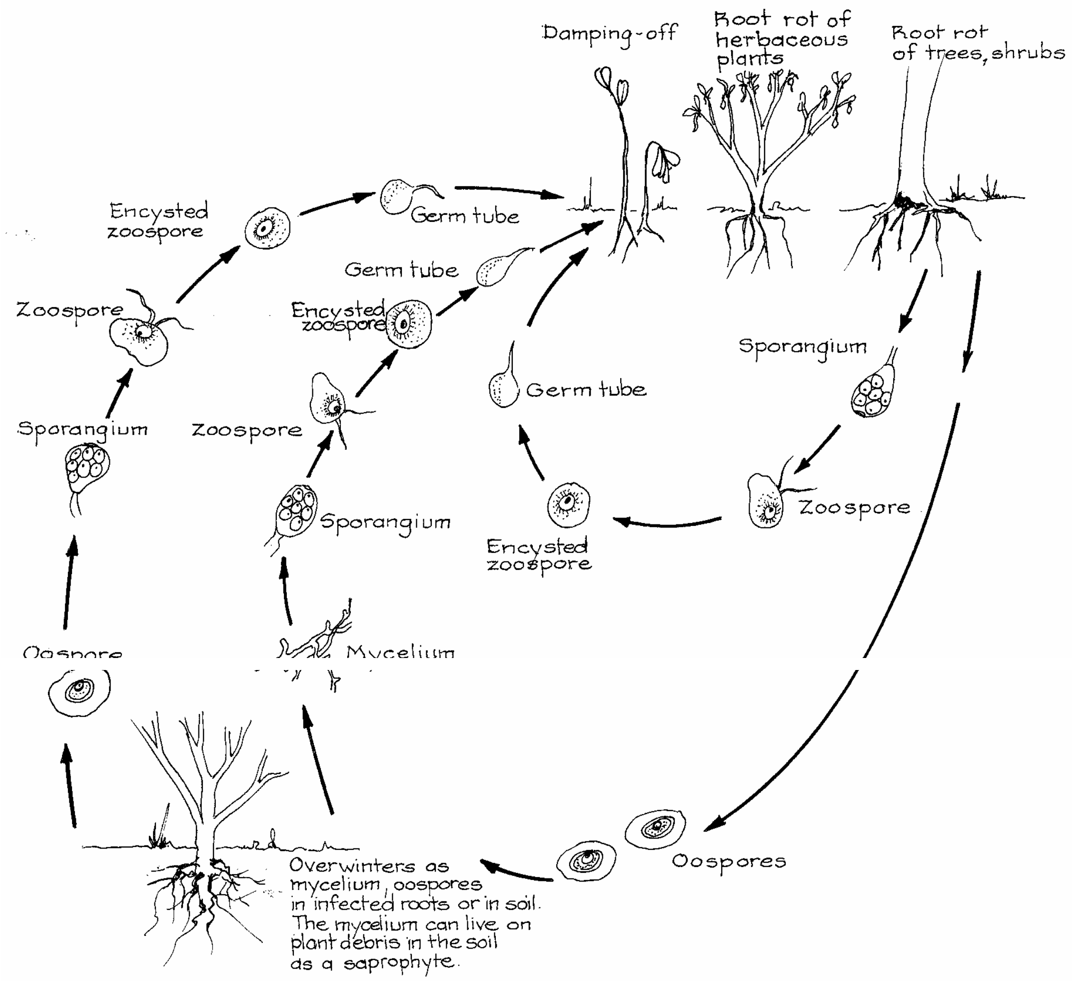


Fig. 206. Disease cycle of *Phytophthora* root rot (*Phytophthora cinnamomi*).

Management (IDM)

1. **Planning.** Soilborne diseases generally are widespread and like other diseases, their control requires appropriate planning and management. **Most states and territories have management plans for *Phytophthora* to reduce its impact and prevent further spread.** Select a program for managing *Phytophthora* for your situation, eg
   - **Biodiversity conservation in forests, bush areas, etc** (Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia) www.cpsm.murdoch.edu.au/
   - **Nursery Industry Accreditation Scheme Australia (NIASA)** is a national scheme for production nursery (growers) and growing-media (potting mix) supplier businesses.
   - **Australian Garden Centre Accreditation Scheme**.
   - **Cutflowers** (*Phytophthora* diseases of cutflower crops).
   - **Key Avocado Management Issues**.
   - Most states provide information on *Phytophthora* management in their region or on certain crops.
   - Management plans are available for many other soilborne diseases, eg Total Crop Management - Clubroot (of Brassicas), Management of Soilborne Diseases in Vegetable crops (Biological Crop Protection www.biolcrop.com.au/).
   - Horseriders, bushwalkers, landcare groups.
2. **Crop, region.** The wide host range of ***Pc*** in many regions means that you must know your crop history and susceptibility, and your local climatic variations favouring ***Pc***.
3. **Identification** by laboratory analysis is essential to ensure effective control and prevent spread (page xiv). **Pre-plant soil tests** can now be carried out months prior to planting. Any **water supplies** in contact with the ground must be suspect, eg dams, streams, soaks must be tested.
4. **Monitor** symptoms and, hygiene procedures and chain of production. Also monitor for the presence of *Phytophthora* in water, soil, roots and other plant material. Record all results. Remember **know when, where, what and how to monitor.**
   - **Symptoms**. First look at plants closely for evidence of wilting. **Examine indicator plants in bush areas**, eg grass trees (*Xanthorrheae* sp.). **Assess root health of potted plants**, eg closely examine the collar region and cut into the internal tissue with a knife to detect evidence of infection, also wash potting mix/soil from roots and examine them under a dissecting microscope against a white background, comparing them with a **known** specimen of healthy root material.
   - If diseased, seek **expert testing**, as there is increased detection of new *Phytophthora* spp.
5. **Threshold.** This will be determined by relevant regulations. Beyond that you will have to decide your own economic, aesthetic or environmental threshold.
6. **Action.** Take appropriate action when any threshold is reached. In practice, this usually includes cultural methods, sanitation (hygiene), quarantine, use of tolerant rootstock, ***Pc***-free planting material and media and the application of fungicides.
7. **Evaluation.** Review the program, compare methods and results with previous years. Make improvements if needed, eg ensure planting material is disease-tested, varieties have some resistance, improve culture and sanitation, preplant soil treatments, eg solarization, bio fumigants, water treatments, etc.

Control methods

Control of root diseases is difficult both in the field and in intensive crop production systems - there is often a combination of 'causes' and **therefore a combination of control methods are required**. Methods used depends on the situation, eg forest, bushland, cutflowers, nurseries, hydroponic systems, containers, soil/media, water sources, etc. The aim being not only to control disease on current crops but also prevent further spread. It is difficult to eradicate *Phytophthora* and other soil diseases from an infested site especially when perennial crops are grown.

LEGISLATION, REGULATIONS.

The Commonwealth's Environment Protection and Biodiversity Conservation Act 1999 seeks to promote the recovery of species and ecological communities that are endangered or vulnerable and to prevent other species and ecological communities from becoming endangered. An off shoot of this law is:

- **A Threat Abatement Plan** enables a national management approach for **Dieback** caused by the root-rot fungus **(*Pc*).**
- **Lists of threatened species** and ecological communities have been prepared. Some states have developed priorities and coordinate management to limit spread of ***Pc*** into area which is ***Pc*-free**.
- **Certification schemes** for the production of ***Pc*** –tested planting material and media.

Cultural methods.

- **Large scale remediation** can protect rare taxa and communities of high conservation value threatened by nearby ***Pc*** infestations. It may involve long term in situ seed conservation and prioritization of certain species.
- **Select sites** unfavourable to ***Pc*** and avoid conditions favouring disease (page 365). Prepare soil appropriately.
- **Grow plants in soilless media** or hydroponics.
- **Suppressive compost and mulches** are suitable only for small areas. Marri, karri and other hardwood bark can be highly suppressive of *Phytophthora* after composting. It suppresses weeds and aids soil moisture retention during summer. Take care not to import contamination. Add organic manures.
- **Maintain crop vigour**. Plant when temperatures are favourable for crop growth, **not *Pc***. Seek advice regarding nutrient requirements for your crop.
- **Irrigation and drainage**
  - **Design, maintain and monitor** irrigation systems to avoid overwatering throughout the year and minimize the time soil is saturated. In infected blocks of trees, adjust irrigation to suit smaller trees. In greenhouses reduce excess water lying in bays.
  - **Sub-irrigation** may result in spread of motile zoospores from infected to healthy plant.
  - **Most serious problem** associated with zero run-off involves ***Pc***. Regulations require zero run-off for some nursery growers resulting in rapid change to closed systems of production.
  - **Use free-draining** potting mixes and avoid over-watering. Improve surface and sub-soil drainage in poorly drained sites by various means including planting into raised beds.
  - **Avoid** exposure of susceptible trunks to infection, eg avoid irrigation spray directly contacting trunks.
  - **Maintain** plantings under sod rather then bare soil; keep areas at base of trees free from weeds.
  - **Surface water management** and drying of sites.
  - **Avoid 'balling roots'** in old potting mix during repotting (page 367).
  - Compacted soil could be ripped, mounded beds.
- **Crop rotation and fallowing.**
  - Avoid continuous cropping with susceptible hosts.
  - Where different species are being planted undertake risk assessment.
  - When replanting understand 'sick soil syndrome'.
  - Consider including a bio-fumigation crop in a rotation (page 267). **Green manure cropping** reduces soil crusting, improves filtration, increases soil organic matter and reduces subsoil compaction. **Brassica** green manure crops produce high concentrations of **bio-fumigants** and may improve soilborne disease management. The native legume (*Acacia pulchella*) protects *Banksia grandis* from infection, suppressing the fungus in the soil.
- **Reduced tillage.**
  - Can encourage some soilborne diseases, eg *Fusarium graminearum*, *F. culmorum, F. avenaceum* of wheat and *Cephalosporium gramineum*, *Pythium* and *Rhizoctonia*. Crop residues can maintain the inoculum of these fungi while fields are left fallow or sown with a non-host break crop.
  - However, **long periods** (10 years or more growing seasons) of stubble retention can induce disease suppression of pathogens such as *Rhizoctonia*. The induced disease suppression is thought to be due to the proliferation of indigenous micro-organisms in the soil, some of which are antibiotic and antifungal that prevent the outbreak of pathogenic fungi.

Sanitation. Hygiene

- **As fungicides often only suppress** and do not eradicate *Phytophthora*, they are not a substitute for **good hygiene and cultural practice**. Maintain cleanliness in propagation and growing-on areas in accordance with measures prescribed by prevent Nursery Accreditation Schemes.
- **Avoid spread of disease by:**
  - **Destroying** all diseased nursery stock, etc.
  - **Either using soil-free media or treat all soil routinely** either by pasteurization or other means.
  - **Foot baths** of Biogram® at the entrances to clean nursery areas and glasshouses and moving from unsurfaced to surfaced areas.
  - **Cleaning, and then sterilizing** footwear, tools, containers, machinery, vehicles, and trolleys using proven procedures, before entering an area (page 343).
  - **Disturbing soil as little as possible** in the bush. Always walk or drive on roads, if involved in off-road activities then clean shoes, camping equipment, tent pegs, etc. Weeders should work in areas free of the pathogen before working in areas known to be infected. Minimize activity when soil is very wet, put weeds in bags for removal from the site.

Biological control.

- **Natural controls.** Many antagonists occur naturally in soils.
  - **Fungal-feeding insects and mites**, eg mites, springtails, protozoans, free-living nematodes and earthworms in soil, feed on fungal organisms and may contribute to their biological suppression.
  - **The role of mycorrhizae** in controlling ***Pc*** infection is not yet clear but on some hosts, eg *Nothofagus* in NZ lack of mycorrhizae may prevent establishment of seedlings.
  - **Mechanisms** by which antagonistic microorganisms effect pathogen populations are not always clear but are generally attributed to one of the following effects:
    1. **Direct parasitism** (penetrating host hyphae) and killing them.
    2. **Competition** with the pathogen for food.
    3. **Direct toxic effects** on the pathogen by antibiotics substances released by the antagonist.
    4. **Indirect toxic effects** on the pathogen by volatile substances, such as ethylene, released by the metabolic activities of the antagonist.
  - **Suppressive soils** with high organic matter content support antagonistic micro-organisms (mostly bacterial, other fungi and actinomycetes) which generally suppress soilborne diseases including ***Pc***. Suppressive soils may also involve non-living factors and may vary with the disease organism and the crop. In most cases there are one or more micro-organism antagonists. They do not allow the disease organisms to reach high enough populations to cause severe disease.
- **Biocontrol agents for certain seed and soil-borne plant diseases**. Effectiveness of antagonistic micro-organisms can be increased by:
  - **Introducing** new or larger populations of fungal or bacterial antagonists, eg
    - ❑ **Fungal** biocontrol agents based on *Trichoderma harzianum, Clonostachys rosea* and *Coniothyrium minitans. C. rosea* is near commercialization and has been proved effective in several crops against certain seed and soilborne diseases. Other fungi include *Gleocladium, Coniothryium, Myrothedium. Candida*. Trials of *Trichoderma* on *Phytophthora* seem to be variable, ie mycelium may be suppressed but oospore production stimulated.
    - ❑ **Bacterial** biocontrol agents based on *Bacillus*, *Agrobacteriaum*, *Pseudomonas* and *Streptomyces*. *Paenibacillus polymyxa.* Also *Burkholdia.*
    - ❑ **The use of several bio-control agents** at once may reduce the effects of root rot disease complexes.
  - **Adding soil amendments** that serve as nutrients for, or otherwise stimulate growth of the antagonists and increase their inhibiting effects on disease organisms. However, these organisms **cannot** maintain themselves very long and organic amendments are not selective enough to select and buildup up populations of the introduced or existing antagonists. Chitin in fertilizer is thought to stimulate antagonistic fungi in soil.
- **Commercially available bio-control agents.**
  There is an increasing number being marketed (page 344, Table 60). These include:
  - ***Trichoderma harzianum*** suppresses many soilborne fungal diseases, eg for *Fusarium, Phytophthora, Pythium* and *Rhizoctonia***.**
  - ***Bacillus subtilis*** as a plant growth promoting, bio-balancing agent, eg for *Pythium*, *Fusarium, Rhizoctonia* and *Phytophthora.*
  - **Mixtures of antagonists.** There is often a combination of causes (several root rotting fungi, nematodes, etc) so it is logical that several antagonists or suppressive agents may be more successful than one. **Nutri-Life TrichoShield™** (*Trichoderma* spp., *Gliocladium virens, Bacillus subtilis*) for seed, seedlings, transplants, bulbs, cuttings, grafts and established crops. **Noculate Liquid** (*Bacillus*, *Trichoderma*, vitamins, humic acid, kelp) is used on professionally maintained turf. **Fulzyme Plus** (*B. subtilis + amino acids*) may suppress *Phytophthora* and *Pythium* in certain situations.
  - **Biofumigation**. Fumafert® (mustard seed meal (*Brassica juncea*) and neem kernel (*Azadirachtin indica*)) is a soil amendment with biofumigant properties which may aid in the control of certain soilborne insects, diseases and nematodes.

Resistant/tolerant varieties.

Although there is a continual development of resistant varieties, little is known about resistance or tolerance to soilborne diseases. Genetic resistance to root diseases is arguably, uncommon. Younger plants may be more susceptible than older plants. Address issues by:

- Increasing the density of tolerant native species.
- **Plant tolerant** cultivars or species when available. Obtain information from relevant authorities.
- **Systemic acquired resistance (SAR)** stimulates the natural **SAR** response mechanisms found in most plant species. **Bion® Plant Activator Seed Treatment** (acibenzolar-s-methyl) suppresses certain soilborne diseases, eg *Fusarium* wilt and black root rot of cotton in **IDM** programs (page 329).
- **GE crops** have been developed with resistance to some soilborne diseases, eg cotton has been genetically engineered to be resistant to *Verticillium* wilt a major disease of that crop.
- **Resistant rootstocks** are useful for some crops, eg avocado, macadamia, pineapple.
  - **Seedling** and M9 rootstocks of **apple** appear to be most resistant to ***Pc***, others are very or moderately susceptible to ***Pc***.
  - **Tomatoes** may be grafted onto rootstocks with some resistance to root knot nematodes, *Verticillium* and *Fusarium* wilts.
  - **The *Phytophthora*-resistant *Westringia fructicosa*** has been found to be compatible with over 40 *Prostanthera* spp.
- **Replacement crops** have been investigated for the jarrah forest area of WA, and it is now known which groups of eucalypts are most susceptible to ***Pc***. Lists of native plants which are tolerant or highly susceptible, under some conditions are available (*Phytophthora* Science and Management). www.cpsm.murdoch.edu.au/

Plant quarantine.

The following notice is not uncommon in some areas:

PROHIBITED AREA
NO ACCESS BEYOND THIS POINT
Phytophthora Infested Area

Plant quarantine, *contd*

- **Australian quarantine**. Many *Phytophthora* spp. and other root rots pose a threat to Australia, eg
  - **Sudden oak death** (*P. ramorum*) has a broad host range of conifers, shrubs, herbaceous plants and ferns. The Californian Oak Mortality Taskforce (**COMTF**) aims to research the management of *P. ramorum*.
  - **Texas root rot** (*Phymatrochium onmivora*) is a destructive soilborne disease of >200 plants including cotton, grains, fruit, eg apple and pear, citrus, nuts, vegetables, nursery and garden plants.
  - **Biosecurity** targets various crops and particular diseases, including *Phytophthora* spp.
- **State/Regional**. 500,000 hectares in WA are under quarantine restrictions by the Forestry Dept. in WA to prevent entry of infested soil on vehicles coming from ***Pc*-infected** areas.
- **Local quarantine**. Protocols developed for production nurseries **prevent** contaminated seed, plants and soil **being brought into** a nursery and **prevent** contaminated plants, soil, etc **being supplied to** growers, landscapers, fruit growers, vegetable growers and cut flower producers (**BioSecure *HACCP***).
  - **Restrict movement** of people, animals, vehicles from contaminated areas to areas of highly susceptible plants or in-ground production areas maintained ***Pc***-free.
  - **Avoid introducing *Pc*-infected** plants, cuttings etc to disease-free areas. Keep new plants separate until their disease-freedom is established. This is practical with container plants but difficult for plants which are to be planted directly into soil.
  - **Movement of soil,** either as deliveries, in containers, adhering to tools, machinery. Footwear is one of the commonest methods of introducing ***Pc*** and other ***Pc*** to previously healthy areas.

Disease-tested planting material

- **Plant certified *Pc*-tested planting material** nursery stock and tube stock, into ***Pc*-tested soil** or treated soil and irrigate with ***Pc*-tested water** and keep it ***Pc*–free**. Monitor parent stock used for propagation for infection and identify unwitting introductions. Although ***Pc*** is not generally seedborne, some other *Phytophthora* species may be seedborne on some hosts.
- **Nursery accreditations schemes** in some states, eg WA, ensure ***Pc*–freedom** in products sold.
- When purchasing land for production of plants susceptible to ***Pc***, check it is ***Pc*-free**.

Physical & mechanical methods

- **Disinfest irrigation water** especially when it is drawn from surface water or is recycled (page 373).
- **Pre-plant pasteurization** of contaminated soil/media is described on page 330.
- **Pre-plant soil solarization**, correctly implemented, prior to planting, may assist control of some disease organisms (pages 330, 438).

Fungicides

- **Remove/destroy** infected plants **before** treatment.
- **If replanting** an infected area seek advice.
- Fungicides do **not** substitute for good cultural practice and hygiene. Although some fungicides (Table 67 below) are registered to control ***Pc***, in reality they mostly **suppress** and do **not** eradicate ***Pc*** in soil or water. Even during foliar sprays, sporangia and zoospores may still be produced from some infected plants. So although sprays slow down disease development, disease may still spread.
- **Longevity** and the depths at which ***Pc*** occurs in soil, precludes any attempt at chemical eradication, although some fungicides **can** be used to contain highly contagious sites and systemic fungicides can be used to save slightly inured plants.
- **Fungicides** such as **phosphonate** can protect trees against infection, limit spread within the plant and increase tree survival and yield. Phosphonate boosts the plants immune system to cure and prevent new infections.
- **Application**. Depending on the situation, fungicides may be applied by foliar sprays, soil drenches or granules and stem injections. It is possible to treat root rot disease by leaf applications but in some cases equal or better control may be achieved by soil applications or a combination of both soil and foliage. Suckers have been dipped in fungicides. In WA fungicides have been sprayed on foliage by mist blowers and aerially from aircraft and helicopters.
- **Follow Croplife Science Resistance Management** strategies and label directions. Permits may be required.
- **Fumigants** (page 267).

Table 67. *Phytophthora* spp. – Some fungicides.

What to use?	When and how to apply?
Foliage sprays **Group 33**, eg Anti-Rot®, Aus-Phoz®, Phospot®, various (phosphorous as acid) – **systemic**	Some plants injured by foliar sprays in hot weather.
Soil applications (drenches, granules) **Group 4,** eg Ridomil® Gold, various (metalaxyl-m); Fongarid® (furalaxyl) – **both systemic** **Group 14**, eg Terrazole® (etridiazole) - **non-systemic** **Group 33**, eg Aliette®, Signature® (fosetyl present as the aluminium salt); Phospot® (phosphorous acid) – **both systemic** **Mixed formulations**, eg **Group 1/14**, eg Banrot® (thiophanate-methyl/etridiazole) which is effective against *Phytopthora*, *Pythium*, *Rhizoctonia* & *Chalara (Thielvaliopsis)* – **systemic/non-systemic** **Group 14/14**, eg Terraclor® Super X EC (etridiazole/ quintozene) – **non-systemic** for seedlings	CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE Note that APVMA has suspended the supply or use of material and products containing quintozene until 12 April 2011
Trunk injections **Group 33**, eg Phospot®, various (phosphorous acid).	Stem injection may provide rapid recovery in high value crops and sites. Stem injections of phosphate protect *Banksia* spp., *E. marginata* from ***Pc*** for at least 4 years
Stem canker topical applications **Group M1**, eg certain copper fungicides	Apply to stems only whenever cankers appear after removing dead tissue. Stem cankers are more difficult to control than root rots.
Fruit rots **Group M4**, eg captan	
Disinfectants Seek advice regarding disinfectants for your situation (page 343)	Disinfect hands and footwear, and vehicles.

Damping off

Scientific name

Common and serious disease of seedlings and cuttings. Caused mainly by soilborne fungi, eg

Oomycota	*Pythium*, *Phytophthora*
Ascomycota	*Botrytis*, *Colletotrichum*, *Cylindrocladium*
Basidiomycota	*Rhizoctonia* - sterile (*Thanatephorus*), *Sclerotium* - sterile (*Athelia*)

Occasionally other fungi, eg *Fusarium* spp. cause damping-off. Bacteria, eg *Erwinia* spp., may also be involved in pre-emergence damping-off.

Host range

Most damping-off fungi have a **wide host range** and most can also grow on plant debris. Almost all seedlings or cuttings are susceptible.

Symptoms

General. Damping-off, the death of seeds, seedlings or cuttings when they are attacked by certain fungi, may take several forms. Affected seedlings may collapse in circles up to 1 m across (page 372). The extent of root infection determines the appearance of symptoms above ground.

Pre-emergence damping-off. Seeds may rot before germinating or seedlings may rot before emerging (Fig.207). It is usually caused by several different fungi and by bacteria.

Post-emergence damping-off occurs after seedlings have appeared and may take various forms (Fig. 207):

- **Stem rot.** Seedlings develop a stem rot near the soil surface and fall over. This is the most common form of damping-off and usually caused by *Phytophthora*, *Pythium* and *Rhizoctonia*.
- **Wire-stem or sore-shin.** Some seedlings, such as cabbages, have rather woody stems. The fungus kills tissues at ground level but the plants remain standing. Seedlings eventually die. Commonest cause is *Rhizoctonia*.
- **Root and stem rot.** Damping-off fungi rot rootlets, and then travel up in stems, killing plants. Commonest cause is *Phytophthora* and *Pythium*.
- **Top damping-off.** Under damp conditions, fungi such as *Botrytis*, *Phytophthora* and *Rhizoctonia* may spread from leaf to leaf or from stem to stem through the tops of the seedlings or cuttings. The fungus rots the top of the plant down to soil level often leaving the crown and roots uninjured. Depending on the fungus, infection may be air-borne or originate from the soil, spreading up the first few plants and then remaining aerial.
- **Cuttings** may rot progressively from cut ends, from root bases or wounds made by the removal of buds or leaves, and even from dead leaf bases. Cuttings are infected through wounds and before they callus over, a wet rot develops.

Older plants. Rootlets, crown and even fruits of plants older than seedlings may occasionally be attacked by some damping-off fungi. Extensive infection of the root system of older plants by *Pythium* may cause slow growth, stunting and yellowing. *Pythium* attacks young roots and soft stems which become water-soaked, darkening with age. *Rhizoctonia* causes root and stem rots often initially at soil level, but under extremely moist conditions can grow on above ground parts webbing the seedlings together.

Diagnostics. Causes of damping-off like root rots generally, are difficult to identify and/or confirm (page 366).

- **Confusion.** It can be difficult to distinguish one damping-off fungus from another. It can also be difficult to distinguish damping-off symptoms from those caused by waterlogging (anaerobic conditions in the root zone); excess soluble salts which can burn roots, etc.
- **Observe seedlings for wilting** and rotting around the collar region. Different types of damping off are shown in Fig.207. below.
- **Carefully remove** and wash soil/media from affected plants and examine under a dissecting microscope. Compare with the root system of a healthy plant. Shrunken lower stem tissue may indicate infection with *Pythium*. Death of fine roots from the tip may **indicate** *Pythium* but is **not** conclusive evidence.
- **Potting mix can be sown with susceptible species**, eg lettuce. Developing seedlings are examined for evidence of infection.
- **Check** if a *Pythium* or other identification kits are available for your situation. An electronic **'Pest, Disease, Beneficial & Weed Identification'** tool available from **NGIA** may assist www.ngia.com.au/
- **Laboratory tests**.
  - **Microscopic examination** enables spore structures to be identified. Taxonomic keys are used by experts to identify species.
  - **Lupin baiting** in laboratories can identify ***Pc*** and *Pythium*, but microscopic examination is needed to tell which species it is. Cultures made from roots into selective media enable identification.
  - **If damping off is a problem, laboratory tests** can identify the causal fungi (page xiv).

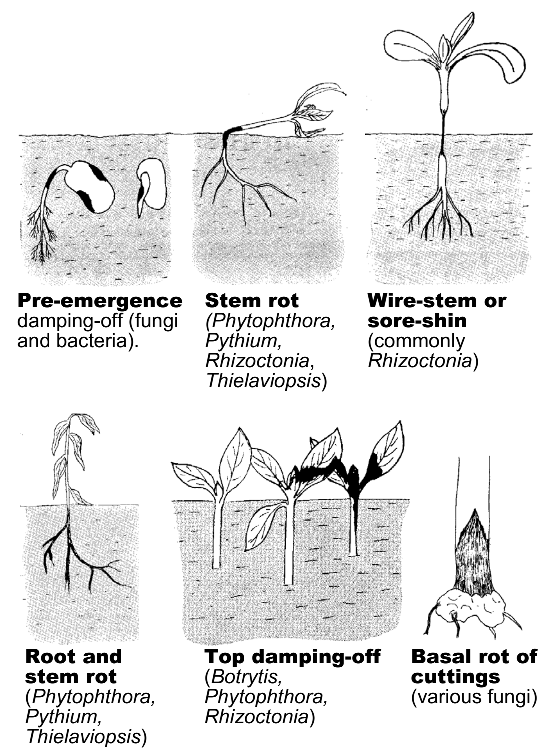


Fig. 207. Symptoms of damping-off.
Photo©NSW Dept. of Industry and Investment.

'Overwintering'

- The disease cycle varies with the fungus (see page for the diseases cycle of *Phytophthora*.
- These pathogens are common soil and potting mix inhabitants. They grow on undecomposed organic matter and survive in soil for years.
- In plant debris or soil, sometimes as **resistant spores** or as **sclerotia** (black resistant fungal bodies), depending on the fungus. Mycelium can grow on plant debris in the soil as a **saprophyte**.
- **Seeds** of some plants with *Rhizoctonia*.

Spread

- Spores of some damping of fungi, eg ***Pc*** and *Pythium*, are spread by **water**, eg rain, irrigation, drainage and recycled untreated drainage water.
- Movement of infested **soil** on machinery, containers and tools; plant debris.
- Movement of **infected plants**, cuttings.
- Spores of some damping-off fungi, eg *Botrytis cinerea* are spread by **wind and air currents**.
- *Botrytis* spores are airborne, also spread by dust.
- **Seedborne** on some hosts, eg *Rhizoctonia.*
- Staff may carry spores on shoes, clothes, hands.
- *Pythium* spores can be spread throughout the greenhouse by **fungus gnats** and shore flies.
- *Pythium* spores can be present in the growing medium of plugs or prefinished plants arriving from another greenhouse, or in soil clinging to benches and used containers.

Conditions favoring

- **Damping off may be endemic** in a nursery without causing damage until conditions favour it, eg high soil moisture, dense seedlings, etc.
- **Each species of fungus** is favoured certain temperatures, moisture, light, etc.
- **Seedlings and cuttings** are most susceptible during **establishment**.
- Conditions unfavourable for growth of the seeds or seedlings, and root development, eg temperatures which are too low or too high.
- **Wet soils with poor drainage** favour *Pythium* and *Phytophthora* while dry soils favour *Rhizoctonia* and *Fusarium*. Drainage water running beneath pots. Under extremely moist conditions *Rhizoctonia* can grow on above ground parts webbing the seedlings together.
- **Overcrowding**, seedbeds sown too thickly:

- Acid soils with a pH of 5.2 or below.
- Soils **low** in organic matter (such soils have low populations of micro-organisms which might be antagonistic to damping-off organisms).
- Excessive amounts of **nitrate** fertilizers during establishment favours *Pythium*.
- Lack of **crop rotation** which can result in a build-up in damping-off organisms in soil.
- By **undecomposed** organic matter.
- *Pythium* prefers young newly established plants. Older established plants may become susceptible when incorrect fertilization causes excessive salt buildup in the root zone.

Management (IDM)

The Nursery Industry Accreditation Scheme Australia **(NIASA)** is a national scheme for production nurseries and grower media supplier businesses. **NIASA Best Management Practice Guidelines** can be purchased. The guidelines are regularly reviewed, ensuring they cover relevant and current production and environmental issues. Other publications on managing with water, pesticide applications, the environment and biosecurity (quarantine), are also available from:

NGIA www.**ngia**.com.au/

1. **Access/prepare a plan** that fits your situation including the management history of plants purchased. Plan to implement preventative cultural and sanitation measures to minimize the possibility of disease.
2. **Crop, region.** Recognize variations. Know which damping-off diseases your crop is susceptible to.
3. **Identification** of the precise cause of damping-off is difficult and it may be necessary to consult a diagnostic service (page xiv). Identification of the fungus must be carried out in a diagnostic lab by a pathologist.
4. **Monitor.** Remember **know when, where, what and how to monitor**. If damping-off is a major problem look for symptoms in seedlings. Test water and media as well, record findings. A general monitoring survey should be carried out on a regular basis in small nurseries. In a large nursery about 10% of the newly sewn nursery beds in the nursery could be surveyed about 1 week after sewing just as seedlings are emerging, using a visual assessment, eg

Scores
Nil
Low - up to 25% seedlings affected
Medium - 25-50% affected
Severe - More than 50% of seedlings affected

5. **Threshold.** How much damage can you accept? Do you need to calculate your own threshold?
6. **Action/control.** Preventative measures should be in place in all nurseries. If seedlings have not been treated within the last month consider treating them or transplanting them into larger containers, treat afterwards. Take appropriate action when any threshold is reached. Manage fungus gnats and shore flies (page 75).
7. **Evaluation.** Review your program to see how well it worked. Recommend improvements if required. If necessary seek further advice.

Control methods

Pythium occurs in virtually all cultivated soils, so eradicate is not really possible. Control fungus gnats and shore flies in greenhouses.

Cultural methods

- **Do not sow** seedbeds or plant cutting beds too thickly as this can encourage spread of disease.
- **Maintain optimum conditions** for plant growth, eg do not plant seeds or seedlings when **temperatures** are too low for optimum growth.
- **Avoid overwatering**. Water in the morning but not late afternoon. Creating a humid atmosphere is a fundamental technique of propagation. Provide adequate moisture in the media (but not too much) to prevent tops from drying out.
- **Provide good drainage** and good air circulation. Improve irrigation management and surface drainage to reduce excess water lying in bays. Use free draining mixes. Subirrigation may result in spread of motile spores from infected to healthy plants.
- **Avoid overfertilizing**, especially with nitrogenous fertilizers to avoid lush growth.

- **Practice crop rotation** in the field, strains of damping-off fungi can develop. Rotate crops every 5 years or as recommended to reduce build-up of root rot fungi in soil. Maintain good soil fertility.
- **Added organic matter** can stimulate growth of antagonistic soil micro-organisms.
- **Soil-less mixtures** and **hydroponic mixtures** are unfavourable to damping-off diseases spread mainly by soil, eg *Phytophthora*, *Pythium*, *Rhizoctonia*.
- **Osmopriming** (controlled hydration of seeds) is promising, as is replacing most of the peat in mixtures with composted tree bark. Both reduce root rot caused by *Pythium* and other root pathogens.
- **Do not mow** or traffic wet turf surfaces, reduce thatch by scarifying and tyning, carefully control moisture on any newly seeded areas.

Sanitation.

- **Practice hygiene** to prevent introduction in potting media, cuttings, tools, personnel, water.
- **Prevent soil** on floors contaminating benches and growing containers.
- **Use only freshly made** disinfectant solutions, when required (used solutions may not work).
- **Store all treated** equipment, containers etc in a clean area or away from dirt and contamination until required.
- **Discard and destroy** any batches of badly affected seedlings, cuttings (and soil), in an area away from other plants.
- **Where hoses** are used for irrigation keep nozzles off the ground to prevent contamination.
- **Remove all dirt** and organic matter (including roots and sap) from surfaces, then thoroughly wash surfaces (benches, tools, equipment, trays, pots), prior to treating them with a disinfectant at the concentration and time recommended.

Biological control.

- **Natural controls** include:
  - Binucleate *Rhizoctonia, Pythium.*
  - Soil bacteria and other micro-organisms.
- **Commercially available**.
  - Trichopel® (*Trichoderma* sp.) may be a hyperparasite. *Trichoderma atroviride* can help prevent *Phytphthora, Rhiozctonia, Pythium, Fusarium.*
  - Companion® (*Bacillus subtilis*) may suppress development of ***Pc***, *Pythium*, *Rhizoctonia* and *Fusarium* on some seedlings.
  - Mycostop® (*Streptomyces griseoviridis*) overseas is used against *Fusarium, Pythium*, ***Pc***, *Botrytis*, etc.
  - See pages 329, 344 (Table 60), 369, 374 (Table 68).

Disease-free media.

- **Use soilless media** in nurseries or treat it.

Disease-tested planting material.

- Take **cuttings** from vigorous disease-free stock plants.
- Some damping-off fungi, eg *Rhizoctonia,* may be **seedborne** on some hosts. Where damping-off is seedborne and a problem on susceptible plants, eg beans, tomatoes, etc:
  - Use high quality disease-tested seeds.
  - Collect seed from vigorous disease-free stock plants.
  - Treat suspect seed with hot water or chemicals.

Physical & mechanical methods.

- **Soil pasteurization** is a pre-plant treatment for container-grown plants, eg seedling trays, not for open beds in the field. Standard treatment is 60°C for 30 minutes which kills most fungi that cause damping-off. Prevent infested soil from re-contaminating pots, potting mixes, cuttings, germinating seeds and seedlings on benches (page 330).
- **Soil solarization** prior to establishing seedbeds, correctly implemented, kills a range of disease organisms but leaves many beneficial's intact, like soil pasteurization (pages 330, 438).
- **Hot water seed treatments.** Damping-off fungi may occur on, or in seed. If suspected, seek advice on treatment as accurate temperature control is essential.
- **Water treatments** are usually only needed for surface run-off water, eg from streams or dams and for recycled water. **Bore water, roof run-off water and town water** is usually free from damping-off organisms and suitable for use without treatment. Choose the right method of disinfesting water for your situation. The following are examples of some treatments may be used singly or in combination:
  - **Chlorination** is a cheap and effective means of treating water to kill damping-off organisms. Most town water supplies are chlorinated and so free of disease organisms. The 3 main sources of chlorine used are calcium hypochlorite, sodium hypochlorite and chlorine gas.
  - **Filtration** to remove disease organisms is effective if the mesh size is of the recommended micro-biological standard. Inclusion of a pre-filter in the system may be an advantage (Handreck and Black 1994). **Slow sand filters** are still being researched in Australia.
  - **Ultra-violet (UV) lights** are available to sterilize water by flowing the water around a UV tube. The UV machines must be calibrated to produce the dose required to kill off all damping-off fungi.
  - **Disinfectants** (pages 340, 343).

Fungicides.

- **Fungicides only suppress** damping-off especially if plants are weakened by high soluble salts and a saturated environment. The fungus is not eradicated. Phytotoxicity may be a problem.
- **Identify the fungus** causing the problem. In past times, the species of fungus causing damping-off was often not known. This meant that fungicides were alternated or mixed in successive treatments. Many nurseries have regular fungicide treatments, eg weekly or fortnightly, depending on plant species, the specific damping-off fungi and available fungicides.
- **Seed treatments.**
  - **Protective seed treatments.** Many seeds, eg peas, are coated with fungicide (and insecticide) before being sold to prevent attack by damping-off fungi (and insect pests) in the field (page 374, Table 68).
  - **Systemic seed treatments** include metalaxyl and fludioxonil (page 374, Table 68).
  - **Combinations**. Often several fungicides are formulated to provide good control of damping off.
  - **Seed treatment is sometimes followed** by spraying seedlings with the same or different effective fungicides than those used for seed treatment (Agrios 2005).
- **Water treatments**
  - See Physical & Mechanical methods above.
- **Media/soil treatments**
  - Fungicides may be **incorporated** into potting mixes.
  - Fumigation (page 267, Table 52.
- **Follow CropScience Australia Resistance Management Strategies** (pages 331, 337)
- If purchasing seedlings, check their management history before buying - if not treated for damping off within the last month then consider treatment.

Table 68. Some damping off fungicides and bio-inoculants.

- **Identify the fungus or complex of organisms** (fungi, bacteria, nematodes etc) causing the problem.
- Read the label for **plants/situations** and **diseases/pests** for which the product may be used.
- Read the label for rates, get the **MSDS**.
- *Botrytis* causes **aerial damping off** and spraying is therefore more effective than soil drenching.
- Although it is necessary for a fungicide to **persist** for short periods to provide effective control/prevention, some fungicides persist for too long for use in a glasshouse/polytunnel.
- Some fungicides, **applied as a foliage spray** will move into the root system to suppress *Pythium.*
- Many now available as **seed treatments**.
- **Individual fungicides** are usually effective against either oomycota (water moulds, eg *Pythium*, *Phytophthora*, downy mildews, or Ascomycota and Imperfect Fungi (powdery mildews, rusts, leaf spots, soil ascomycetes). Some exceptions. Products often formulated as mixtures.

What to use?	Some diseases effective against
Group 3, eg Octave®, Protack®, Sportak® (prochloraz)	Many diseases, but **not** downy mildews, *Pythium, Phytophthora.*
Group 4, eg Fongarid® (furalaxyl); Ridomil® (metalaxyl)	Damping off (*Pythium, Phytophthora*), also downy mildews.
Group 14, eg Terrazole® (etridiazole), Chloroturf®, Terraclor® (quintozene) **Note that APVMA has suspended the supply or use of material and products containing quintozene until 12 April 2011**	**etridiazole** *Phytophthora, Pythium, Rhizoctonia* **quintozene** Sclerotia-forming fungi eg *Botrytis, Rhizoctonia, Sclerotinia, Sclerotium.*
Group 28, eg Previcur®, Proplant® (propamocarb)	*Phytophthora,* damping off *(Pythium),* downy mildews, **not** powdery mildews.
Group M3, eg Thiram®, TMTD® (thiram)	Damping off, eg *Pythium*; also turf diseases.
Group M4, eg Captan®, Merpan® (captan)	Damping off (*Pythium*), black spot, grey mould (*Botrytis*), many other fungal diseases.
Seed treatments Seed treatments continue to offer the best control measures for most **seedling pathogens**. However, there is currently no adequate control measure for black root rot (*Chalara*). Seed treatments are also available for insect pests (see below).	**Seeds are mostly treated prior to purchase**. **Do not use treated seed for food, feed or oil.**
Fungicides, eg **Group 2**, eg Rovral® Liquid Seed Dressing, various (iprodione) **Group 4**, eg ApronXL Fungicide Seed Treatment (metalaxyl-M) **Group 12**, eg Maxim® Fungicide Seed Treatment (fludioxonil) **Group M3**, eg thiram	Suppresses *Rhizoctonia* in lupin seedlings, potato tubers. Seedling diseases caused by *Pythium* and *Phytophthora* in cotton, peas and other crops. Damping off caused by *Fusarium* spp., *Pencillium* spp. in maize and sweetcorn and *Rhizoctonia solani* (black scurf) and *Helminthosporium solani* (silver scurf) and the suppression of seed-borne *Streptomyces* spp. (common scab) in potatoes. Damping off diseases of chickpeas, lupins, sorghum, eg *Pythium, Botrytis, Ascochyta.*
Fungicide mixtures, eg **Groups 11/12/4**, eg Dynasty® Fungicide Seed Treatment (azoxystrobin/**fludioxonil**/metalaxyl-M) **Groups 3/4**, eg Dividend® Fungicide Seed Treatment (**difenoconazole**/metalaxyl-M) **Groups 12/4**, eg Maxymyl® Fungicide Seed Treatment (**fludioxonil**/metalaxyl-M) **Groups 1/M3**, eg Fairgo® Liquid Fungicidal Seed Dressing (thiabendazole/thiram)	For the control of certain seedborne and seedling root diseases of certain crops.
Insecticide/Fungicide mixtures, eg **Group 4A Insecticide/Group 3 Fungicide.**, eg Hombre® (imidacloprid + tebuconazole)	For control of aphids and prevention of spread of barley yellow dwarf virus in cereal crops. Also for control of bunt, flag smut and loose smut of wheat. For control of covered and loose smuts of barley and oats
Insecticides, eg **Group 4A**, eg Cruiser® Insecticide Seed Treatment (thiamethoxam) See page 57 (general), page 140 (thrips), page 189 (earwigs), page 285 (preventing virus spread)	Treatment of cotton, sorghum and sunflower seed to control various early season soil and sucking insect pests.
Potato tuber treatments **Group 20**, eg Monceren® (pencycuron)	Seed-borne infection of *R. solani* in potato tubers.
Bio-inoculants **Trichopel® P. G and R, Trichodry®, Trichopel® Turf, Trichoflow® Turf, Trichodex®, Unite® Natural Protectant Bio-Fungicide** (*Trichoderma* sp.) **TrichoShield**™ (*Trichoderma* spp., *Gliocladium virens, Bacillus subtilis*) **Companion, Fulzyme Plus**™ (*Bacillus subitilis*)	*Trichoderma* suppresses damping off of seedlings caused by *Rhizoctonia solani* and *Pythium* spp. and root rots cause by *Cylindrocladium destructans, Phytophthora* spp. (page 344, Table 60). Suppresses soilborne diseases**,** eg *Fusarium, Phytophthora, Pythium* (page 344, Table 60).
Fumigants page 267, Table 52.	
Disinfectants page 343, Table 59.	

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List the **distinctive features** of fungi.
2. Explain how fungi **reproduce** and **infect host plants**.
3. Describe **symptoms** on leaves, flowers, fruit, seeds and seedlings, stems, branches and trunks, bulbs, corms and tubers, roots, crowns and collars, produced by **local** fungal diseases. Name 1 example of each.
4. **Recognize by sight**, powdery mildews, downy mildews, rusts, fungal leaf spots, damping off and other **local** fungal diseases.
5. **Distinguish** between **powdery** and **downy mildew** diseases on the leaves of selected host plants and plants which get both.
6. **Distinguish between symptoms** caused by peach leaf curl and green peach aphid on peach leaves.
7. **Distinguish between symptoms** caused by **plague thrips** and ***Botrytis* petal blight** on flower **petals**.
8. **Differentiate** between the symptoms/damage caused by the following to the trunks of trees:
   Wood rot Borers Termites
9. Describe how you would distinguish between **symptoms** caused by *Phytophthora* root rot from those caused by other factors such as too much water, too little water and salt toxicity on the **foliage** and **roots** of selected plants.
10. **Distinguish between symptoms** caused by *Armillaria* root rot, *Phytophthora* root rot and other local soil fungal diseases.
11. **Describe** the first sign(s) that there is wood rot in a tree
12. **Describe** the part of the wood rotting fungus that causes the wood to rot.
13. **Distinguish between fungal leaf spots** and those caused by bacterial and other agents.
14. Recognize by sight, **local beneficial fungi** including:
    Fungal diseases of insects
    Mycorrhizae
    Saprophytic fungi
15. Describe 3 types of **disease cycles**. Name 1 example of each.
16. Describe 4 ways by which fungal diseases may **'overwinter'**. Name 1 example of each.
17. Describe 5 ways by which fungal diseases may **spread**. Name 1 example of each.
18. Describe **conditions favouring** any 2 common fungal diseases.
19. Why is knowledge of the **disease cycle** important in determining control measures? Use peach leaf curl as an example.
20. Describe State/Territory/Commonwealth **legislation** which provides for the control of some local fungal diseases.
21. List **control methods** for fungal diseases. Describe 1 example of each.
22. Explain the meaning of the following terms as they apply to the **mode of action** of fungicides. Explain the advantages and disadvantages of each type and how it may be used to **control** foliage fungal diseases:
    Non-systemic and systemic
    Protectant and eradicant
23. Provide the active constituent, some trade names, mode of action and some uses for **1 fungicide** belonging to each of the following groups/types:
    Group 3
    Group 4
    Group 14
    Group 33
    Group M1
    Group M2
    Group M3
    Bio-fungicides and similar products
    Disinfectants
24. List the fungal characteristics used to **classify fungi** into **Phyla**.
25. Name the **Phyla of fungi** to which the following fungi belong:
    Downy mildews
    Powdery mildews
    Rusts
    Phytophthora
    Wood rots
    Damping-off
26. Explain why it is necessary to know which **Phylum** a fungal disease belongs to.
27. **Provide the following information** for powdery and downy mildews, rusts, damping-off and other local fungal diseases:
    Common name
    Cause
    Host range
    Symptoms
    Disease cycle
    'Overwintering'
    Spread
    Conditions favouring
    IDM & Control
28. Prepare/access an **IDM** program for a fungal disease at your work or in your region.
29. Locate **reference material** and know where to obtain advice on the identification and control of local fungal diseases.

SELECTED REFERENCES

University of Sydney http://bugs.bio.usyd.edu.au/
Australasian Plant Pathology Society www.australasianplantpathologysociety.org.au/
American Phytopathological Society www.apsnet.org/
The Australasian Mycological Society www.australasianmycology.com/
Mycorrhizas www.anbg.gov.au/fungi/mycorrhiza.html
GRDC Rust links www.grdc.com.au/
Nursery & Garden Industry Australia (publications and resources are listed on www.ngia.com.au/ eg
Australian Garden Centre Accreditation Scheme (AGCAS)
Major Pests and Diseases of Nursery Plants
Nursery Industry Accreditation Scheme Australia (NIASA Best Management Practice Guidelines
Water management *EcoHort Guidelines*
Biosecurity HACCP (quarantine risks)

Fact Sheets by State/Territory Depts of Primary Industries, Nursery Papers, etc are available online, eg
Powdery mildews *Downy mildews* *Rusts*
Disease and Pest Guides for Fruit, Vegetables, etc
Disease Awareness in the Nursery

Ute/Pocket Guides

NSW DPI. *Field Identification Guide : Pests, Diseases, Disorders and Beneficials in Ornamentals*.
Wallwork, H. 2000. SARDI/CSIRO, Melbourne.
Cereal Diseases : The Ute Guide (TOPCROP/GRDC).
Cereal Root and Crown Diseases (SARDI/CSIRO)
Cereal Leaf and Stem Diseases (SARDI/CSIRO)

IDM

AUSVEG www.vgavic.org.au/vegetables-victoria-researchers.htm
Crop monitoring www2.dpi.qld.gov.au/horticulture/18606.html

Biological control

Organic Crop Protectants www.ocp.com.au/
Becker Underwood www.beckerunderwood.com

Keys

Lucid keys www.cbit.uq.edu.au/
Interactive Key to the Fungi of Australia
Key to Common Microscopic Fungi (for schools)
Fungi of Australia
Key to 101 Forest Fungi of Eastern Australia
Lucid keys of DIRECT Relevance to Quarantine, Plant Health and Invasive Species

Organic standards

AS 6000—2009. *Standards Australia Organic and Biodynamic Products*. Standards Australia.
Organic Federation of Australia www.ofa.org.au for organic certifiers, products etc
Caldwell, B., Rosen, EB., Sideman, E. a, Shelton, A.M. and Smart, C. D. 2000. *Resource Guide for Organic Insect and Disease Management.*

Quarantine

Commonwealth quarantine www.daff.gov.au/aqis
PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.padil.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. www.daff.gov.au and search for target lists

Fungicides

Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
HerbiGuide, WA www.herbiguide.com.au/
Croplife Australia www.cropelifeaustralia.org.au/
Chemical Toxicity to Beneficials www.goodbugs.org.au/
Kondinin Group: Field Crop Fungicide & Insecticide Guide www.kondinin.com.au/
MSDS www.msds.com.au/ Company websites
Company websites labels and MSDSs
Best Practice Manual for Pesticide Application in the Nursery & Garden Industry (CD)

General

Agrios, G. N. 2005. *Plant P.* 5th edn. Academic Press, NY. also 4th edn 1997.
Atkinson, I. (ed.). 2000. *Hygiene and Sanitation of Working Surfaces in the Nursery*. The Nursery Papers 2000/03.
American Phytopathological Society (APS) Press, St. Paul, Minnesota produces compendiums on diseases and pests of particular plants. www.shopapspress.org
Bodman, K., et al. 1996. *Ornamental Plants : Pests, Diseases & Disorders*. Q196001. Qld DPI, Brisbane.
Brown, J. F. and Ogle, H. J. (eds). 1997. *Plant Pathogens and Plant Diseases*. Rockvale Pub., Armidale, NSW.
Cooke, T., Persley, D. and House, S. 2009. *Diseases of Fruit Crops in Australia.* CSIRO Pub.
Drenth, A., et al. 2006. *Development of a DNA-based Method for Detection and Identification of Phytophthora species.* Australasian Plant Pathology. 35. 147-159.
Environment Australia. 2001. *Threat Abatement Plan for Dieback caused by the Root-rot* Fungus *Phytophthora cinnamomi*. Environment Australia/Natural Heritage Trust, Canberra.
Fungi of Australia. CSIRO, Melbourne.
Funhrer, B. 2005. *A Field Guide to Australian Fungi*. Bloomings Books, Melbourne.
Grey, P. and E. 2005. *Fungi Down Under: The Fungimap Guide to Australian Fungi.* ed. Leon Costermans. Fungimap, RBGM. Royal Soc. Vic. www.rbg.vic.gov.au/fungimap /welcome/
Goodwin, S., et al. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* Agrilink. QAL0004, NSW Agric. Sydney.
Goodwin, S. and Steiner, M. (eds). 2000. *The Pests, Diseases, Disorders and Beneficials in Ornamentals – Field Identification Guide.* DPI. will be avail as electronic pocket for use in the field.
Hall, R. (ed.). 1997. *Principles and Practice of Managing Soil-borne Plant Pathogens*. APS Press, MN.
Handreck, K. and Black, N. 1994. *Growing Media for Ornamental Plants & Turf.* UNSW Press, NSW.
Horne, P. de Boer, R. and Crawford, D. 2002. *A Field Guide to Insects and Diseases of Australian Potato Crops.* Melbourne University Press.
Horst, R. K. (ed.), 2008. *Westcott's Plant Disease Handbook*. 7th edn. eReference, originally published by Springer, NY.
Jones, D. L. and Elliot, W. R. 2000. *Pests, Diseases & Ailments of Australian Plants.* Lothian, Melbourne.
Keane, P. J., Kile, G. A., Podger, F. D. and Brown, B. N. (eds). 2000. *Diseases and Pathogens of Eucalypts.* CSIRO Pub., Vic.
Kita, N., et al. 2003. *Guide to the Common Diseases and Disorders of Bunching Vegetables*. DPI
Marks, G. C., Fuhrer, B. A. and Walters, N. E. M. 1982. *Tree Diseases in Victoria.* Forests Com., Vic.
Matheny, N. P. and Clark, J. R. 1994. *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas.* 2nd edn. Inter. Soc. of Arboriculture, Illinois.
Mattheck, C. and Breloer, H. 1994. *The Body Language of Trees*. HMSO, London.
McMcMaugh, J. 1994. *What Garden Pest or Disease is that?* Lansdowne Press, Sydney.
McCracken, A. R. 2005. *Rust Diseases of Willow and Poplar*. CABI, Pub., UK.
Moore, S. R. 1996. *Bicarbonates Offer Effective Disease Control*. GrowerTalks, Feb.
Parke, J., Pscheidt, J.W., Regan, R., Hedberg, J. and Grunwald, N. 2008. *Phytophthora Online Course: Training for Nursery Growers*. Oregon State University. currently available at http://oregonstate.edu/instruct/dce/phytophthora/
Persley, D., Cooke, T. and House, S. 2009. *Diseases of Vegetable Crops in Australia*. CSIRO Pub.
Pscheidt, J. W. 2009. *Diagnosis and Control of Phytophthora Diseases*. Oregon State University
Stephens, R. (ed.). 2005. *Nursery Industry Accreditation Scheme, Australia (NIASA). Best Management Practice Guidelines.* www.ngia.com.au
Reid, A. 2006. *Phytophthora Diseases of Cutflower Crops*. Bull 4682. State of WA. avail online
Rolfe, C., Yiasoumi. W. and Keskula, E. 2000. *Managing Water in Plant Nurseries.* NSW DPI.
Shearer, B. L., Crane, C. E., Fairman, R. G. and Dunne, C. P. 2009. *Ecosystem Dynamics Altered byPathogen-mediated Changes Following Invasion of Banksia Woodland and Eucalyptus marginata Forest Bionemes of South-western Australia by Phytophthora cinnamoni.* Australasian Plant Pathology, Vol.38.4.
Stephenson, S. L. 2010. *The Kingdom Fungi : The Biology of Mushrooms, Molds & Lichens.* Timber Press, OR.
Strouts, R, G. and Winter. 1994. *Diagnosis of Ill-health in Trees*. 2nd edn. DTER, UK.
Tesoriero L, Forsyth L and Carrus R (2008) *Biocontrol of Phytophthora RootRot of Lettuce Growing in Hydroponic Systems*. The Australian and New Zealand Biocontrol Conference, Sydney, Australia
Vegetable Industry Centre Newsletter. Dec 2007. 2007. *Improved Management for Root Disease of Hydroponic Lettuce*. HAH/AUSVEG.
Young, T. and Smith, K. 2004. *A Field Guide to the Fungi of Australia.* UNSW Press.

Parasitic Flowering Plants

Dodder (*Cuscuta* sp.) sends **haustoria** (projections) into the host stem to absorb nutrients and water.

BIOLOGY & IDENTIFICATION

Parasitic flowering plants

NO. SPECIES IN AUSTRALIA

There are more than 100 species in Australia, but only a few are important weeds.

SOME DISTINCTIVE FEATURES

PARASITIC FLOWERING PLANTS PRODUCE FLOWERS AND SEEDS similar to those produced by the plants they parasitize.

- They belong to several widely separated botanical families.
- Their parasitism is generally regarded as a degenerative process whereby plant species became dependent for their existence on the host plant.
- They have developed specialized organs which penetrate the vascular tissue of the host plant, and absorb nutrients and/or moisture from it.

PARASITIC PLANTS VARY IN DEPENDENCE ON THEIR HOST PLANTS. However, there are, in general, 2 groups:

- **Hemi-parasites possess chlorophyll** and can carry out photosynthesis, some possess roots while others do not, eg
  - Native cherry (*Exocarpos cupressiformis*) - root parasite
  - Western Australia Christmas tree (*Nuytsia floribunda*) - root parasite
  - Witchweeds (*Striga* spp.) - root parasites
  - Mistletoes (*Amyema* spp., *Dendrophthoe* spp., *Notothixos* spp.) - stem parasites
  - Quandong, sandalwood (*Santalum* spp.) - root parasites
  - Devil's twine, dodder laurel (*Cassytha* spp.) - stem parasites
- **True parasites lack chlorophyll** and have **no true roots**, eg
  - Dodder (*Cuscuta* spp.)
  - Broomrape (*Orobanche* spp.).

WEED STATUS OF PARASITIC PLANTS

THE EFFECT OF A PARASITIC PLANT ON ITS HOST IS VARIABLE, eg

- Relatively few of the known parasitic higher plants cause important diseases of agricultural crops or forest trees.
- Some, eg dodders, branched broomrape, witchweed, are declared **noxious weeds** in some areas of Australia (pages 412, 417).
- Large infestations of mistletoe can **kill trees**.
- Broomrape and dodder infestations can dramatically **reduce crop yields**.

BENEFICIAL VALUES

FOOD POTENTIAL, OIL, CEREMONIAL, BIO-CONTROL AGENTS, eg

- In Australia some parasitic plants produce edible fruits, eg mistletoes, quandong (*Santalum acuminatum*) and yellow plum (*Opilia amentacea*).
- Sandalwood oil from *Santalum* spp. (root parasite of trees).
- Some have ceremonial use, eg mistletoe and love.
- Devil's twine (*Cassytha pubescens*) has potential to reduce gorse infestations.
- Some, eg mistletoes, provide habitat and food for many birds and mammals. Honeyeaters feed on nectar in mistletoe flowers.

IDENTIFICATION

IDENTIFYING THE PARASITIC PLANT

- This is an essential **1st step** in understanding its biology, impact and control.
- To the average gardener and grower some parasitic plants, eg dodder and devils twine, can look alike, and the actual species of a parasitic plant can be even more difficult to identify (weed identification, page 412).

HELP WITH IDENTIFICATION

- Most botanic gardens and State diagnostic services can assist (page xiv).
- There are free specialist diagnostic services in some areas for some species, eg broomrape in WA (**Grain Guard** or **AGWEST Plant Laboratories**).
- Check with the diagnostic service on how to submit the specimen, eg leave broomrape attached to the host if possible, to aid identification.

CONFUSION

Do **not** confuse **stem parasites** with non-parasitic plants which may:

- Just **twist their way around plants**, strangler-type plants, eg jasmine.
- Produce **suckers on their stems** and attach themselves to fences, buildings, other plants, eg some ivies.
- **Produce tendrils** which twine around other plants, fences etc, eg *Sollya*.
- **Be epiphytes**, which are plants which grow on other plants and use them mostly for **physical support** and **protection**. They are **not parasites** and cause no harm to the plants on which they grow, eg most orchids in tropical areas which have both chlorophyll and aerial roots.

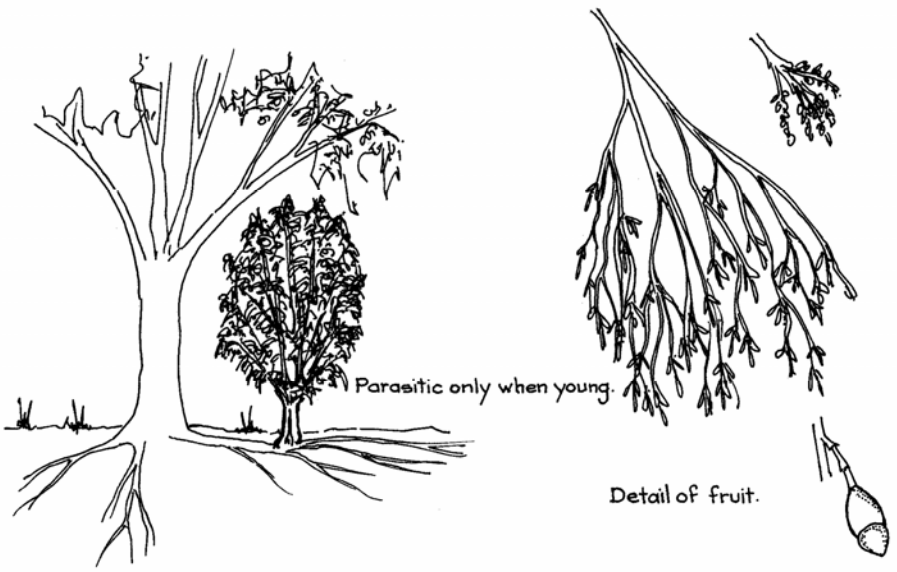
HEMI-PARASITES

Hemi-parasites **possess chlorophyll** and can carry out photosynthesis. Some hemi-parasites possess roots while others do not.

NATIVE CHERRIES (*Exocarpos* spp., Santalaceae)

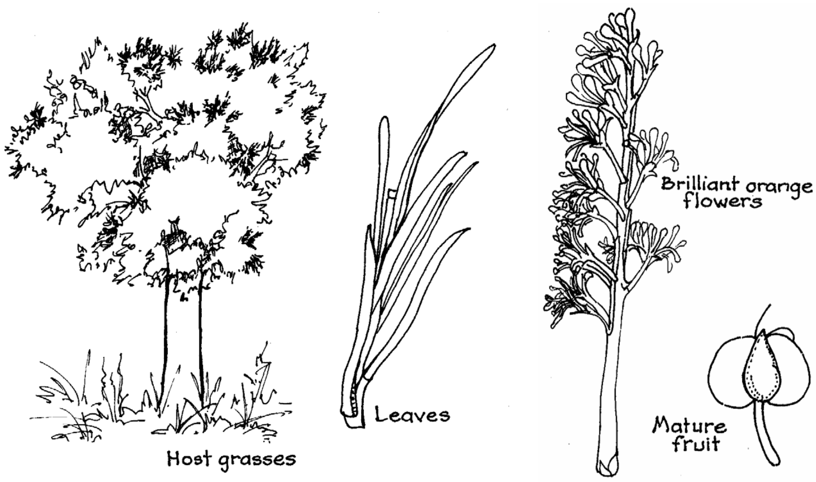
- **Have chlorophyll.**
- **Have normal roots**. Depend on their hosts for **water** and **some nutrients**.
- **Woody shrubs** to 5 meters or small trees to 10 meters, **parasitic on roots** of host plants, eg eucalypts, wattles. Foliage resembles cypress, casuarina.
- **Propagated** by seed, stem or root cuttings.
- Native cherries are **not generally a problem** in forest, bushland or remnant vegetation, an exception is *Exocarpos strictus* which parasitizes *Eucalyptus camaldulensis* forests on the central Murray River Valley.

Every 3-4 years there may be a big seed set on native cherry



WESTERN AUSTRALIA CHRISTMAS TREE (*Nuytsia floribunda*, Loranthaceae) also known as the Swan River blaze tree. Endemic to WA.

- **Has chlorophyll.**
- **Has roots.** Secures water and certain nutrients by tapping the roots of adjacent plants.
- **Small woody tree**, may grow up to 10 meters high often in apparent isolation. Brilliant orange flowers. **Parasitic on the roots** of grasses and other plants. Its favored host appears to be *Banksia* spp.
- Reproduces in the wild by **suckers**, can be propagated by seed, cuttings.



HEMI-PARASITES ***(contd)***

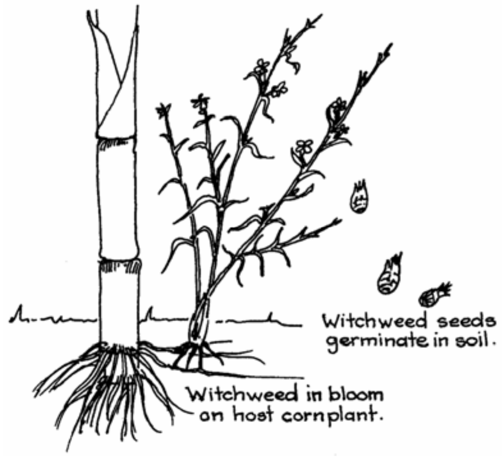
Generally not important parasites in Australia

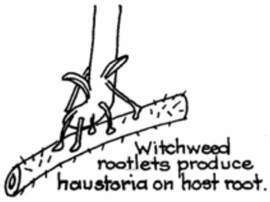
WITCHWEEDS (*Striga* spp., Scrophulariaceae)

- **Have chlorophyll.**
- **No true roots**. Depends on their hosts for water, minerals and probably some organic substances.
- Stiff upright **annual herbs** up to 30 cm high (*S. asiatica*), flowers red, yellowish or whitish, **parasitic on the roots** of many **monocotyledons**, eg maize, sorghum, sugarcane, rice. Heavily infested hosts wilt.
- **Reproduces** by seed. As many as 90,000 seed can be produced per plant. Seeds need a resting period of 15-18 months before they germinate but can remain viable for up to 14 years. Life cycle of 90-120 days.
- **Spread** by contaminated crop (host) seed, forage, bags, containers, vehicles, machinery.

The exotic witchweeds are **among the worst weeds of the world**, causing up to 40 per cent yield losses in severely-affected crops. Australia is the only country in south east Asia that is free from the witchweeds *S. asiatica* and *S.angustifolia*.

Australia has **native witchweed** species, one of them has proved a problem on Qld sugarcane.



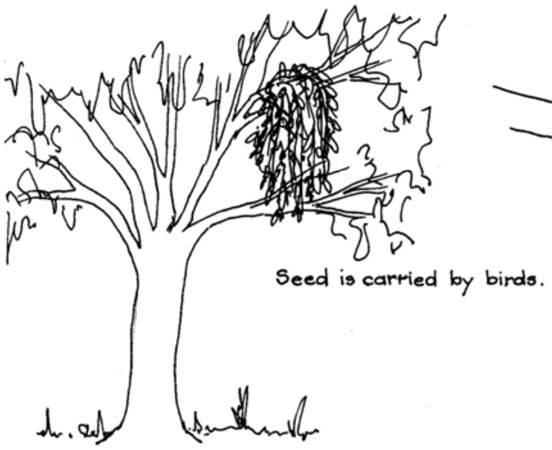


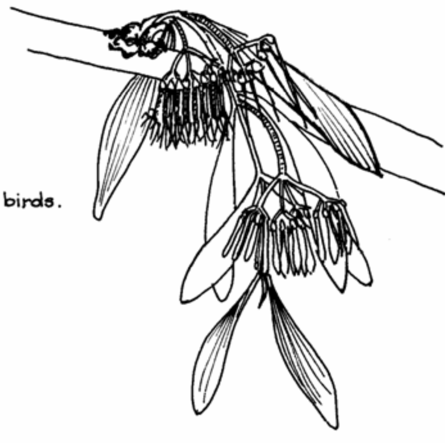
MISTLETOES (Loranthaceae, Viscaceae). There are about 70 species in Australia but most do little harm. All species in Australia are native plants and include include *Amyema (*commonly *A. miguelii, A. pendula)*, *Dendrophthoe* spp. and *Notothixos* spp.

Mistletoes have a life span of 20-30 years, eucalypts may live for >150 years

- **Have chlorophyll.** Mistletoes are more apparent on isolated trees or at the edges of forests and in the higher branches of trees, and on stressed trees.
- **No roots**. Depend on their hosts for water and all minerals.
- **Perennial shrubs**, often pendulous, **parasitic on upper stems** of native and exotic plants, eg eucalypts, conifers, wattles, birch.
  Many species have attractive red flowers, leaves may mimic their hosts**.**
- **Spread** by birds, eg mistletoe bird (*Dicaeum hirundinaceum*), and animals which eat the seed and deposit them in their droppings. Seeds stick to the host.
- **Damage.** Can be serious pests of natural forests, plantations, orchards and ornamental trees. A single mistletoe usually has little effect on a healthy tree but if many mistletoes grow on one host, the tree may die as a result of environmental stress and the mistletoe.

Mistletoe attachments on a branch of silver birch.
Photo©CIT, Canberra (P.W.Unger)





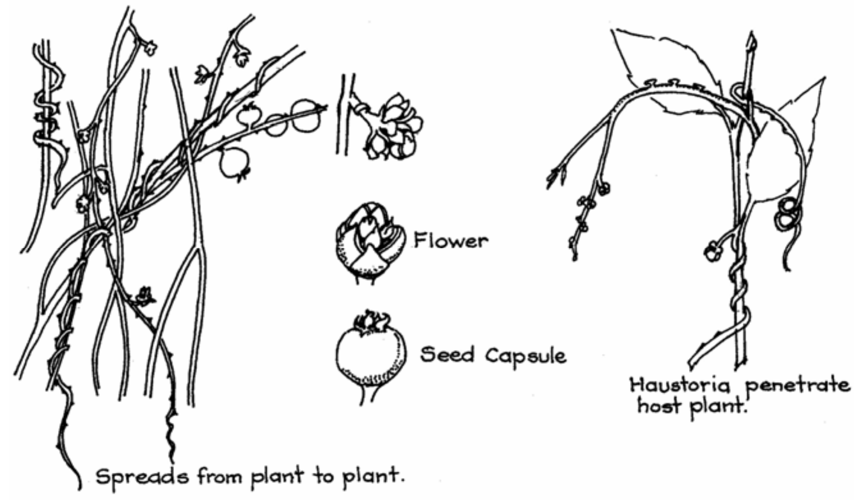
HEMI-PARASITES
(contd)

Not usually economically important but smothers smaller native plants in bush areas, mainly a problem in bushland

Tangle of devil's twine.
Photo©CIT, Canberra (P.W.Unger).

DEVIL'S TWINE, DODDER LAUREL (*Cassytha* spp., Lauraceae)

- **Has chlorophyll.**
- **No true roots**. Depend on their hosts for water and some nutrients.
- **Straggly perennial climber**, stems generally green, or yellowish- green. Leaves scale-like. Flowers small and white. **Parasitic** on **stems** of mainly **woody plants**, eg wattles. Do not confuse with dodder (*Cuscuta* spp.).
- **Spread.** Seed is spread by birds. Seedlings climb up nearby hosts, roots die after contact is made with the host, severing connection with the soil.
- Smothers hosts and causes general debilitation. In exceptional circumstances kills the host. Infestations are rarely economic in crop plants.



TRUE PARASITES

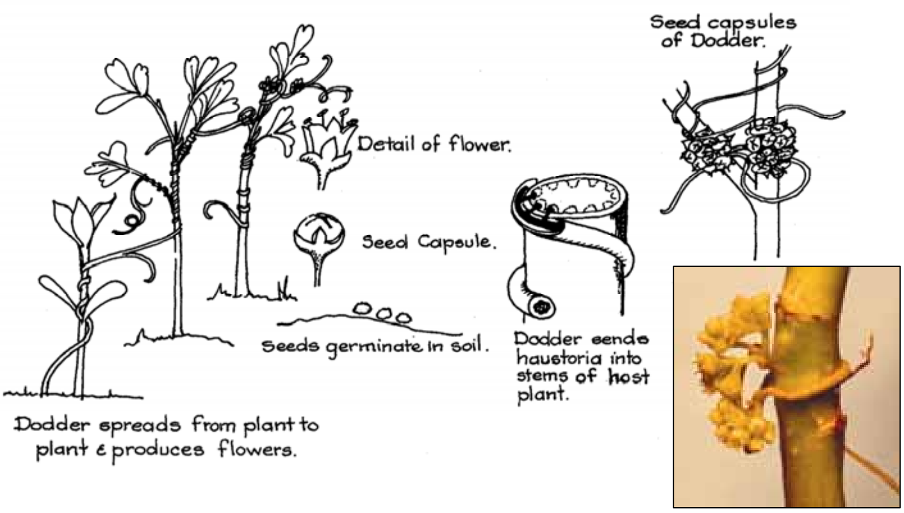
Do not confuse with Devil's twine

True parasites **lack chlorophyll and have no true roots**, depend entirely on their host plants for food and water. Some are native, others are introduced.

DODDERS (*Cuscuta* spp., Convolvulaceae)

- **Have no chlorophyll.**
- **No true roots.**
- **Straggly annual climber**. Distinctive fine leafless, yellow or brown, wiry stems, can twine around **herbaceous plants** completely covering the host. Flowers are small cream or white clusters produced in summer. Host crops include lucerne, red clover, vegetables, eg carrots, onion, annual ornamentals, eg aster, weeds, eg skeleton weed. Host range can vary depending on species. One dodder plant can spread up to 2 meters in diameter.
- **Spread** by contaminated seed, hay, harvesting machinery, running water or in manure. As many as 3000 seeds may be produced by a single plant. Seeds can germinate in the soil immediately or **remain dormant** for 20 years. Seedlings climbs up any nearby host, then sever their connection with soil.
- Infestations reduce yield and may kill crops.
- May spread virus diseases of the host plants.

Thin yellowish dodder stems on calendula seedlings in a punnet.
Photo©CIT, Canberra (P.W.Unger).



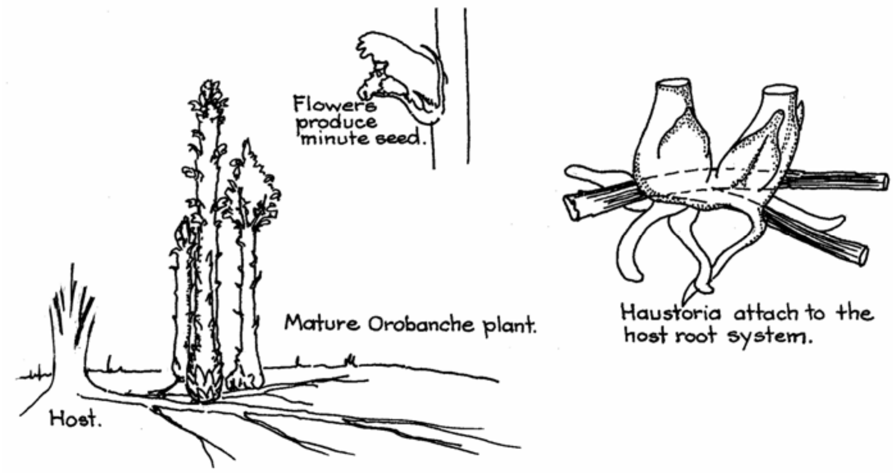
TRUE PARASITES *(contd)*

BROOMRAPES (*Orobanche* spp., Orobanchaceae). In Australia three species are known to be present. *O. cernua* var. *australiana*, a native species that does not attack crops, lesser broomrape (*O. minor*) which is a common minor weed and branched broomrape (*O. ramosa*) which is under an eradication program.

- **Have no chlorophyll.** Difficult to control
- **No true roots.**
- **Annual flowering plant** (occasionally biennial). Stems are erect, brownish, and grow to about 20-40 cm high. Scale-like leaves, flowers inconspicuous. By the time flowering stems emerge it is usually too late to save the crop. **Parasitic on the roots** of **broadleaved** vegetable and field crops, eg clover, legumes, ornamentals, eg gazania and some weeds, eg skeleton weed.
- **Spread** interstate by travellers, via transport or other material. Seed is spread by soil on machinery, contaminated soil, sand, animal manures, livestock through the gut, wool, fur and in soil, manure attached to animals. To a lesser extent by wind and flooding. Seeds are small, like dust. One broomrape plant can produce up to 500,000 seeds with a **dormancy** of 10 years or more!
- **Broomrapes are serious weed pests** of certain crops affecting yields, eg canola, and can stain crops such as celery and cabbage. Ornamentals often appear to be unaffected when only a few broomrape plants are present.

Branched broomrape is distinguished from the common variety by its typically branched flowering stems and often bright blue flowers.

Broomrape stems range from 20-40cm in height. Photo©CIT, Canberra (P.W.Unger).



INTEGRATED WEED MANAGEMENT (IWM)

MAIN STEPS

The National Branched Broomrape Eradication Program commenced in 2000 to eradicate branched broomrape (*Orobanche ramosa*) from South Australia.

1. **Plan ahead**. Commercial growers should contact their **local authority** for information on quarantine status and protocols for management of the parasitic plant in question. Keep records of the crop, eg source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides. National Eradication Programs are in place for some parasitic weeds, eg branched broomrape.
2. **Crop, region.** List parasitic plants which are likely to occur in your crop or region. Some parasitic plants are declared noxious weeds only in some areas. **Management plans are available for some parasitic plants, eg broomrape, mistletoes**.
3. **Identification** must be confirmed. Send specimens to a diagnostic service if necessary (page xiv). Once identified obtain information on its life cycle, population dynamics and likely impact on the crop and control. Obtain Fact Sheets.
4. **Monitor. Know when, where, what and how to monitor**. Early detection of a parasitic plant in a crop assists control (page 429). Record results as recommended.
5. **Threshold** may be determined by legislation which may impose a nil tolerance or specific threshold through Noxious Weed Acts, Seed Acts and Quarantine Acts. If not you may need to work out your own threshold.
6. **Action/control.** There may be legislative requirements. Protocols are available for the control of *Orobanche ramosa* in SA. **Certified seed** is available for some crops. Use control measures strategically and early be it chemical or biological or both and potential major weed problems may be avoided.
7. **Evaluation.** Continue monitoring after treatment. Review **IWM** program to see how well it worked. Recommend improvements if required.

CONTROL METHODS
Legislation
Cultural methods
Sanitation
Biological
Resistant varieties
Plant quarantine
Pest-tested material
Physical/mechanical
Pesticides

CONTROL METHODS

Some parasitic flowering plants can be difficult to control once established so early detection should be followed by prescribed control measures. Some produce seeds prolifically with a long dormancy period and viability, eg broomrapes. As crop cultivation intensifies, parasitic plants are gaining significance as **weeds**. Also it may be that only a certain species requires control.

For all these reasons, it is essential that parasitic plants be **accurately identified** (pages 378, 412). For example, in states where branched broomrape (*Orobanche ramosa*) is under eradication, suspect broomrape plants should be dug up with the host still attached, and sent to the nearest office of Agriculture or one of the diagnostic services set up to identify broom rape plants.

LEGISLATION

- **Native Vegetation Acts**. Approval must be obtained before taking any activity against native species, eg mistletoes (South New England Landcare, 2008).
- **Noxious Weed Acts (or their equivalent)**. Some parasitic plants are declared noxious weeds, eg some dodders (*Cuscuta* spp.) in NSW, Vic., SA, WA and Tasmania, witchweed (*Striga* sp.) in Qld, and branched broomrape (*Orobanche ramosa*) in SA and are subject to obligatory control measures. Failure of landowners to follow Codes and Protocols in some regions can lead to prosecution.
- **Quarantine Acts**, eg all *Orobanche* spp. are prohibited imports.
- **Seeds Acts**. Several States/Territories have regulations against the importation and/or sale of crop seed infested with seeds of parasitic plants, eg dodder (page 386).
- **The Branched Broomrape Eradication Program** is underway in some states. Farmers want compensation for quarantine and a Quality Assurance scheme to ensure the integrity of the eradication scheme.

Code for the Control of Branched Broomrape

CULTURAL METHODS.

- **Deep ploughing** to bury seeds to a depth where they could no longer germinate and infect their hosts and minimum tillage which exposes seeds to extremes of temperature and moisture reducing crop infections, are not usually recommended today. Dodder seeds can survive for 20 years.
- **Planting time**. Higher density plantings can reduce witchweed plants perhaps due to extra shading. Later plantings of some crops can reduce witchweeds and broomrapes, due to lower soil temperatures but may also reduce potential crop yield.
- **Trap crops**.
  - **Catch crops are susceptible plants** grown on land kown to be infested. They stimulate germination of witchweed seed and become infested themselves. The crop must then be destroyed either by ploughing under or applying herbicides before the parasite matures and sets seed.
  - **False hosts** (decoy crops), eg non-host legumes, stimulate germination of witchweed seeds which, however, cannot infect the false host and in the absence of a true host **starve** to death. False hosts have been used in crop rotations to reduce seed populations in soil but results have been disappointing.
  - **Variations**. Flax can serve as a catch crop for broomrape. The flax root exudates stimulate broomrape seed to germinate and these then infect the flax but broomrape cannot flower on it.
  - **In the long term**, the only option for severe infestations may be to switch to non-host plants.
- **Broomrape** (*Orobanche* spp.)
  - **Heavy grazing** by sheep if there is a history of infestation before planting crop.
  - **Cultivation** of some, eg broomrape, can give some control if deeply buried.
  - **Flooding** as for rice growing reduced infestation of broomrape (*O. cernua*) in following tobacco crops. Seeds lose their viability after one month's under water.
  - **Change of crop**. In severe infestations of broomrape, the only options may be to switch to non-host plants such as cereals, orchards or vines.
- **Dodder** (*Cuscuta* spp.)
  - **Crop rotation.** Use a non-susceptible rotational crop and control susceptible weeds. When planting new areas, especially river flats, plant crops other than summer growing legumes for 2-3 years before sowing lucerne to clean up possible dodder and general weeds. Note that that it takes 10-20 years of **fallow** needed to deplete dodder seed in soil. This is completely impractical.
- **Witchweeds** (*Striga* spp.)
  - **Fertilizers.** Witchweeds are frequently associated with infertile soils, especially those deficient in nitrogen. Nitrogenous fertilizers are sometimes used to suppress witchweeds but the precise process is not understood.
- **Allelopathy**. Overseas *Orobanche crenata* causes huge damage to legume crops. Field trials indicate that *O. crenata* infection of faba beans and peas is reduced when these host crops are intercropped with oats. It has been suggested that this is due to allelochemicals released by cereal oats inhibiting the germination of *O. crenata* seeds, thus reducing infection of faba beans and oats.

CONTROL METHODS ***(contd)***

SANITATION

In urban gardens diligent pruning or removal of all traces of the parasite may mean **sacrificing** plants. This coupled with regular inspections can be very slow and not practical for large areas.

- **Broomrape** can be pulled up by hand or hoeing before seed is set to reduce damage to the current crop and future infestations. Minimize weed hosts, eg skeleton weed.
- **Tangled masses of devil's twine** can be pulled off host stems as early as possible before seed is set. Prune off badly affected sections of host. It may be necessary to sacrifice whole plants.
- **Dodder**. Prune off infested plant parts. If this is done before the dodder produces seed this may eradicate it from a small area. Destroy patches of dodder and host plants as soon as noticed, by mowing, and burning the cut material where it lies or killing the standing crop plants by spraying with a herbicide and then burning. Infested crops can also be **grazed** by sheep and residual clumps of dodder later slashed. Control weeds between crop rows.
- **Prune out large mistletoes** early on isolated plants **well below the point of attachment** to the host branch to prevent regeneration. It may be necessary to remove the **whole branch** if damage is severe, cutting off the mistletoe where it joins the host branch is not sufficient. After removing the mistletoe improve tree vigor by fertilizing and watering. Cherry pickers have been used in large areas. Occasionally whole trees, eg silver birches, may have to be removed.
- **Clean equipment** before moving from infested to dodder-free areas. Similarly limit movement of domestic animals.

BIOLOGICAL CONTROL

Like other plants, parasitic flowering plants have natural enemies, eg

- **Broomrape** (*Orobanche* spp.) has been controlled overseas to some extent, in some crops by a fly (*Phytomyza orobanchiae*), myco-herbicides, eg *Fusarium* spp., and by the fungus *Trichoderma* when combined with a herbicide spray.
- **Dodder** (*Cuscuta* spp.) has been controlled in soybeans in China by the fungus (*Colletotrichum gloeosporioides*). *Fusarium* spp. have been used overseas to control dodder in cranberry crops (Brown and Ogle 1997).
- **Mistletoe** (various species).
  - **Mistletoe browntail moth** (*Euproctis edwardsii*) larvae are banded light and dark grey, up to 40 cm long and have irritation hairs. Other moth larva and beetles can infest mistletoe wood but none of these offer any control.
  - **Long term mistletoe management strategies** should encourage formerly abundant predators such as possums and gliders, or hyperparasites, such as harlequin mistletoe (*Lysiana exocarpi*), to help control some mistletoe species.

RESISTANT, TOLERANT VARIETIES

Although resistance has been bred into some crops, there are few examples of success, and it has been overcome.

- **Broomrape.** Sunflowers resistant to broomrapes are grown in Russia.
- **Witchweeds**. Cowpea in West Africa and sorghum in India have shown high levels of resistance to witchweeds (Brown and Ogle 1997).
- **Mistletoes**. *Eucalyptus nova-anglica* and *E. viminalis* appear to have some resistance to some species of mistletoe in some localities.
- **Dodder.** Wheat, barley, oats and cereal rye crops are poor hosts. Summer grain crops, eg maize and sorghum are resistant to golden dodder (*Cuscuta campestris*).

In Israel, some carrot and tomato cropping lands have been abandoned due to Egyptian broomrape (*O. aegyptiaca*) infestations

PLANT QUARANTINE

- **AQIS (Australian Quarantine and Inspection Service).** Because of difficulty in controlling parasitic plants after establishment, all **broomrapes**, **witchweeds** and **dodder** are **prohibited imports** (page 383). If some become established even in small areas, Australian export markets could be affected as many of our trading partners prohibit their import. Although seeds of these plants are a prohibited import, seeds could enter undetected via contaminated soil, machinery livestock clothing. Northern Australian Quarantine Strategy (NAQS) monitors for exotic witchweeds and other target weeds during regular surveys of land across northern Australia and in neighbouring countries.

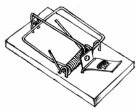
  PaDIL - Pests and Diseases Image Library   www.**padil**.gov,au

  Target lists   www.**daff**.gov.au   www.**daff**.gov.au/**aqis**
- **State/Territory quarantine.**
  - The recently introduced branched broomrape (*Orobanche ramosa*) is a prohibited species in WA and SA. There are protocols for the **movement** of horticultural produce, grain, straw, soil, conservation fodder, machinery and livestock in the quarantine area. There is a Code for the Control of Branched Broomrape on the **GRDC** website with prescribed treatments to eradicate infestations and prevent spread and seed set.   www.**grdc**.com.au/
  - Pest-free status for dodder weed (*Cuscuta* sp.) must be demonstrated for henbane (*Hyoscyamus niger*) seed grown in the Ord River Irrigation Area in North WA for export to the US without need for treatment.
- **Local quarantine.** Prevent spread of seed to areas where temperature and other environmental conditions favour the parasitic plant in question.

CONTROL METHODS *(contd)*

WEED-TESTED PLANTING MATERIAL

- **Do not plant** crop seed, use hay contaminated with broomrape, dodder or witchweed seed, or strip seed or cut hay from contaminated crops.
- **Certified seed.** For some crops certified seed is available and crops grown for seed or hay, eg lucerne, must be inspected for signs of infestation before harvest.
- **Dodder** (*Cuscuta*). Some states and the federal government have Seeds Acts and regulations against the importation and/or sale of infested seed and weed seed limits (max. no. seeds per kg) are in place for castor oil plant seed (nil dodder seeds).
- **Seed treatments** with herbicides of differing toxicity are being researched.



PHYSICAL AND MECHANICAL METHODS

- **Pre-plant solarization** controls **broomrape**, also nematodes, weeds and soil fungi, but its high cost precludes its use in most situations.
- **Burning** (fire) is used to destroy small isolated patches of dodder in lucerne crops to reduce the amount of seed which is set and seed already shed. Mistletoe could be scalded rather than burnt with flame throwers.
- **Rifle shooting** branches with mistletoe that are beyond the reach of other methods may be useful in certain circumstances.
- **Heat treatments** have been used to devitalize niger seed (*Guizotia abyssinica*) contaminated with dodder imported into the USA for feeding of wild birds.

HERBICIDES

- **Obtain recommendations for registered herbicides** for specific parasitic weeds from your local Department of Primary Industries. Table 69 below indicates a few of the problems associated with the use of herbicides to manage parasitic plants.
- **Broomrape has developed resistance** to some herbicides.
- **Germination stimulants** promote suicidal germination of seeds, ie in the absence of hosts the germinating seeds die, reducing the seed bank. Overseas a synthetic germinating agent for broomrapes is being researched.
- **Pre-emergence herbicides** (for **preventing** attachment) can be used to control dodder seedlings. **Fumigants** may also be used to kill seed in soil.
- **Post-emergence herbicides** (treatment **after** attachment).
  - **May be applied selectively**, non-selectively and as a directed spray.
  - **Anti-transpirants.** Most parasitic flowering plants have high transpiration rates associated with the stomates that remain open under most, if not all conditions. This cools the plant under hot conditions. Anti-transpirants which mechanically impede water loss cause leaf temperatures to rise and rapidly kill **emerged** witchweed plants during hot dry conditions.
- **Southern New England Landcare (2008)** has published comparisons of the use of various herbicides and other treatment for mistletoe control (avail. online).

Table 69. Parasitic flowering plants **Permits are often required**

What to use?	When and how to apply?
SOIL	
Pre-emergent herbicides (seeds) **Group D**, eg Dacthal® (chlorthal-dimethyl)	• Dacthal is registered for **dodder** control in various crops.
Fumigation	• **Not really an option**
POST-EMERGENT HERBICIDES	
Non-selective directed	• Non-selective sprays kill the parasite and the crop. • Glyphosate has been used as a **directed spray** to control **broomrape** in some crops.
Selective **Group B**, eg metsulfuron-methyl is registered for control of brush and **broad leaved weeds** including **golden dodder** (*Cuscuta australis*) as a spot spray in native pasture, rights of way, commercial, industrial areas. **Group I**, eg various 2,4-D sprays in **experimental work** in spring or summer have killed more than 50% of the **mistletoes** with little injury to the hosts.	• **No truly selective herbicides** are available to control parasitic plants in broadleaved crops. Some are available for certain types of pasture and as spot spray. • 2,4-D herbicides are **not registered** for mistletoe control and broad scale spraying of these herbicides is not permitted today.
Tree injection, frill and daub, painting	• Tree injection for **mistletoe** control has had varied success. Mistletoe has been painted with glyphosate when it emerges from 'roots' within stems but this is generally impractical.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. **Distinguish between** an epiphyte, a hemi-parasite and a true parasite. Name 1 example of each.
2. Describe how parasitic plants may cause **disease**.
3. **Recognize by sight**, mistletoe and other local parasitic plants.
4. **Provide the following information** for selected local pest species of parasitic plants:

Common name	'Overwintering'
Scientific name	Spread
Host range	Conditions favouring
Effect and impact	**IWM** & Control
Life cycle	

5. How does **knowledge** of the life cycle of a parasitic plant assist with making decisions about **control**?
6. Describe **non-chemical methods** of controlling pest parasitic plants.
7. List 2 difficulties with **using herbicides** to control pest parasitic plants.
8. Prepare/access an **IWM** program for a parasitic flowering plant at your work or in your region.
9. Locate **reference material** and know where to obtain advice on the identification and control (if applicable) of parasitic plants.

SELECTED REFERENCES

Australian Bushfood & Native Medicine Forum www.**bushfood**.net/ and

Australian Native Plants Society (Australia) ANPSA (formerly ASGAP) http://**asgap**.org.au/ link to photo gallery

Botanic Gardens www.**anbg**.gov.au/ and follow the links to other Botanic Gardens and Arboreta

Council of Heads of Australasian Herbaria (CHAH). Australian Plant Census www.**anbg**.gov.au/chah/apc/

Australian Biological Resources Study (ABRS Online Resources) www.**environment**.gov.au/**biodiversity**/abrs/

Department of the Environment, Water, Heritage and the Arts www.**environment**.gov.au/

Fact Sheets by State/Territory Depts of Primary Industries, GRDC, Grain-Guard, Hort-Guard, RIRDC, Wild Life Notes, Farmer Alert and Landcare Groups are available online, eg
Broomrape
Dodder
Mistletoes

Keys

Lucid keys www.**lucidcentral**.com/
Declared Plants of Australia

Quarantine

Commonwealth quarantine www.daff.gov.au/**aqis**

PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.**padil**.gov.au

Target lists of weeds, insects, plant and animal pests and diseases. www.**daff**.gov.au and search for target lists

State websites have information of certain parasitic weeds quarantine restrictions in their states

Herbicides

Pubcris. APVMA. Canberra www.**apvma**.gov.au
Infopest, Qld www.dpi.qld.gov.au/**infopest**
HerbiGuide, WA www.**herbiguide**.com.au/
Croplife Australia www.**cropelifeaustralia**.org.au/
MSDS www.**msds**.com.au/
Company websites have labels and MSDSs
State/Territory authorities

General

Agrios, G. N. 2005. *Plant Pathology*. 4th edn. Academic Press, CA.

Auld, B. A. and Medd, E. W. 1987. *Weeds : An Illustrated Botanical Guide to the Weeds of Australia*. Inkata Press, Melbourne.

Brown, J. F. and Ogle, H. J. (eds). 1997. *Plant Pathogens and Plant Diseases*. Rockvale Pubs, Armidale, NSW.

Commonwealth of Australia. *Flora of Australia*. AGPS, Canberra.
Vol.1 - List of State/Territory/Regional Floras and Censuses.
Vol.2 - Lauraceae, eg devil's twine.
Vol.22 - Loranthaceae, eg mistletoe.
Vol.30 - Convolvulaceae, eg dodder.
Vol.32 - Scrophulariaceae, eg Western Australian Christmas tree, witchweed.
Vol.33 - Orobanchaceae, eg broomrape. Santalaceae, eg native cherries. Viscaceae, eg mistletoe.
Vol.47 – Orchidaceae, eg orchids.

Costermans, L. 2000. *Native Trees and Shrubs of South-Eastern Australia*. Reprinted from 1983, revised edn. Reed New Holland.

Hadlington, P. W. and Johnston, J. A. 1988. *Australian Trees : Their Care and Repair*. NSW University Press, Sydney.

Hasem, A. 2005. *A FinalReport Prepared for the Grains Research and Development Corporation : Management of Dodder : a New Parasitic Weed in WA cropping systems.* Dept. of Agriculture, WA.

Heide-Jorgensen, H. S. 2008. *Parasitic Flowering Plants*. Brill, Leiden. The Netherlands.

Keane, P. J., Kile, G. A., Podge, F. D. and Brown, B. N. (eds). 2000. *Diseases and Pathogens of Eucalypts*. CSIRO Pub., Collingwood, Vic.

McMaugh, J. 1994. *What Garden Pest or Disease is That?* Lansdowne Pub., Sydney.

Parsons, W. T. and Cuthbertson, E. G. 2001. *Noxious Weeds of Australia*. 2nd edn. CSIRO, Melbourne.

Press, C. and Graves, J. 1995. *Parasitic Plants*. Kluwer Academic Pub., MA, USA.

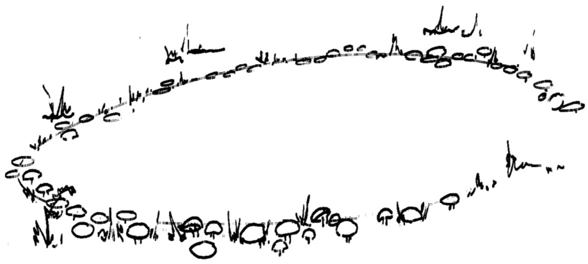
South New England Landcare. 2008. *Methods to Manage Mistletoe: A Landholder's Guide.* Armidale, NSW.

Thomas, A. 2001. *Misunderstood Mistletoe*. Science Online, 11 Jun 2001.

Wrigley, J. W. and Fagg, M. 2003. *Australian Native Plants*. 5th ed. Reed New Holland, Sydney.

NON-PARASITIC PESTS AND DISEASES

LIVING AGENTS



Fairy rings in turf grow on organic matter in soil.

NON-LIVING AGENTS

Environment
Seedling on right is elongated due to lack of light

CAUSES & DIAGNOSTICS

WHAT ARE NON-PARASITIC PESTS AND DISEASES

THOSE CAUSED BY LIVING AGENTS

These living agents (plants and animals) which damage plants mechanically, or in some way other than by obtaining their food from the plants. They are **not** parasitic on plants. Examples include:

- **Insects** , eg leafcutting bees, soldier beetles, fungus gnat larvae.
- **Fungi**, eg fairy rings, lichens, slime moulds.
- **Lichens**, liverworts, moss, algae.
- **Animals**, eg cats, dogs, earthworms, and **humans**, eg children, adults.
- **Weeds**, also come within this group, but because of their economic importance and number, are studied as a separate group (page 409).

Fig. 208. Leafy and bushy lichens on a dead limb. Each lichen consists of an **alga** and a **fungus** which are mutually beneficial **(symbiosis)**. The green alga manufactures the food and the fungus absorbs and stores moisture. They do **not** obtain their food from the tree. Lichens commonly grow on cooler southern shady sides of trees in the southern hemisphere, and on rocks, fences and sheds. They can be used to monitor atmospheric pollution especially sulphur and hydrogen fluoride. Photo©NSW Dept. of Industry and Investment.

THOSE CAUSED BY NON-LIVING AGENTS

Non-living agents are by far the largest group and are almost infinite in number and type, and include:

- **Environment agents**, eg heat/cold, drought/waterlogging, etc.
- **Nutrient deficiencies and toxicities**.
- Acid soils.
- **Salinity.**
- Pollution, eg pesticide injury.
- Mechanical injuries.
- Genetic abnormalities.

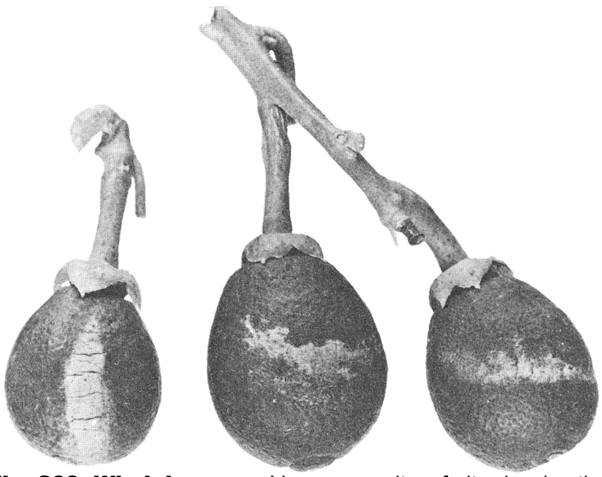


Fig. 209. Wind damage. Very young citrus fruits showing the effect of abrasion during wind. Windbreaks filter wind, reducing the velocity of wind in protected areas. They reduce plant stress and physical damage. Photo©NSW Dept. of Industry and Investment.

SYMPTOMS AND DAMAGE

Symptoms and damage caused by non-parasitic pests and diseases are literally infinite and include:

Some symptoms that **appear** to be abnormalities are normal plant structures, eg **'burr' knots'** and **lignotubers** which can produce shoots if the upper parts of the tree is damaged

Symptoms are often **indistinct** and closely resemble those caused by fungi, bacteria, viruses, root pathogens

DIRECT DAMAGE

LEAVES
- **Blights,** eg frost, pesticide injury
- **Chlorosis,** eg nutrient deficiencies and excesses, pesticide injury, senescence, natural variegated varieties
- **Dead areas within the leaf margin,** eg sunscorch
- **Dead tips and edges,** eg too little/too much water, salt toxicity
- **Distortion,** eg hormone herbicide injury
- **Galls,** eg oedema
- **Leaf spots,** eg contact herbicide injury, senescence
- **Stunting,** eg herbicide injury, deficiencies, sports

FLOWERS
- **Blights,** eg frost
- **Mechanical damage,** eg wind, rain

FRUIT
- **Distortion,** eg boron deficiencies (pome fruit)
- **Colour changes,** eg sunscorch, lack of light
- **Mechanical injury,** eg rain, hail
- **Russet,** eg pesticide injury, frost
- **Rotting,** eg calcium deficiency (blossom end-rot of tomatoes)
- **Splitting,** eg rain, hail, uneven watering

STEMS
- **Etiolation,** eg lack of light
- **Dieback,** eg senescence
- **Distortion,** eg fasciation
- **Mechanical injury,** eg lawn mowers, cars, stakes, sprinklers
- **Dead areas, peeling bark,** eg sunscorch damage
- **Galls,** eg 'burr' knots (*Prunus* spp.)

CROWNS
- **Galls,** eg lignotubers in eucalypts
- **Dead areas, peeling bark,** eg waterlogging, sunscorch

ROOTS
- **Forking,** eg poor soil structure, excess fertiliser
- **Distortion,** eg pot bound plants
- **Rotting,** eg waterlogging
- **Splitting**, eg overmaturity (carrots, parsnips, etc)

INDIRECT DAMAGE

- Environmental effects on development of pests, diseases and weeds. Nutritional imbalances, high and low temperatures, high humidity, over or under-watering and other factors, can **predispose** plants to diseases or pests.

DIAGNOSTICS

SOME NON-PARASITIC PROBLEMS CAN BE DIFFICULT TO IDENTIFY

Some are easily recognized by distinct symptoms the cause of which is known. Often, though symptoms are indistinct and closely resemble those of some parasitic pests and diseases. Some are misleading, eg the cause of wind blown trees may be wood rot, borer attack or wet soils.

- **Know what a healthy or normal plant** looks like, eg
  - Leaves of many deciduous trees and shrubs at the **end of the season** (autumn) look tatty before finally falling.
  - Evergreens such as camellia loose their older leaves after flowering as new leaves are emerging in spring.
  - Frost damage in field peas can be difficult to recognize; flowers are most vulnerable to frost, developing seeds shriveled or absent, blackening inside, pods blister.
- **Be able to recognize symptoms** of common non-parasitic problems, eg iron deficiency symptoms which are common on your crop.
  - **A magnifying glass** or small stereo microscope can assist identification and eliminate certain parasitic problems. Identification is often complicated because proof of absence of a parasitic pest or disease may be required.
  - **Tools which assist with the diagnosis** of non-parasitic problems include pH and conductivity meters, maximum and minimum thermometers, soil and water tests, light meters. **Grow-on tests** may confirm certain non-parasitic problems where plants **recover** after initial exposure whereas pathogen-related problems **persist** into new growth.
  - **Seek expert help**. They can perform specialist media and plant tissue analysis and other tests, and confirm the absence of a parasitic problem (page xiv).
- **Know the problems that affect your crop** in your area. Obtain a Fact Sheet for each problem.
- **Know potential local problems.** Some problems may be widespread in some areas, eg phosphorus sensitivity of Proteaceae plants.
- **Manage** the crop as recommended and record its history, eg irrigation, fertilizer, herbicide, insecticide, fungicide applications, salinity problems.

EXAMPLES OF NON-PARASITIC PROBLEMS	TYPE	EXAMPLES	PLANTS AFFECTED (not exhaustive)
 Mushroom	**LIVING AGENTS**		
		Animals (trampling, etc)	Crops
		Birds	Flowers
		Dog and cat urine	Lawns, turf
		Fairy rings	Lawns, turf, pasture
		Leafcutting bees	Lilac, rose
		Lichens	Older trees
		Mycorrhoza (lack of)	Most plants
		Slime moulds	Turfgrass, vegetables
		Soldier beetles	Flowers
		Sooty mould	Native plants, citrus
		Vandalism (children, adults)	Wide range
	NON-LIVING AGENTS		
Agrios 2005 Bodman 1996 Brown & Ogle 1997	**ENVIRONMENT**		
	Temperature (low & high temperatures)	Frost	Leaves, flowers, fruit, seeds
		Cool temperatures	Tomato not ripening
		Sunscorch	Leaves, flowers, fruit, trunks and limbs of trees
	Moisture (low & high soil moisture low relative humidity)	Drought injury	Almost any plant
		Fruit cracking	Tomato, grape, plum
		Oedema	Camellia
		Waterlogging, poor drainage	Almost any plant
	Inadequate oxygen	Lawn compaction	Turf, roots under paths
		Black heart	Potato (high temperatures)
	Insufficient light	Etiolation	Seedlings
		Lack of flowering	Many plants
	Soil structure	Forked roots	Carrots
		Shallow roots	Trees
		Compaction	Turf
		Soil gradient changes	
	Wind	Stressed plants	Many species
		Mechanical injury	Trees blown over
		Wind erosion, sandblasting	Emerging crops, esp. dicots
Do not confuse deficiencies or toxicities with pesticide injury	**NUTRIENT DEFICIENCIES & TOXICITIES**	Iron deficiency	Azalea, citrus
		Magnesium deficiency/excess	Shrubs, citrus, rose
		Nitrogen deficiency	Citrus, daphne
		Nitrogen drawdown	Some native plants
	Major nutrients trace elements	Phosphorus toxicity	Native trees, shrubs, turf
		Salt toxicity, Mn & Zn toxicity	Especially young plants
		Over-fertilizing	Many plant species
		Cadmium/Zinc toxicities	Contamination of vegetables
	ACIDITY	Acid mat, 50% of the grains cropping area affected	Turf, grasses, crops and other acid-sensitive plants
	SALINITY	Widespread across Australia	Trees, shrubs, grasses, crops
	SODICITY	Widespread across Australia	Trees, shrubs, grasses, crops
Symptoms of chemical damage vary from sluggish growth to severe leaf burn or yellowing (leaf burn at too high dose)	**POLLUTANTS**	Fertilizers	Almost any plant
	Fertilizers Pesticides others	Herbicide injury, eg 2,4-D, MCPA	Broadleaved plants
		Herbicides in pots	Some plants always sensitive
		Insecticide injury, eg sulphur	Many plants
		Plant growth regulators	Fruit trees, flower crops
		Formulations	May damage some species
		Disinfectants	Solvents in liquid concentrates
		Soil pollutants	Pesticides
		Atmospheric pollutants, eg gases, acid rain, smog, ozone	Some plants more sensitive, eg lichens
		Water pollutants	Pesticides, fertilizers in hydroponic systems
		Chlorine	Plants around pools
		Ethylene (ripening fruit)	Flowers, fruit, vegetables
	MECHANICAL INJURIES	Rain, hail and snow	Trees, shrubs, fruit
		Root binding	Container plants
		Car damage	Trunks of trees
		Machinery damage, digging	Trunks/roots of trees, irrigation
		Inappropriate pruning	Trees and shrubs
		Lawn mowers	Turf, base of tree trunks
		Support wires	Trees, shrubs, vines
		Cultivation	Crop preparation, weeding
	GENETIC ABNORMALITIES	Fasciation (mutation)	Daphne, euonymus
		Sports (mutation)	Euonymus
		Rootstock/scion incompatibility	Lilac (on privet rootstock to minimize suckering)
		Seed variation	Pea (albino seed)
		Varietal degeneration	Some rhododendron varieties

Living agents

Fig. 210. Leafcutting bee damage to rose leaves. Bees cut out pieces of leaves with their jaws to make nests.

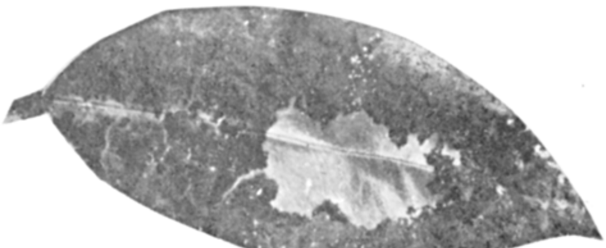


Fig. 211. Sooty mould on an orange leaf. Black fungal hyphae grow on the honeydew secreted by some sap sucking Hemipterous insects, eg aphids, leafhoppers, lerps, soft scales and whiteflies. Sooty mould disfigures plants. If the insects producing the honeydew are controlled the sooty mould will eventually dry out and fall off or can be hosed off leaves. Photo©NSW Dept. of Industry and Investment.

Fig. 212. Wood rotting fungus in a container. The mycelium which produces the mushroom grows on uncomposted material in the soil. Photo©CIT, Canberra (P.W.Unger).

Fig. 213. Fairy rings in a lawn. The mycelium of the fungus growing on the organic matter in the soil grows in all directions from a central point to form a large invisible circle. Fruiting bodies or mushrooms are formed at the edge of the mycelium in the soil and form a ring, usually in autumn after the first heavy rains. In addition to the circle of mushrooms, there may be changes in grass color and height. Bare patches may develop. Photo©CIT, Canberra (P.W.Unger).

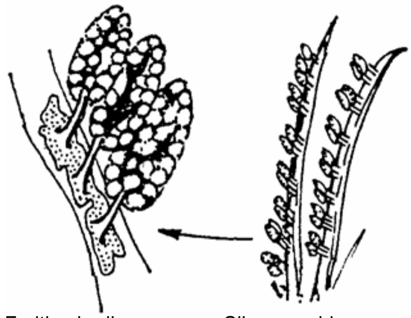


Fig. 214. Slime moulds (Myxomycota). Commonly blackish fruiting bodies (1-2 mm high) appear in late spring or autumn after prolonged wet weather. Slime moulds exist as jelly-like blobs up to several centimeters across which move very slowly feeding on microorganisms and small pieces of plant material in shady damp places. They are only noticed when they move up onto grass or other low lying plants such as strawberries or onions, to produce spores which usually disappear after 2-3 weeks depending on the weather.

Fig. 215. Liverworts (Bryophyta) can be a major weed problem in nurseries especially in cool shady areas. They reproduce by both spores and vegetative reproduction.

Non-living agents

ENVIRONMENT

Fig. 216. Water stress. If the problem is **too little** water, tips and margins become **brown** and **brittle**. If the problem it **too much** water, tips and margins become **brown** and **soft**; also caused by excessively high concentrations of salts, or by chemical injury. The whole leaf may be affected and die.

Fig. 217. Sunscorch. Camellia leaf showing symptoms of sunscorch injury. Brown scorched areas often start **within** the leaf margin but not always so. The whole leaf may become scorched.

Fig. 218. Sunscald injury. ***Left:*** Capsicum, affected areas are bleached and sunken. ***Right:*** Affected area on the shoulder of an immature tomato is grayish-white and has a paper-like surface. Compare with blossom-end rot (see Fig. 232). Photo©NSW Dept. of Industry and Investment.

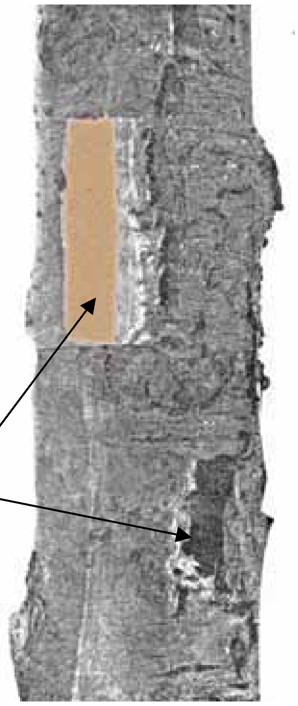


Fig. 219. Sunburn injury on a tree branch. Cracking of bark and discoloration of the wood beneath the dead bark where it was peeled back. Sunburnt areas are entry points for wood rot fungi. Photo© NSW Dept. of Industry and Investment.

Fig. 220. Rind splitting in orange. Some strains of Washington Navel orange are prone to split due to the internal pressure of the pulp. It often occurs after a drop in average maximum day temperature with the approach of winter and an increase in relative humidity when the rate of fruit growth is decreasing. Photo©NSW Dept. of Industry and Investment.

Fig. 221. Cracking in tomato fruit is due to rapid growth following favorable weather conditions of high temperatures and good soil moisture just prior to harvest. Photo©NSW Dept. of Industry and Investment.

Non-living agents *(contd)*

ENVIRONMENT

Fig. 222. Cold weather injury to carnations. Twisted leaves on carnation caused by unseasonable cold weather. Photo©NSW Dept. of Industry and Investment.

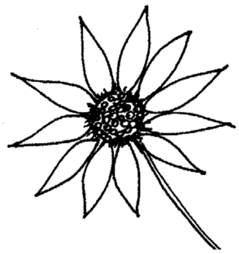


Fig. 223. Flowers of many plant species are more sensitive to frost than the leaves, eg chrysanthemum.

Fig. 224. Etiolation. ***Left:*** Healthy seedling ***Right:*** Spindly growth due to insufficient light.

Fig. 225. Oedema on umbrella (*Schefflera actinophylla*) leaf. Oedema occurs when plants absorb more water through the roots than they can transpire through the leaves, so the surface cells of the plant burst. Small masses of tissue may expand and break out on the surface of the leaf (or other plant part) causing watery swellings, small galls or rings which later becomes corky brown or gray and scabby. Oedema often appears on the under surface of leaves near the ground, eg camellia, geranium. Restricting water supplies during cloudy weather may lessen the problem but control is not really necessary. Photo©CIT, Canberra (P.W.Unger).

Fig. 226. Enlarged lenticels on a potato tuber due to the excessive soil moisture before harvest. Photo© NSW Dept. of Industry and Investment.

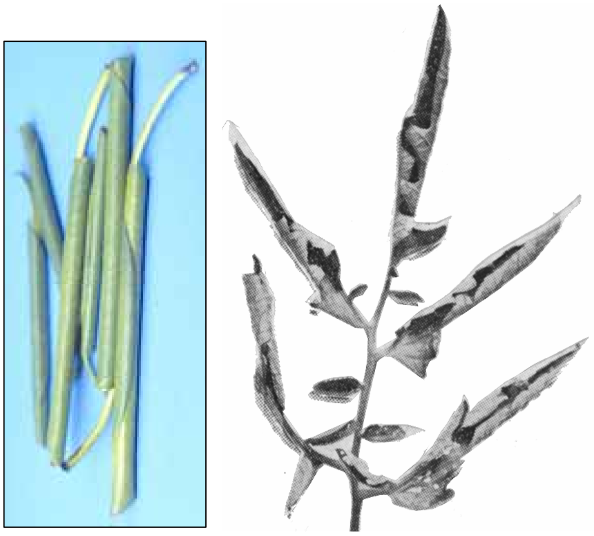


Fig. 227. Leafrolling may be due to a range of environmental causes. ***Left:*** Tightly rolled rhododendron leaves. Photo©CIT, Canberra (P.W.Unger). ***Right:*** Rolled tomato leaves due to high soil moisture or excessive pruning. Plants absorb more moisture through their roots than they can transpire through their leaves. Rolling usually begins on the mature foliage at the base of the plant; affected leaves are leathery, firm and thickened. In most cases yield is not affected. Leaf rolling on **potato** is caused by the **potato leaf roll virus**. Photo©NSW Dept. of Industry and Investment.

Non-living agents *(contd)*

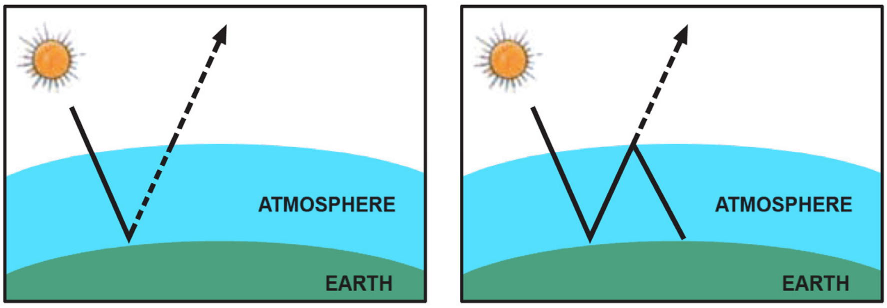
CLIMATE CHANGE, SALINITY

CLIMATE CHANGE
'global warming' 'greenhouse effect'

Although the term 'climate change' can refer to any variation in climate or atmospheric conditions which has taken place over millions of years, in recent times, the term is taken to mean changes in climate that are the direct result of human activity.

- The most important greenhouse gases are water vapour, carbon dioxide, methane and ozone. Increases in these gases over recent decades are considered to be due to human activity, eg transportation, agriculture, etc. The effect on sea levels, water and food supplies, pests, weeds, social conflict and the migration of peoples is being researched.

Dept. of Climate Change www.climatechange.gov.au/



***Left:* Sun and Earth Under Normal Conditions** The greenhouse effect is a natural process - incoming solar radiation (short-wave radiation) is absorbed by the earth's surface. This energy is then redistributed around the globe through atmospheric and oceanic circulation patterns (winds, ocean currents, etc). Energy is then radiated back from the earth into the atmosphere as long-wave radiation. Over time long and short wave radiation should balance. ***Right:* Increasing energy radiated back to earth.** Greenhouse gases absorb some of the energy radiated back into the atmosphere as long wave radiation. Increasing concentrations of these gases mean that more is absorbed and less released into space - radiation is trapped in the atmosphere and reflected back to earth causing a heating of the earth's surface (adapted from The United Kingdom Environmental Change Network www.ecn.ac.uk)

SALINITY

Do not confuse salinity with acid soils or sodicity:

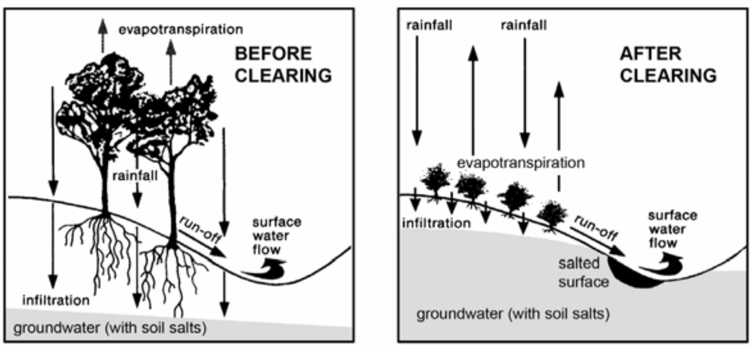
- **Sodicity** refers to soil containing levels of sodium that affects its **physical properties,** when they become wet, clay particles lose their tendency to stick together, become unstable, erode and impermeable to water and roots
- **Acid soils** are a condition in which the surface soil pH has declined to **less than pH 5.5** as a result of human activity, such as agriculture (page 395 Fig. 228)

Saline soils are defined as those in which the **concentration of soluble salts** in soil and water is sufficient to restrict plant growth, increase soil erosion and salt pollution of rivers, water supplies, irrigation systems, damage roads, fences and buildings.

Department of Agriculture, Fisheries & Forestry www.daff.gov.au/

- **Primary or natural salinity** has developed in former marine areas or on rocks which contained trapped marine salts that break down to form soils.
- **Secondary or induced salinity** occurs when surplus water percolates into the water table making it rise. Naturally occurring salts found in the soil and rock are dissolved and brought to the surface, coming into contact with vegetation.
  - **Irrigation salinity** results from poor irrigation practices. More water is applied than can be used by the crop, excess water causes water to rise bringing the salts into contact with plants.
  - **Dryland salinity** is typically caused by extensive clearing of vegetation (mainly trees) for agricultural and grazing land.

  CSIRO Land & Water www.clw.csiro.au/issues/salinity/
- **Effects on soils and plants**. Soils crust on the surface, soil clays swell and fine soil particles disperse. Salt in soil reduces the availability of water to plants and at high enough concentrations can kill plants, it may also result in toxicity of certain ions namely sodium and calcium, nutritional imbalances and deficiencies, and favour some diseases, eg *Phytophthora* root rot of some tomato cultivars. **Salt-affected sites are complex** and are influenced by interaction between soil, water, plant species and climate. Salt may occur in the soil/media, fertilizer or irrigation water. Some forms of fertilizers are more prone to result in salinity problems, eg potassium as potassium chloride (potassium as potassium sulphate less likely)

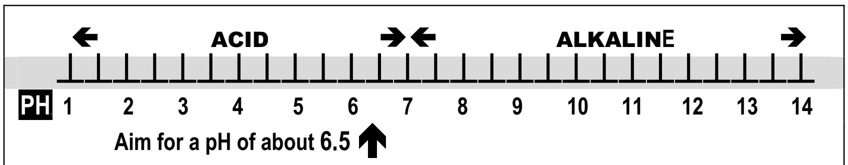


Plants continually remove water from soil via evapo-transpiration. ***Left:*** Trees have deeper and more extensive roots systems and extract more water from the ground than do grasses and shallow-rooted crops. ***Right:*** When trees are removed and replaced with shallow-rooted grasses and crops, surplus water percolates into the water table causing it to rise bringing dissolved salts with it (adapted from Wakefield 1994).

Non-living agents *(contd)*

NUTRIENT DEFICIENCIES & TOXICITIES, PESTICIDE INJURY, ACID SOIL.

Fig. 228. Soil acidity.



Soil acidity is a major agricultural and turf problem in Australia. Soil acidification is a gradual lowering of soil pH. It is a natural process which can be accelerated by agricultural practices, especially:

- When large quantities of biomass are harvested and removed from the land.
- Where recycling of nutrients is inefficient and nitrate is allowed to leach into soil.
- Where ammonium-based fertilizers are used.
- Soil acidification results in increased availability of aluminum and manganese which become toxic. Phosphates and molybdenum become less available while leaching may deplete cations such as calcium, magnesium and potassium.
- More than 70% of the continent is covered with soils that have either a pH < 5.5 (acidic) or > 8.5 (alkaline) in which chemical toxicities and deficiencies abound.
- **Soil alkalinity** may occur if soil is naturally alkaline or if there is prolonged irrigation with alkaline bore water, recycled household water, etc. Trace elements may be unavailable in alkaline soils, eg iron, zinc and manganese.

Fig. 229. Magnesium deficiency on Valencia orange leaves, note yellow V-shaped pattern on leaves. Photo©NSW Dept. of Industry and Investment. (M.Senior).

Fig. 230. Iron deficiency on citrus leaf, note yellowing between green veins. Photo©CIT, Canberra (P.W.Unger).

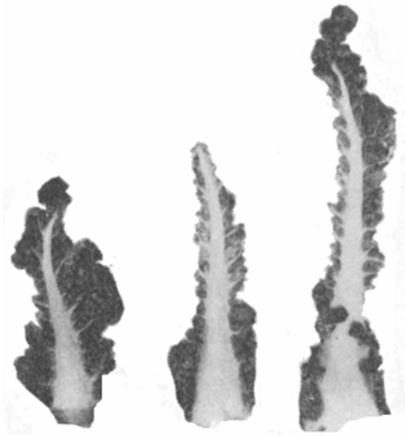


Fig. 231. Whiptail (molybdenum deficiency) on small heart leaves of cauliflower. Photo©NSW Dept. of Industry and Investment.

Fig. 232. Blossom-end rot of tomato due to a calcium deficiency in the **blossom end** of the developing fruit, favored by inadequate calcium in the soil, high salt concentrations in the soil, dry soil, hot windy conditions, vigorous vegetative growth, uneven watering, etc. Do not confuse with sunscald injury (Fig. 218). Photo©CIT, Canberra (P.W.Unger).

Fig. 233. Simazine injury to *Prunus* sp. Leaves yellowed but veins remained green. New growth the following spring was normal. A heavy thunderstorm after application washed the simazine down hill. Do not confuse with deficiencies. Photo©CIT, Canberra (P.W.Unger).

Non-living agents *(contd)*

POLLUTANTS, MECHANICAL INJURIES

High concentrations of pollutants cause dead or discoloured areas to develop on plants. At low levels, growth and productivity may be reduced, prolonged exposure may make them more susceptible to pests and diseases.

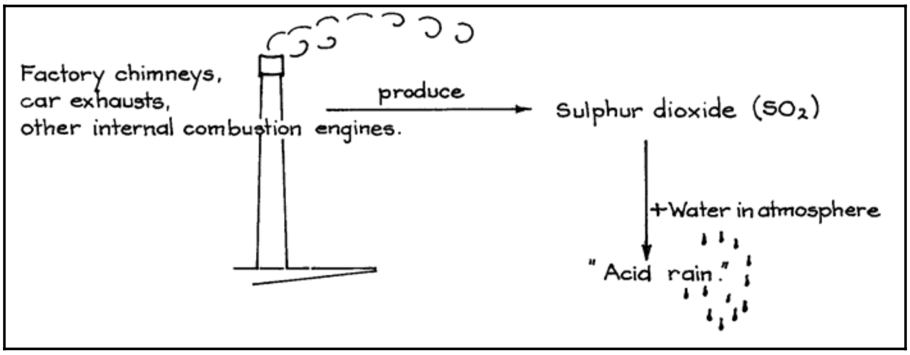


Fig. 234. Acid rain injury to plants usually occurs in the vicinity of heavy metals industries, eg Queenstown, Tasmania. **Sulphur dioxide** pollution from power stations, cars and lorries is the main source of acidity in rain. Sulphur dioxide reacts with water in the atmosphere to form sulphuric acid (acid rain) which is injurious to plants. Decline in sulphur dioxide pollution in air in Britain has seen many species of lichens become more common. **Nitrogen oxide pollution** from cars and lorries also creates acid rain when it is oxidized to form nitric acid. Both types of acid rain fall in rain or snow. It appears that acid rain becomes even more acid during thunder-storms.

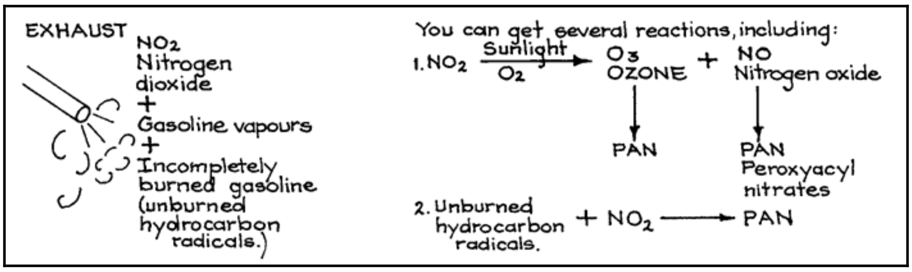


Fig. 235. Smog is a condition caused by the action of sunlight on the exhaust gases from cars, homes and factories. NO_2 and PAN are the most common components of smog.

SOLID WASTE PARTICLES		**COME TO REST ON PLANTS**	
Motor vehicle emissions	Burning vegetation	Carbon	Chloride
Emissions from backyard incinerators	Dust	Sulphates	Silica
Waste from industrial furnaces/incinerators	Sea salt	Sodium	Lead
		Nitrates	Etc

Fig. 236. Smog waste particles in the atmosphere may settle on plants, reducing their capacity to photosynthesis, and in some situations, having a toxic effect. This is especially serious on evergreen plants which do not shed all their leaves every year so that leaves tend to accumulate wastes over several years. Norfolk Island pines on the coast in Sydney in the past, were thought to have been damaged by salt, detergent and other wastes blown in from the sea

Fig. 237. Lawn mower injury. Photo©CIT, Canberra (P.W.Unger).

Fig. 238. Pot bound roots. Photo©CIT, Canberra (P.W.Unger).

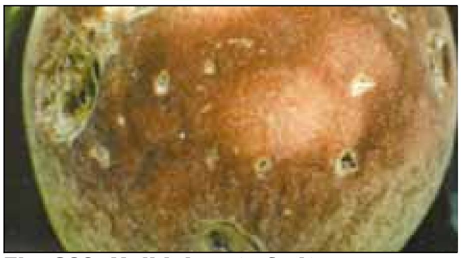


Fig. 239. Hail injury to fruit. Photo©CIT, Canberra (P.W.Unger).

Non-living agents *(contd)*

GENETIC ABNORMALITIES

A **mutation** is an abrupt appearance of a new characteristic as the result of an accidental change in a gene or chromosome. Some mutations may be beneficial, eg Washington Leng navel oranges which have no seed originated from such a mutation.

Fig. 240. A chimera is a tissue segment with a different genetic makeup from adjacent cells. In Greek mythology a chimera is a fire-breathing hybrid possessing a lion's head, goat's body and a serpent's tail (Tan 1997). Some plant species or varieties commonly produce chimeras. ***Left:*** Normal yellow tulip on left, one with a 50% red chimera on right. ***Right:*** An apple showing a mutant section of more deeply colored skin. Photo©CIT, Canberra (P.W.Unger).

Fig. 241. Linear fasciation in a **rose** cane. clusters of leaves at the end of the fasciated area. Fasciation is common in many plants, eg daphne, euonymus, cucumber. Photo©CIT, Canberra (P.W.Unger).

Fig. 242. A variegated lemon leaf (genetic makeup).

Fig. 243. 'Burr knots' on *Prunus* spp. are tissue which can produce adventitious shoots if necessary, eg if the top of the tree was lopped off. They have a similar function to the lignotubers of eucalypts. Photo©CIT, Canberra (P.W.Unger).

Fig. 244. Mutant orange with a very thick rind. Rind thickness can also vary with the variety, eg the rind of Meyer lemons is much thinner than that of Eureka or Lisbon. Photo© NSW Dept. of Industry and Investment.

Delayed effects, Spread, Conditions favouring

DELAYED EFFECTS	The number is infinite. • **Symptoms of non-target drift** from glyphosate applications to control weeds in autumn around deciduous shrubs and climbers only become apparent when new spring growth commences in spring. • **Too many oil sprays** may affect fruiting in citrus. • **Alkalinity problems** associated with certain improperly aged or composted materials may only slowly become apparent over months or years. Mushroom compost is usually alkaline. • **Frost damage** to early flowering fruit trees in colder areas may only be obvious in spring when fewer fruit develop. In plums, flowers not totally killed by frost develop russet patches as damaged areas enlarge. • **Years of below average rainfall** which deplete soil moisture cause a gradual decline of established trees and shrubs over many years. • **Lack of flowering** in bulbs due to prolonged water stress, flowers laid down the previous season. • **Wind damage** to young leaves and developing fruit becomes more obvious as they grow in size. • **Pollutants**.
SPREAD	• **Herbicides may leach** through the soil or be washed over the surface of soil on sloping areas, to sensitive sites. • **Seed sources** may not be reliable; varieties may not be suitable for the particular season. • **Soil deliveries** which include mushroom compost, etc. • **Soil deliveries** which are hygroscopic.
CONDITIONS FAVOURING	• New varieties may not live up to their promise, eg may not grow so well under certain conditions. • Planting the wrong variety for the district or season, planting too early or too late. • Rootstocks which are incompatible with scions, understand why rootstocks may flourish at the expense of the scion. • Poor culture, eg incorrect pruning may lead to lack of flowers or fruit, excess applications of phosphorus and nitrogen contribute to development of algal blooms. • Lack of appropriate environmental monitoring, eg the degree of frost injury may depend on the suddenness in the drop in temperature rather than the absolute temperature. • Applying certain pesticides when conditions favour pesticide injury to crops and non-target plants, eg sulphur sprays at temperatures >30°C, excessive wind. • Application of pesticides in enclosed areas with poor ventilation and high humidity.

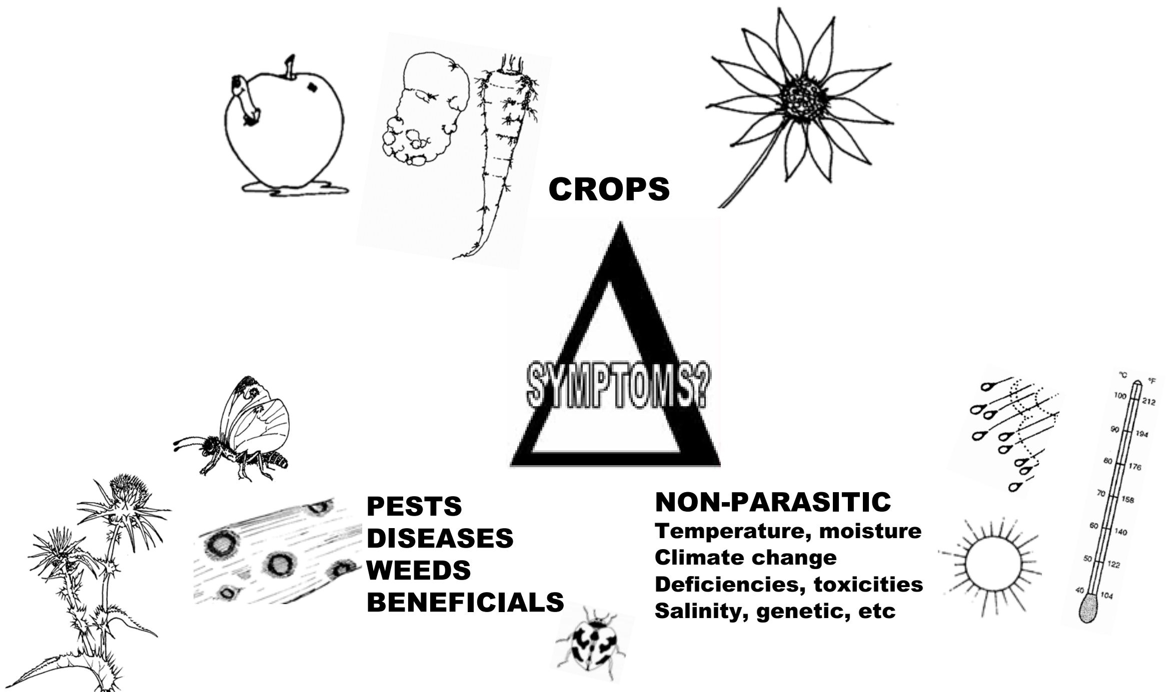
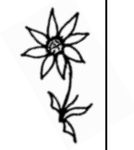


Fig. 245. Non-parasitic disease triangle

INTEGRATED DISEASE MANAGEMENT (IDM)

MAIN STEPS
PLAN
PLAN
PLAN



1. **Plan** an **IDM** program in advance. One that fits your situation and the particular type of problem. Keep records of the crop, eg source of planting material, planting and sowing dates, temperature, irrigation, fertilizer and pesticide records.
2. **Crop, region. IDM** programs are available for problems on a range of crops in many regions. Check if an **IDM** program is available for **your problem(s) on your crop or in your region**, eg
   - Best Management Practice Guidelines are available for a range of crops.
   - Nursery Industry Accreditation Scheme www.**nasaa**.com.au
   - Australian government publications and websites www.**nrm**.gov.au/
   - Water management strategies for commercial crops, eg peanuts. Home gardeners can access various waterwise programs (Walsh 2004).
   - AS 6000—2009. Organic and Biodynamic Products www.**standards**.org.au/
     Organic Federation of Australia www.**ofa**.org.au/
     Biological Farmers of Australia www.**bfa**.com.au/

3. **Identification** of non-parasitic problems can be difficult. Understanding conditions favouring the problem is necessary for solving the problem. Identify frost-prone or poorly drained areas or pockets, physically map or mark areas. Obtain relevant Fact Sheets. Sophisticated programs such **Plant Efficiency Analysis** measure and interpret chlorophyll fluorescence emissions from leaves of plants before visible symptoms of stress appear. Consult a diagnostic service if necessary that can perform various tests and provide advice (page xiv).

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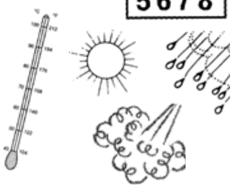
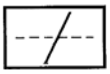


4. **Monitoring. Know when, where, what and how to monitor**. Know what you can regularly monitor and record, eg symptoms on leaves or fruits, impact of problem, distribution in the field. Arrange regular soil, plant and water tests if necessary and have the results interpreted correctly.
   - **Early warning systems** used by commercial growers to predict frost, etc.
   - **Microclimate and soil maps** may help predict problems in your area. **Probes** are available for soil moisture and compaction.
   - **Global positioning systems (GPS)** and foot slog mapping can indicate spread of a problem, eg salinity.



5. **Threshold.** This may be decided for you by legislative requirements. Your own threshold will depend on economic, aesthetic and/or environmental factors. Do you need to calculate your own threshold?

?

6. **Action/control.** Many non-parasitic problems are **preventable**, so avoid over-fertilization, planting poor quality seed, etc. Apply pesticides and other chemicals according to label directions for use. It may be necessary to cease certain activities, or modify fertilizer and irrigation regimes, drainage methods or pesticide use. Australian government publications and websites provide vast amounts of information on sustainable agriculture and horticulture, controlling salinity, conserving biodiversity etc. Record your actions.

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7. **Evaluation.** Review the **IDM** program. Make improvements if necessary which may involve continued monitoring.

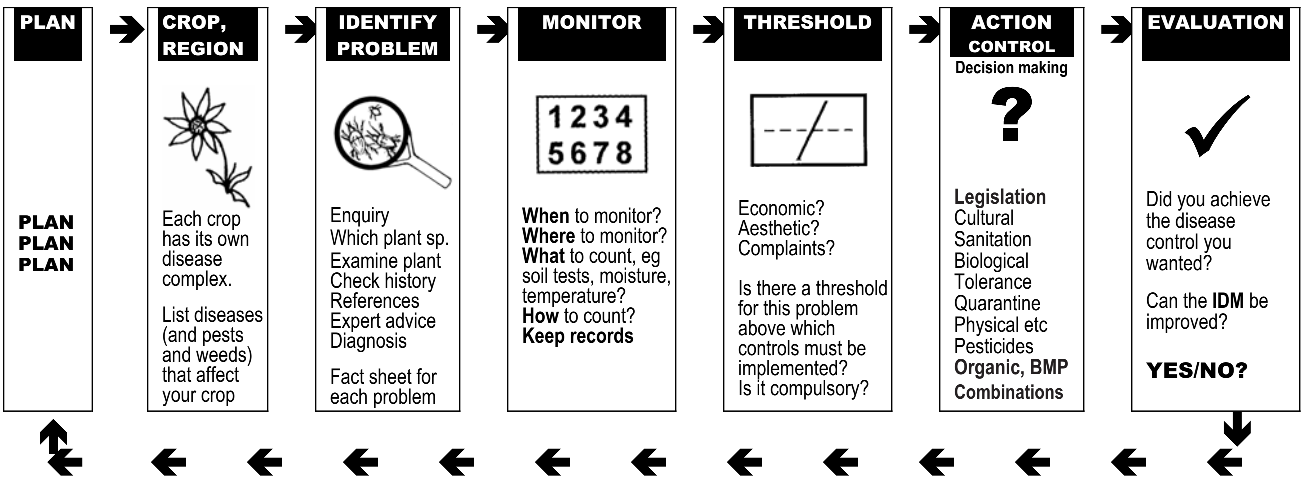


Fig. 246. Steps in IDM.

Control methods

CONTROL

LEGISLATION, REGULATIONS, ETC

- Various Food Acts, Pesticide Acts, Pollution Acts, Environment Protection Acts, etc prescribe and regulate residues in food, and in food and feed products. Restrictions apply to the application of hormone herbicides, eg 2,4-D, MCPA, within a prescribed distance of grapevines which are extremely sensitive to such herbicides.
- Quarantine Acts reduce the risk of introducing exotic non-parasitic living agents, eg algae and mosses.
- Standards are available for pruning certain plants, quality of tomatoes, etc.

CULTURAL METHODS

- **Environmental factors. Temperature and moisture** are the most important environmental factors affecting plants, pests, diseases and weeds. Environmental factors are used to control growth and flowering. Always be aware of the weather conditions prevailing before or during the appearance of symptoms.
  - **Weather warning programs** provide information on weather events, for particular crops/different regions, eg temperature ranges, rain, hail and dew points, etc. During transport and storage of temperature-sensitive goods such as flowers and plants, various systems monitor temperature, sounding a warning alarm when conditions stray outside a predetermined range.
  - **Plant Efficiency Analysis** measures and interprets chlorophyll fluorescence emissions from leaves of plants before visible symptoms of stress appear. **Trees showing symptoms** of dead branches in the canopy, sparse leaf cover, curling browning or drooping leaves, earlier than normal autumn colours, deep bark cracking, need watering long before these symptoms are visible. Many young trees newly planted need special attention by watering. Public tree plantings may need watering.
  - **Temperature** requirements influence planting dates, eg varieties of pome and stone fruits that flower later may miss late spring frosts. High temperatures may slow ripening of tomato and increase a plant's need for water, etc.
  - **Water management programs and initiatives.** Most states/territories and crops/ situations have water management progams. Use computerized systems if available.
    - **The National Water Initiative (NWI)** is Australia's enduring blueprint for water reform. Through it, governments across Australia have agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water.
    - **AQUAMAN, AQUA SPY** takes the guess work out of irrigating; details are set up for each paddock, including location and soil type. Reports can be generated instantly for each paddock taking into account the holding capacity and other features of the soil as well as recent rainfall and weather conditions. A major cause of lower yield in peanut crops is a lack of timely and adequate irrigation 2007.
    - **'Global drying' describes three types of water** (Ridout, Landline 16/8/2009). **Green water** is the rainwater that hydrates food crops. **Blue water** comes from surface or underground resources; it's the rivers and reservoirs on which the irrigated regions rely. **Esoteric grey water**, which could be called diluted water; it's the amount needed to dilute waste water from industry and crops.
    - **Australia Golf Course Environmental and Water Initiatives**, AGCSA **Water/irrigation** provides advice on irrigation regimes and drainage.
    - **Waterwise programs are available for home gardeners** (Walsh, 2004). Six vital principles include reduce areas of lawn, group plants according to water needs, use drought tolerant plants, maintain the garden, use mulch, water efficiently. Know the aspect of your garden, eg winter sunshine, etc. Identify the plants with high water needs and group them in an area where they can receive the extra water. Place plants in groups of 3 or more for maximum effect.
    - **Soil moisture probes and sensors** connected to irrigation controllers assist with scheduling of irrigation in shallow rooted crops.
    - **Water quality**. All water sources should be analyzed. Water testing of recycled is readily available, eg www.**lanfaxlabs**.com.au/
    - **Follow water restrictions guidelines** and consult with water authority or industry specialists about efficient irrigation products and how to use them, 'More crop for the drop' (Landline 21/9/2008)
    - **Soil mulch** Know your soil how it drains or holds water, adding composted organic matter is one of the best ways to increase water retention plus there are commercial water saving products available.
  - **Light**, eg primary factors regulating flowering are daylight (photoperiod) and temperature. Many shrubs and other plants require a certain amount of sun to grow and flourish. However, many plants require shade - make a shade map of you garden and utilize shade of surrounding plants, grow trees to increase shaded areas. Indoor plants may suffer from insufficient light.
  - **Other environmental factors** include wind, mechanical injuries, and soil structure.

REMINDER

Relative humidity, wind and high temperatures.

Lack of moisture in the atmosphere (low RH) is usually temporary and seldom causes damage but when combined with high wind velocity and high temperatures may lead to excessive loss of water from the foliage and may result in leaf scorching or burning, shriveled fruit and temporary or permanent wilting of plants (Agrios 2005).

CULTURAL METHODS *contd*

Prognostic rather than **diagnostic**

- **Nutrient deficiencies & toxicities.** Maintain appropriate fertilizing, some nutrient deficiencies and toxicities are common, eg
  - **Guard against over-fertilization** which is common when plants are young. Overuse of some fertilizers can cause environmental, agronomic, management and economic problems for many growers. Nitrogen runs out first in nurseries.
  - **Nutrient charting** is a means of obtaining early warning signs of nutritional disorders and is used to anticipate deficiencies and toxicities so they can be corrected before they become chronic. It is also used to check on the adequacy of fertilizer programs and perhaps a guide to a new one and indicate when a crop needs top dressing. The procedure is **prognostic** rather than **diagnostic**.
    NGIA Nursery paper www.**ngia**.com.au
  - **Identify micronutrient deficiencies** with plant tissue, soil and water tests.
  - **Know your fertilizer source wel**l, eg the pros and cons of them. Is it from poultry, horses, lofted cattle, pigs or bio-solids which might include human waste?
  - **Organic fertilizers programs** may provide long-term soil benefits but are not the answer to immediate crop nutrition needs (Norwood 2010).
  - **Specific toxicities** might apply, eg phosphorus toxicity in certain proteaceous plants. Cadmium in monitored in fresh vegetables.
  - **Specific deficiencies** may occur in certain areas, eg boron in the southern tablelands of NSW.
  - **Understand conditions favouring nutrient deficiencies and toxicities**, eg soil pH, lack of mycorrhiza, nitrogen drawdown in mulches, irrigation practices.
  - **Tree implants** provide phosphate to promote healthy growth/root development, potassium for cell strength rigidity and other nutrients.
- **Others cultural controls** are infinite.

TOLERANT VARIETIES

Some plant varieties now available have some tolerance to drought, temperature extremes, saline soil, etc. Many crops have been bred to have multiple resistances. Possibilities are endless.

- **Ornamentals,** eg purple-leaf cherry plum (*Prunus cerasifera* 'Nigra') has some tolerance to warm dry conditions.
- **Fruit,** eg rootstocks of apple (Malling Merton 104 (MM104)) have some resistance to drought.
- **Vegetables,** eg some varieties of broad bean, eg 'Coles Dwarf Prolific' are less susceptible to wind damage than others.
- **Indoor foliage plants** can be grouped according to tolerance of low light.
- **Trees**, eg varieties of casuarina, eucalypt, wattle have tolerance to salt. Eucalypts are bred for salt and stress tolerance.
- **Turf seed** is selected for heat, wear, shade, salt tolerance, grey leaf spot and brown patch resistance. **DNA** analysis is used to examine the differences within the natural selections of kikuyu, **DNA** can also be used to distinguish genetic diversity among a wide range of turfgrass, eg perennial ryegrass, buffalograss, and couchgrass, Kentucky bluegrass. Future work in kikuyu will focus on resistance to kikuyu yellows and tolerance to a range of environmental stresses.
- **Salt tolerant plants and crops**. There is much ongoing research on how native and exotic plants and animals cope with different levels of salinity. Some plants are naturally salt tolerant but they can also be bred or genetically engineered. **Halophytes** are salt tolerant plants that grow naturally in salt affected soil, eg saltbush. The development of salt tolerant crops, eg grass and wheat hybrids and saltbushes that will tolerate high levels of salt and soil waterlogging, offer hope to salt-affected land.
- **Irrigating** salt tolerant grasses using saline ground water.
  Salt water can be used when fresh water resources are limited. But requires a well integrated management program to prevent off site impacts etc.
- **Genetically modified (GE) crops**, eg
  - Some transgenic cotton has some tolerance to waterlogging, various herbicides and *Helicoverpa* caterpillars. Tolerance to drought is also under development.
  - Recently a gene involved in the proliferation of roots of certain crop plants has been identified enabling in crops plants growing in low fertility soils to develop more extensive root systems.
  - Research continues on sugarcane to alter plant growth, enhance drought tolerance and nitrogen use efficiency, to alter sucrose accumulation or to improve cellulose ethanol production from sugarcane biomass.
  - Genetic approaches and environmental factors may be used to control growth and flowering.

Postharvest life of certain fruits could be **extended** significantly by silencing the genes that make fruit go soft after ripening. This does not require the introduction of foreign genes.

TOLERANT VARIETIES *contd*

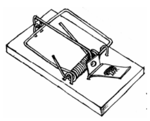
- **Plant selection for drought tolerance.** Many plants survive on little water but:
  - All plants need some water especially when first planted until establishment or when in a hot sunny position. Carefully monitor till established.
  - Some are naturally tolerant to drought, eg cacti and succulents, grey foliage plants, some culinary herbs, grasses.
  - Try not to plant new plant out in the hottest months or if you do, plant at night and consider a temporary shade structure.
  - Select plants that come from parts of the world that are similar to the area to be planted.
  - Do not assume that Australian native plants are drought tolerant; many come from high rainfall zones or cool mountain zones.
  - Look for plants with adaptations to enable them to withstand drought, eg small narrow leaves, grey or silver foliage, furry texture, water retaining succulent leaves, modified or absent leaves, summer dormancy.
  - Are some of these plants likely to become future weeds?

PLANT QUARANTINE

- Quarantine prevents the import or export of food or feed products containing excessive pesticide residues.

PROBLEM-TESTED PLANTING MATERIAL

- Certification schemes ensure that seed of good genetic quality, physically undamaged, stored correctly and free of weed seed is available to growers.



PHYSICAL & MECHANICAL METHODS

- **Wind machines** or helicopters may protect crops from frost.
- **Shade clothes can protect crops** from damage due to suncorch, frost, hail, wind. **UV resistant fabrics** can provide climate control, temperature reduction, energy savings, light spectrum management and protection from insects and birds which comply with **ISO 9002** and **EQNet** Standards and increase yields. Insect-proof greenhouses prevent aphids from attacking plants and spreading virus diseases and are used routinely for plant quarantine purposes.
- **Minimize overhead irrigation and wind damage** to trees and flowers, prevent and repair wounds to trees and shrubs caused by cars and machinery.
- **Genetic defects**, eg fasciation can be pruned out.

PESTICIDES & OTHER CHEMICALS

- **Occasionally registered pesticides** may be used for **non-parasitic living problems**, eg liverworts, algae, mosses, but there are few problems of this type, eg
  - **Kendocide® (dichlorophen)** is currently registered to remove liverwort and algae and moss from synthetic courts, pavements, lawns and pots.
  - **Insecticides** are used to rid plants of insects that produce non-parasitic honeydew on which sooty mould grows.
- **Plant growth regulators (PGRs)** are widely used in the horticulture and may be applied as soil applications or foliar sprays (page 403, Table 70).
  - **Many are used to modify plant form** and development, improve crop quality and/or reduce production time. Some are rooting powders.
  - **Others are naturally occurring plant hormones** that control development in plants, others are synthetic chemicals that either mimic the action of a plant hormone or interfere with the action of natural hormones.
  - **Some are regulated by pesticide legislation**. They vary in shelf life, from at least 2 years to indefinite. Some may injure some plants, bees and wild life. Others may have long withholding periods, eg months.
- **Leaf anti-transpirants, soil wetting agents, water storage gels.**
  - **Foliage anti-transpirants** reduce water loss by up to 50% from leaves and protect plants from extremes of drought, heat, sun, wind and frost and improves survival rate of cuttings (page 405, Table 71).
  - **Soil wetting agents** improve water retention properties of certain hydrophobic soil types (page 405, Table 71).
  - **Water storage agents** absorb and store water applied to soil or potting media for release to plant roots when needed. When mixed with water, crystals swell up to many times their weight in water, store water near plant roots (page 406, Table 71).
- **Pesticide and other chemical injury, excess residues.**
  - **Avoid spray drift.** Symptoms of chemical damage vary from sluggish growth to severe leaf burn or yellowing. Upgrade training in pesticide applications.
  - Damage from chemicals and chemical applications is **not uncommon**, eg in enclosed spaces as in greenhouses, herbicides when applied to pots (some plant species are always sensitive), disinfectants, gas leakage from heaters.
  - Wettable powder formulations are less likely to cause plant damage than some solvents in some liquid formulations, eg emulsifiable concentrates.

AVOID SPRAY DRIFT
Follow label directions

Table 70. Plant growth regulators (PGRs) ***some examples***

THE PRODUCT		SOME USES Read label, obtain advice from company	
TYPE	**Trade name Active constituent**	**CROPS TREATED**	**EFFECTS**
STIMULATES ROOTS ON CUTTINGS	**AUXINONE, VARIOUS** IAA (indole acetic acid) + NAA (naphthalene acetic acid)	Ornamentals, vegetables, turf. Cuttings, sugarcane (setts), tissue culture, in budding and grafting to stimulate callus 	**Rooting powders** production on cuttings (stimulates cell enlargement, plant growth and feeder root production), also prolongs life of cut flowers, stimulate root
	VARIOUS NAA (naphthalene acetic acid)	Ornamentals, apples, pears, olives, pineapples, cuttings.	**Thins apples** controls preharvest drop, preventing fruit fall, promotes rooting of herbaceous plants.
	VARIOUS IBA (indole butyric acid)	Ornamentals, cuttings. 	**Cutting & rooting powders, gels, liquids** promotes the development of feeder roots
SMOKE	**SMOKE** aerosol, smoke water, bushland soil, applied directly to seeds, active principle is unclear	Certain Australian native seed	**Breaks seed dormancy** more uniform and earlier germination, more robust seedlings of difficult-to-germinate species
GERMINATION STIMULANT	**KARRIKINOLOIDE** naturally occurring germination stimulant	Broadacre weed control	**Seeds in the dormant seed bank** to reduce the extent to which cultivation is used to stimulate weed emergence and improve the sustainability of minimum tillage.
BEDDING PLANTS, ETC	**ALAR, DAZIDE** daminozide	Ornamentals, fruit, vegetables, all dicotyledons, not monocotyledons 	**Dwarfs plants, reduces internode elongation** controls height and promotes flowering of ornamental plants
TREES, SHRUBS, TURF, ETC	**CONDENSE, CLIPPER, GRO-SLOW, SHORTSTOP, VARIOUS** paclobutrazol may be formulated with fertilizer	Container ornamentals, fruit, turf, amenity trees (along street, under power lines, near buildings and in open spaces) 	**Reduces vegetative growth** reduces vegetative growth in vigorous young trees, permits denser plants, promotes early production and increased fruit size, turf **Clipper** - Application by injection into the base of the tree trunk by specially designed injection equipment. Clipper reduces annual vegetative growth by up to 40%. Moves upwards and outwards in the tree, accumulates within the shoots and leaves of the crown, controlling growth for up to 3 years or more (depending on the species). **SHORTstop** – for the suppression of winter grass & growth regulation in turf
	CLUPLESS, PRIMO MAXX TURF, LAWN TAMER trinexapac-ethyl	Reduces leaf and stem growth of grass species, reduces need for mowing by up to 50%. Grass is healthier, stronger, thicker, tougher and can better withstand heat, drought, cold and disease	**Turf growth inhibitor** inhibits the formation of gibberellic acid within grasses; only works on grasses which then rarely flower or produce seed heads helping to control weedy annuals like **winter grass**, reduces the amount of pollen in springtime, reducing problems for asthma and allergy sufferers
CUT FLOWERS	**METHYLCYCLOPROPENE, SMARTFRESH SMARTTABS** 1-methylcyclopropene	Certain cut flowers, fruits, vegetables	**Anti-ethylene treatment** post-harvest treatment for improved quality after shipping, storage or handling
VEGETABLES	**POTATO STOP-SPROUT TATO-VAPO, VARIOUS** chlorpropham (carbamate)	Potatoes	**Prevents potatoes sprouting** do not use on or near seed potatoes.
	ROYAL MH, SLOW GROW maleic hydrazide	Onions, potatoes, tobacco	**Controls sprouting, sucker development** prevents of premature sprouting in potato tubers, onions and garlic, tobacco sucker control

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 70. Plant growth regulators (PGRs) *some examples (contd)*

THE PRODUCT		SOME USES Read label, obtain advice from company	
TYPE	**Trade name Active constituent**	**CROPS TREATED**	**EFFECTS**
FRUIT Ethylene generator	**ETHEPHON, GALLEON. VARIOUS** ethephon an anti-cholinesterase compound, increases ethylene production in plants	Cotton, certain fruits, grapevines, sugarcane, tomato	**Plant growth regulator** for crop thinning, loosening or ripening, stimulate flowering, accelerating boll opening, defoliation & pre-conditioning, control mistletoe, anti-lodging in barley
Gibberellins (many functions, isolated from higher plants and the fungus *Gibberella fujikurai*)	**CYTOLIN** gibberellins A4 & A7 + benzyladenine	Red Delicious and Gala apples, cherries ETY DIRECTIONS BEFORE OPENIN Cytolin® Plant Growth Regulator	**Improves fruit typiness** stimulates cell division, enlargement and elongation enhanced, more pronounced calyx lobes, selectively thins some apple varieties, promotes lateral growth
	GA, GALA, PROGIBB GA, RALEX, STRETCH, VARIOUS gibberellic acid	Certain varieties of fruit , eg currants, wine grapes, lemons, mandarins, oranges, stone fruits	**Plant growth regulator** promote desirable harvest effects (stretch bunches, reduce bundle density) in wine grapes. Reduction of flowering & fruiting (thinning) in the next cropping season of some fruits.
Cytokinins	**MAXCEL, CYCLEX, VARIOUS** benzyladenine often mixed with Gibberlins A_4 and A_7 (Cytolin)	Certain varieties of apples	**Plant growth regulator** reduces fruit set, increases fruit size, & improves firmness of harvested apples
Naturally occurring plant growth regulator	**RETAIN** aminoethoxyvinylglycine A BFA REGISTERED PRODUCT	certain apple & stone fruit varieties (not cherry) ETY DIRECTIONS BEFORE OPENING ReTain PLANT GROWTH REGULATOR	**Plant growth regulator** can improve harvest management, fruit quality and enhance storage potential
Hormone herbicide (phenoxy herbicides	**COMMERCIAL CITRUS STOP DROP** 2,4-D amine	Citrus (grapefruit, mandarin, orange).	**Plant growth regulator** reduction of pre-harvest drop and control of colouring of citrus fruit
	WILLIAM PEAR STOP DROP 2,4-D sodium salt	Pears	**Plant growth regulator** reduces premature falling of William pears
Quaternary ammonium compound	**CYCOCEL, VARIOUS** chlormequat chloride	Currants, wine grapes, wheat	**Plant growth regulator** increases berry set and yield in wine grapes, increases setting of currants, increase grain yield and prevention of lodging in wheat
Miscellaneous	**CYAN, DORMEX, DUOMAX, VARIOUS** cyanamide	Grapefruit, kiwi fruit	**Promotes uniform bud break in spring** increased and earlier than normal bud break
	DPA 310 SCALD INHIBITOR, VARIOUS diphenylamine	Apples and pears	**Plant growth regulator** retards storage scald, in the USA , treated fruit must be labeled
	BIOTHIN, THIN-IT, VARIOUS ammonium thiosulphate	Certain varieties of plums, & of low chill peaches	**Plant growth regulator** desiccation of blossoms and reduction in fruit set
	ARM0THIN BLOSSOM THINNER alkoxylated fatty alkylamine polymer	Certain varieties of plums & peaches	**Plant growth regulator** desiccation of blossoms & reduction of fruit set
COTTON	**MEPIQUAT, REWARD** mepiquat	Cotton	**Shortens plant** lessens shedding of flowers and bolls which mature earlier and more uniformly
	HARVADE dimethipin	Cotton	**Defoliation** apply at correct time prior to harvest
OIL SEED POPPIES	**SUMAGIC, SUNNY** uniconazole-P	Oil seed poppies	**Reduction in plant height; also the potential increase in crop yield**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

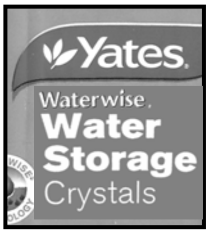
Table. 71. Leaf anti-transpirants, soil wetting agents, water storage *some examples*

TYPE	THE PRODUCT Trade name Active constituent	SOME USES Read label, obtain advice from company
FOLIAGE ANTI-TRANSPIRANTS	Foliage anti-transpirants may reduce water loss from leaves by up to 50% and protect plants from extremes of drought, heat, sun, frost, wind and salt damage. Often used when transplanting seedlings to allow time for roots to recover. Improves survival rate of cuttings by up to 90 days. As the plant expands the film becomes thinner (fast growing plants may require more frequent applications). Follow label directions for use as some anti-transpirants can be phytotoxic depending on the temperature, plant species, etc. Anti-transpirants have been used as weed control agents.	
	ANTI-STRESS blend of non-toxic soluble polymers suspended in water	Foliar spray on grapes designed to reduce damage to crops when exposed to frost, wind and excessive heat.
	ENVY carboxylated hydrophilic polymer	Used for relief of wilt and water stress, improvement of water use efficiency and protection against fungal diseases, eg rusts, powdery mildews. Sprayed on leaves to prevent water loss, improve survival of transplants and reduce water use while rooting ornamental cuttings.
	THERMOMAX composted valerian, dandelion and chamomile herbs	Has provided a better than 50% increase in fruit set (on apples) over the control at -2°C of frost in NZ. An organic frost spray can increase fruit set on various fruit crops, including grapes in frosts down to -2°C (Rebbeck and Knell, 2007).
	**DROUGHTSHIELD, STRESSGUARD** blend of acrylic polymers	Contains a blend of 'acrylic polymers' (water soluble type of plastic). This clear, flexible and biodegradable 'plastic' film coats the leaves and will expand to some degree with leaf growth and expansion, to reduce transpiration, UV light and frost damage. May be used to extend the life of cut Christmas trees.
SOIL WETTING AGENTS **Some are called soil penetrants**	Soil wetting agents may be applied to the surface or mixed into the top few centimeters of soil or potting mixes which have become water repellent. Soil wetting agents overcome the waxy coating of soil particles and allow water to penetrate into the pore spaces between them. They help water penetrate into hard soils. Soil wetting agents decreases surface tension and aids the successful rewetting of soils (Leeson 2009). Wetting agents affect fish and tadpoles so do not use near water. • **Attributes of a soil wetting agent.** – Ability to provide good even wetting of the soil both laterally and vertically to prevent preferential flow. Usually impact on water repellency to a depth of 1-2 cm, a very few to 5 cm. – Persist in the soil for the maximum time (several years) while being non-toxic and finally breaking down into non-toxic residues, biodegradable. They allow water to rewet soil effectively. – Should not cause run off or leaching of nutrients and pesticides from the root zone. – Wetting agents must be designed for use in soil, must be safe to use on plants (some may damage some plants; inhibit seed germination, leaf burn). • **Soil wetting agents**. – **Does your soil need a soil wetting agent?** Is it hydrophobic? Put some soil in a dish, make a well and pour on some water, if hydrophic it will sit there, if not, the water is quickly absorbed. – **Soil wetting agents are not the wetting agent**s used when applying certain pesticides. – **May be applied as liquids or as granules** of clay or other inert material impregnated with surfactant. Granules have low burn potential, are expensive, but are easy to apply to garden beds and surrounds, or at turf renovation. – **Active constituents**. Soil wetting agents are typically polymers, ie most are **co-polymers** (long lasting but more phytotoxic than some newer types), **lubricant poly-oxyalkylene glycols** (shorter lasting but less phytotoxic, good soil wetting properties, applied more frequently). – **Eco-friendly** wetting agents are highly biodegradable so they are short-lived and rewetting is severely diminished so need to be applied more frequently. They are non-phytotoxic. • **Use one for your situation**, eg **Aquaforce for turf**.	
	ECOWET Mixture of ingredients determined not to be hazardous. Not classified as hazardous according to the **NOHSC**. (National Occupational Health and Safety Commission).	
	SACOA PERSIST SOIL WETTER polyether modified polysiloxane	A non-ionic wetter, spreader and penetrant for use with agricultural pesticides.
	SEASOL SUPER SOIL WETTER & CONDITIONER active ingredients not stated on label	**Seasol** is an organic plant conditioner. Taken up by the plant, helps improve drought and frost tolerance, improves plant establishment and disease resistance.
	YATES SOIL SATURATOR surfactants, seaweed, acrylic copolymer, trace elements	

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table. 71. Leaf anti-transpirants, soil wetting agents, water storage *some examples contd*

TYPE	THE PRODUCT Trade name Active constituent	SOME USES Read label, obtain advice from company
SOIL WATER STORAGE	Water-storing crystals, granules or gels are designed to increase/improve the water-holding capacity of the soil, so that more water is held for plant use. They are biodegradable. • **Water storage crystals are made of polymers** that are designed to absorb up to 400-500 times their weight in water and nutrients, slowly releasing these to the root system when needed by the plant. • **They increase the water holding capacity of the soil**, reduce watering frequency by up to 50%, reduce water evaporation from soil, limit the leaching of nutrients and fertilizers, enhance plant growth and survival and improve soil porosity and aeration. • **During rain or irrigation, water is absorbed by the crystals**, so water is prevented from draining away and being lost. As water is needed the plants will tap into the hydrated crystals and is used over time. Some brands can remain active for 3-5 years and the cycle of water absorption and release can be repeated many times with only a very slight loss in efficiency. • **They can be applied** in planting holes and water added before planting, can also be dug into surrounding soil. They can be put in a bucket and pre-swelled then placed in the planting hole beneath the root ball. More effective than applying crystals directly (Nichols 2007). • **Rechargeable solid water** bags with water crystals inside are marketed under a variety of names. **In forestry** they can be used when planting trees, bushes and saplings reducing their mortality rate due to transplant shock and enhance root development, resulting in more rapid growth etc. http://www.**rechargeablesolidwater**.com/introduction.htm • **Soil humectant compounds** attract and/or retain moisture in soil, they work by reducing moisture loss and attracting water vapour back. These compounds are very hydrophobic, this makes them suited for reducing water losses from sandy soils. Humectants have soil wetting properties but do not perform as well as soil surfactants in this role. They tend to move slowly in the soil and so concentrate in the first few centometres of soil profile. Addition of surfactants to the formulation helps overcome this problem. Advantages they have over soil wetting agents is their very low burn potential and ability to convert water into water that the plant can use (Leeson 2009). • **Formulations of water crystals and fertilizers** are now available.	
	YATES WATER STORAGE CRYSTALS acrylic polymer	When added to potting mix or garden soil, crystals absorb up to 400 times their own weight in water. This water is then released back to the plants over time as they require it. The crystals reduce water wastage, increase the time between waterings and promote improved plant survival during dry times. The crystals are effective for up to 5 years, then biodegrade harmlessly. 
	SANOPLANT GRANULES Silicate-based natural stone powders to which is added high resistible carbon compounds and special cellulose. Not a "polymer", or "water crystal". www.**sanoway**.co.au/	A granular soil amendment/conditioner which stores water and nutrients and promotes healthy plant growth. • It improves the storage of water and nutrients in any type of soil but is most effective in sandy soils, particularly for use in arid regions. • It can rapidly absorb and hold rainfall, can hold 16 times its own weight of water which is plant available (held under moderate tension). • Can be installed into existing playing fields using specially modified machines. • About 50% of irrigation water can be saved! • Renders any fertilizer use more effective.
	OTHER SYSTEMS Solid water	

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. Describe **non-parasitic** pests and diseases. Name examples of each type.
2. Describe **symptoms** produced on leaves, flowers, buds, fruit, seeds and seedlings, branches, trunks, bulbs, corms and tubers, roots, crowns and collars by non-parasitic pests and diseases. Name 1 example of each.
3. Tissues damaged by non-parasitic pests and diseases are often the **entry point** for fungal and bacterial rots and occasionally provide shelter for insects and allied pests. Describe 2 examples.
4. Distinguish between **leaf symptoms** on selected plants caused by:

PARASITIC PESTS & DISEASES	**INSECTS & ALLIED PESTS:** Lace bugs Leafhoppers Mites Thrips **DISEASES:** Root knot nematode Fungal root/wilt diseases Virus diseases
NON-PARASITIC AGENTS	Senescence Herbicide injury Genetic variegation Deficiencies

5. Distinguish between **leaf symptoms** on **selected plants** caused by:
   Salt toxicity
   Excess water
   Insufficient water
   Sunscorch
6. Describe the effects of **'climate change'** on 2 commonly grown **crops/plants** in your area.
7. Describe the effects of **'climate change'** on 2 common **plant pests or diseases** in your area.
8. **Describe 5 tests** that could be performed to determine the cause of certain symptoms on plants.
9. **Describe 3 'prognostic' tests** that could be performed.
10. **Recognize by sight**, symptoms and damage caused by 5 of the following **non-parasitic** agents:

LIVING AGENTS	Black scum (algae) Dogs & cats Fairy rings Leafcutting bees Lichens Slime moulds Soldier beetles Sooty mould
NON-LIVING AGENTS	**ENVIRONMENTAL** **Temperature, eg** Sunscorch injury to leaves, fruit, trunks Frost **Moisture, eg** Excess water, too little water, oedema **Light, eg** Etiolation **Wind** **SOIL STRUCTURE, ETC** Shallow soil Stony soil Type of soil **DEFICIENCIES & TOXICITIES, ETC** Iron, magnesium, nitrogen, other local deficiencies, pH Salinity Sodicity Acidity **POLLUTANTS** Herbicide injury Fertilizer damage Insecticide injury Pollution **MECHANICAL INJURIES:** Hail damage Vandalism **GENETIC ABNORMALITIES** Fasciation Variegated flowers and leaves Sports Graft incompatibility Varietal gumming. **MISCELLANEOUS:** Bud drop, cat face, Failure to set fruit, fruit splitting

11. List **control methods** for non-parasitic pests and diseases. Name 2 examples of each.
12. Locate examples of **non-parasitic problems** for your business, home garden or nominated crop or area.
13. Prepare/access an **IDM** program for a non-parasitic disease at your work or in your region.
14. Locate **reference material** and know where to obtain advice on the identification and control of **non-parasitic** pests and diseases.

SELECTED REFERENCES

Fact Sheets by State/Territory Depts of Primary Industries are available online, eg
Nutrient deficiencies on specific crops
Interpretation manuals

Keys
Lucid problem solver

Climate change
Dept. of Climate Change www.climatechange.gov.au
Each state has its own climate change website, eg www.lgat.tas.gov.au/site/page.cfm?u=540
The United Kingdom Environmental Change Network www.ecn.ac.uk/Education/climate_change.htm
IPCC (2007). "Summary for Policymakers" *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change.

Salinity
Future Farm Industries CRC www.futurefarmcrc.com.au/
GRDC. www.grdc.com.au/
Productive Soils to Dryland Salinity: Mapping, Measuring, Monitoring, Plant Improvements.
Environment Friendly Management Systems for Grain & Livestock Producers
Productive Solutions to Dryland Salinity 2001
Land and Water Australia (LWA) www.lwa.gov.au
National Dryland Salinity Program www.ndsp.gov.au

Organic standards
Organic Federation of Australia www.ofa.org.au to find organic certifiers, the draft national standard and publications, etc/
Bioglobal www.bioglobal.com.au/
Caldwell, B., Rosen, EB., Sideman, E. a, Shelton, A.M. and Smart, C. D. 2000. *Resource Guide for Organic Insect and Disease Management.*

Plant growth regulators, spray injury
Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
Croplife Australia www.cropelifeaustralia.org.au/
MSDS www.msds.com.au/.
Nufarm Spraywise® program reduces the incidence and risk of spray drift damage to a diversity of crops without compromising spraying efficacy. www.nufarm.com/au
Company websites provide labels and MSDSs
Regional Orchard Pest & Disease Handbooks
Dean, N. (ed). 2005. *Field Crop Fungicide and Insecticide Guide 2 (includes Plant Growth Regulators)*. 2nd edn. Kondinin Group.

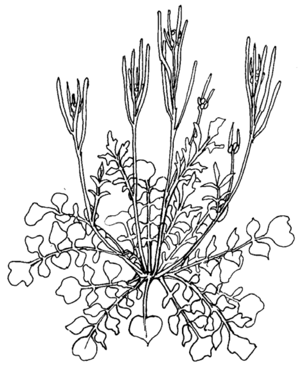
General
Agrios, G. N. 2005. *Plant Pathology*. 4th edn. Academic Press, CA.
American Phytopathological Society (APS) Press, St. Paul, Minnesota produces compendiums on diseases and pests of particular plants. www.shopapspress.org
Peate, N., MacDonald, G. and Talbot, A. 2006. *Grow What Where.* 3rd edn. Blooming Books.
Bodman, K., Carson, C., Forsberg, L., Gough, N., Hughes, I., Parker, R., Ramsey, M. and Whitehouse, M. 1996. *Ornamental Plants : Pests, Diseases & Disorders.* Q196001. Qld DPI, Brisbane.
Bodman, K., McDonald. J. and Hunter, M. 1997. *Plant Growth Regulators in Nursery Crops*. Qld DPI, Brisbane). QNIA, Salisbury, Qld.
Brown, J. F. and Ogle, H. J. (eds). 1997. *Plant Pathogens and Plant Diseases.* Rockvale Pubs., Armidale, NSW.
Chen, D. M. 1999a. *Tackling Salinity with Trees*. Aust. Hort., April.
Chen, D. M. 1999b. *Tackling Salinity with Trees*. Aust. Hort., May.
Fitzpatrick, R. W. 2002. *Land Degradation Processes*. avail online. In: McVicar, T. R. et al. 2002. *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*. ACIAR Monograph No. 84, 119-129.
Garner, J. 2007. *Dryland Gardening Australia: Sustainable Drought-Proof Gardening from the Soil Up*. Murdoch Books.
Goodwin, S., Steiner, M., Parker, R., Tesoriero, L., Connellan, G., Keskula, E., Cowper, B., Medhurst, A. and Rodriguez, C. 2000. *Integrated Pest Management in Ornamentals : Information Guide.* NSW Agric. Sydney. Also a *Field Guide.*
Handreck, K. 2001. *Gardening Down-Under : A Guide to Healthier Soils and Plants.* 2nd edn., CSIRO, Melbourne.
Handreck, K. and Black, N. 2002. *Growing Media for Ornamental Plants and Turf.* NSW University Press, Kensington, NSW.
Horst, R. K. (ed.). 2008. *Westcott's Plant Disease Handbook*. 7th edn. eReference, originally published by Springer, NY.
Jones, D. L. and Elliot, W. R. 2000. *Pests, Diseases & Ailments of Australian Plants.* Lothian Pub., Sydney.
Keane, P. J., Kile, G. A., Podger, F. D. and Brown, B. N. (eds). 2000. *Diseases and Pathogens of Eucalypts.* CSIRO Pub., Collingwood, Vic.
Kerruish, R. M. 2007. *Plant Protection 4: How to Diagnose Plant Problems.* RootRot Press, ACT.
Leeson, G. 2009. *Wetting Agents*. Golf & Sports. Ground Magazine. avail online.
Marcar, N., Crawford, D., Leppert, P., Jovanovic, T., Floyd. R. and Farrow, R. 1995. *Trees for Saltland : A Guide to Selecting Native Species for Australia.* CSIRO, Melbourne.
McMaugh, J. 1994. *What Garden Pest or Disease is that?* Lansdowne Press, Sydney.
Nichols, D. 2007. *Wetting Agents or Water-storing Gels*? Aust. Hort... Jan.
Norwood, C. 2010. Organic Manures Need Time to Supplement Soil Nutrition. GRDC. Jan-Feb.
Pigram, J. 2007. *Australia's Water Resources: From Use to Management*. CSIRO Pub.
Rebbeck, M. A. and Knell, G. R. 2007. *Managing Frost Risk: A Guide for Southern Australian Grains.* SARDI/GRDC.
Rengasamy, P. and Bourne, J. 1997. *Managing Sodic, Acidic and Saline Soil.* CRC for Soil & Land Management. avail. online
Reuter, D. and Robinson, J. B. (eds). 1997. *Plant Analysis: An Interpretation Manual.* 2nd edn. CSIRO Pub.
Rolfe, C. 2000. *Managing Water in Plant Nurseries.* NSW Agric.
Spennemann, D. H. R. 1997. *Urban Salinity as a Threat to Cultural Heritage Places.* The Johnstone Centre, CSU, Wagga Wagga, NSW.
Tan, B. 1997. *A Close Look at Chimeras of the Plant World*. Aust. Hort., March.
Wakefield S. M. 1994. *Farm Trees 1 : Why You Need Trees on Farms*. NSW Agric., Sydney.
Walsh, K. 2004. *Waterwise Gardening*. 3rd edn. Reed New Holland,

Nutrient Deficiencies and Toxicities
Bennett, W. F. (ed.). 1993. *Nutrient Deficiencies & Toxicities in Crop Plants.* APS Press, St. Paul, MN.
Foster, E. F. 2000. *Nutrient Deficiencies and Toxicities of Plants.* CD-ROM. APS Press, 3340 Pilot Knob Road, St. Paul, MN 55121-2097.

The books in the following series each have sections on:
1. Gathering the facts.
2. Diagnosis from visible symptoms.
3. Confirming the diagnosis – trial treatment of a portion of crop, plant tissue analysis, and soil and water analysis.
4. Correcting the problem.
5. Following up, has the crop responded to treatment?

Cresswell, G. C. and Weir, R. G. 1998. *Plant Nutrient Disorders 5 : Ornamental Plants and Shrubs.* Inkata Press, Melbourne.
Weir, R. G. and Cresswell, G. C. 1992a. *Plant Nutrient Disorders 1 : Temperate and Subtropical Fruit and Nut Crops.* Inkata Press, Melbourne.
Weir, R. G. and Cresswell, G. C. 1992b *Plant Nutrient Disorders 3: Vegetable Crops.* Inkata Press, Melbourne.
Weir, R. G. and Cresswell, G. C. 1994 *Plant Nutrient Disorders 4 : Pastures and Field Crops.* Inkata Press, Melbourne.
Weir, R. G. and Cresswell, G. C. 1995. *Plant Nutrient Disorders 2 : Tropical Fruit and Nut Crops.* Inkata Press, Melbourne.

WEEDS



Bittercress, cardamine, flick weed (*Cardamine hirsuta*)

BIOLOGY, CLASSIFICATION & IDENTIFICATION

Flowering plants, ferns, etc

NO. SPECIES IN AUSTRALIA

Australia has more than 3000 species of 'weeds' but probably only a few hundred have major impacts on food production and ecosystems. Main websites include:

Weeds in Australia www.**weeds**.gov.au/
Weeds Australia www.**weeds**.org.au/

WHAT ARE WEEDS? (pest plants)

The Australian National Weeds Strategy of 1999 defines a weed as

'a plant that has or has the potential to have, a detrimental effect on economic, social or conservation values'

A common definition is:

'a plant growing where it is not desirable or wanted'

Most plants, including those usually considered beneficial, may be weeds at times.

WHY ARE SOME PLANTS LIKELY TO BECOME WEEDS?

The 3 most important factors influencing plant weediness are their ability to colonize areas, impact on crop yields, bush areas and their potential for wide distribution.

EFFICIENT AND SUCCESSFUL REPRODUCTION AND SPREAD

Weeds produce large numbers of seeds, fruits and vegetative propagules, eg stem fragments, leaf propagules, tubers, corms and cormlets, bulbs, suckers, stolons, rhizomes and root layers. Weeds also spread efficiently, eg

- **Wind** can spread light seeds of many weeds, eg dandelion, serrated tussock.
- **Running water**. Other weed seeds, eg docks are adapted to float on water or are moved by the force of running water, willow parts are washed down stream.
- **People and animals**. Some seeds have adaptations which enable them to attach themselves to clothes and wool, eg Noogoora burr.
  - **Soil**. Seeds, stolons, bulbs, may be carried in soil in containers, soil or gravel deliveries and on contaminated machinery.
  - **Vehicles and machinery** can spread soil, weed seeds and plants.
  - **Birds** and other animals pass seed in their dropping, manure deliveries.

Noogoora burr

SURVIVE UNDER UNFAVORABLE CONDITIONS

Weeds are persistent, mechanisms of survival include:

- **Invasiveness**. Weeds are able to rapidly invade, establish and dominate disturbed or new sites and consequently extend their distribution and their impact.
- **Seed dormancy/seed banks.** Some seeds can survive long periods in conditions unfavorable for germination, eg chickweed and lamb's tongue can germinate after surviving for 10 years in the soil. Hence the saying:

  '1 year's seed, 7 years' weeds'

- Seeds have a wide germination range, short life cycle, quick maturity, quick production of seed, and rapid early growth after seed germination.
- Strongly competitive with rapid root growth; flourish in disturbed environments.
- Able to self-pollinate or pollination not required.
- Can enter dormancy, eg bulbs, corms; possession of deep roots or tap roots.
- Wide ecological adaptation, eg waterways to deserts. They can tolerate drought, frost, salt, low nutrient levels.
- Weeds are generally fast growing, hardy and highly adaptable.
- Often unpalatable to stock.

Some consider that rats, cockroaches, nettles and thistles will flourish at the expense of more specialized wild organisms

TYPE OF PHOTOSYNTHESIS

Photosynthesis is the combination of carbon dioxide **(CO_2)** with water **(H_2O)** in the presence of chlorophyll to produce plant tissue (Parsons and Cuthbertson 2001).

- Plants use one of 3 different chemical pathways to achieve this reaction.
  - **C_3 or Calvin cycle plants**. Most **crops** cultivated by humans belong to this group, eg wheat, apples, sunflower, soybean, most vegetables were originally developed in temperate regions of the world. **Weeds** in this group include fat hen, wild oats.
  - **C_4 or dicarboxylic acid plants**. **Crops** in this group include sorghum, sugarcane and maize. **Weeds** in this group include couch grass, Johnson grass, summer grass.
  - **CAM (crassulacean acid cycle) plants**, eg prickly pear.
- While only a small proportion of all plants are either **C_4 or CAM**, many **plants** in these 2 groups are weeds. The competitive advantages of **C_4 or CAM plants** include reduced transpiration rates, increased high light-intensity and temperature tolerance and more efficient photosynthesis which make them more suited to semi-arid subtropical and tropical areas, and more efficient as weeds than most **C_3** plants (Parsons and Cuthbertson 2001).

CO_2
+
H_2O
+
chlorophyll
= plant tissue

HARMFUL EFFECTS OF WEEDS
(weed impacts)

DIRECT EFFECTS

- **Weeds cost Australia around $4 billion** per year (2008) in cost of control, lost production and contamination and rank with salinity as one of Australia's most serious problems environmentally. In 2006-2007 farmers spent more than $1.6 billion on weed control alone. Weeds degrade our environment and ecosystems, threaten native flora and fauna and reduce amenity for humans.
- **Weeds compete** strongly with crop plants for moisture, nutrients and light, reducing yields and/or quality to the extent that an operation may no longer be profitable. Weeds occupy potentially useful space.
- **Presence of weeds can devalue land in rural areas**. A history of cape tulip or Paterson's curse may result in additional management costs.
- **Appearance**. Customer tolerance of weeds in containers in nurseries is low. Weeds are offensive to look at, interrupt views and crowd out desirable species.
- **Biodiversity**. Introduced weeds (and animals) are second only to habitat clearing as the greatest threat to biodiversity in bush land. Weeds displace plants found naturally in a particular area and cause habitat loss.

Lantana alone threatens 1246 plant species and 41 animal species

- **Waterways**. Riparian weeds, eg willows, impede water flows and reduce access by stock and humans. Aquatic weeds, eg, salvinia blocks waterways and impede recreation activities. Herbicides in drainage water from treated areas may contaminate water ways.
- **Contaminate produce**, eg weed seeds lower the value of cereal grain for sowing in clean areas. It is illegal to sell contaminated grain or fodder. Weed seeds are often found in coarse grains used for feeding pigs, some are harmful to pigs, eg potato weed (*Heliotropium europaeum*), Mexican poppy (*Argemore ochroleuca* and *A. Mexicana*). Some weeds have an offensive odour, eg some thornapples (*Datura* spp.). Milk and meat of animals grazing on certain plants may be tainted. Wild garlic will flavour milk within 4-5 minutes of feeding.
- **Interfere with agricultural operations**, eg burry seeds are problems for shearers and pickers. Skeleton weed and wild melons become tangled in machinery. Weeds interfere with transport and recreation. Weeds under power lines, on railways and obscuring road signs must be suppressed. Blackberries are impenetrable to live-stock, vehicles and bush walkers. Boneseed and bridal creeper impede beach users.
- **Domestic animal losses are not uncommon**. Cape tulip can cause losses in stock newly introduced to it. Annual rye grass toxicity **(ARGT)** affects cattle grazing on Wimmera rye grass infected by nematode-carrying bacteria which produce a toxin. Animals with light colored skins feeding on St John's wort or lantana become more sensitive to sunlight which may lead to skin diseases and eventual death.

Paterson's curse is toxic to stock, especially toxic to horses

SOME OTHER EFFECTS **Almost infinite**

- **Human fatalities are rare**. Few plants have been known to cause human death, eg angel's trumpet, Datura (*Brugmansia* spp.), arum lily (*Zantedeschia aethiooica*), lantana (*Lantana camara*), oleander (*Nerium oleander*), poison hemlock (*Conium maculatum*), white cedar (*Melia azerdarach*), yellow oleander (*Thevetia peruviana*).
- **Hay fever and dermatitis.** Pollen of many grasses and weeds cause **hay fever** in susceptible people, eg annual ryegrass, plantain, privet, capeweed. The majority of plants producing pollen which trigger hay fever were introduced from the northern hemisphere. Rashes, swellings, **dermatitis**, pain, localized burning or infections may occur in susceptible people when some weeds are handled or brushed against, eg St John's wort, Bathurst Burr, scarlet rhus, some *Grevillea* spp., poison ivy.

Seeds are often the most toxic part

- **Mechanical injury**. Spiny leaves, stems and seed heads of thistles, galvanized burr, etc, may injure feet, legs, mouthparts, ears and eyes and other parts of animals. Burry or corksrew seeds may adhere to the wool, hair and feathers of animals and trouser legs/socks of humans. Nettles sting animals and humans.
- **Harbour diseases, pests and vermin.** Prickly lettuce is a host of powdery mildew of cucurbits, brassica weeds for cabbage aphids, common sowthistle for cineraria leafminer, white clover for western flower thrips (**WFT**) and tomato spotted wilt virus (**TSWV**). Thickets of blackberry harbour rabbits.
- **A fire hazard** when bulky perennial grass weeds dry off in spring/summer, eg mission grass (*Pennistemon polystachion*).
- **Genetic pollution**. Pollen disperses more widely than seed. Garden and crop plants can be improved by genetic engineering for drought hardiness, however, this may also increase their chances of becoming weeds.
- **Some weeds release chemicals** into the soil that retards crop growth (**allelopathy**), eg aqueous extracts of the pasture weed, lippia (*Phyla canescens),* can inhibit seed germination of certain pasture and crop species.

> **Control methods**, eg cultivation, burning, herbicides may have **adverse effects** on soil, crops, and the environment.

BENEFICIAL EFFECTS OF WEEDS

- Leguminous weeds add nitrogen to the soil, eg white clover.
- Provide fodder for animals, eg weed grasses, Salvation Jane, during hard times.
- Provide pollen and nectar for bees, eg Salvation Jane.
- Source of food for beneficial insects, encourage a diversity of beneficial insects.
- Prevent or reduce soil erosion and rain compaction where there is no other vegetation, eg bitou bush.
- May be a source of food for humans, eg chicory.
- Some weeds are reputed to produce beneficial exudates.
- May improve drainage, soil structures, add organic matter. Deep rooted species may retrieve scarce nutrients from the subsoil.
- Certain weeds act as indicators of nutrient imbalances or soil problems, eg sorrel indicates acidity.

WEED IDENTIFICATION

WHY IDENTIFY THE PLANT/WEED CORRECTLY?

- **Weed ID is the 3rd step in effective weed management** (page 429), Before recommendations for control can be made, both the weed and the surrounding plants must be correctly identified. As some herbicides are applied to weed seedlings, it is also necessary to recognize different stages of weed growth.
- **The plant species** may **not** be a weed, it might just be a nuisance weed.
- **Some weeds are difficult to identify** at certain stages of growth.
- **Having identified the weed** you can access information about the weed, eg likely impact on your crop, etc, and controls, if required, will be more effective.
  - **The recognized common name(s) of the weed** and/or, if necessary, the botanical name. Only some species of cotoneaster are weeds in some areas.
  - Whether it is a **grass** or **broadleaved weed**.
  - Its **biology** and **ecology**, eg life cycle, annual or perennial, habitat, etc.
  - If it is a **noxious** or other type of weed...
  - Obtain/prepare a **Fact Sheet**:

> Common name of weed
> Scientific name, weed type, eg
> Crop, situation, other habitat
> Weed damage (impact, etc)
> Weed cycle (annual, perennial, etc)
> Overwintering, oversummering (seed banks, etc)
> Spread
> Conditions favoring
> **Integrated Weed Management** (**IWM**)
> **Control methods**
> Legislation (**noxious, WONS, garden escape, etc?**)
> Cultural methods
> Sanitation
> Tolerant crops
> Biological control
> Plant quarantine
> Weed-tested planting material
> Physical & mechanical methods
> Herbicides

STEPS IN IDENTIFICATION OF PLANTS/WEEDS

1. Identify the crop/site, where the plant is growing, and/or **other plants growing near**, or around or under the weeds to be treated, eg whether they are broadleaved plants or grasses and whether they are annual or perennial plants, etc.

2. Examine flowers, seeds, leaves, roots etc. A **hand lens** may be needed to examine plant parts, especially grasses.

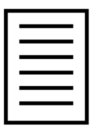
3. During an on-site visit you can ask about the history of weed infestation in your crop or local area. **GPS** can assist with distribution. What is the habitat, eg riparian, and land use management system, eg crop, amenity, environmental, turf? If you can't visit the site you can ask questions instead.

4. Consult a reference

Weeds in Australia has a **Weed Identification Tool** on their website www.**weeds**.gov.au

- **Consult a reference** to:
  - ❑ Assist with identification of the plant.
  - ❑ Confirm the identification of the plant. Plants can also be distinguished by their leaf type, root system, flowering times and methods of reproduction.
  - ❑ Obtain information on biology and ecology of the plant, eg its life cycle, spread, etc.
  - ❑ Options for prevention and control, eg cultural, sanitation, biological.
- **What references to use?**
  - ❑ A colleague may be able to help.
  - ❑ State/Territory Department of Agriculture leaflets are excellent.
  - ❑ Books, pressed specimens, collections.
  - ❑ Computing programs, web sites, photo libraries.
  - ❑ Botanical keys, Floras of particular regions/states.

5. Seek expert advice (page xiv).



- Obtain plant recording sheet forms, etc.
- Find out how to send plant specimens. Samples should be fresh.
- Collect flowers and seeds, leaves, and roots if weed is small.
- Do not wrap specimens in plastic or wet them, use clean dry paper.
- The diagnostic service will identify the plant to species level and, if a weed, provide recommendations on Integrated Weed Management **(IWM)**. Industry groups may provide **IWM** information for specific crops, eg grapevines.

CLASSIFYING WEEDS

HABITAT, eg

- Terrestrial, eg lantana
- Parasitic, eg broomrape
- Aquatics weeds, eg salvinia
- Riparian (creeks, rivers), eg willow
- Turf, pasture, eg oxalis
- Agricultural weeds, eg wild oats
- Cultivated land, eg barnyard grass
- Garden weeds, eg chickweed
- Stockyards, eg fat hen
- Waste places, eg wireweed

LAND-USE MANAGEMENT SYSTEMS.

In nine land management systems associated with cropping in Australia, weeds were ranked as the worst problem by over 90% of farmers. Annual ryegrass, wild oats and wild radish rated highest (Sindel 2000).

- Crop weeds, eg annual ryegrass
- Pasture weeds, eg serrated tussock
- Environmental, eg bitou bush
- Vegetables, eg barnyard grass
- Tree crops, viticulture, eg cape weed
- Lawns and sports turf, eg paspalum
- Plantation forests, eg lantana
- Australian rangelands, eg rubber vine
- Aquatics, eg water hyacinth

ANNUALS, BIENNIALS, PERENNIALS. **Life history**

Annual weeds are mostly opportunists that germinate when the soil is at least partially bared through seasonal conditions following overgrazing, mowing, cultivation, burning or other site disturbance.

- **Annuals.** Plants which flower, produce seeds and die in **1 year or less**, eg chickweed. Control should aim to prevent further seeding. Roots are usually shallow and plants easily hoed, hand pulled or controlled with herbicide.
  - Seed production commences after a short period of vegetative growth, with flowering and seed production high in good seasons, but low in poor seasons.
  - Seed persistence, long period of seed survival, size of the seed bank.
  - Germination, seedling growth and establishment is rapid.
- **Biennials.** Plants which live for **2 years/seasons** may produce seeds within 12 months or in the 2nd year. Not many weeds are true biennials; Paterson's curse is sometimes biennial. Control in the 1st year of a biennial plant's life before it sets seed.
- **Perennials** live for **3 years or more**, may be short or long lived, they may be herbaceous or woody species. Plants have rhizomes, corms, lignotubers, deep roots or similar structures and so can regrow year after year. Most reproduce also by **seed**. Control aims to deplete root reserves so that no new shoots can develop. For some, cultivation should be avoided, as this can lead to further spread. Those with shallow roots and not prone to sucker can be dug out. Systemic herbicide applications may be required for control of deep roots, bulbs and other underground structures.

Perennial weeds are difficult to control due to their underground vegetative structures, eg rhizomes, bulbs, etc. Most roots can grow as deep as 45 cm below ground sometimes as deep as **3-4 meters** (see inside back cover).

GROWTH HABIT, TISSUE STRUCTURE, HERBACEOUS, WOODY.

- **Growth habit**, eg
  - Grasses, herbs
  - Trees and shrubs
  - Climbers, creepers, scramblers, vines
- **Tissue structure**, eg
  - Rosette, eg dandelion, capeweed
  - Stolons, eg couch grass
  - Rhizomes, eg Mullumbimby couch
  - Suckers, eg poplar
  - Tubers, eg nutgrass
  - Corms, eg onion grass (Guildford grass)
  - Bulbs, eg wild onion
- **Herbaceous, woody**, eg
  - Herbaceous weeds, eg ryegrass
  - Woody weeds, eg some species of willow, hawthorn, camphor laurel

INTRODUCED AND INDIGENOUS WEEDS.

In their native country these weeds are kept in check by climate, soils, associated vegetation, insects and diseases

- **Introduced (alien, exotic) weeds** are plants growing in an area where they are not native, eg those native to a region outside Australia. The great majority of weeds in Australia are introduced plants, some of which are also desirable crop, pasture, forestry and ornamental plants.
  - **Pioneer species** quickly colonize disturbed and denuded land, so many are weeds of cultivation, pastures, roadsides, waste places, bush land and park land.
  - **Casuals or casual aliens** are those that only survive for a short time because they cannot establish self-sustaining populations and only persist by new introductions.
- **Australian native plants** are plants that have evolved in Australia or migrated by long distance dispersal **before** European settlement.
  - **Indigenous plants** are found naturally in a **particular area** in Australia, but not in Australia generally, eg sweet pittosporum is indigenous to east Victoria.
  - **Indigenous weeds**. Many plants native to Australia can themselves become environmental weeds within Australia, eg sweet pittosporum from east Victoria is an environmental weed in SA and NSW and coastal Victoria. Golden wreath wattle (*Acacia saligna*) from WA is now found along the NSW coast.

CLASSIFYING WEEDS (*contd*)

Australia's floral emblem (*Acacia pycnantha*) is indigenous to NSW, Vic and SA but is widely naturalized in WA.

Not all naturalized weeds are environmental weeds, some are restricted to farmland, roadsides

INVASIVE SPECIES, NATURALISED WEEDS

- **Invasive species** colonize and persist in an ecosystem where they did not occur previously. CSIRO Australia www.csiro.au/science/**InvasivePlants**.html
WWF-Australia www.wwf.org.au/ourwork/**invasives**/
- **Invasiveness** is one of the 3 most important factors influencing plant weediness, the other two are impacts and potential distribution.
- **Naturalized weeds** are invading species that can become established and reproduce for several generations in the wild without human assistance. Most serious weeds are also naturalized plants. Invasive species that are naturalized and widespread pose a major threat to the environment or agriculture, their containment or control will protect values of national environmental significance. They are mostly:
  - **Introduced weeds**, but some are **indigenous weeds**, eg *A. baileyana.* They have been cultivated outside their limited native range, adapted to the conditions there, escaped cultivation and **become naturalized**. It is estimated that about 10 new species escape and become naturalized in the environment each year.
  - **New naturalizations** are listed on the website www.**weeds**.gov.au/

WEED LISTS

DEFINITIVE WEED LISTS are based on a **Weed Risk Assessment (WRA)** process and directed at different levels of the ecological hierarchy – global, national, state, regional or local for management action. There is now a multitude of weed lists and the number of plants considered 'weedy' is increasing. **Only a few lists are legally binding**, or have government or scientific authority. The degree of risk posed by any plant will depend on where it is growing. A weed may be on several 'lists'.

National Weeds Lists www.**weeds**.gov.au/

TARGET WEEDS Weeds not yet in Australia

- **NAQS Target List for Weeds (NAQS)** is a list of **41 species** regarded as serious threats to Australia's productivity, export markets and the environment. It focuses on the potential for weeds to enter Australia from Timor Lestse, Indonesia or Papua New Guinea via the Australian northern border by natural or non-conventional pathways including wind currents, migratory animals, traditional vessel movements and illegal fishing activity.
- **AQIS Targeted Lists of Weeds** can be found on the following Department of Agriculture, Fisheries and Forestry (DAFF) website
www.daff.gov.au/aqis/quarantine/naqs/**target-lists**

EMERGING or SLEEPER WEEDS Weeds already in Australia.

Barker, etc al. 2006. *Weeds of the future: Threats to Australia's Grazing industry by Garden Plants*. Meat & Livestock Australia/CRC WMS. avail online

Blood, K. 1999. *Future and Expanding Weeds.* Plant Protection Quarterly Vol.14(3).

- **Naturalized Invasive** and **Potentially Invasive Garden Plants** is a database which identifies many sleeper weeds that have not yet increased their distribution significantly and could be controlled before numbers explode. Weeds on this list are naturalized invasive species currently with a restricted range and whole eradication is feasible and cost-effective.
- **National Environmental Alert List** is an important subgroup of emerging or sleeper weeds. These are plant species in the early stages of establishment with the potential to become a significant threat to Australian Biodiversity. This list consists of **28 non-native plants** that have established naturalized populations in the wild and threaten biodiversity and cause other environmental damage across Australia.
National Environmental Alert List and *Alert list for Environmental Weeds: Weed Management Guides* www.**weeds**.gov.au/
- **Eradication and Containment Lists** (currently none have official status)
  - An Eradication and Containment list impacting **natural ecosystems** has **34 naturalized species** compiled by scientists to include species that pose a direct threat to natural ecosystems because of their potential impact on native species.
  - An Eradiation of and Containment List impacting **agricultural ecosystems** has **27 naturalized species** compiled by scientists to include species that pose a potential threat to agricultural ecosystems should they ever spread further.
  - An Eradication Candidate List of **17 sleeper agricultural weeds** compiled by scientists for cost-effective eradication **before** they become major agricultural weeds.

NOXIOUS WEEDS Mostly agricultural/horticultural crop weeds

State/ Territory

Some plants may be noxious in one State or Shire but not in another

- **A 'noxious' weed** is a plant that has been **legally** declared under State/Territory legislation (page 432). These weeds have a negative impact on crop (or animal) production and are variously referred to as **noxious weeds, declared weeds or proclaimed weeds**. In Australia, about 200 weeds are classified as noxious, and there are legal provisions requiring landowners (public and private) to control them.
- **Most are agricultural** weeds which are **difficult to control**.
- **Most are perennial** plants, many spread by **rhizomes and similar structures**.
- **Different noxious weed lists** exist for each region; **get your local list** which is available from local council or shire offices.
- **Lucid keys**, eg *Identifying Declared Plants of Australia* **www.lucidcentral.com/**
- **The Australian Weeds Committee** provides an intergovernmental mechanism for identifying and resolving weed issues at a national level, eg updates the 'Noxious Weed Lists for Australian States and Territories. The entire noxious weed list (in table form) can be accessed on the **Weeds in Australia** website.

CLASSIFYING WEEDS (*contd*)

Australia's 20 worst weeds

WEEDS OF NATIONAL SIGNIFICANCE WONS

WONS is a list of Australia's worst weeds which have been legally declared by the Federal government with restrictions on their propagation, trade or sale applying to all states/territories. State cooperation should ensure a nationally effective program of prevention, eradication and control. **WONS** threaten tourism, cropping, forestry, plant communities, recreation (sailing), human safety (spines), pastoral industries (horses), water quality, cultural values (water birds), endangered species (competition), community (fire), infrastructure (roads). None of the **WONS** have reached their full range.

- **An inaugural list of 20 WONS** (page 416-418) were selected from more than 3,000 non-native naturalized plants in Australia. Criteria used to prepare the **WONS** list included invasiveness, economic, environmental and social impacts, distribution, potential for spread, cost of control. Best Practice Manuals are available.
  Weeds Australia www.**weeds**.gov.au/
  Global Compendium of Weeds http://www.hear.org/**gcw**/
  Lucid key *Weeds of National Significance* www.**lucidcentral**.com/

Local areas

ENVIRONMENTAL WEEDS Many definitions

Environmental weeds are mostly cultivated plants which invade natural ecosystems and threaten survival of local plants and animals. They:

- **Can invade** natural communities without need for disturbance.
- **Smother** slower growing native plants and threaten the existence of already endangered or vulnerable species of flora and fauna.
- **Are mainly introduced plants** but there are some native species which have spread outside their natural range.
- **Check the National Environmental Alert List** (page 414).
- **Most States/Territories** produce brochures on environmental weeds.
- **Lucid keys**, eg *Suburban and Environmental Weeds of South East Queensland*, *Environmental Weeds of Australia*, *Environmental Weeds of South-east Queensland, International Environmental Weed Foundation-Keys to Local Area Weeds* www.**lucidcentral**.com/

Inaugural list of 52 species

GARDEN ESCAPES, GARDEN PLANTS UNDER THE SPOTLIGHT (GPUTS)

Some invasive garden plants become weeds of bush and farming areas, hence the names garden escapes, garden thugs, eg Paterson's curse (*Echium plantagineum*). Of the roughly 2780 weed species currently in Australia about 1800 are introduced garden plants.

- **Most States/Territories** produce brochures relating to garden escapes which will help you identify plants that can escape from your garden area. Victoria has produced a list of invasive weedy garden plants that may be restricted and removed from sale. A voluntary list of **52 plants** has been agreed upon.
- **A Code of Practice** to be developed will include preventing nurseries from selling or displaying ornamental plants that may become environmental weeds. The Nursery & Garden Industry (**NGIA**) has a **Grow Me Instead** program.
- **Lucid key** *Common Suburban Weeds* www.**lucidcentral**.com/.
- **Information** on future environmental weeds and their sale are documented (Moss & Walmsley 2005, Barker et al 2006, Blood 1999). Check also www.**weeds**.gov.au/

Understanding the different types of weeds will help you **control** them effectively, eg selective herbicides are used to control broadleaved weeds in grass crops

Auld, B. A. and Medd, R. W. 1986. *Weeds : An Illustrated Botanical Guide to the Weeds of Australia.* ***Inkata Press, Melbourne.***

BOTANICAL GROUPS

- **Class Angiosperms (flowering plants).** Weeds occur in **> 50 families** of flowering plants. Some families have a known weed history.
  - **Subclass Dicotyledons (broadleaved weeds).** Two cotyledons or seed leaves; network of veins in leaves; flower petals usually in multiples of **4 or 5**; often have a tap root, eg
    Family Asteraceae (daisy family), eg capeweed, daisies, thistles. The Asteraceae constitute about 40% of all agricultural weeds.
    Family Brassicaceae (mustard family), eg wild turnip.
    Family Fabaceae (legume family, pea family), eg burr medic, white clover.
    Family Malvaceae (mallow family), eg marshmallow.
    Family Polygonaceae (dock family), eg curled dock.
    Family Rosaceae (rose family), eg blackberry.
    Family Solanaceae (nightshades, potato family), eg blackberry nightshade.
  - **Subclass Monocotyledons (narrowleaved weeds).** One cotyledon or seed leaf; parallel veins in leaves; flower petals in **multiples of 3**; usually fibrous root system, eg
    Family Poaceae (grass family), eg summer grass, paspalum (about 1/3rd of Australia's grasses are introduced).
    Family Iridaceae (iris family), eg cape tulip (many South African species have known weed potential).
- **Pteridophytes (ferns).**
  Family Dennstaedtiaceae, eg bracken fern.
  Family Salviniaceae, eg salvinia.
- **Detailed information on botanical groups** may be found in many texts.

LIST OF SOME SPECIES	COMMON NAME	TYPE OF WEED Check current status of weeds			
	DICOTYLEDONS (broadleaved weeds)				
Annual & herbaceous weeds	**Annual & herbaceous weeds**	NOXIOUS (in some areas)	WONS 20	ENV (in some areas)	Garden escapes
	1. Some have broad leaves.				
	<u>Some are rosettes at certain stages of growth</u>				
	Capeweed (*Arctotheca calendula*)				
	Catsear (*Hypochoeris radicata*)				
	Dandelion (*Taraxacum officinale*)				
	Lamb's tongue (*Plantago lanceolata*)				
	<u>Some are not rosettes</u>				
	Bittercress, flickweed (*Cardamine hirsutus*)				
	Common sowthistle (*Sonchus oleraceus*)				
Many weeds are just **nuisance weeds,** (not declared noxious, or of national or environmental significance); but they can still cause problems in some areas	Curled dock (*Rumex crispus*)	Noxious			
	Indian hedge mustard (*Sisymbrium orientale*)				
	Parthenium weed (*Parthenium hysterophorus*)	Noxious	WONS		
	Paterson's curse (*Echium* spp.)	Noxious			
	Prickly lettuce (*Lactuca serriola*)				
	Scotch thistle (*Onopordum acanthium*)	Noxious			
	Soursob (*Oxalis pes-caprae*)	Noxious			
	Spiny emex (*Emex australis*)	Noxious			
	Turnip weed (*Rapistrum rugosum*)	Noxious			
	Variegated thistle (*Silybum marianum*)	Noxious			
	Wild radish (*Raphanus raphanistrum*)	Noxious			
	2. Some have small or fine leaves.				
	<u>Many are flat or mat forming</u>				
	Chickweed (*Stellaria media*)				
	Mouse ear chickweed (*Cerastium glomeratum*)				
	Petty spurge (*Euphorbia peplus*)				
	Sheep sorrel (*Rumex acetosella*)				
	Skeleton weed (*Chondrilla juncea*)	Noxious			
	Wire weed (*Polygonum aviculare*)				
Woody weeds	**Woody weeds**				
	Bitou bush, bone seed (*Chrysanthemoides monilifera* spp.)	Noxious	WONS	ENV	✓
	Blackberries, brambles (*Rubus* spp.)	Noxious	WONS	ENV	✓
	Camphor laurel (*Cinnamomum camphora*)	Noxious		ENV	✓
	Candle bush, Ringworm shrub (*Senna alata*)	Noxious		ENV	✓
	Cape or Montpellier broom (*Genista monspessulana*)	Noxious		ENV	✓
	Chinese apple, Indian jujube (*Ziziphus mauritiana*)	Noxious		ENV	✓
	Cotoneaster (*Cotoneaster* spp.)	Noxious		ENV	✓
	English broom, broom (*Cytisus scoparius*)	Noxious		ENV	✓
	Gorse (*Ulex europaeus*)	Noxious	WONS	ENV	✓
	Lantana (*Lantana camara*)	Noxious	WONS	ENV	✓
	Mesquites (*Prosopis* spp.)	Noxious	WONS	ENV	✓
	Mimosa, giant sensitive tree (*Mimosa pigra*)	Noxious	WONS	ENV	✓
	Privet (*Ligustrum* spp.)	Noxious		ENV	✓
	St John's wort (*Hypericum perforatum*)	Noxious		ENV	✓
	Sweet briar (*Rosa rubiginosa*)	Noxious		ENV	✓
	Sweet pittosporum (*Pittosporum undulatum*)	Noxious		ENV	✓
	Tamarisk, Athel tree (*Tamarix aphylla*)	Noxious	WONS	ENV	✓

WEED PROBLEMS ARE EVER-CHANGING.

- **Shifts in weed flora** have taken place throughout history, the status of weeds is continually changing.
- **Obtain up-to-date local information** on **noxious weeds**, **WONS**, environmental weeds (**ENV**) and garden escapes either from your State/Territory Dept of Agriculture or an appropriate website.
- Noxious weed lists for Australian states and Territories are regularly updated www.**weeds**.gov.au/

LIST OF SOME SPECIES*(contd)*

Woody weeds

COMMON NAME	TYPE OF WEED Check current status of weeds			
DICOTYLEDONS (broadleaved weeds) ***(contd)***				
Woody weeds ***(contd)***	**NOXIOUS** (in some areas)	**WONS 20**	**ENV** (in some areas)	**Garden escapes**
Tree of Heaven (*Ailanthus altissima*) (one of the few trees that are noxious weeds)	Noxious		ENV	✓
Monterey pine, radiata pine (*Pinus radiata*)	Noxious		ENV	✓
Parkinsonia (*Parkinsonia aculeata*)	Noxious	WONS	ENV	✓
Polygala, purple broom (*Polygala virgata*)			ENV	✓
Prickly acacia (*Acacia nilotica*)	Noxious	WONS	ENV	
Spanish heath (*Erica lusitanica*)	Noxious		ENV	✓
Willow (*Salix* spp. except weeping willow, pussy willow and sterile pussy willow)	Noxious	WONS	ENV	✓
Vines and creepers				
Cape ivy, ivy groundsel (*Delairea odorata*)	Noxious		ENV	✓
Dolichos pea (*Dipogon lignosus*)			ENV	✓
Himalayan honeysuckle (*Leycesteria formosa*)	Noxious		ENV	✓
English ivy (*Hedera helix*)	Noxious		ENV	✓
Madeira vine (*Anredera cordifolia*)	Noxious		ENV	✓
Purple morning glory (*Ipomoea indica*)	Noxious		ENV	✓
Rubber vine (*Cryptostegia grandiflora*)	Noxious	WONS	ENV	✓
Wandering jew (*Tradescantia fluminensis*)			ENV	✓
OTHER DICOTYLEDONS				
Cacti (Cactaceae)				
Harrrisia cactus (*Eriocereus martinii*)	Noxious		ENV	
Prickly pear (*Opuntia* spp.) (some spp. only; introduced as a living hedge in Qld)	Noxious		ENV	✓
Parasitic plants				
Broomrapes (*Orobanche* spp.) (page 382)	Noxious			
Dodders (*Cuscuta* spp.) (page 381)	Noxious			
Witchweeds (*Striga* spp.) (page 380)	Noxious			
MISCELLANEOUS GROUPS				
Ferns (Pteridophytes)				
Bracken fern (*Pteridium esculentum*)				
Horsetails (*Equisetum* spp.)	Noxious	WONS		✓
Water weeds (aquatic weeds)				
Alligator weed (*Alternanthera philoxeroides*)	Noxious	WONS	ENV	✓
Cabomba (*Cabomba caroliniana*)	Noxious	WONS	ENV	✓
Elodea (*Elodea canadensis*)	Noxious		ENV	✓
Hydrocotyle (*Hydrocotyle ranunculoides*)	Noxious		ENV	✓
Lagarosiphon (*Lagarosiphon major*)	Noxious			
Parrots feather (*Myriophyllum aquaticum*)	Noxious		ENV	✓
Pond apple (*Annona glabra*)	Noxious	WONS		
Salvinia (*Salvinia molesta*)	Noxious	WONS	ENV	✓
Water hyacinth (*Eichhornia crassipes*)	Noxious		ENV	✓
Water lettuce (*Pistia stratiotes*)	Noxious			
Riparian weeds				
Riparian weeds include grasses and bulbs, eg kikuyu; herbaceous plants, eg docks; shrubs, eg blackberry; trees, eg willows and vines, eg cape ivy (Ede and Hunt 2008)				

LIST OF SOME SPECIES*(contd)*

> **There are many potentially serious grass weeds not yet in Australia, eg**
> Asian strangletop
> Japanese lovegrass

COMMON NAME	TYPE OF WEED Check current status of weeds			
MONOCOTYLEDONS (narrowleaved weeds)				
Grass family (Poaceae)	NOXIOUS (in some areas)	WONS 20	ENV (in some areas)	Garden escapes
Annual ryegrass (*Lolium rigidum*)				
Rhizomatous bamboo (*Phyllostachys* spp.)	Noxious			
Barley grasses (*Hordeum* spp.)				
Blady grass (*Imperata cylindrica*)				
Blue couch grass (*Cynodon incompletus*)				
Couchgrass (*Cynodon dactylon*)			ENV	
Brome grasses (*Bromus* spp.)				
Giant reed (*Arundo donax*)	Noxious		ENV	✓
Olive Hymenachne (*Hymenachne amplexicoulis*)	Noxious	WONS	ENV	
Pampas grass (*Cortaderia selloana*)	Noxious		ENV	✓
Parramatta grass (*Sphaerobolus fertilio*)			ENV	
Paspalum (*Paspalum dilatatum*)	Noxious		ENV	
Summer grass (*Digitaria sanguinalis*)				
Wild oats (*Avena fatua, A. ludoviciana*)				
Winter grass (*Poa annua*)				
African love grass (*Eragrostis curvula*)	Noxious		ENV	
Chillean needlegrass (*Nassella neesiana*)	Noxious	WONS		✓
Lobed needle grass (*N. charruana*)	Noxious			
Mexican feather grass (*N. tenuissima*)	Noxious		ENV	✓
Serrated tussock (*N. trichotoma*)	Noxious	WONS	ENV	✓
Asparagus family (Asparagaceae)				
Asparagus fern (*Asparagus scandens*)			ENV	✓
Bridal creeper (*Asparagus asparagoides*)	Noxious	WONS	ENV	✓
Iris family (Iridaceae)				
Cape tulips (*Moraea* spp.)	Noxious		ENV	
Harlequin flower (*Sparaxis bulbifera*)	Noxious		ENV	✓
Monbretia (*Crocosmia* x *crocosmiiflora*)	Noxious		ENV	✓
Onion grass (*Romulea* spp.)	Noxious			
Watsonia (*Watsonia meriana* var. *bulbillifera*)	Noxious		ENV	✓
Lily family (Family Liliaceae)				
Onion weed (*Asphodelus fistulosus*)	Noxious			
Three-corner garlic (*Allium triquetrum*)	Noxious		ENV	✓
Sedges (Cyperaceae)				
Mullumbimby couch (*Cyperus brevifolius*)			ENV	
Nutgrass (*Cyperus rotundus*)	Noxious		ENV	
Tall spikerush (*Eleocharis sphacelata*)				
Rushes (Juncaceae)				
Toad rush (*Juncus bufonius*)				✓
Family Araceae				
Arum lily (*Zantedeschia aethiopica*)	Noxious			✓
Family Typhaceae				
Cumbungis (*Typha* spp.)	Noxious			

WEED PROBLEMS ARE EVER-CHANGING

- **Shifts in weed flora** have taken place throughout history, the status of weeds is continually changing.
- **Obtain up-to-date local information** on **noxious weeds**, **WONS**, environmental weeds (**ENV**) and garden escapes either from your State/Territory Dept of Agriculture or an appropriate website.
- Noxious weed lists for Australian states and Territories are regularly updated www.**weeds**.gov.au/

Description of some weeds species

Dicotyledons (broadleaved weeds) – ROSETTES

(some weeds are only rosettes at certain stages of growth)

CAPEWEED (*Arctotheca calendula*) — Asteraceae

Type Annual or biennial herb. Declared **noxious weed** in Tasmania. Agricultural weed, can be abundant in waste places, pasture, taints milk. Host for redlegged earth mites.

Leaves Deeply lobed to the midrib. Thick, fleshy, very hairy, silvery gray-green above, **silvery white down beneath**. Rosetted **with no milky sap**.

Flowers Solitary, single **yellow with black or orange center**, on singular stems.

Seeds Small nutlets enclosed in a woolly ball.

Roots Strong fibrous roots.

Spread By seed.

Flowering plant, yellow flowers

DANDELION (*Taraxacum officinale*) — Asteraceae

Type Persistent but shortlived, herbaceous perennial herb. Garden weed, waste places, invades lawns. Often confused with catsear (*Hypchaeris radicata*) which has thinly branched flower stems (see front cover).

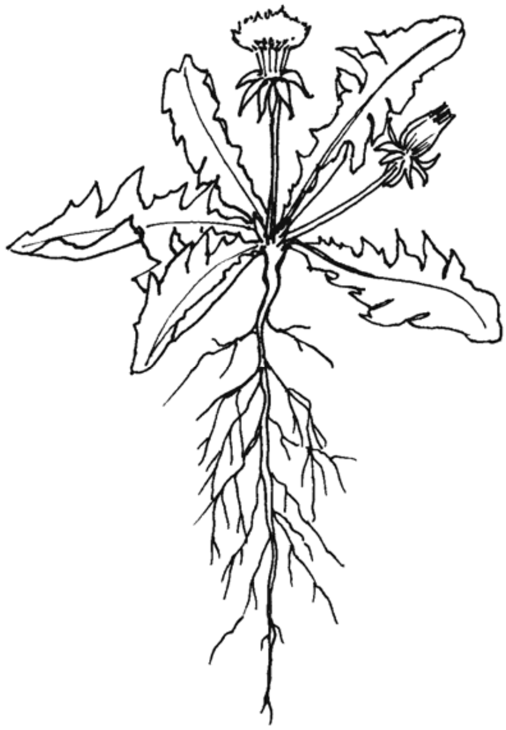
Leaves Irregularly toothed, smooth shiny light green with milky sap (latex), rosette.

Flowers Solitary double **yellow daisy** on single hollow stem.

Seeds With a pappus. Widespread in temperate Australia.

Roots Thick, deep fleshy tap root.

Spread By seed and by cut-up pieces of root; spread by cultivation.



Flowering plant, yellow flowers, tap root

Description of some weeds species *(contd)*

Dicotyledons - broadleaved weeds – NOT ROSETTES.

FAT HEN (*Chenopodium album*) — Chenopodiaceae

Type Annual herb with an erect, angular stem which can grow up to 1 meter. Agricultural weed, weed of cultivated land, can be toxic to pigs.

Leaves Upper leaves are entire and lance-shaped, but lower leaves may be lanceolate or the wider ones may be rhomboid. Leaf edges usually slightly toothed. Leaves may have a mealy appearance, particularly on the undersurface.

Flowers Small green-white flowers occur in hanging clusters, placed either terminally or in the axils of the upper leaves. Each flower has an **inconspicuous** floral envelop of 5 lobes and 5 stamens. The inflorescence has an overall mealy appearance.

Seeds Generally black and shiny.

Roots Fibrous.

Spread By seeds.

Flowering stem, greenish flowers

VARIEGATED THISTLE (*Silybum marianum*) — Asteraceae

Type Stout erect bushy annual or biennial herbaceous weed, can grow to 2.5 meters. Weed of disturbed areas, waste ground, near creeks and rivers old stockyards, may cause nitrate poisoning in stock. **Noxious weed** in SA, Tas. & Vic. Can take over pastures or crops. Many other thistle species are weeds in Australia.

Leaves Strong spiny bracts surround the base of the flower and stem.

Flowers Single and terminal on branches. Flower heads are large (up to 60 mm across) and showy with clusters of bright purple florets surrounded by long stiff spiny bracts.

Seeds Are about the size of a grain of wheat.

Roots Fibrous.

Spread By seeds via uncleaned cereal seed, feet of humans and livestock, fleece of sheep, wheels of vehicles, run off water.

Flowering stem, purple flowers

Description of some weeds species *(contd)*

Dicotyledons - Broadleaved weeds – SMALL OR FINE LEAVES.

(many flat or mat forming)

CHICKWEED (*Stellaria media*) Caryphyllaceae

Type Overwintering delicate herbaceous annual weed. Occurs universally in cultivated ground in high rainfall areas. Garden weed, competes with desired annual plants, eg flowers, vegetables. Do not confuse with petty spurge. Mainly vigorous in spring.

Leaves Small, light green, shiny and soft, on scrambling angular stems. Elliptical and opposite.

Flowers Very small, white, star-like, solitary on thin axillary stems.

Seeds Red-brown in colour.

Roots Fine and fibrous. Not stoloniferous. Does not resist close mowing. Can be hand weeded.

Spread By seed.

Leaves on young plant

PETTY SPURGE, RADIUM WEED (*Euphorbia peplus*) Euphorbiacese

Type Often a persistent small annual widespread herbaceous weed of cultivation. Occurs in gardens and surrounds. Been associated with poisoning of livestock, loss of appetite, reduced egg laying in fowls. Do not confuse with chickweed.

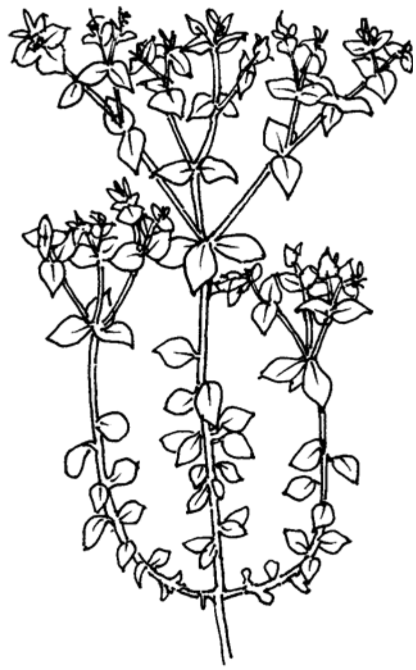
Leaves Small, light green, opposite, oval on many finely branched stems. Reddish stems with milky sap. Leaves often infected with rust.

Flowers Small inconspicuous yellow-green on flat-topped clusters of stems.

Seeds Pale gray, pitted. Can reproduce all the year round.

Roots Fine fibrous or tap root, stems break at the crown allowing the root to regrow.

Spread By seed.



Leaves and flowers

Description of some weeds species *(contd)*

Dicotyledons - broadleaved weeds – .WOODY WEEDS.

BLACKBERRY (*Rubus fructicosa*) Rosaceae

Type Introduced perennial deciduous shrub for berry jams, etc. Dense thicket-forming shrub from 2-6 m. **Noxious weed** in ACT, NSW, Vic, Qld, SA, Tas and WA. **WONS, ENV, Garden Escape**. Often common along waterways.

Leaves Usually dark green on the upper side and lighter green, often with whitish hairs on the underside; alternate; 3 or 5 toothed, oval to ovate leaflets with short prickles on leaf stalks or undersides of veins.

Flowers White or pink, 2-3 cm in diameter formed in clusters at the end of short branches, 5 petals.

Fruit A berry changing colour from green to red to black as it ripens, 1-3 cm in diameter consisting of an aggregate of juicy segments each containing 1 seed.

Seeds Light to dark brown, sometimes triangular, 2-3 cm long, deeply and irregularly pitted.

Roots Most roots occur in the top 20 cm of soil but a few to 1 m deep. There is a well defined crown at ground level.

Spread By seed spread by birds, foxes, creeks and rivers. Dislodged stem-tip rooting and root suckering, crowns, root pieces and stem fragments, by machinery, slashing and during removal.

Flower, berry clusters and leaves

BITOU BUSH, BONESEED (*Chrysanthemoides monilifera*) Asteraceae

Type Perennial erect woody shrub up to **3 meters tall**. **Noxious weed** in NSW, Vic, Qld, SA and WA. **WONS, ENV, Garden Escape**. Stems woody much branched, upper stems often purplish.

Leaves Alternate, 3-8 cm long, ovate to spoon-shaped, tapering at base, smooth-edged or slightly toothed. Shortly stalked, practically hairless, except for a cottony growth on young leaves.

Flowers Florets, bright yellow on shortly stalked heads, 2-3 cm in diameter clustered at the ends of branches, petals 5 or 6 occasionally 8 per head. Chrysanthemum-like hence botanical name *Chrysanthemoides*.

Fruit Berries are round, green, 5-7 mm in diameter and hang in clusters at the end of branches, during ripening they become black.

Seeds Seeds are globular or ovoid, 5-7 mm long and 3-4 mm in diameter, very hard and bonelike in color **(boneseed).** One mature bush can produce 50,000 seeds in 1 season. Most seeds remain viable for 2-5 years.

Roots Shallow, no distinct tap root. Rotundata roots on prostrate stems in contact with soil.

Spread By seed, was introduced as a sand dune stabilizer, dumped with rubbish. Birds, rabbits, foxes and cattle spread seed in their dropping. Contaminated gravel. Seed and ripening fruits by running water.

Leaves and flower cluster

Description of some weeds species *(contd)*

Monocotyledons (narrowleaved weeds) – GRASS WEEDS

(Family Poaceae)

COUCH, BERMUDA GRASS (*Cynodon dactylon*)

Type Sometimes sown as lawn grass, recreational turf. Perennial grass weed common in all states. Known to cause cyanic acid poisoning under some conditions but generally can be eaten without damage. Various turfgrass cultivars are used in the turf industry.

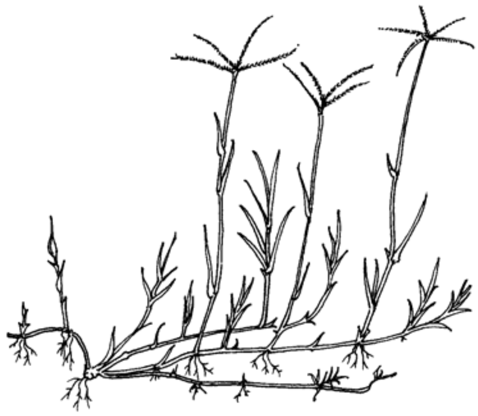
Leaves Prostrate rhizomes and stolons, perennial grass with hairs arranged in 2 rows on opposite sides of the stem. Commonly some specimens have sparse hairs on the top of the sheath and blades.

Flowers The inflorescence is finger-like. Spikelets are single-flowered and small. They occur in 2 rows on the under side of flattened main axis of the spike.

Seeds Only produces seed heads in neglected areas. Seed heads often infected with a smut disease (*Ustilago* sp.).

Roots Stolons root readily at nodes.

Spread By seed, rhizomes and stolons and by cut-up pieces of rhizomes and stolons during cultivation.



Leaves, inflorescences, stolons, rhizomes and roots
One of the world's worst crop weeds

PASPALUM (*Paspalum dilatatum*)

Type Perennial summer growing grass which can grow up to **1 meter** in favorable conditions. Can be a useful pasture plant. Naturalized in all states, often troublesome in gardens especially in lawns. Will crowd out clover and become dominant.

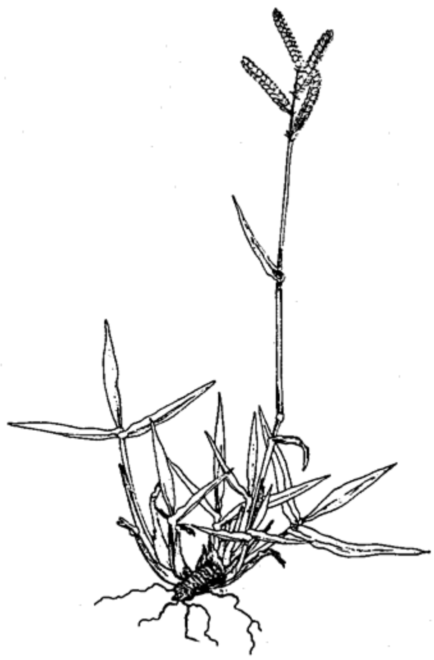
Leaves Rolled in bud leaf, medium texture, gray green, long parchment ligule.

Flowers Spikelets of 3-7 arms. Inflorescence is sticky to touch.

Seeds Seed heads may be infected with paspalum ergot (*Claviceps paspali*).

Roots Deep, fibrous from strong short woody stolons and rhizomes.

Spread By seed, by the growing of stolons and rhizomes and by cut-up pieces of stolons or rhizomes spread during cultivation.



Leaves, flowers and roots
Major world weed especially in perennial crops.

Description of some weeds species *(contd)*

Monocotyledons (narrowleaved weeds) – GRASS WEEDS. *(contd)*

(Family Poaceae)

SUMMER GRASS (*Digitaria sanguinalis*)

Type Annual summer grass weed.. May disappear with the onset of winter. **Do not confuse with paspalum**. Sometimes called crabgrass. Very common in temperate areas occurs in all states especially where summer water is available, as in suburban gardens.

Leaves Rolled in bud leaf, medium texture. Soft, gray-green. Ligule very long, parchment, white, pink, tipped. Hairy sheath and reddish-brown stems.

Flowers Fine widely branched spikelets. Whorled stems.

Seeds Seeds profusely.

Roots Fine, vigorous, fibrous from extensive stolons.

Spread By seed. Plant more-or-less lies on the ground and tends to root at the stem nodes.

Leaves, inflorescences, stolons and roots

WINTER GRASS (*Poa annua*)

Type Annual grass weed, but can be a short-lived perennial depending on the situation. Cosmopolitan, occurs widely in temperate areas of Australia. On paths and similar situations it is very small or almost prostrate but can grow up to 30 cm high. Mainly a winter and spring weed which disappears with the onset of summer. Can withstand close mowing in lawns and turf. Weed of cultivation, lawns and wasteland.

Leaves Folded in bud leaf, light green, fine texture with crimped blades. Long parchment ligule.

Flowers Short panicles or spikelets.

Seeds Seeds small and flattened.

Roots Fine, short, fibrous from tillers.

Spread By seed.

Leaves, flowers and roots

Description of some weeds species *(contd)*

Monocotyledons (narrowleaved weeds) – SEDGES *(contd)*

(Family Cyperaceae)

MULLUMBIMBY COUCH (*Cyperus brevifolius*)

Type Persistent herbaceous perennial up to 15 cm high. Resists close mowing. A true sedge not a grass. Pest in lawns and occasionally pasture.

Leaves Grass-like, shiny light green, linear, in three's. Triangular stems. Pungent odour when bruised.

Flowers Terminal, globular or cone-shaped knobs, green to white when mature.

Seeds Seeds freely.

Roots Masses of fibrous roots developing from creeping stolons with extensive shallow rhizomes.

Spread By seed and by stolons and rhizomes.

Leaves, inflorescence and stolons

NUTGRASS (*Cyperus rotundus*)

Type Persistent perennial herb usually 20-50 cm high, troublesome weed of cultivation., gardens and surrounds. Does not resist close mowing as in golf and bowling greens. Probably indigenous to Australia. A true sedge not a grass. **Noxious weed** in SA; is said to be the world's worst weed; it occurs as a weed in at least 100 countries and is possibly the gardener's worst nightmare.

Leaves Grass-like, shiny dark green, linear, in three's. Triangular stems.

Flowers Terminal umbels of feathery, grass-like, brown flowers.

Seeds The 'seed' is three-angled and less than half the length of the enclosing glume.

Roots A mass of deep rhizomes with underground tubers up to 25 mm long attached which give rise to shoots and rhizomes. Chains of up to 15 tubers develop.

Spread By seed and by rhizome roots with tubers readily spread by cultivation, is the basis of its troublesome nature.

Flowers, rhizomes and tubers
One of the world's worst weeds.

REPRODUCTION

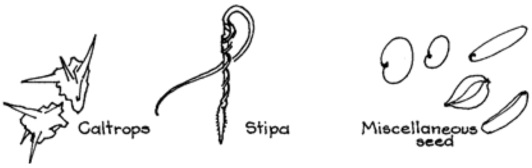
Know when weed seeds will germinate and the length of the germination period

Caltrops means many-pointed

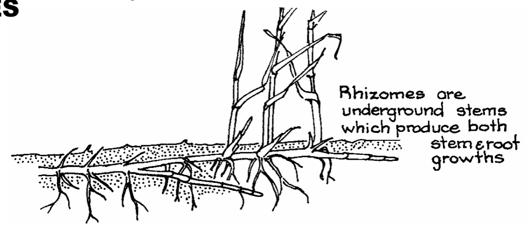
Stipa means stem-like

Weeds mainly reproduce by **seeds.** However, they may reproduce by **other means**, eg **stolons**. Some weeds reproduce by more than one method. It is important to know all the methods by which your weed reproduces.

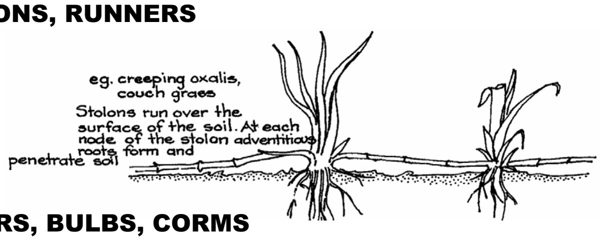
SEEDS



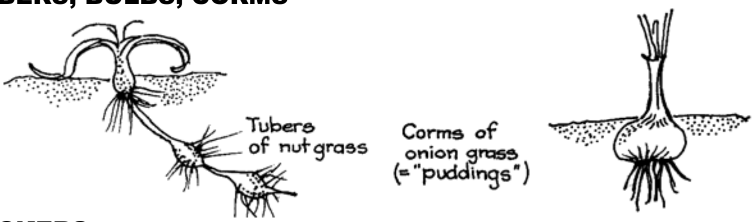
RHIZOMES



STOLONS, RUNNERS



TUBERS, BULBS, CORMS



SUCKERS

ROOT PIECES

Skeleton weed is troublesome because it can reproduce freely from both seed and pieces of underground stems. Tools and machinery used in cultivation cut up underground stems encouraging development of more plants.

OVERWINTERING, OVERSUMMERING, THE SEED BANK

With poorly competitive crops, seedbank levels can reach **10000 ryegrass seed/m²**

There can be 75000 seed/m² of perennial veldt grass after fire

WEEDS 'OVERWINTER' IN MANY WAYS, eg

- Contaminated produce and planting materials, eg stored grain, seed, bulbs, tubers.
- As biennial and perennial weeds.
- Weed seed and vegetative propagules, eg cuttings, bulbs, tubers.
- **Soil** acts as the primary storage bank for **vegetative propagules** and **seeds**, eg
  - **Rhizomes**, stolons, runners, tubers, bulbs, corms, suckers, root pieces.
  - **Roots** may grow to a depth of **more than 2 metres** (inside back cover).
  - **Seed banks** refer to the existing seeds in soil. The weed seed bank is a reservoir of weed seed in the soil or on the soil surface. Seed content of soil can be determined and used to predict future weed problems in the field and aid in the development of effective weed management systems. One **broom plant** can produce thousands of seeds that remain viable for many years. Up to 15,000 seeds/square meter of **Chilean needle grass** are found beneath infestations. New weed seeds are continually added to the soil so weeds are never eliminated. The seed bank largely determines the species composition and potential densities of weeds that subsequently develop with crops during the growing season. **Annual grasses** are an exception as seeds of few grass species persist for longer than 4 years. Poppy seeds persist for decades.
  - **Reducing the weed seedbank** assists in the fight against herbicide resistance. Researchers are focusing on ways to lower the numbers of seed in the soil, in an effort to lessen dependence on herbicides.

Weed Seeds – Breaking the Bank www.grdc.com.au/

SPREAD (dispersal)

Weeds spread very efficiently by:

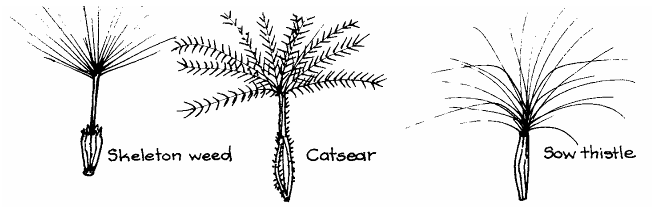
RHIZOMES, STOLONS, TUBERS, SUCKERS (page 426)

Climbing weeds, eg bridal creeper, will climb over adjacent plants.

WIND AND AIR CURRENTS

Some weed seeds are very light and have attachments of silky hairs, parachute-like structure or downy coverings which may travel for many miles on air currents. Wind can blow seeds. Pampas grass can produce 100,000 seeds per plume which can be carried more than 39 km to invade the bush.

Weeds generally spread very efficiently and are spreading faster across Australia than they can be contained



EXPLOSIVE MECHANISMS

Seed capsules of oxalis and flickweed (*Cardamine hirsutus*) open explosively and spread to adjacent pots.

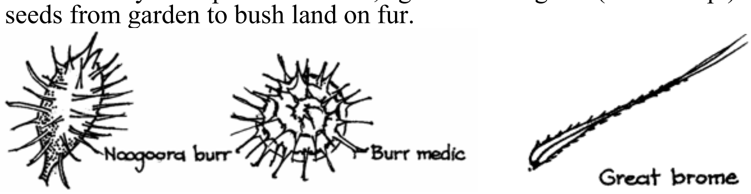
H_2O

WATER

Some weeds, eg Noogoora burr, are adapted to float on water or to be moved by the force of running water. Generally seeds, fruit, bulbils and other plant parts can wash down drains into waterways where they grow and spread. Irrigation water can be a source of weed entry. Floods spread seed of *Mimosa pigra* and willow parts.

ANIMALS

- **In manure.** Some weed seeds may pass undigested through animals, eg birds, feral pigs, possums, stock, foxes, so that their manure may carry viable weed seeds some weeds. **Manure deliveries** may contain weed seeds, eg nettle seed in sheep manure.
- **Birds** eat fruits and seeds of weeds, eg blackberry, cotoneaster, lantana, mistletoe, privet, spreading seed through bush where the seed germinates. The seeds of cotoneaster can be carried for many kilometers in the digestive tract of animals. **Flying foxes** eat fruit and seed and carry it to nearby bushland.
- **Adherence to animals.** Seeds with burrs may attach to wool, fur, feathers and feet of animals and may even penetrate hides, eg corkscrew grass (*Aristida* sp.). Pets carry seeds from garden to bush land on fur.



HUMANS

- **Quarantine.** Up to **70% of weeds** were **intentionally** introduced to Australia in the early days of settlement for crops, pasture or as ornamental plants. Seeds and other plants have been brought in **unintentionally** in agricultural products aboard ships and air craft, importing contaminated seed from overseas. Many plants previously used as crops or ornamentals are today's weeds.
- **Crop seed** unintentionally sown after harvesting from weed-infested crops.
- **Sale** of invasive or potentially invasive plants.
- **Nursery containers** may contain weeds, weed **seeds** or **stolons** of weeds, eg creeping oxalis, flick weed. Weeds spread to gardens, parkland, etc.
- **Movement of contaminated fodder hay**, chaff, or mulch, agricultural produce can result in weed outbreaks in new areas, eg dodder, thistles.
- **Seeds with burrs** which attach to clothing, socks, trouser legs, shoes.
- **Garden plants** which have spread from where they were originally planted in gardens and urban parks, eg Scotch broom, lantana, hawthorn, gorse.
- **Dumping** of garden waste, eg rhizomes, bulbs, cuttings and prunings which may produce new plants, over back fences or into bushland or forests. Emptying aquarium plants into drains, waterways, eg water hyacinth, salvinia, equisetum.
- **Direct invasion from neighbouring properties**, eg ivy may creep vegetatively from gardens into parkland.
- **Moving soil and plant material** through the landscape, eg soil deliveries, soil and gravel removed from river banks, etc.
- **Machinery and vehicles.** Seeds, bulbs, and other plant parts are carried on slashers, graders, mowers, vehicle tyres, tools, boats, trailers, camping equipment.
- **Unfiltered or recycled** water, recycled potting mix.
- **Fortuitously**, eg vehicles parked under trees which are seeding, eg alder trees.

CONDITIONS FAVOURING

Global proliferation of environmental weeds has coincided with the huge population explosion and led to an increasing similarity of plant species in regions with similar climates.

Evolution scientists warn that the spread of a global pest and weed environment, where less specialized animals and plants such as cockroaches, rats, nettles & thistles will flourish at the expense of more specialized wild organisms.

Weed Wizard warns of potential weed problems while they are still avoidable. **Wizard** simulates the interaction between weather, paddock management and seed biology and so tracks and predicts the number, ages and soil depths, dormancy levels, viability and germination of seeds in soil.

CONDITIONS FAVOURING WEED INFESTATIONS

- **The three most important factors** influencing weediness of a plant are invasiveness, impacts and potential distribution.
- **Poor crop planning**, limited **IWM** (Integrated Weed Management).
- **Management practices**, eg
  - **Weed floras change with changes in agricultural and horticultural practices**. Recent emphasis on crop diversification and reduced tillage has created new weed problems, weed species which were previously controlled by tillage, including perennial weeds and some annual grasses, are controlled by changes in chemical use and possibly by periodic cultivation every few years.
  - **Reduced crop diversity.** Many growers have moved away from crop rotations to growing a single crop continuously.
  - **Grazing intensity and timing** is often a major contributor to pasture decline and weed invasion, which may result in more acid soil, water leakage, reduced organic matter, reduced biodiversity above and below the surface, increased dryland salinity and lower water quality all causing reduced productivity and profitability, droughts exacerbate the weed problem.
  - **Disturbance** is a precursor to invasion by some weeds, eg thin turf, over-grazing, agriculture, fertilizers, erosion, trampling, clearing, landscaping, road making.
  - **Properties with uncropped areas** always have greater weed problems than where weeds are well controlled throughout. Weeds may first grow in wasteland around buildings, paddocks and on fallow land, then produce seed or rhizomes which spread to adjacent crops.
  - **Incorrect timing** of weed control, eg cultivation, mowing, herbicide applications.
- **Temperature and moisture** are critical for weed seed germination; weather forecasting systems can help pin down when weeds will emerge.
- **Climate change**. Simulation models predict future distribution of weeds. Weeds may be favoured over native flora. Tropical weeds may extend their range, fewer frosts mean some weeds will spread to new areas, alpine plants will decline, and unpalatable grasses will grow more densely, creating a greater fire fuel load. Bumble bees are efficient pollinators and if exotic species are introduced they may better pollinate existing weed species.
- **Lack of knowledge** of weed problems, eg **large seed banks**, which exist and may increase, in present and future crops.
- **Herbicide resistance.** Repeated use of many herbicides has lead to resistance problems. so that many weeds are hard to control, eg annual ryegrass.
- **Empty niches**, eg many grass weeds establish in sunny pockets in the bush. Sites such as shady areas under trees, burnt out areas after fires.
- **Continuous cropping**, resulting in volunteer crop plants regarded as weeds.
- **Fertilizer.** Exotic weeds thrive in soils enriched by run-off from lawns, gardens, crops, nurseries and where fertilizers are used in excess. High phosphorus content of many fertilizers may kill or weaken native vegetation which competes with weeds.
- **In their natural habitat** plants are often controlled by climate, predators, etc. In regions with very cold winters many plants are killed each winter and do not have time to become pests. When introduced to warmer climates such plants can grow throughout the year or have only very short periods of dormancy with no natural means of control, eg no imported pests and diseases.
- **Many garden plants** still being purchased plants from hardware and garden suppliers and nurseries, have the potential to become weeds, eg ornamental grasses.

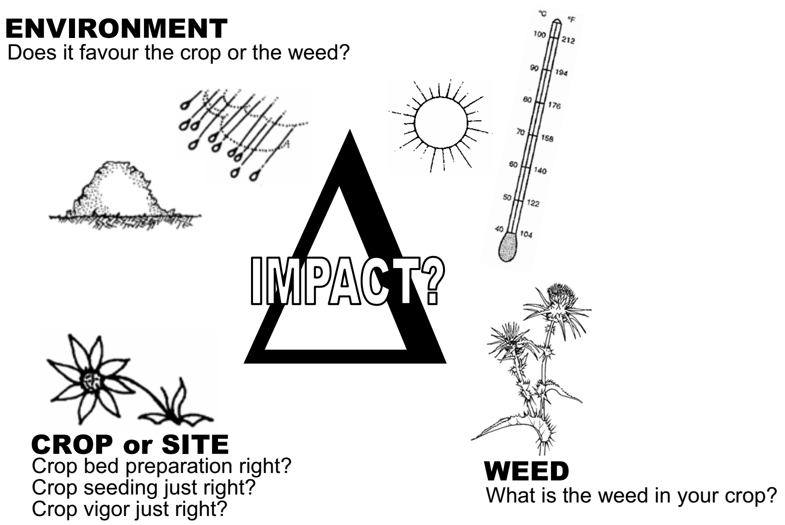


Fig. 247. Weed triangle.

INTEGRATED WEED MANAGEMENT (IWM)

MAIN STEPS

IWM is not a specific set of rules, there is no central program for everyone

PLAN
PLAN
PLAN

1 2 3 4
5 6 7 8

?

✓ X

IWM aims to achieve **long term, sustainable weed management**, including the management and minimization of herbicide resistance.

1. **Plan** well in advance to use an **IWM** program that fits your situation. Some expertise is needed to use an **IWM** plan. Plan to keep records of the crop, eg pre-plant weed control, source of planting material, planting/sowing dates, temperature, irrigation, fertilizers and pesticides, cultivation, minimum tillage.
2. **Crop/region. IWM** programs are available for weeds in a range of crops, regions and situations. Check if one is available for **your weeds**, eg
   - Most commercial crops have weed management programs.
   - Weed Management in Woody Cut Flower Plantations.
   - Integrated Weed Management Manual www.**weeds**.gov.au/
   - GRDC Weedlinks www.**grdc**.com.au/
   - Management Guides are available for all **WONS** www.**weeds**.org.au/
3. **Identify** and collect information on weeds in your crop/region. Grass weeds can be difficult to identify. Consult a diagnostic service if necessary (page xiv). Successful **IWM** depends on **sound knowledge** of weeds, their life cycles, spread, conditions favouring, population distribution, and possible control measures. Obtain a fact sheet for each weed. **Early detection and identification** of weed species is essential for effective management of weed problems before they escalate.
4. **Monitor, record and map** presence of weeds early to assess their impact, rate of spread and effectiveness of earlier control measures. National classification systems of weed mapping are available for some weeds. Keep accurate and consistent records.
   - **For crop areas**, **know when** to monitor, eg weather warning systems can indicate when temperature and moisture are critical for weed seed germination - the **Weed Seed Wizard** simulates interactions between weather and agronomic practices to predict likely weed seed germination. **Know where** and **what** to monitor, eg existing weeds, stages of **weed/crop** growth, seeds/rhizomes in the surface layers of the soil, seedbank. **Know how** to monitor, eg map existing weeds, visual assessments can be made on foot with GPS. Serrated tussock and scotch thistle infestations have been mapped by airborne and satellite imagery. Conduct soil germination tests for weed seeds and rhizomes in the surface layers. Overseas equipment has been developed to estimate the density of weeds in the soil seedbank from soil cores.
   - **For environmental areas**, you also need to **know when**, eg during autumn, **where,** eg bush areas, **what**, eg autumn colours of certain weeds, and **how** to monitor, eg on foot, by vehicle or canoe, by aerial photography or satellite imagery.
5. **Thresholds** for selected weeds in a particular **crop/region** should be set then efforts made to achieve them. Has a threshold been established? If so, what is it, economic, aesthetic, environmental? What level of weed control is necessary? Set targets; will these weeds affect my yield? Do they affect biodiversity, etc?
6. **Action/Control**. Requirements of **legislation**, **organic or other standards** must be met, otherwise try to implement **preventative** measures strategically and early to avoid potential major weed problems. Available weed control methods do not eradicate weeds unless they have been selected for a national or state eradication program. Actual methods used will also depend on the situation, crop and the weed.
   - For **weeds not yet in Australia, or a State/Territory**, quarantine can prevent entry.
   - For **new arrivals** or those of limited distribution, spread can be minimized by early detection and **Weed Incursion Rapid Response Programs**. Noxious weed legislation and other regulations are most effective during early stages of invasion. Eradication could be attempted and their availability restricted/banned.
   - For **established weeds eradication is not usually possible, and the aim is to control existing weeds, prevent spread, reduce seed set and the seedbank.**
7. **Evaluate** the program. **Performance standards** for weed management are being developed. **Record findings** and adapt the program from year to year as weed problems change and new control methods, herbicides and equipment become available, eg if weeds had already formed seeds, begin control earlier next year.

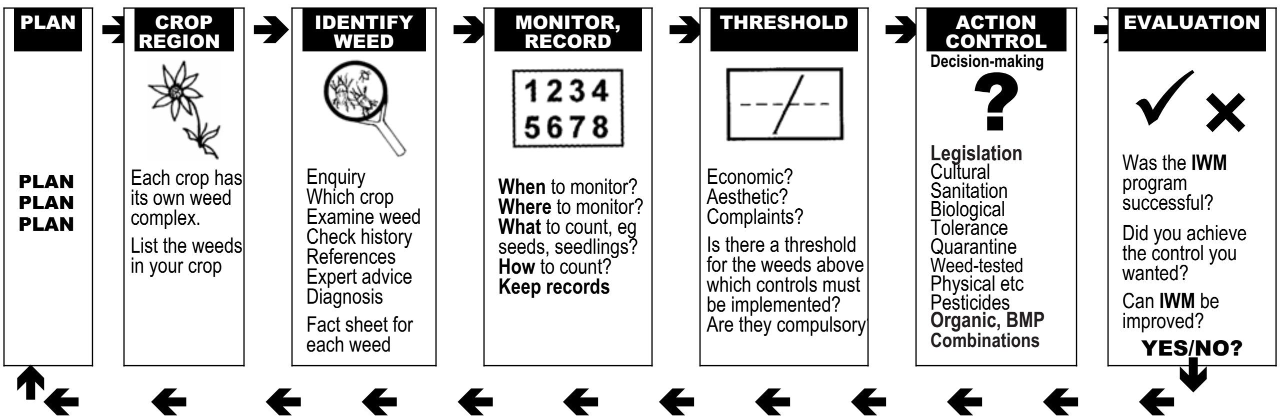


Fig. 248. Steps in IWM.

EFFECTIVE WEED MANAGEMENT

A coordinated approach to weed management is necessary. In Australia, effective weed management is hampered by:

- **Extensive nature** of Australia's agriculture, bushland, etc.
- **Some of the 'worst' weeds** may be so well adapted to the niches they exploit, that measures taken to control them may have only limited effectiveness.
- **Multiplicity of landholders**, both private and public together with the many additional organizations that have indirect influence over land. People who influence the weed flora in Australia are the agricultural and horticultural industries, nurseries, parks, catchments authorities, and so on.
- **Multiple lists** of different types of weeds, eg **WONS**, Alert lists (pages 414-415).
- **Large bureaucracy and websites** which seem to be becoming even larger and more complex, even duplicating each other.
- **Prevalence of herbicide resistance** and large seed banks.
- Because many other countries have lost their natural biodiversity and most floras have come from naturalized species from other areas, Australia is one of the very few countries of the world trying to manage invasive plant species (Thorp 2008).

www.**daff**.gov.au/

TRAINING

- **National Competencies for Weed Management**:
  www.**weeds**.org.au/
- **Training Schemes** are available for specific groups of people, eg
  - Weed Control Assistants
  - Weed Spray Operators
  - Weed Control Officers (Local Government)
  - Weed Control Contractors
  - Parks Rangers
  - Bush Regenerators
  - Landholder Government Advisors
  - Labour Market Programs
  - Managers of Weed Management programs at all levels
  - Volunteers, eg Landcare, Conservation volunteers, Greencorp
- **Special courses/guidelines/best management practice** are available for managing specific **weeds and crops**, etc, including
  - **Specific weeds**, eg bitou bush, cape ivy, Paterson's curse, willows, serrated tussock (**WEEDNet**), managing wild radish.
  - **Specific crops**, eg agricultural crops, turf, fruit trees, vegetables, viticulture, containers, cut flowers.
  - **Riparian weeds in waterways**.
  - **Best Management Practice** for 20 **WONS**, National Weed Strategy
  - **Nurseries**, eg Bush Friendly Nursery Schemes.
  - **Weed Seeds–Breaking the seedbank**, eg **GRDC** www.**grdc**.com.au/
  - **Management Guides** for wild radish, wild oats, pasture, Paterson's curse, ragwort.
  - **Environmental Weed Best Practice Management Guides**, eg Scotch broom, bitou bush, boneseed, blackberry, bridal creeper, St John's wort, horehound.
  - **Workshop proceedings**, eg thistle, bitou bush, wild radish, arum lily, survey workshop, spiny emex, St John's Wort, broom.
  - **Weed Seed Wizard** (treat the seeds not the weeds) is a management tool for farmers to assess weed populations, reduce viable seed in the soil seed bank.
  - **Introductory Weed Management Manual** www.**weeds**.gov.au/
  - **Integrated Weed Management Manual** www.**weeds**.gov.au/
  - **What Does Your Garden grow?** Available online.
- **Weed courses include the following segments**.
  - **Legislation.**
  - **Licensing of operators.**
  - **Identification of weeds**, including weed seeds, weed seedlings, mown weeds, but especially grass species.
  - Type of weed, life cycle, overseasoning, spread, conditions favouring. Fact sheets for each weed.
  - Weed mapping, weed tests for soils by germination.
  - Integrated weed management (**IWM**)
  - Methods of non-chemical and chemical weed control
  - Apply herbicides safely and effectively.

Control methods

LEGISLATION

GLOBAL

- **The Convention on Biological Diversity (CBD)** is a global agreement to conserve biodiversity, to sustainably use the components of biodiversity and to share the benefits arising from the commercial and other use of genetic resources in a fair and equitable way.
  Convention on Global Diversity www.**cbd**.int/
- **The Global Invasive Species Information Network (GISIN)** is a web-based network of data providers, eg government, non-government, non-profit, educational, and other organizations that have agreed to work together to provide increased access to data and information on **Invasive Alien Species (IAS)** around the world.
  GISIN www.**gisinetwork**.org/

COMMONWEALTH LEGISLATION, REGULATIONS, ETC

These publications are available online

- **Environmental Protection and Biodiversity Conservation Act1999** (the **EPBC** Act) is the Australian Governments central piece of legislation of environmental legislation. The **EPBC** Amendment (Invasive Species) Bill 2002, prohibits the trade in invasive plant species of national importance, combined with state and territory commitments to prohibit these same species under their respective laws. The Senate Committee Report, *Turning Back the Tide: The Invasive Species Challenge*, describes the regulation, control and management of invasive species.
- **Legally-binding weed lists** include **WONS**, *National Environmental Weed Alert List* (page 414).
- **Quarantine Act 1908 (*Cwlth*)** which includes lists of prohibited weeds, eg search for *Target List for Weeds* and *Permitted Seeds* on www.daffa.gov.au/**aqis**/
- **Australian Standards**, eg www.**standards**.com.au/
  - *Composts, Soil Conditioners and Mulches*
  - *Potting Mixes, Composts and other Matrices - Examination for Legionella species.*
  - *Synthetic Weed Blocking Fabric.*
  - *Organic and Biodynamic Products Draft for public comment*
- **Advisors and policy makers** include:
  - The **Weeds in Australia** web site provides information on weeds and weeds management at the national level. It links to information and services on Australian Government and selected state and territory web sites. www.**weeds**.gov.au
  - National Weeds Management Facilitator and the network
  - **The National Weed Strategy: A Strategic Approach to Weed Programs of National Significance 1999**, charges the Australian Weeds Committee to ensure an effective integrated approach to all aspects of weed management through **cooperation** with environmental agencies, land managers, landcare and nursery groups, landscaping and turf industries, botanic gardens, local government, community groups.
  - The **World Wildlife Fund (WFF)** has examined the **effectiveness** of National and State legislation in dealing with weeds, especially those emanating from horticulture. www.wwf.org.au/ourwork/**invasives**/
  - Bureau of Rural Sciences
    The **BRS advises policy makers** in the management of weeds in Australia (currently **WONS** and agricultural sleeper weeds) based on ecological modeling and risk assessment, eradication studies and managing weed information www.daff.gov.au/**brs**/**land**/**weeds**
- **Accreditation schemes**, Best Practice Management Guidelines, Codes of Practice, etc, exist for businesses. The **Nursery Industry (NGIA**) aims to:
  - **Implement a mandatory national plant labeling scheme** at point of sale identifying potentially invasive species in certain areas of Australia, their means of disposal, poisonous nature, etc (Spencer 2006). It means that all plants sold through association nurseries would be labeled with correct botanical names, intellectual property such as Plant Breeder's Rights and trademarks, plant growth requirements and indicate whether they are potentially hazardous to health and the environment.
  - **Advise against the production of plants for sale or trade** if they are on the **WONS** list in all jurisdictions of Australia and if they are on the **Alert List** and **Noxious Weeds List**. This list will be jurisdiction-specific and will affect what may be sold in various regions. The label should state any restrictions to where the plant is grown. It also recommends plant management guidelines if a plant shows invasive tendencies such as "remove seedlings after flowering, and dispose of plant or fruit via burial or at an approved composting facility."
- **The Australian Weeds Research Centre**, funded by the government, aims to reduce the impact of weeds on farm and forest productivity and biodiversity.
- **The National Weed Detection Network (NWDN)** detects new incursions at a stage when eradication or containment is possible, minimizing control costs and impacts. Volunteers are called **weed spotters** who employ fortuitous surveillance (spotting weeds while engaging in other activities). Specimens are identified by botanists, fully documented and recorded, the government notified of any new naturalizations, new occurrences of declared weeds and any new and emerging weeds.

LEGISLATION

contd

STATE/TERRITORY/REGIONAL/LOCAL COUNCIL LEGISLATION

- **Noxious weed legislation** exists in all States/Territories and varies slightly from state to state and between local council areas. Noxious weeds are grouped into classes which can vary from a few to many, depending on the state/territory. However, in all cases the legislation aims to reduce the negative impact of **significant** weeds on the economy, community and environment, by establishing control measures to prevent the introduction and establishment of new weeds, restricting the spread of existing weeds and eradicating specified weeds. Control measures are prescribed by legislation and depend on the weed in question. The **Australian Weeds Committee** prepares and updates the 'Noxious Weed Lists for Australian States and Territories. Individual weeds, State and Territory lists or the entire noxious weed list (in table form) can be accessed via the following website:
  Weeds in Australia www.**weeds**.gov.au/

Obtain a summary of **local weed legislation** which will have current lists of declared weed species and your responsibilities

Councils often have designated Weeds Officers

  – **'Prohibited' weeds** pose a serious threat and have potential to spread, **notification** of their presence is required; they may need to be continually suppressed, contained or eradicated and it is illegal to keep, sell or move them.
  – **'Restricted' weeds** have potential to spread, trade in these weeds and materials containing them is prohibited.
  – **Eradication** of pest plants from the state or parts of the state may be required.
  – **Contain, suppress, and control** certain weeds in only parts of the state/territory.
  – **Weeds not to be introduced** into the state/territory.
  – **Penalties.** Control of noxious weeds is legally the responsibility of the private landholder, local authority (councils etc) or State/Territory government
  – **Others**, eg compulsory control of certain weeds on public or government land.
- **Specific Acts/Tree orders/Taskforces**, etc
  – **Various taskforces** have been set up, eg NSW Lantana Taskforce, Prickly Pear Act.
  – **Seed Acts** make it illegal to sell grain, fodder or crop seed which contains seeds or any other parts of a noxious weed capable of growing.
  – **Quarantine** legislation.
  – **Tree Preservation Orders** may conflict with weed legislation. If a 40 meter tall 'protected' tree is found to be an environmental weed, how do you prevent seeding.
- **Many voluntary schemes,** eg **Weed Swaps** for less invasive species. Spencer (2006) suggested 'retro-fitting' gardens, eg a property could be certified weed-free, issued with a voucher to purchase alternative plants from the nearest garden centre.
- **States/Territories/Shires/Councils** have weed information on their websites. An **Exotic Weeds Watch List** is available online.

CULTURAL METHODS

CROP COMPETITION

Many crops compete strongly with weeds when established but need protection during their early growth. Some crops, eg onions which germinate and grow slowly, have narrow erect leaves and wide row spacings, compete poorly with weeds.

- **Control weeds prior to planting**, eg tillage, herbicides, slashing, green-manuring, grazing.
- **Increase and maintain 'crop' vigor** to compete effectively with weeds during germination, establishment and maintenance, to reduce the need for weed control and reduce flowering and seed set on surviving weeds.
  – **Cultivar selection, smothering out weed competition early.**
    - ❑ Select varieties adapted to site, soil, water availability and season.
    - ❑ Select perennial pasture species to reduce weed establishment and assist in reducing existing weed infestations.
    - ❑ Choose wheat varieties with leafy and strong early growth.
    - ❑ Trees dominate site and shade out weeds. Mass plantings or dense prostrate species control weeds by early canopy closure, crowding and shading. Useful for rockeries and general plantings between trees and shrubs, vegetable gardens.
    - ❑ Crops can be **genetically engineered to** more effectively compete with weeds, resulting in increased production and reduced need for herbicides (page 436).
    - ❑ Legume pasture can substantially reduce a ryegrass seedbank.

A **seed bank** is supplemented by incoming weed seeds transported via wind, etc. It is important to **regulate** seed populations

  – **Sowing dates** should coincide with optimum soil temperature, moisture, etc for the crop, to encourage rapid establishment and growth. **Fertilisers** are more efficient when weeds are controlled at planting.
  – **Sow at rates** so that crops rapidly occupy all space above and below ground. Narrow row spacing with high sowing rates can quickly shade areas between plants in some cases.
- **Control pests and diseases**, gaps and weakened plants can reduce yields and provide space for weeds to grow.
- **Replacement vegetation**. Accompany weed removal with a planting program, eg planting a crop, re-vegetation of bush areas by seed or tube stock, replacing invasive plants with safer alternatives. Local councils have lists of alternatives suitable for their regions. **NGIA** is expanding the **Grow Me Instead** program.

Grow Me Instead Programs

CULTURAL METHODS
(contd)

CROP ROTATION

- **Crop rotations are designed to control weeds**, some pests and diseases, and to retain and build up soil fertility and structure.
- **Appropriate crop bed preparation** after a rotation, prior to planting.
- **Intercropping**, eg companion crop, undersowing, hedges, brassicas crops, wind breaks, permaculture systems.
- **Green manure crops**, living mulch, grazing, cash crop sequence, fallowing. Organic matter or green manure crops must be allowed to decay and organisms can destroy weeds seedlings. Brassicas can suppress weeds.
- **Crop rotations, seedbank monitoring and careful management** have allowed farmers to contain the seedbank of herbicide-resistant ryegrass to manageable levels, ie to less than $1000/m^2$ (from highs of $10000/m^2$) (page 426).

Why reduce the weed seed bank in the target area over time?

- By maintaining a falling trend in the size of the seedbank (page 426), there are fewer weeds to be sprayed, weed control methods are more effective and there is reduced the risk of developing herbicide resistance (page 450).

What can you do?

- Prevent introduction of viable weed seed from external sources, eg control weeds in surrounding areas before they set seed, do not introduce infested soil, seed, etc.
- Prevent established weeds in the target area from setting seed, eg control weed seedlings, eg rogue, mow, spray, when weed populations are low and before seed set.
- Practice recommended crop competition, crop rotation, etc.
- Practice seedbank monitoring.
- Follow specific guidelines produced by **CropLife Australia** and **GRDC** and follow resistance management strategies on herbicide labels.

CropLife Australia www.**croplifeaustralia**.org.au/
Weed Seeds – Breaking the Bank www.**grdc**.com.au/

CULTIVATION

Know conditions and practices which encourage weed seed germination

- **Reasons for cultivation – weed control**
  - **'Tickle' or shallow cultivation** promotes earlier and more uniform germination of certain weed seeds by placing seed in a better physical position in the soil, eg contact with moisture, protection from drying out, prior to sowing the crop. These germinating weeds can then be controlled either by further cultivation, herbicides, etc. However, some weeds, eg radish, germinate sporadically so that late germinations flushes can be difficult to control.
  - **A naturally occurring germination stimulant**, karrikinolide is being trialed to reduce the extent to which cultivation is used to stimulate weed emergence and improve the sustainability of minimum tillage farming systems. Karrikinolide promotes weed seed germination so they can be controlled by fewer herbicide or other treatments.
  - **Pre-sowing cultivation** (or herbicide application) effectively controls young weed seedlings and annual weeds that have been allowed to develop (see above), reducing weed infestations in new plantings. The smaller the weeds at cultivation the more rapidly, efficiently and cheaply, they are destroyed. Cultivation kills weeds by burying shoots to prevent re-growth, roots and shoots exposed to air dry out and die. More effective if carried out on warm days.
  - **Cultivation can be used to control weeds during a fallow**, ie the non-crop period. Traditionally fallow management is based on clean cultivation.
  - **Cultivation at the correct time** prevents existing weeds from seeding and exhausts food reserves of perennial weeds through repeated disturbance.
  - **Cultivate only as needed** to limit soil disturbance and to keep weeds from competing with the crop or from setting seed. **Soil disturbance** can dramatically reduce the effectiveness of pre-emergents.
  - Cultivation also aids moisture and nutrition retention.
- **Disadvantages of cultivation.**
  - If soil is too wet or too dry, cultivation can exacerbate rain and wind erosion.
  - Frequent cultivation reduces organic matter, adversely affecting soil structure.
  - Cultivation can damage crop roots and must be > 30 cm from tree stems.
  - Weeds with hard underground parts or deep roots may form more shoots.
  - **Perennial weeds** may remain alive buried in soil for some time and may be re-distributed, eg corms, cut up root pieces. Roots of perennial weeds which produce suckers may require herbicide treatment to stop regrowth from their roots.

CONSERVATION TILLAGE (CT)

- **CT** is aimed primarily at soil conservation and the need to conserve moisture to sustain productivity. **CT** eliminates some or all operations involving soil disturbance.
- In **CT** systems, **post-emergent herbicides** have largely replaced cultivation for weed control; modified implements allow sowing into stubble/uncultivated soil and more compacted seedbeds. In conventional crop production systems herbicides supplement tillage. As tillage is **reduced** the diversity of weeds may decrease but the numbers of these weeds surviving may increase.
- **In no-till systems** up to 70% of weed seed is on the soil surface and may be taken by ants and other predators, some will be decayed by fungi and other micro-organisms but some still remains. If stubble remains on the surface then conditions remain favourable for germination. These can be controlled with herbicides or suppressed by mowing, slashing or heavy grazing (page 438).

CULTURAL METHODS

(contd)

MULCHES

- **Suppress annual weeds** by excluding light needed for growth.
- **Are not very effective against perennial weeds**, eg tap rooted dandelion, stolons of couch grass. Nutgrass may grow through polythene film < 0.2 mm thick. Weed mat may be laid beneath mulches to prevent roots of perennial weeds which do develop in the mulch, from penetrating deep into the soil, making removal easier.
- **Must be porous** to allow water to seep through and air to circulate, of the correct depth, and aged and/or composted before use. Preferably lay when soil is moist.
- **Before applying mulch**, remove or spot spray weeds, especially perennials weeds.
- **Mulches protect soil** from wind and sun, reducing losses from evaporation.
  - Reduces soil temperature fluctuation, eg by up to 5°C in summer, in winter mulches shade soil from spring sunshine, slowing spring crop growth.
  - Protect surface and shallow feeder roots, increase beneficial soil microbes.
  - Coarse mulches control windblown weed seeds better than fine mulches.
  - Provide cleaner and easier harvesting of strawberries and ginger roots, etc.
- **Mulches** may be:
  - **Inorganic,** eg woven plastic weed mats, blue metal, crushed brick, river gravel mostly need to be applied to a depth of **9-10 cm** to provide adequate weed control.
  - **Organic**, eg bark, wood chips, sawdust, straw, hay, compost, pine needles, leaf litter. Pre-cut disks of breathable durable recyclable polypropylene can be placed around new or existing tress and shrubs, posts and in planters. Paper (pellets, sheets, rolls), cardboard, seaweed, wool, etc.
  - **Mulches provide shelter** for termites, slaters, etc. They can be a fire hazard.

SANITATION

CAREFUL MANAGEMENT

Sanitation may **overlap** with Physical and Mechanical Methods (page 438).

- **Sanitation** is important at all levels of **quarantine** to prevent spread of weeds, eg **washdown facilities** in the NT for barges going to the Tiwi Islands. **Cleaning** mowers, slashers, vehicles and earthmoving equipment after use in weedy areas before using in clean areas to **reduce spread** of weeds such as Chilean needlegrass.
- **Suppress weeds** by persistently preventing seed set and spread when weed populations are low as well as suppressing outbreaks of new weeds as soon as they occur by cultivation, mowing or herbicides, etc.
- **For greenhouses** maintaining a 3–6 meter weed-free barrier outside the greenhouse helps to minimize weed seeds entering via vents and doors.
  - **Screening vents** prevent windblown seeds. Porous concrete walkways and geo-textile fibre mats under benches help prevent establishment of weeds.
  - Keep potting mixes and ingredients covered.
  - Pots may be isolated from direct soil contact by use of screenings (8–10 cm of 18–20 mm gravel or blue metal) and concrete paths.
  - **Nursery accreditation schemes** specify weed control measures.
- **Disposal of garden waste, weeds.**
  - There are still many species in gardens that could naturalize in Australia.
  - **Do not dump** garden waste in bushland, over fences or cliffs or into creeks.
  - **Recycle** waste through local council or take it to the local tip.
  - **Cover trailers** when taking garden waste to the tip so seeds and cuttings do not fall off and invade roadside bushland. Double bag garden waste (place in one bag, knot, then place in another bag to stop seeds being spread en route, compost garden waste at home or take to a recycling site.
  - **Composting** garden waste at 60°C for 30 minutes will **not** kill most weed seeds. Properly carried out composting of bark will kill most weed seeds and plant parts.
- **Hand pulling and digging** out annual or herbaceous perennial weeds before they set seed, is suited for small shallow rooted weeds and small infestations. Easiest when soil is soft and moist. A mattock is useful for digging out many weed species. Hand weeding is laborious and can be an ineffective means of selectively removing weeds in large areas. Remember the soil disturbance will move more weed seeds into the germination zone.
- **Cutting woody weeds**. Use secateurs, hand saw or chainsaw is often used for controlling woody weeds and for some species that do not re-shoot, can be done without need for herbicides, eg wattles, pines (pages 467-468).
- **Control weeds on non-crop areas** around the nursery, farm, etc before they set seed. Immediate removal of undesirable weeds or strategic spot spraying can halt spread of weeds and reduce or eliminate use of herbicides.
- **Prevent spread** especially when moving soil and plant material through the landscape.
- **Some systems allow for the collection of weed seeds** at harvest.

BIOLOGICAL CONTROL

CLASSICAL BIOLOGICAL CONTROL is the deliberate release of a pest or disease after careful screening, to control a particular weed. Successful biological control is the most effective way to control most weeds in the long term.

- **Weeds targeted for biological control** are listed on the website below:
  Target species for biological control www.weeds.org.au/**target**.htm
- **Biological Control Act 1984 (*Cwlth*)** provides for the control of persons releasing agents, choice and declaration of target organisms and biological control agents, and approval for release.
- **The introduction of a potential biological control agent** is separately assessed under the **Quarantine Act 1908** and the **Environment Protection and Biodiversity Conservation Act 1999**. The assessment involves comprehensive host testing (testing what plants the biological control agent will attack) before release.
- **Releases** of biological control agents are made by a range of organizations, eg
  - Division of Entomology, CSIRO, Canberra.
  - Cooperative Research Centre for Weeds Management Systems.
  - Various task forces, eg NSW Lantana Biological Taskforce.
  - State Departments, eg Qld Dept. of Natural Resources.
  - Private companies.
- **Self-sustaining.** Classical control offers the only possibility for controlling many environmental weeds. Once established the pest or disease can spread naturally and reach long term equilibrium with its weed host, eg
  - Prickly pear by caterpillars of the *Cactoblastis* moth.
  - Skeleton weed by several insects and mites, and a rust disease.
  - Paterson's curse by several beetles and a leafmining moth.
  - Blackberry by a rust disease.
  - Bitou bush by various insects and a rust disease. Bitou bush is rated as the worst pest plant in the Australian coastal environment. Control has been hampered by drought during which leaves lose nutritional value making it difficult for young larvae to get a niche among the growth tips (*Tortrix* leafrollers) but other biological control agents such as the bitou tip moth (*Comostolopsis germana*) and the seed fly (*Mesoclanis polana*) are doing better.
  - St John's wort by a leaf beetle, various other insects and a rust disease.
  - Giant sensitive plant (*Mimosa pigra*) by more than 5 biocontrol agents.
  - Bellyache bush (*Jatropha gossypifolia*) by insects in Qld.
  - Bridal creeper by the bridal creeper leafhopper (*Zygina* spp.).
  - Salvinia by a weevil (*Cyrtobagous salviniae*).
  - Parkinsonia seed pods are eaten by camels reducing the plants ability to reproduce.
  - **Lucid Keys** *Identification Tool for Weevil Biological Control Agents of Aquatic and Terrestrial Weeds in the United States and Canada.*

BY BIO-HERBICIDES **(mostly myco-herbicides)**

Also called microbial agents

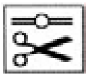
- **Bio-herbicides are fungi**, bacteria and other microorganisms, applied as a spray to weeds, causing an immediate epidemic resulting in death or reduced vigour. Effects tend to be short term in much the same way as chemical herbicides, eg
  - **Overseas a fungus** (*Ascochyta caulina*) can kill the main weeds affecting 10 major crops in Europe. It must be applied early otherwise weeds outgrow the fungus. It will not be available commercially for many years. **Mycoherbicides** including a fungus (*Phytophthora* spp.), are being researched to control the strangler weed in citrus orchards in Florida.
  - **In Australia**, *Colletotrichum orbicular* is being researched to control Bathurst burr (*Xanthium spinosum*) and *Drechslera avenacea* to control wild oats.
- **Main constraint** to the development of commercial mycoherbicides is the requirement of fungi for high moisture or free water environment. Formulations have been developed to overcome these constraints.

Mycoherbicides require a moist environment

- **Contraceptive sprays**. Self-incompatibility (SI) is a biological system that prevents certain plants from fertilising themselves with their own pollen thus reducing the production of fertile seed. Research is proposed to apply non-toxic sprays that mimic chemicals produced by certain plants to prevent self fertilization, allowing the plant to detect and ignore its own pollen. Wild radish (*Raphanus raphanistrum*) is one of the weeds to be trialled.
- **Allelopathy** is a release of a chemical by one plant species into the environment, which interferes with weed seed germination and growth of surrounding plants.
  - Massive reductions of **fat hen** has occurred in **sunflower** crops, sown **no-till** into desiccated green **rye** cover crops.
  - However the use of **white mustard** green manure (*Sinapis alba*) to control weeds in spinach and pea was more toxic to these crops than to weeds.
  - Several rice strains that apparently exude a chemical keep weeds at bay.

  www.regional.org.au/au/**allelopathy**/2005/2/1/index.htm

TOLERANT, WELL ADAPTED PLANT VARIETIES



SELECT PLANT VARIETIES WELL ADAPTED TO SOIL, CLIMATE, SEASON

- **Plant selection.**
  - Choose species that tolerate the proposed growing conditions well.
  - Do not select, grow or sell plant species known to become bush weeds in gardens, parks, roadsides. Plant alternative species. Hardy plants can become hardy weeds!
- **Genetic engineering (GE)**.
  - **Herbicide Resistant Crops by Biotechnology (HRCB**) aims to permit more effective control of weeds in particular crops, eg Roundup-Ready® cotton seed.
    - ❑ **Clearfield Production Systems** for canola, wheat and maize, eg the canola crop is tolerant to Intervix® (imazamox/imazapyr) which provides early post emergence control of certain grass and broadleaved weeds in canola crops.
    - ❑ **Cotton with tolerance to Basta**® (glufosinate-ammonium), **bromoxynil**, **2,4-D**.
    - ❑ **Tomato plants tolerant to paraquat**.
    - ❑ **TT canola** (Triazine Tolerant canola).
    - ❑ **RoundupReady** canola and cotton systems.
    - ❑ Herbicides are recommended to control Roundup Ready Canola Volunteers.
  - **Improving crop competition with weeds**.
    - ❑ **With herbicide resistance** a significant issue, improving **wheat's** ability to compete better with weeds will take the pressure of herbicides and probably reduce weed costs
    - ❑ **Competition.** Rice strains with early rapid growth and spreading leaves which cast wide shadows, can beat the weeds and deliver higher yields.
  - **Genetically modified organisms** are not permitted in the growing and processing of Certified Organic products (AS 6000—2009. Organic and Biodynamic Products).

PLANT QUARANTINE

AUSTRALIAN QUARANTINE & INSPECTION SERVICE (AQIS)

- **AQIS Import Conditions database (ICON)** offers up-to-date information on plants which are denied entry to Australia or may be imported upon the granting of an import permit from **AQIS**. There is a long list of **prohibited weeds** which occur overseas but not in Australia.
  - **Exotic weeds watch list.** If you find a weed on this list or one that you haven't seen before, report it immediately as this is the key to successful eradication or containment. It can also prevent or minimize the costs associated with an incursion such as market losses, eradication, and ongoing control and monitoring.

  www.**daff**.gov.au/

WRA

- **Weed Risk Assessment (WRA)**.
  - **All soil** and **some plants** are prohibited.
  - There is a **Permitted Seeds List** which is reviewed at intervals.
  - All plants imported to Australia are assessed by **AQIS** for their potential to become weeds. **WRA** assesses information and scores plant **invasiveness**, **reproductive capacity**, **impact**, **potential distribution**, etc, to determine how likely it is to behave as a weed. Weed control can be **prioritized**, contingency plans prepared on a large scale in a short time. It can still be difficult to be confident that a plant is non-invasive. Plants are assessed for this weediness by being given a score for their weedy characteristics, the larger the score the weedier it is.
  - Recording standards of weed control, eg weed mapping.
- **How do weeds enter Australia?**
  - More than 70% weeds have been introduced deliberately to Australia.
  - As accidental seed or vegetative material contaminants:
    - ❑ Of crop or pasture seeds, eg giant sensitive plant.
    - ❑ Of packing material, eg seeds in straw.
    - ❑ Adhering to clothes and shoes of people visiting farms, rural areas, and markets.
    - ❑ Of soil on used vehicles, agricultural machinery, barges and boats.
    - ❑ Incorrectly named plants.
- **Quarantine inspections** intercept illegal entries:
  - Make sure plants, bulbs and seed ordered via the internet or mail order are cleared by quarantine before coming into the country.
  - Thorough cleaning and inspection of equipment, personal belongings, boots and webbing from East Timor prevents entry of seeds of Siam weed into Australia. The seeds are so small they can survive washdown.
  - Bulb collectors may acquire them, often in ignorance through the internet, etc; they may then escape detection by customs.
- **Some of our worst environmental weeds** have originated from South Africa which has a climate similar to parts of Australia. Unfortunately they do not bring the pests and diseases which kept them in check in their place of origin. Other countries with climates similar to ours include California and Mediterranean regions.
- **Rapid response programs** are in place to coordinate resources and deal with certain weed species should they enter.

Some Australian native plants have become weed species overseas, eg *Melaleuca* in Florida, eucalypts, wattles and melaleucas have spread across tracts of the African countryside.

PLANT QUARANTINE

(contd)

INTERSTATE AND REGIONAL PLANT QUARANTINE

Containment of weeds already in Australia is difficult because weeds which are classified as noxious in one state/region, may pose no threat in another, and, may even be for sale in another, etc. Paterson's curse (Salvation Jane). The nursery industry has a problem knowing which plants are weeds and which lists should be referred to (page 414).

- **Weeds in Australia** has an excellent website providing information on weed management in each state/territory. www.**weeds**.gov.au/
- **All states/regions**, have legislation to control entry of certain weeds, eg inspection of seeds from interstate, transport of fodder, plants, soil, etc, eg
  - Tiwi Islands in the NT have quarantine procedures in place to prevent weeds spreading from the mainland to the Tiwi Islands via barges, machinery, hay, etc.
  - Roper River, Control of Devils'Claw at Gregory National Park.
  - Rubber vines buffer zone (100km within Qld border. WONS Strategic Plan.
- **Many weeds have entered Australia** and spread throughout Australian states/ territories, new weeds are continually being detected in individual states either from overseas or from other states within Australia. Needle burr (*Amaranthus spinosus*) was detected in WA pasture seed sourced from Qld. Mexican feathergrass in the ACT Some of which are under national eradication, eg mile-a-minute (*Mikania micrantha*).
- **Once in a state/territory** their spread, distribution and level of infestation are monitored, eg skeleton weed found on 53 new properties during 2005.
- **Weed Alert Programs** operate in some states to prevent serious new weeds establishing in particular areas, eg Victorian Volunteer Weed Spotters look out for and report certain serious uncommon weeds.

Individuals may informally "quarantine" their properties to **reduce** weed inputs

'LOCAL' QUARANTINE

- **Prevent viable weed seeds** from being added to the soil seedbank, prevent introduction of viable weed seed from external sources.
- **There is no legislation** covering 'local' quarantine. Weed seeds, rhizomes, root pieces, weeds themselves may be introduced to gardens, nurseries and orchards via:
  - **Organic mulches**, manures, fodder.
  - **Soil** in pots, containers, deliveries and on uncleaned machinery.
  - **Crop seed**. Use certified weed-free seed.
  - Plants disposed over garden fences, waterways.
  - Uncovered trailers, vehicles.
- **Wear clothes** that don't catch weed seeds, keep boots, vehicles, tools soil-free.
- **Minimize stock movement** from infested to clean areas. **Confine new stock** to a small area to allow viable weeds **seeds** in their digestive tract to be expelled. Purchase shorn sheep as there is less chance of transporting weed seeds in their fleece. Check feed brought into a confined area.
- **Don't gift garden plants** as cuttings etc which may be easy to grow but invasive, take care not to import weeds with new plantings.

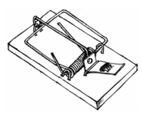
WEED-TESTED PLANTING MATERIAL, SOIL, ETC

Buy weed-free inputs, products, seed, etc

SEED, BULBS, CUTTINGS, SOIL, ETC MAY BE CONTAMINATED

- **Legislation.** Various Seed Acts regulate the sale of seed, grain or fodder. It is illegal to sell specified seed, grain or fodder which contains seeds or any other parts of a noxious weed which are capable of growing. Seeds of thistles, cape tulip and ragwort are often found in hay. There are limits on dodder seeds in WA.
- **Contaminated crop or pasture seed**.
  - **Certification schemes** provide seed or vegetative propagation material guaranteed free from specified weeds, diseases and pests to the grower.
  - **Buy locally produced seed**, if certified seed is not available.
- **Bulbs**, etc may be contaminated with weed seeds or rhizomes, etc.
- **Hay, fodder**. Ideally weeds should be controlled before harvesting, if not, then hay should not leave the farm. Purchasers of hay should check to ensure produce if free of weed contaminants. Agents who purchase, sell or transport fodder or grain should also ensure that the produce is clean.
- **Soil, potting media, mulches and improperly prepared compost** and other products can all contain weed seeds, weed rhizomes, and other plant parts. This applies to large deliveries or the purchased of potted plants at a retail outlet.

PHYSICAL & MECHANICAL METHODS



Knowledge of how plants respond to damage can be applied to develop more effective physical control methods for weeds.

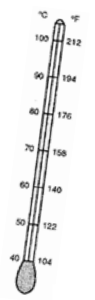
Blade ploughing ***Mimosa pigra*** cuts off plants about 10 cm below ground level and is more effective than cutting them at ground level or 15cm above ground level which results in most plants resprouting

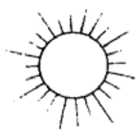
PROBABLY THE OLDEST METHODS OF WEED CONTROL

- **Barriers.** Garden beds can be edged to prevent weeds entering from lawns. Weed Gunnel is a permeable and degradable weed barrier which can be placed around trees and shrubs, also used for fence lines and various sizes of pots.
- **Hand weeding, chipping, hoeing**, before flowering or seed set, controls scattered weeds and small patches of **annual weeds** in garden beds and landcare areas. **Some woody weeds** are easy to pull out. Can be **labor intensive** and costly for large areas, and not suitable for median strips, parking areas where pebbles might be disturbed.
- **Various tools** have been developed to remove broadleaved weeds in lawns, tractor-mounted mechanical weeders work around fruit trees and vines.
- **Mowing, slashing, grazing** weeds before seed set prevents viable weed seeds from being added to the soil seedbank and is useful for controlling **annual** and **biennial** weeds.
  - **Some weeds tolerate close mowing,** eg winter grass in turf. May encourage growth and flowering of prostrate plants such as white clover and wireweed.
  - **Repeated** mowing, slashing and grazing will restrict some **perennial** weeds by weakening food reserves, by defoliation and preventing flowering and seed set.
  - Used to **reduce fire risks** associated with grass and other weeds.
  - **Cheaper** than cultivation and it preserves the ground cover reducing erosion and improving access in wet weather.
  - **Mowing** may be used in conjunction with herbicide applications.
  - **Selective grazing** by stock can cause unpalatable ungrazed species to become dominant and troublesome. Pastures and grazing management includes grazing regimes, prudent fertilizers, heavy grazing forces stock to eat the less palatable weeds. Sheep graze closer to the ground than cattle so do more damage to weeds. Avoid overgrazing, use appropriate stocking rates, rotational grazing to avoid overgrazing, bare ground and subsequent weed invasion. Goats graze on thistles, bracken and gorse.
  - **Protect trees** from lawnmower, whipper-snipper (and herbicide) damage.
- **Equipment trailed behind harvesters**, which destroys any weed seeds in harvester chaff and re-spreads the chaff over the field, is currently being researched.
- **Rolling weeds** and cover crops with special machinery, flattens them; they then break down slowly into mulch.
- **Scalping** is used in forestry for plantation establishment, and involves the removal of the weeds and topsoil with a tractor or bulldozer on flat sites, but there are costs and tree nutrition problems, resulting from removal of topsoil.
- **Some implements bury seeds** (rotovators), while others lift them up to the surface (spring tines) where they can be removed mechanically as they germinate.
- **Aquatic weed harvesters** cut, load and dump weeds out of waterways.
- **Flooding** is timed in rice fields so that weed seed germination is suppressed and growing weeds drowned meanwhile the more water tolerant rice is unharmed.

HEAT

Plastic irrigation equipment does not respond well to being flamed





- **Burning** weeds and crops using flame throwers (low pressure gas burning torches), are occasionally used by trained personnel, but may be prohibited by local legislation or at certain times of the year. **Flames or superheated steam (searing)** boils moisture in weeds which die back to the crown. They may be hand-held or tractor-mounted. Most effective on weeds with unprotected growth points and/or thin leaves, eg chickweed, and weeds with a low capacity for root suckering, thin bark, etc. Degree of control of woody weeds depends on the species.
  - **Does not kill perennial weeds** the effect on weeds being similar to that of mowing or slashing except that burning is more complete.
  - **Many natural ecosystems are adapted to regular fires** and species diversity may decline unless they are burnt. Burning may **stimulate germination** of some soil-stored weed seeds such as some legume seeds. The intensity of fire determines which seeds are stimulated. **Too frequent burning** can lead to fire-resistant weeds, loss of surface organic matter, poor soil stability, loss of the desirable species in pasture, erosion and depletes reserves of phosphorus. Can kill seed present on the **soil surface** of natural bushland, eg boneseed.
  - **Ideal for suppressing weeds** where chemical use is **not appropriate** or where machines cannot access, eg paths, lawns and gardens against fences, and around trees. Selectively controls weed seedlings in established cotton and maize crops.
  - **Stubble burning**, followed by a post-emergent herbicide, can reduce weed seeds.
  - **Does not disturb the soil** and the technique is accepted by organic groups.
- **Infrared weedkillers** of various types are being developed overseas; some of which look like mowers, can be wheeled down greenhouse/nursery rows to clean up crop debris, kill weeds, weed seeds and spores. Hand held types are also available.
- **Pasteurization.** Aerated steam (60°C for 30 minutes) is used to treat potting and propagation media in nurseries to kill most plant disease organisms, leaving some beneficial microflora. Some weed seeds are killed, but higher temperatures are needed to kill many species of weed seeds.
- **Solarization** prior to planting, properly implemented can cause soil temperatures to increase to such an extent that some young weeds, many seeds and some plant disease organisms are destroyed (page 330). Solarization is not possible in mixed or perennial plantings. Often not very effective against weeds with deep roots and rhizomes. Water beds before solarization to improve control. Moisture under the plastic helps conduct heat and stimulates weed seeds to germinate prior to killing them.

LIGHT & SEED GERMINATION

Seed germination of some weed seeds, eg sowthistle, is favoured by light, however, some germination occurs in the dark as well.

HERBICIDES

AS 6000—2009. Organic and Biodynamic Products (Standards Australia) outlines minimum requirement to be met by growers and manufacturers wishing to label their products organic or biodynamic

LEGISLATION

- **Commonwealth legislation** provides for a national system of pesticide **registration** up to the point of sale. Registration is the responsibility of the Australian Pesticides and Veterinary Medicines Authority (**APVMA**).

> **APVMA** www.apvma.gov.au/ and search **PUBCRIS** for registered chemicals
> or purchase **Infopest** www.dpi.qld.gov.au/infopest
>
> To check for products **permitted in organic systems**
> **AS 6000—2009. Organic and Biodynamic Products** www.standards.org.au/
> Organic Federation of Australia (OFA) www.ofa.org.au/
> Biological Farmers of Australia www.bfa.com.au/
> National Association for Sustainable Agriculture, Australia **(**NASAA**)** www.nasaa.com.au/
> Organic Growers of Australia (OGA) www.organicgrowers.org.au/

- **State/Territory/Regional legislation** currently regulates the **use** of pesticides. However, it is intended that there be a national system. All persons using pesticides **commercially** must undergo **training** in the safe handling and use of pesticides.

HERBICIDE APPLICATIONS

> Contact **CropLife Australia** for updates of **Herbicide Mode of Action Resistance Groups**
> **www.cropelifeaustralia.org.au/**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Fig. 249. Some glyphosate labels (more than 100 formulations).

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

HERBICIDE APPLICATION

HERBICIDES MAY BE USED TO TREAT

PLANTS AND SOIL

- **The foliage**. These herbicides are commonly applied to leaves, stems, apical shoots, etc as sprays, aerosols and wipe-ons. They may have contact action, eg Shirquat® (paraquat) or be systemic, eg Roundup® (glyphosate).
- **The soil.** Herbicides may be applied as sprays or granules. They are usually systemic, persist for long periods, are taken up from the soil by **germinating seeds and established weeds**. Some have pre-emergent selective activity at low rates, but provide total vegetation control at higher rates, eg simazine.
- **The trunks of trees, etc.** These herbicides are commonly applied as liquids in holes or cuts in stems. They must be **systemic** to be taken up in the sap stream, eg Roundup® (glyphosate), Garlon® (triclopyr).

TREATMENTS

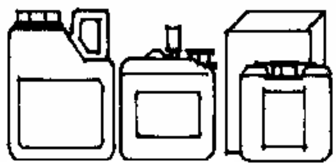
TREATMENTS include:

- **Broadcast treatment.** Cover an entire area (plants and/or soil surface) evenly, either by spraying a liquid or spreading a granular herbicide.
- **Band treatment.** A relatively narrow band is treated with herbicide, eg a crop row, along the edge of paths. Weeds between crop rows can also be controlled by cultivation, mowing, etc.
- **Directed spraying**. Herbicide is applied directly to the area between plants, or inter-row area, care being taken to avoid any contact with the crop plants.
- **Spot treatments** are directed to the foliage of weed clumps in weed-free areas, eg orchards or wiped on the foliage of individual weeds in lawns or garden beds. Containers may be spot treated. Also used in pastures, non-crop situations to reduce the amount of herbicide used.

FORMULATIONS

COMMON FORMULATIONS which can be purchased include:

- **Liquids**, eg liquid carriers:
  - Dry flowable concentration
  - Water dispersable granules
  - Emulsifiable concentrates
  - Suspension concentrates
  - Liquid concentrates
- **Solids,** eg solid carriers:
  - Soluble powders, water soluble granules, some are pre-packaged
  - Wettable powders
  - Dusts
  - Granules
- **Others**, eg aerosols, gels. Herbicide-coated fertilizers have been found to be effective in controlling weeds while reducing runoff.



The formulation is the product purchased

SURFACTANTS
Adjuvants

SURFACTANTS include wetters and stickers which may be added to herbicide formulations either during manufacture or just before application when needed.

- Make water-based herbicides **'wetter'** so that they stick to and spread over waxy or hairy leaf surfaces rather than forming into drops and rolling off like rain drops (pages 444, 445).
- Increase the **rate of absorption** of the herbicide through leaf surfaces thereby reducing selectivity. A change in droplet size can have the same effect. Surfactants may affect the final site of action in the plant.
- Only add surfactants if the **label** recommends it, and only use recommended ones, otherwise crops may be damaged and weed control ineffective.
- Carriers (materials used to dilute the herbicide prior to application) such as diesel enable better penetration of herbicides, used for basal bark treatments.

MARKER DYES

Marker dyes are used to indicate spray coverage (page 456).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

HERBICIDE APPLICATION EQUIPMENT

Like formulations, application equipment is improving all the time, eg digital controls can keep equipment in line and improve application of chemicals and fertilizers, causing less plant damage.

SPRAY APPLICATIONS

HERBICIDES ARE DILUTED mostly with water to aid even distribution over the area to be sprayed. The **volume of water carrier** can affect both the efficiency of weed control and the selectivity of the herbicide.

- High volume **(HV)** applications are usually greater than 1,000 litre spray/ha.
- Low volume **(LV)** applications usually range from 100 – 400 litre spray/ha.
- Ultra-low volume **(ULV)** applications are usually less than 5 litre spray/ha, small volumes of spray to treat large areas. Spray domes prevent drift.

SPRAY APPLICATION EQUIPMENT, eg

- **Hydraulic sprayers**, eg knapsacks, power sprayers, trailer sprayers, booms.
- **ULV** (ultra-low volume).
  - **Ground applications** of various types, eg Micron Herbi.
  - **Aerial applications** which are used for large areas or situations which are inaccessible to ground equipment, eg field crops, pastures, forest areas, firebreaks, electricity lines, mountainous areas, etc.

GRANULE DISPENSERS

HAND-HELD, LARGER TYPES

- **A few residual soil-active herbicides**, eg pre-emergents, are formulated as small granules which are spread over moist soil at an even rate.
- **A spreader or shaker** is usually required to obtain uniformity and it must be carefully calibrated before application starts. Herbicides are applied dry **not** mixed with water.
- **Incorporation**. Sometimes the granules have to be worked mechanically into the upper few centimetres of soil while others are moved into the top centimeters of soil by rain or irrigation.
- **Activation**. The herbicide must be dissolved by water in the soil, by rain or irrigation and taken up by the roots of the germinating seeds.

WIPERS

SELECTIVE WIPERS

- Application is a means of **selectively wiping tall weeds** with glyphosate, a non-selective herbicide. Shorter crop plants are unaffected.
- Hand-held units used in home gardens while larger tractor units are used in turf and broadacre farming.
- **Ropewick applicators** wipe a very small amount of concentrated translocated herbicide onto shoots of the weeds to be killed.
  - **Product is diluted** as per label directions for use with a very small amount of water and is carried from the reservoir to the ropewick by gravity and capillary action so that there is a uniform flow of herbicide along the rope-wick.
  - **The ropewick is moved** along just above or beside the crop so that it contacts the foliage of the weeds but not the crop. By only wiping the herbicide onto the weeds a high **degree** of selectivity is achieved.
  - **Home garden wipers** may have a brush instead of a wick.

DISPOSABLE SELF-DISPENSING APPLICATORS

LARGE RANGE OF APPLICATORS including:

- Hose-connected spray packs
- Gun
- Aerosols

Hose-on

Gun


Weeding brush

STEM TREATMENTS

RANGE OF EQUIPMENT FOR TREATING STEMS

- Frill treatment
- Cut stump (hack and squirt)
- Stem injection of woody growth with translocated herbicides in liquid form
- Spot gun
- Also pages 467, 468

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

NON-SYSTEMIC & SYSTEMIC HERBICIDES
Contact & translocated herbicides – Movement in weeds

NON-SYSTEMIC HERBICIDES

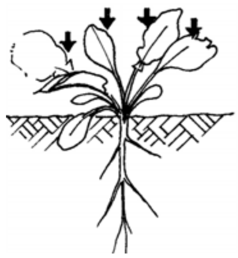
Contact

NON-SYSTEMIC HERBICIDES are only active at the point of application (leaves, stems, roots); they are **not** absorbed by the plant.

- They are mostly applied to **leaves and stems**.
- They often have **no action** through the soil.
- Normally act **rapidly**, good coverage is necessary for maximum effectiveness.
- Useful for controlling **annual weeds** and **perennial weed seedlings** with no underground reserves of food or buds from which to regrow after treatment.
- Contact herbicides may be either **non-selective** or **selective.**

NON-SYSTEMIC FOLIAGE, eg
Sprayseed®, Tryquat® (diquat + paraquat)
Basta®, various (glufosinate-ammonium) - slightly systemic

Contact action, perennial weeds may regrow from tap roots, etc



SYSTEMIC HERBICIDES

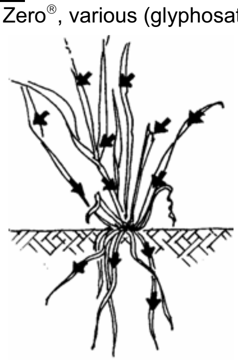
Translocated

SYSTEMIC HERBICIDES are applied to the **leaves and stems** of weeds, they then enter the plant and move through the stems to the roots, eventually killing the weed. Systemic herbicides may also be applied to the **soil** to control germinating weed seeds (pre-emergent herbicides) or taken up by roots.

- May either be **non-selective** or **selective** at normal dose rates.
- **Herbicides enter leaves** through upper or lower leaf surfaces (lower surface is more permeable). Entry is mostly via the cuticle but also occurs via the stomates.
- **Most effective against actively growing weeds** which can circulate the herbicide through the plant effectively.
- **Dosage rates must be low** enough for absorption and maximum translocation by the plant to take place. At excessively high dosage rates many systemic herbicides are least effective, merely acting like a contact herbicide.
- **Mainly act slowly** often taking several weeks for maximum effect.
- **Advantages of systemics**.
  - Whole plant surface need not be treated, eg may be applied as foliage, root and soil or tree injection treatments. Active at sites remote from where they are applied.
  - When applied to the soil, systemic herbicides dissolve in soil water and are taken up by the roots. The soil must be kept moist for continued uptake.
  - Once systemic herbicides have been absorbed by the foliage they cannot be washed off by rain or irrigation. Allow sufficient time for absorption.
- **Disadvantages of systemics**.
  - Excessive residues may still occur unless withholding periods are observed or there is excessive application.
  - May control weeds more slowly than contact non-systemic contact pesticides.

For **perennial weeds** the aim is to kill the plant's underground parts.

SYSTEMIC FOLIAGE, eg
Roundup®, Zero®, various (glyphosate)



SYSTEMIC ROOTS, SOIL, eg
Diuron®, various (diuron)

NON-SELECTIVE & SELECTIVE HERBICIDES
Broad & narrow spectrum herbicides

SOIL STERILANTS

These herbicides are **toxic to all plant and animal organisms in the soil**, eg diuron, many fumigants.

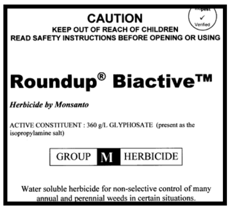
NON-SELECTIVE HERBICIDES

Broad spectrum

These herbicides are **toxic to most plants**.

Non-selective herbicides kill or suppress all vegetation to which it is applied, eg

- Some foliage herbicides are **systemic** herbicides, eg Roundup® (glyphosate) which is absorbed through the foliage and green stems and is translocated to the roots, killing many species of annual and perennial weeds.
- Some foliage herbicides are **contact** herbicides, eg **Tryquat®** (paraquat + diquat), which kill foliage of weeds but not root systems, so perennial weeds may regrow.
- Non-selective herbicides can be **applied selectively** (page 445).
- **Soil residual** herbicides are applied to **soil** where they remain active for some time after application. The extent to which a herbicide has a residual affect in the soil will vary depending upon several factors, eg soil pH and solubility of the herbicide. Soil residual herbicides are used to control:
  - Germinating weed seeds (pre-emergent herbicides) or
  - Roots of brush etc
  - For total vegetation control (soil sterilants)



NON-SELECTIVE FOLIAGE, eg
Roundup®, Zero®, various (glyphosate)

NON-SELECTIVE ROOT, eg
Diuron®, various (diuron)

SELECTIVE HERBICIDES

Narrow spectrum

Selective herbicides are more damaging to some plants (certain weeds) than to other plants (desired plants or crops), eg MCPA is used to control broadleaved weeds in turf.

SELECTIVE FOLIAGE, eg
2,4-D, dicamba and MCPA

Broadleaved weeds

SELECTIVE FOLIAGE, eg
Fusilade®, various (fluazifop-p-butyl)

Grass weeds

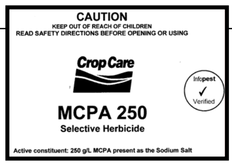
SELECTIVE FOLIAGE, eg
Garlon®, various (triclopyr)

Woody plants, broad leaved weeds, legumes

SELECTIVE FOLIAGE & ROOT, eg
Propon®, Atlapon® (2,2-DPA)

Most annual & perennial grasses

Some herbicides can be taken up by both foliage and roots.



CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

NON-SELECTIVE & SELECTIVE HERBICIDES *(contd)*
Broad & narrow spectrum herbicides

WHY ARE SOME HERBICIDES SELECTIVE?

Selectivity may be achieved in many different ways, eg

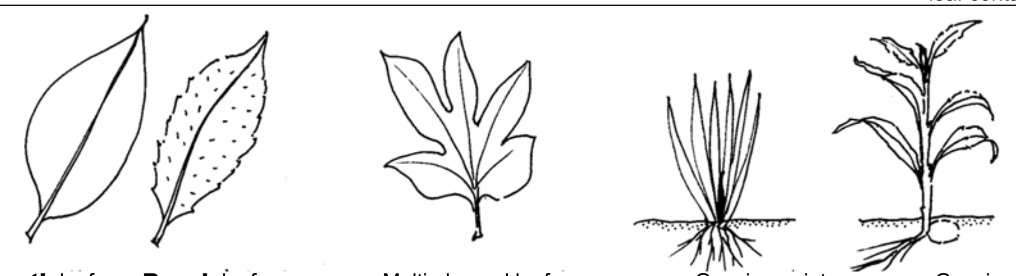
- **Physiological differences between weeds and desired plants**, eg
  - Rate of herbicide uptake by **roots**.
  - Rate of herbicide movement in the **phloem** (food conducting) or **xylem** (water conducting).
  - Different rate of herbicide **breakdown** in the plant.
  - Different degree of herbicide **tolerance**, eg this may be due to the physical characteristics of the leaves such as cuticle penetration. Other herbicides may interfere with photosynthesis or respiration in certain plants.
  - Some herbicides affect chemical processes within the weed but not the crop.
  - Breakdown of herbicide by **some** plants and not others, eg maize, but not some weeds, can metabolize atrazine to a non-toxic compound so that maize is not killed but the weeds are.
  - Much of their selectivity depends on their rate of absorption through the leaf surface. They generally are more likely to injure plants if they are absorbed rapidly. **Selectivity** is determined by the ability of the plant to either tolerate the herbicide or break it down to harmless substances as it is absorbed.
- **Leaf structure**, eg
  - Leaf area (narrow or broad leaf), eg rosette broad leafed weeds catch and hold more spray than grasses.
  - Leaf arrangement (open or closed).
  - Nature of leaf structure (hairy, waxy, etc).
  - Location of growing point (exposed, protected).

Large leaves catch hold **more** chemical

Small leaves catch and hold **less** chemical

Open arrangement of leaves, **good** leaf contact

Restricted arrangement, of leaves, **poor** leaf contact



Smooth leaf, herbicide **runs off**

Rough leaf, herbicide **retained**

Multi-channel leaf, herbicide **caught** in hollows

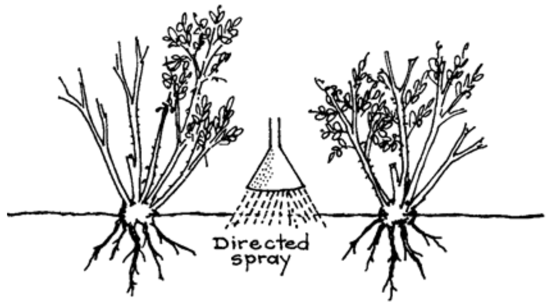
Growing point **protected**

Growing point **exposed**

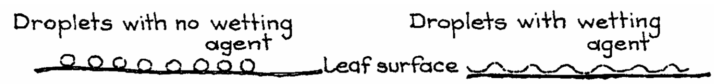
NON-SELECTIVE & SELECTIVE HERBICIDES *(contd)*
Broad & narrow spectrum herbicides

WHY ARE SOME HERBICIDES SELECTIVE *(contd)*

- **Stage of crop growth.** Some crops are **only tolerant** of recommended rates of a herbicide at certain stages of growth. Herbicides must be applied at the appropriate stage of the crop, eg **before** the crop has been planted, **after** the crop has been planted but **before** emergence of the crop, or **after the crop has emerged** (page 446).
- **Stage of weed growth.** Many herbicides are effective only against certain growth stages of the weed, eg roots, foliage, germinating seeds (page 447).
  - Many are more effective when weeds are young and actively growing rather than older and growing slowly.
  - Those herbicides active against germinating seeds can be used amongst established plants in orchards, arboreta and containers.
  - **Spray topping** is the application of a sub-lethal dose of non-selective herbicides to pastures at flowering. It is used to prevent the formation of viable weed seeds without inducing a winter feed shortage. Spray topping can be very effective in reducing the weed seed bank.
- **Herbicide application techniques**, eg
  - **Non-selective herbicides**, eg Roundup® (glyphosate) may be applied as a directed spray, spot spray or wiper application to avoid contact with desired plants.



  - **Placement of herbicide in the soil**. Selectivity of herbicides absorbed by the roots may be influenced by the **depth** of the plant root system. Herbicides may be fixed in the top few layers of soil so that tree or shrub roots are not damaged. **Seed** may be placed below a treated soil zone.
  - **Type of formulation**. Granular herbicides may be used which bounce off the crop onto the soil, thereby killing germinating weed seeds only.
  - **Addition of wetting agents** (surfactants or spray oils) increases herbicide uptake by plants, **reducing selectivity** resulting in reduced crop tolerance. In general, the smaller the droplet size the greater the number of spray droplets retained by the leaf. Wetting agents lower the surface tension of the leaf, increase the droplet number retained on the leaf and reducing run-off.



- **Some herbicides are selective at low rates only.** Such herbicides may become non-selective when applied at higher rates. Generally the higher the rate a herbicide is applied the less selective it is.
- **Environmental conditions.** affect herbicide selectivity, eg soil moisture and air temperature. Some are less effective at low temperatures but too effective at high temperatures damaging crops in glasshouses. Many herbicides only work when weeds are young and actively growing.

WHEN CAN HERBICIDES BE APPLIED – STAGE OF CROP GROWTH.

Timing is all important, otherwise significant crop damage may occur and weeds may not be controlled (check keys and books describing the growth stages of crops).

FALLOW PERIOD

WEEDS IN THE FALLOW PERIODS between crops may decrease stored soil moisture, carry over diseases and insect pests to affect subsequent crops and increase the viable weed seed content of the soil. These weeds may be controlled mechanically or chemically after the weeds had germinated.

PRE-PLANT, PRE-SOWING

If residuals are used ensure they do **not** affect the subsequent crop, emerging crops must be tolerant

PRE-SOWING APPLICATIONS are made to assist seed bed preparation or to kill weeds that would otherwise have germinated with the crop.

- **Non-selective systemic foliage herbicides** can be applied **prior** to planting or sowing the crop, eg Roundup® (glyphosate).
- Herbicides that require deep **physical incorporation** into soil can only be applied before the crop is sown, later incorporation would damage the crop.
- Herbicides that are incorporated into the soil by **rainfall or irrigation** may be applied either before or after the crop is planted.

AT PLANTING

PRE-EMERGENCE HERBICIDES may be applied **at planting**, eg Dacthal® (chlorthal).

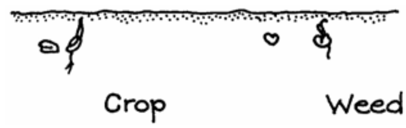
POST-PLANT HERBICIDES

Specific examples have been given but **always** follow label instructions before using herbicides in any particular setting

Herbicides are applied **after** the crop has been planted. The crop must be tolerant, but it may be only tolerant at certain stages.

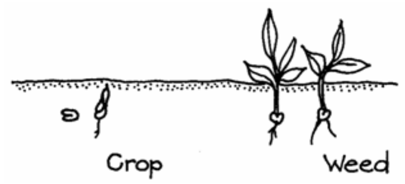
PRE-EMERGENCE CROP AND PRE- EMERGENCE WEED

The herbicide is applied **before either** the crop or weeds have emerged from the soil. Examples include:
Dacthal® (chlorthal)
simazine (in lupins)



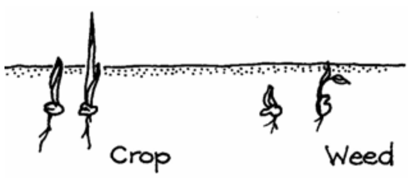
PRE - EMERGENCE CROP AND POST- EMERGENCE WEED

Non-selective contact or translocated herbicides are applied **before** the crop has emerged but **after** weed seedlings have emerged from the soil, eg
atrazine



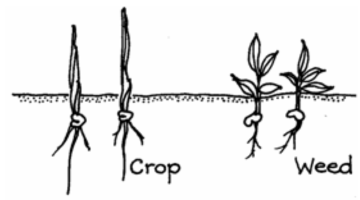
POST - EMERGENCE CROP AND PRE - EMERGENCE WEED

The herbicide is applied **after** the crop has emerged but **before** the weeds have emerged. Examples include:
Tramat® (ethofumesate)



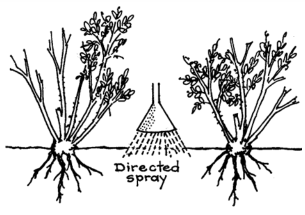
POST- EMERGENCE CROP AND POST- EMERGENCE WEED

A selective herbicide is applied **after both** the crop and the weeds have emerged through the soil. Crop is unharmed. Examples include:
Fusilade® (fluazifop-p)
MCPA



PERENNIAL CROPS

Non-selective post-emergent herbicides must be applied as directed sprays, eg **amongst** trees and shrubs, roses, fruit trees and vines, where weeds to be controlled have emerged. **Pre-emergent herbicides** can be applied as directed sprays before weeds have emerged.



FOLLOW UP TREATMENTS

This is critical when controlling many perennial weeds, eg

- **Nutgrass** has underground nutlets, **onion weed and three-cornered garlic** have underground bulbs. **Couchgrass** produces stolons and rhizomes. Months after treatment with glyphosate, small leaves will emerge and follow up applications are needed. It is important not to let these plants flower and seed.
- **Woody weeds** such as **gorse** may require further treatments to control regrowth and seedlings.

WHEN CAN HERBICIDES BE APPLIED – STAGE OF WEED GROWTH.

Again timing is important, otherwise significant crop damage may occur and weeds may not be controlled (check keys and books describing the growth stages of weeds).

POST-EMERGENT HERBICIDES

Knockdown herbicides

Applied to the foliage of emerged existing weeds. Young actively growing weeds are more easily controlled than older well established plants. They may need to be applied at a certain stage, eg seedling 2-leaf stage. They may be:

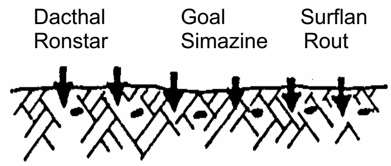
- **Contact herbicides** (non-systemic), eg Basta® (glufosinate-ammonium), affect only the part of the plant they touch; they have short duration, fairly rapid action.
- **Translocated** (systemic), eg Glypho®, Roundup®, Zero® (glyphosate) and are taken up by the foliage/stems and translocated into the root system. They may be:
  - Non-selective, eg Roundup® (glyphosate) which kills annual and perennial weeds.
  - Selective, eg MCPA® controls broadleaved weeds in grass crops.

PRE-EMERGENT HERBICIDES

Do you know when your weeds emerge?

- No pre-emergent kills all weed seeds
- The crop or the emerging crop must be tolerant
- Soil residual up to 6 months kills germinating weed seeds
- Many herbicides show more than one type of activity, eg post-emergent and some pre-emergent.

Weed seeds usually germinate in the upper centimeter (small seeds) to 10cm (large seeds) of soil depending on the availability of moisture near the surface. Pre-emergents aim to kill germinating weed seeds before they emerge from the soil (page 458).



For effective application:

- **Pre-emergent herbicides are formulated** to remain near the soil surface where weed seeds germinate and not to move deeper where they could affect roots of established plants. Soil compaction, solubility of herbicide, soil organic matter or clay also affects their activity. Seedbeds must be clump-free, apply to weed-free soil.
- **Even incorporation** ensures that pre-emergent herbicides are applied at the correct depth to contact the roots or shoots of germinating weed seedlings. Some pre-emergents break down in sunlight or are volatile (rapidly evaporate damaging nearby crops) and must be incorporated within a few hours of application or will lose their effectiveness.
  - **Irrigation/rain incorporation** can be pre-or post-plant. Some pre-emergents are fairly soluble in soil moisture and are sufficiently mobile by themselves, or with only a little rain or irrigation to move into the upper few centimeters of soil where they will actively control weeds. Furrow irrigation or drippers are not suitable. Check weather, rainfall, temperature, wind, volatilization, and photo-degradation.
  - **Mechanical incorporation** into the soil surface of some herbicides is pre-plant only, to avoid damaging crop seeds. They are either less soluble/mobile in the soil or must be carried to greater depths to control larger seeded and deeper germinating weeds. Mechanical incorporation is a major cause of damage to soil structure, not suitable for conservation tillage (CT) systems.
- **Activation.** Soil moisture is essential for activating and dissolving pre-emergents. Roots or shoots of germinating weeds then take up the herbicide.
- **Soil disturbance** can have a dramatic effect on the effectiveness of pre-emergents.
- **Pre-emergents** may generally be:
  - **Non-selective**, eg Surflan® (oryzalin), Ronstar® (oxadiazon).
  - **Selective**, eg Goal® (oxyfluorfen), Dual® (metolachlor), Casoron® (dichlobenil).

RESIDUAL ACTIVITY IN SOIL

- If residuals are used ensure they do **not** affect subsequent crops.
- Some are only effective against germinating seeds (pre-emergent herbicides), while others control established weeds.
- Examples of soil residual herbicides which kill established weeds include diuron, Casoron® (dichlobenil

NON-RESIDUAL HERBICIDES break down quickly in soil, eg Tryquat® (diquat + paraquat) allowing a crop to be planted soon afterwards.

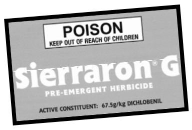
RESIDUAL HERBICIDES persist in the soil for long periods and are taken up by the roots and shoots of germinating seedlings and roots of established weeds. They can be **selective** or **non-selective**.

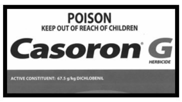
- **Pre-emergent herbicides** at **selective** rates provide long term control of **weed seedlings**, protecting the crop during its early growth stages when it is most sensitive to weed competition, during high growth seasons of spring and autumn.
  - Select pre-emergents and adjust application rates to leave no damaging residues in the soil after the crop is harvested to interfere with growth of subsequent crop.
  - At higher application rates some soil residual pre-emergent herbicides are non-selective and kill all plant growth, eg simazine.
- **Soil sterilants** used **non-selectively at high rates** give long-term control of all plant growth, usually in non-crop situations, eg fire breaks and around buildings and industrial installations. Herbicide remains in soil for a considerable time, eg
  - simazine (6 months to more than 12 months)
  - diuron (years)
- **Factors affecting residual activity** in the soil include:
  - Residual activity can vary from a few weeks to a year or more.
  - Concentration, generally the higher the rate the longer the residual effects.
  - High temperatures favour the breakdown of herbicide.
  - Leaching by soil water, which will depend on rainfall, soil type, herbicide solubility.
  - Ultra-violet light, which can breakdown some herbicides, eg simazine.
  - Volatilization may occur under high soil temperatures and dry conditions.
  - Microbial breakdown in the soil.
  - Adsorption by humus and clay may render a herbicide unavailable to the plant.
  - Some post-emergent herbicides may fall on soil and be active for a short time against subsequent crops, eg glyphosate. Check label for **plant-back time**.

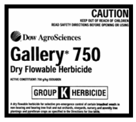
SUMMARY & EXAMPLES

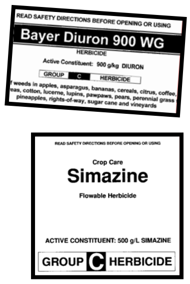
Fig. 250. HERBICIDES (page 450)

- **POST-EMERGENT Foliage - Knockdown**
  - **NON-SELECTIVE**
    - **NON-SYSTEMIC Contact** burns foliage
      - **Basta®** (glufosinate-ammonium)
      - **Bioweed®** (pine oil)
      - **Sprayseed®** (diquat+paraquat)
      - **Shirquat®** (paraquat)
    - **SYSTEMIC Translocated** to roots
      - **Glyphosate®** (kills roots of annuals & perennial grasses & broadleaved weeds)
  - **SELECTIVE**
    - **NON-SYSTEMIC Contact**
      - DSMA
    - **SYSTEMIC Translocated** to roots
      - **Broadleaved weeds in grass crops**
        - Hormone herbicides, eg 2,4-D, dicamba MCPA
      - **Grass weeds in broadleaved crops**
        - **Fusilade®** (fluazifop-P)
- **SOIL RESIDUALS**
  - **PRE-EMERGENT**
    - **NON-SELECTIVE**
      - **Casoron®**
      - **Sierraron®** (dichlobenil)
      - **Dacthal®** (chlorthal-dimethyl)
      - **Ronstar®** (oxadiazon)
      - **Surflan®** (oryzalin)
      - **Simazine®**
    - **SELECTIVE**
      - **Exporsan®** (bensulide)
      - **Gallery®** (isoxaben)
  - **SOIL STERILANTS**
    - **Diuron®** (diuron)
    - **Simazine®** (simazine)









CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

RESISTANCE

WHAT IS RESISTANCE?

Australia has a very high level of herbicide resistance

- Glyphosate resistant weeds have been confirmed in Australia, eg **ARG**, awnless ryegrass and liverseed grass.
- When growing herbicide-resistant crops take care that weeds in the crop do not become resistant to the herbicide being used.

Herbicide resistance is the ability of a weed to survive a herbicide rate that would normally control it. If resistance develops, other herbicides, or more expensive, or less effective control methods, may have to be used. Once developed, herbicide resistance can persist for many years. Keep accurate records of herbicide usage.

- **In 2005, in 40 countries**, there were at least 178 documented cases of grass and broadleaf species of weeds resistant to herbicides belonging to most mode of action groups, including glyphosate. In Australia, weeds which are **resistant to at least one mode of action group** of herbicides include annual ryegrass (**ARG**, *Lolium rigidum*), wild oats (*Avena* spp.), barley grass (*Hordeum leporinum*), wild radish (*Raphanus raphanistrum*), Indian hedge mustard (*Sisymbrium orientale*), common sowthistle (*Sonchus oleraceus*), prickly lettuce (*Lactuca serriola*) www.**weedscience**.org
- **Cross-resistance. ARG** shows what is known as cross-resistance which means that ryegrass which develops resistance to one herbicide will develop resistance to herbicides with similar modes of action.
- **Conditions favouring herbicide resistance**.
  - **Most weed populations** contain a small number of resistant plants able to survive an application of a particular herbicide. **Repeated use/over-use** of one herbicide, or other herbicides with the same mode of action, will kill susceptible weeds, but allow survivors to grow and multiply, these surviving resistant weeds become common.
  - **Levels of resistant weeds** depend on whether the grower uses non-chemical methods, as these influence herbicide group selection and application frequency.
  - **In Australia ARG** resistance is the world's worst case of herbicide resistance. There are many reasons for this. Arguably **ARG** was once regarded as a valuable pasture grass (60 million acres of it). When these pastures were converted to crops, **ARG** became a weed of crops grown under minimum tillage and a reliance on herbicides for weed control. Also farming in Australia is extensive, with lower yields, no subsidies, and so lower rates of certain herbicides are applied than in other countries.
- **Commercial herbicide resistance testing services** operate for a range of grass and broadleafed weeds. Weed seed is collected at certain times of the year and screened for resistance to herbicides using various techniques. The number of resistant seeds per square meter can be monitored over a period of time to determine whether the resistant seed bank is increasing or decreasing. The effect of various cropping systems on the replenishment of resistant seed can also be determined.

RESISTANCE MANAGEMENT STRATEGIES

Classification by Croplife Australia is according to **how the pesticides kill the insect, fungi and weeds** and is used for resistance management.

It does **not indicate toxicity,** it is true that some groups are more toxic than others as indicated by the signal headings on their labels (see page 237).

Applications may fail for reasons other than resistance, eg

- Incorrect identification of the weed.
- Wrong herbicide may have been used.
- Applied at wrong time.
- Weather is unsuitable for application.
- Equipment not calibrated properly.
- Application errors, wrong rates, nozzles, etc.
- If resistance is suspected, resistance testing can be arranged.

The application of herbicides must be part of an **IWM** program (page 429) which includes non-chemical methods, eg maximizing crop competition (pages 432, 433).

- **Herbicide Resistance Management Strategies**.
  - **CropLife Australia** has classified herbicides into **mode of action resistance groups** which indicate the mode of action of the herbicide on a metabolic process in the weed, ie **how it kills or suppresses the weed** (page 450, Table 72). Contact **Croplife Australia** for updates on classification and click on **Resistance Management**: www.**croplifeaustralia**.org.au/
  - **To minimize the development of resistance** and prolong the life of existing herbicides, observe **ABC.... groups** on **commercial herbicide labels**. Follow resistance warnings. Rotate herbicides between different modes of action as recommended. **Home garden products available from garden centres are not required to have herbicide mode of action groups on them**.
  - **CropLife Australia** has also prepared *Specific Guidelines* for particular groups of herbicides and a *List of Herbicide Resistant Weeds in Australia* and *Protection Guides* for some crops, eg rice. There are links to the *Glyphosate Sustainability Working Group,* the *Integrated Weed Management Manual* and the *Monsanto Australia's Roundup Ready Flex® Cotton Technical Manual.*
- **Follow label instructions and warnings**, which include resistance strategies. Application of some herbicides for control of some weeds is **restricted** in order to prevent or delay the likelihood of resistance developing. **"Example"** and **"Company"** are used in the following resistant weeds warning notice to avoid using specific herbicide or company names.

> **RESISTANT WEEDS WARNING**
>
> GROUP **M** HERBICIDE
>
> **Example** is a member of the Glycines group of herbicides. **Example** has the inhibition of EPSP synthase mode of action. For weed resistance management **Example** is a Group M herbicide. Some naturally occurring individual weed biotypes resistant to **Example** and other Group M herbicides may exist through normal genetic variability in any weed population. The resistant individuals can eventually dominate the weed population if these herbicides are used repeatedly. These resistant weeds will not be controlled by **Example** or other Group M herbicides. Since occurrence of resistant weeds is difficult to detect prior to use, **Company** accepts no liability for any losses that may result from the failure of **Example** to control resistant weeds.
>
> Growers must practice preventative resistance management strategies.........

HERBICIDE MODE OF ACTION GROUPS

• Herbicides are classified by **Croplife Australia** into mode of action groups which assist in **resistance management.** • The following tables are a summary guide only, and not a substitute for reading a currently registered label, the MSDS and obtaining up-to-date advice. • The tables also provide an overall picture of the types of insecticides available for crop protection. • **Mark herbicides you use at work.**	Contact **Croplife Australia** for a full list of herbicides, updates of the classification and further information: www.**croplifeaustralia**.org.au Check **Pubcris** for current **registration** status: www.**apvma**.gov.au/ **Infopest** can be purchased www.dpi.**qld**.gov.au/

Table 72. Herbicide Mode of Action Groups (2009) ***some examples***

CHEMICAL FAMILY		THE PRODUCT		SOME USES Read label, obtain advice from company	
MODE OF ACTION GROUP	**SUBGROUP**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**WEEDS CONTROLLED, SUPPRESSED**
A Inhibitors of acetyl coA carboxylase (inhibitors of fat synthesis/ACC'ase inhibitors **HIGH RISK**	**Aryloxy-phenoxy-propionates (Fops)**	**FUSILADE, VARIOUS** fluazifop-p may be formulated with other herbicides	**Post-emergence Translocated** (systemic) spot spraying	Certain broadleaved crops, field, forage & seed crops, fruit, vegetables, bush land, ornamentals	**Selective** certain annual & perennial **grasses**, including couch, paspalum
		HALOXYFOP, VARIOUS haloxyfop	**Post-emergence Translocated** (systemic)	Certain broad leaved crops, field & seed crops, forestry, fruit	**Selective** certain annual & perennial **grasses**
	Cyclohexane diones (Dims)	**SERTIN, VARIOUS** sethoxydim may be formulated with other herbicides	**Post-emergence** (systemic)	Ornamentals, vegetables, field crops & pasture	**Selective** certain annual **grasses**, most perennial grasses
	Phenyl--Pyrazoles (Dens)	**AXIAL** pinoxaden (+cloquintocet-mexyl, a herbicide safener)	**Post-emergence Translocated** (systemic)	Wheat, barley	**Selective** key **grass** weeds
B Inhibitora of aceto-lactate synthase (ALS inhibtors **HIGH RISK**	**Sulfonyl-ureas (SUs)**	**BUSHWACKER, BRUSH-OFF, VARIOUS** metsulfuron-methyl may be formulated with glyphosate p	**Post-emergence Translocated** (systemic) soil active but may be foliage absorbed, persists in soil	Non-crop, commercia & industrial areas, rights-of-way, some cereal crops, pastures, forests	**Selective** **broadleaves**, bracken, certain brush species, gorse, blackberry
		OUST, VARIOUS sulfometuron -methyl may be formulated with other herbicides	**Post-emergence Pre-emergence** soil residual	Commercial & industrial areas, buildings, rights of way	**Non-selective** certain annual & perennial **grass & broadleaved weeds**
	Imidazo-linones (Imis)	**ARSENAL, VARIOUS** imazapyr may be formulated with other herbicides, eg MCPA, glyphosate, imazapic	**Post-emergence Pre-emergence** absorbed through foliage & roots, translocated to roots persists up to 1 yr.	Non-crop situations, conifers may be tolerant, **Clearfield production system** for canola & wheat	**Non-selective** certain annual & perennial **grass & broadleaved weeds**
	Triazolo-pyrimidines (Sulfonamides)	**ECLIPSE, VARIOUS** metosulam	**Post-emergence** Control/suppression	Winter cereals, lupins, certain tree plantations	**Selective** certain **broadleaved weeds**
	Pyrimidinyl-thiobenzoates	**STAPLE** pyrithiobac-sodium	**Post-emergence**	Cotton	**Selective** certain **broadleaved weeds**
C Inhibitors of photo-synthesis at photosystem 11 **MODERATE RISK**	**Triazines** includes TT canola(Triazine Tolerant canola)	**SIMAZINE, VARIOUS** simazine may be tank mixed with post-emergents, eg glyphosate	**Pre-emergence Root absorbed Soil residual** Control for 3-6 months at low rates; 6-12 months at high rates	Non-crop, fruit & field crops, **TT canola**, vineyards, forestry, ornamentals, around shrubs & trees at specified rates	**Used selectively** certain annual grasses & broadleaved weeds, perennial species
		ATRAZINE, VARIOUS atrazine May be mixed with other herbicides	**Pre & post emergence Root absorbed** soil residual, some foliage action, used selectively	Sorghum, maize sugarcane, lucerne, TT canola, forestry plantations, rights of way	**Used selectively** certain annual & perennial broadleaved & grass weeds
	Triazinones	**HEXAZINONE, VELPAR** hexazinone may be formulated with diuron **Used selectively**	**Pre-emergent Post-emergent Soil residual** (1-2 yrs) root absorbed, stem injection, spotgun	Non-crop, industrial & commercial sites, rights of way. *Pinus radiata* plantations, some pastures	**Used selectively** certain broadleaved weeds, annual & perennial grasses, woody weeds
		SENCOR, VARIOUS metribuzin	**Pre-emergent Post-emergent** absorbed by roots, shoots & leaves	Broadacre & vegetable crops, sugarcane **Used selectively**	**Used selectively** **Broadleaved weeds & some grasses**
	Uracils	**HYVAR, VARIOUS** bromacil may be formulated with other herbicides	**Post-emergence Pre-emergence** Mainly root absorbed long term soil sterilan	Non-crop industrial areas, rights of way, crops, eg asparagus, citrus, pineapple	**Used selectively** annual broadleaved weeds & grasses, especially perennial
		SINBAR terbacil may be formulated with other herbicides	**Pre-emergence** persists in soil	Apples, peaches, seed lucerne, peppermint	**Used selectively** most annual grasses & broadleaved weeds

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 72. Herbicide Mode of Action Groups (2009) ***some examples (contd)***

CHEMICAL FAMILY		THE PRODUCT		SOME USES Read label, obtain advice from company	
MODE OF ACTION GROUP	**SUBGROUP**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**WEEDS CONTROLLED, SUPPRESSED**
C ***contd*** MODERATE RISK	**Pyri-dazinones**	**PYRAMIN** chloridazon	**Pre-emergence** **Post-emergence** Absorbed mainly by roots	Beets	**Selective** annual broadleaves, some grasses
	Phenyl-carbamates	**BETANAL** phenmedipham	**Post-emergence** absorbed by foliage, apply to young weeds	Young beet crops, mangolds, non-fruiting strawberries	**Selective** broadleaves, some grasses
	Ureas	**DIURON, DIUREX, VARIOUS** diuron often formulated with other herbicides	**Post-emergence** **Pre-emergence** **Soil residual** (1-2 years) **Mainly root absorbed** Translocated (systemic)	Non-crop**,** commercial areas, road medians, **selective** weed control in certain fruits, field crops, vegetables, cotton, bulbs	**Non-selective** annual grass & broadleaves, ***not*** some hard-to-kill deep rooted perennial weeds **Selective (low rates)** pre- & post-emergence (some crops)
	Amides	**PROPANIL, VARIOUS** propanil	**Post-emergence** **Contact herbicide**	Rice	**Selective** barnyard grass
	Nitriles	**BROMICIDE, VARIOUS** bromoxynil may be formulated with other herbicides	**Post-emergence** **Contact herbicide**	Certain cereals, linseed, clover, lucerne pastures, turf, non-crop, road-sides, rights of way	**Selective** broadleaves, not established perennial weeds
	Benzothia-diazinones	**BASAGRAN** bentazone may be formulated with MCPA, dicamba	**Post-emergence**	certain bean crops, eg dwarf French beans, Haricot beans, peanuts, soybean	**Selective** certain broadleaves
D Inhibitors of micro-tubule assembly MODERATE RISK	**Dinitro-anilines (DNAs)**	**ORYZALIN, SURFLAN, VARIOUS** oryzalin may be formulated with oxyfluorfen (Rout), or trifluralin (Yield)	**Pre-emergence** Systemic, soil active	Ornamentals, fruit & nuts, vineyards, field grown nursery trees, shrubs, amenity plantings	**Selective** certain annual grass & broadleaves, not established weeds
		TRIFLURALIN, TREFLAN, VARIOUS trifluralin may be formulated with oryzalin (Yield)	**Pre-plant** **Pre-emergence** Must be incorporated into soil (exceptions) Persists in soil	Certain field crops, vegetables, orchards, vineyards,; impregnated into drippers (Rootguard[R] technology)	**Selective** annual grasses & certain broadleaves
	Benzoic acids	**DACTHAL, VARIOUS** chlorthal-dimethyl	**Pre-emergence** Active for several months in soil	Certain ornamentals, strawberries, vegetable, field crops, lawns	**Selective** certain annual grasses & broad leaves, summer & winter grass
	Benzamides	**KERB, WINTER GRASS KILLER** propyzamide	**Pre-emergence** **Post-emergence** **Early post-emergence**	Sports turf & home lawns, lettuce, legume seed crops & pastures	**Selective** certain grass weeds**,** **(**especially winter grass & broad leaves
	Pyridines	**DIMENSION** dithiopyr	**Pre-emergence** **Post-emergence** Absorbed by both roots & shoots of weeds; more effective on grasses than broadleaves	Turf	**Selective** summer grass, certain other annual grasses & broad leaves
		VISOR thiazopyr	**Pre-emergence**	Non-crop situations, when planting *Pinus radiata* and certain *Eucalyptus* spp.	**Selective** annual grasses and certain broadleaf weeds
E Inhibitors of mitosis/ microtubule organi-) zation MODERATE RISK	**Carbamates**	**POTATO STOP SPROUT, VARIOUS** chlorpropham	**Plant growth regulator**	Stored potatoes	**Plant growth regulator** prevents sprouting in storage
F Bleachers: Inhibitors of carotenoid biosynthesis at the phytoene desaturase step (PDS inhibitors) MODERATE RISK	**Nicotin anilides**	**BRODAL, VARIOUS** diflufenican may be formulated with MCPA, bromoxynil, clopyralid	**Pre-emergence** **Early post-emergence**	Field peas, lentils, lupins, oilseed poppies, clover-based pasture	**Selective** certain broadleaved weeds
	Picolin-amides	**SNIPER** picolinafen may be formulated with MCPA (Paragon)	**Early post-emergence** foliage absorbed, some **pre-emergence** activity	Field peas, narrow leaf lupins	**Selective** wild radish, suppresses capeweed
	Pyrida zinones	**ZOLIAR** norflurazon	**Pre-emergence**	Cotton, asparagus, citrus, grapes, nuts, pome & stone fruits	**Selective** nutgrass & other grass & broad-leaved weeds

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE – ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 72. Herbicide Mode of Action Groups (2009) ***some examples (contd)***

CHEMICAL FAMILY		THE PRODUCT		SOME USES Read label, obtain advice from company	
MODE OF ACTION GROUP	**SUBGROUP**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**WEEDS CONTROLLED, SUPPRESSED**
G Inhibitors of proto-porphyrinogen oxidase (PPOs) MODERATE RISK	**Diphenyl ethers**	**OXYFLUORFEN, GOAL** oxyfluorfen may be formulated with oryzalin (Rout)	**Pre-emergence Post-emergence** Non-systemic (contact)	Tree fruit, nuts & vines, vegetables, forestry trees, cotton, coffee. prior to sowing some crops	**Selective** broadleaves & some grasses
	N-phenyl-phthalimides	**PLEDGE, VALOR** flumioxazin **when mixed with certain glyphosate or paraquat/diqat herbicides**	**Post-emergence Rapid knockdown**	Prior to sowing certain crops	**Non-selective** various grass & broadleaved weeds
	Oxadiazoles	**OXADIARGYL** oxadiargyl	**Pre-emergence**	Couch turfgrass	**Selective** summer & winter grass
		RONSTAR oxadiazon may be formulated with fertilizer	**Pre-emergence**	Woody ornamental shrubs, trees in nurseries; turf	**Selective** broadleaved weeds mainly, but some grasses
	Triazoli nones	**AFFINITY, VARIOUS** carfentrazone-ethyl	**Post-emergence Contact action**	Winter cereals, pyrethrum; rice	**Selective** certain annual broadleaved weeds; aquatic weeds (in rice)
MODERATE RISK	**Pyrimidindio nes**	**LOGRAN B-POWER** butafenacil	**Pre-plant Pre-emergence Knockdown Contact action Residual control**	Wheat	**Non-selective** Certain broadleaf weeds & grasses
	Phenylpyraz ole	**ECOPAR** pyraflufen-ethyl may be formulated with other herbicides	**Post-emergence Contact action** also defoliation & boll opening in cotton	Winter cereals;	**Selective** annual broadleaved weeds
H Bleachers: Inhibitors of 4-hydroxyphenol-pyruvate dioxygenase (HPPDs)	**Pyrazoles**	**TAIPAN** benzofenap	**Pre-emergence Early post-emergence**	Rice	**Selective** certain broadleaved weeds
	Isoxazoles	**BALANCE** isoxaflutole	**Pre-emergence Early post-emergence**	Sugarcane, chickpeas	**Selective** control & suppression of certain broadleaf weeds & grasses
I Disruption of plant cell growth (distorts new growth)	**Phenoxys (hormone herbicides)** **Spray drift can cause severe damage to cotton, grapes, tomatoes, oil seed crops, ornamentals (page 460)**	**MCPA, VARIOUS** MCPA often formulated with other herbicides, eg dicamba 198 products containing MCPA, also fertilizers	**Post-emergence Systemic**. Some formulations can be very volatile and damage non-target species	Non crop, commercial & industrial areas, turf, pasture, cereal crops, linseed rice, peas, spot spraying	**Selective** certain broadleaved weeds
MODERATE RISK		**2,4-D, VARIOUS** 2,4-D 181 products may be mixed with other herbicides	**Post-emergence Systemics**	Non-crop, fallow, turf, cereal crops, pastures, sugarcane, spot spraying	**Selective** certain broadleaved weeds
More than 90 registered herbicides contain dicamba	**Benzoic acids** (similar mode of action to the phenoxys)	**DICAMBA, VARIOUS** dicamba often formulated with MCPA to improve activity against broad-leaved weeds	**Post-emergence Pre-emergence Systemic** remains in soil 2-3 months	Non-crop, turf, pasture, cereal crops, maize, rice, *Pinus radiata,* conservation tillage	**Selective** certain broadleaved weeds
	Pyridine carboxylic acids (pyridines)	**BLACK BERRY & TREE KILLER, VARIOUS** triclopyr often formulated with picloram, also other herbicides	**Post-emergence Systemic** Foliage, stem & root absorbed,	Non-crop, industrial, fallow, fencelines, fire breaks, industrial, forests, pasture	**Selective** certain woody & broadleaved weeds
		TORDON, VIGILANT HERBICIDE GEL picloram often formulated with triclopyr, MCPA	**Post-emergence** Systemic, foliar and root absorption soil residual	Non-crop, rights of way, grazing pastures, forestry	**Selective** certain woody weeds and some other species
		CLOPYRALID, CLOMAC FORESTRY, VARIOUS clopyralid may be formulated with 2,4-D, dicamba	**Post-emergence** absorbed by leaves & roots	Certain field crops, pastures, fallow land, forests, industrial sites	**Selective** certain broadleaved weeds
	Quinoline carboxylic acids	**DRIVE** quinclorac	**Post-emergence Systemic**	Certain established turf species	**Selective** summer grass, white clover, suppresses kikuyu

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 72. Herbicide Mode of Action Groups (2009) ***some examples (contd)***

CHEMICAL FAMILY		THE PRODUCT		SOME USES Read label, obtain advice from company	
MODE OF ACTION GROUP	**SUBGROUP**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**WEEDS CONTROLLED, SUPPRESSED**
J Inhibitors of fat synthesis (not ACCase inhibitors) MODERATE RISK	**Chlorocarbonic acids**	**ATLAPON, PROPON** 2,2-DPA	**Post-emergence** Systemic also root absorbed	Non-crop, irrigation channels, certain field crops, fruits, pasture, cotton vines, tea tree	**Selective** certain annual & perennial grasses
	Thio carbamates	**SATURN** thiobencarb	**Pre-emergence**	Rice	**Selective** grass weeds & certain annual sedges
		TRI-ALLATE, AVADEX, VARIOUS triallate	**Pre-emergence**	Certain field crops, eg barley, wheat, faba beans, peas, canola, lupins, safflower	**Selective** wild oats
	Phosphoro dithioates	**EXPORSAN** bensulide	**Pre-emergence**	Certain turf species in bowling green & greens	**Selective** winter grass
	Benzofurans	**OBLIX, MATRIX, TRAMAT, VARIOUS** ethofumesate	**Pre-emergence Post-emergence**	Certain non-crop sites, onions, oil seed poppies, beet crops, some pastures & seed crops, established turf	**Selective** certain grass and broadleaved weeds especially winter grass
K Inhibitors of cell division/Inhibitors of very long chain fatty acids (VLCFA inhibitors) MODERATE RISK	**Acetamides**	**DEVRINOL** napropamide	**Pre-emergence**	Almonds, grapevines, stone fruit, tomatoes (direct seeded, & transplants)	**Selective** mostly grass weeds, some broadleaved weeds
	Chloro-acetamides	**DUAL GOLD** s-metolachlor	**Pre-emergence** short residual	certain crops, eg barley oats, wheat, canola, broccoli, green beans, sweet potato, sorghum, sugarcane, maize, canola	**Non-selective** certain annual grasses and broadleaved weed
L Inhibitors of photosynthesis at photosystem 1 (PSI inhibitors) MODERATE RISK	**Bipyridils** More than 70 registered products contain paraquat	**PARAQUAT, GRAMOXONE, VARIOUS** paraquat **DANGEROUS POISON** often formulated with diquat (SpraySeed, Tryquat))	**Post-emergence Contact action** Rapidly desiccates plant tissue. Rapidly inactivated in soil. No residual weed control	Non-crop, industrial areas, row crops, certain other crops, seed-bed preparation, preplant herbicide, directed spray, spray topping, etc	**Non-selective** annual broadleaved & grass weeds, perennial weeds may regrow
M Inhibitors of EPSP synthase More than 352 registered herbicides contain glyphosate **Revolutionized control of many hard-to-kill perennial weeds** MODERATE RISK	**Glycines** **includes Roundup Ready crops, eg soybean, cotton, alfalfa, corn**	**GLYPHOSATE, GLYFOS, ROUNDUP, WIPE-OUT VARIOUS** glyphosate present as the isopropylamine salt May be **formulated** with: with several other herbicides May be **tank mixed** with other post- or pre-emergence herbicides, or soil residuals **Bioactive™** has no surfactants & may also be used in aquatic areas	**Post-emergence Systemic** absorbed by **foliage, green stems and bark** in actively growing plants, translocation from foliage to roots. Little soil activity, but check plant back times Withering & yellowing of foliage not visible for several days to several weeks. Do not disturb perennials weeds for 2 weeks after treatment.	Non-crop, paths, fencelines, fruit, ornamentals, vegetables field crops, forests, in shrub beds and around trees; to control weeds **prior to planting** crops, turfgrasses, vegetables, etc; tree poisoning, woody weeds	**Non-selective** annual & perennial broad leaved weeds & grasses **Selectivity** can be achieved by using as directed spray or wipe-on applicators for grasses & sedges, deep rooted perennial weeds, etc
	Dual Salt Technology	**WEEDMASTER DUO, RAZOR, VARIOUS** glyphosate present as the isopropylamine & mono-ammonium salts	**Post-emergence Systemic** ammonium improves the performance of glyphosate	Wide range of situations	**Non-selective** wide range of annual and perennial weeds
		ERADICATOR, VARIOUS glyphosate present as the monoethanolamine salt	**Post-emergence** Systemic	Wide range of situations	**Non-selective** wide range of annual and perennial weeds
		TOUCHDOWN glyphosate-trimesium	**Post-emergence** Systemic	Wide range of situations	**Non-selective** wide range of annual and perennial weeds
N Inhibitors of glutamine synthetase MODERATE RISK	**Phosphinic acids**	**BASTA, FINALE, LIBERTY, VARIOUS** glufosinate-ammonium	**Post-emergence Contact action** Knockdown, burns off green plant parts contacted by spray **Non-residual control** Fast effective control	Non-crop, commercial and industrial areas, bananas, grapes, pome & stone fruits weeds in bulb beds before bulbs emerge around trees, paths	**Non-selective** annual and perennial broadleaved & grass weeds, perennial weeds may regrow from roots Non-residual control of certain broadleaf weeds in **Liberty Link® cotton varieties**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 72. Herbicide Mode of Action Groups (2009) *some examples (contd)*

CHEMICAL FAMILY		THE PRODUCT		SOME USES Read label, obtain advice from company	
MODE OF ACTION GROUP	**SUBGROUP**	**Trade name Active constituent**	**Mode of action**	**CROPS, SITES TREATED**	**WEEDS CONTROLLED, SUPPRESSED**
O Inhibitors of cell wall (cellulose) synthesis MODERATE RISK	**Nitriles**	**CASORON, SIERRARON, ROOTFOAM, VARIOUS** dichlobenil	**Pre-emergence Soil residual** Season long control. Absorbed through roots, upwardly translocated	Commercial and industrial areas, orchards, vineyards, ornamentals, around trees/shrubs nursery stock aquatic areas	**Selective** certain annual & perennial weeds. Also registered for prevention of tree root regrowth & entry into sanitary, septic and storm water sewers after mechanical clearance (only to be sold to and used by trained plumbers & other operators)
	Benzamides	**FLEXIDOR, GALLERY** isoxaben May be formulated with Florasulam (X-Pand)	**Pre-emergence Persistent** will accumulate in soils	Fruit & nut orchards, vine-yards, nursery & amenity trees, pyrethrum crops	**Selective** certain broadleaf weeds
P Inhibitors of auxin transport MODERATE RISK	**Phthalamates**	**ALANAP-L** naptalam **This product is no longer being manufactured**	**Pre-emergence** Incorporation into soil	Cucurbits	**Selective** certain broadleaf weeds
Q Bleachers:Inhibitors of carotenoid biosynthesis unknown target	**Triazoles**	**AMITROLE T** amitrole + ammonium thiocyanate amitrole may be formulated with other herbicides	**Post-emergence** Systemic, absorbed by roots & leaves Pre-plant treatments	Industrial situations orchards, vineyards irrigation ditches, roadsides, some field crops, certain tree plantations	**Non-selective** annual & perennial grass & broadleaf weeds
MODERATE RISK	**Isoxazolidinones**	**COMMAND, MAGISTER** clomazone may be formulated with other herbicides	**Pre-emergence** Uptake through roots & foliage, moves upwards in plant	Rice, certain vegetable crops, poppies, tobacco	**Selective** certain annual broadleaf & grass weeds
R Inhibitors of dihydro pteroate synthase (DHP inhibitors) MODERATE RISK	**Carbamates**	**ASULAM, ASULOX, RATTLER** asulam	**Post-emergence** Systemic, taken up by both roots and leaves	Apples, hops, onions, potato, pasture, lucerne, ryegrass seed production, sugarcane	**Selective** especially established perennial grasses, bracken
Z Herbicides with unknown and probably diverse sites of action	**Arylamino-propionic acids**	**MATAVEN L, VARIOUS** flamprop-m-methyl	**Post-emergence**	wheat, triticale, selective spray topping of wild oats in wheat	**Selective** wild oats (black oats)
	Dicarboxylic acids	**WINTER GRASS KILLER. POACHEK** endothal	**Post-emergence Contact action**	Certain turf and lawn species	**Selective** winter grass
MODERATE RISK	**Organo-arsenicals**	**DSMA, VARIOUS** disodium methyl-arsonate (DSMA)	**Post-emergence Contact action**	Certain sports turf & lawns, cotton, non- agricultural areas, cotton	**Selective** certain broadleaf weeds & grasses & sedges

Table 73. Other products, plant extracts, etc. some agricultural biological products

	TYPE	Trade name Active constituent	SOME USES		
	Aquatic herbicide	**MAGNACIDE H** acrolein	For use in water to control submerged & floating weeds and algae in **irrigation systems. Only to be supplied to and used by a an authorized person**		
	Hydrocarbon oils	**DIESEL FUEL** petroleum oil (may be mixed with certain herbicides)	**Pre-emergence Post-emergence Contact action,** persists in soil	Non-crop, lines in playing fields, use as a directed spray	**Non-selective** general weeds
	Inorganic metals	Arsenic, boron copper sulphate iron sulphate sodium chlorate sodium chloride ammonium sulfamate	Inorganic metals do not contain carbon, generally derived from mineral ores. When used as herbicides they directly poison plants, ie kill parts of plants with which they come in contact **Bluestone (copper sulphate)** controls algae in paths and ponds, copper deficiency **Sulphate of iron** (ferrous sulphate) contact effect, mosses in lawns		
		LAWN SAND Wear gloves, using a plastic measuring cup, place equal parts of dry washed sand, sulphate of potash and iron sulphate in a plastic bucket	Mix immediately and sprinkle directly onto weeds, not the whole lawn. Apply in the evening so any dew can activate the process or lightly sprinkle. To control all weeds every 2nd week. Wear gloves (check Gardening Australia for details). Doesn't store.		**Selective** certain broadleaved weeds in turf
	Plant extracts, other products	**BIOWEED, INTERCEPTOR** pine oil	**Post-emergence Contact action** Rapidly desiccates weeds	Paths, driveways, around sheds, spot spraying in lawns	**Non-selective** seedling weeds & grasses, suppresses established weeds
		CALLISTO mesotrione (from roots of the bottlebush plant (*Callistemon citrinus*)	**Pre and Post emergent control Allelochemical**	Maize	**Selective** certain broadleaf weeds
CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE		**BEAT-A-WEED NATURAL WEEDKILLER** acetic acid + sodium chloride	**Post-emergence Contact action** Repeated applications need for long term control of perennial weeds	Gardens, paths, spot spray in lawns with care	**Non-selective** annual broadleaf weeds, algae, lichens, liverworts, moss
ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE		Ammoniated soap of fatty acid, vinegar, lemon juices, pelargonic acid, etc. are nonselective, they suppress annuals weeds and kill the tops of perennial weeds which regenerate after a one application.			

EXAMPLES OF WEED SITUATIONS

Adjuvants (spray additives)

- An adjuvant is broadly defined by the **APVMA** as 'any substance (other than water) that is added to an agricultural chemical product to alter its physico-chemical properties and/or improve its efficacy'.
- They are added to pesticides prior to application mainly to improve their effectiveness, eg spreaders and stickers to improve spray coverage, and/or plant safety, eg compatibility or to reduce drift.
- Most spray additives are of **low hazard** but some may damage the **environment**, eg fish; others may **damage crops** under some conditions.
- Always check **sequence** of sprays and their **compatibility** with **pesticide(s)** being applied.
- Many are for use with **particular products** only, eg **Nufarm Bonus** (alkyl ethoxy phosphate trolamine salt) for use with Nufarm Credit Broadacre herbicide; **Trilogy** (octyl phenol ethoxylate) to enhance glyphosate performance on grasses in cold environments; **Hydrogel** spray additive for diquat which causes the mix to submerge and attach to the target submerged aquatic weeds.
- **Guides available online** include *Understanding Spray Oils and Adjuvants*, *Herbicide Adjuvant Guides*.
- Companies may **specialize** in adjuvants, eg SACOA www.sacoa.com.au/, SST Australia www.sstaustralia.com
- Adjuvants are listed under product type on **PubCris** on the **APVMA** website www.apvma.gov.au/

Table 74. Adjuvants, spray additives. - some examples.

TYPE	THE PRODUCT Trade name Active constituent	SOME USES Read label, obtain advice from company
GENERAL SPREADERS AND STICKERS	**AGRAL spray surfactant, VARIOUS** nonylphenol ethylene oxide non-ionic organic surfactant	For use with horticultural insecticides, fungicides and herbicides
	WETTER TX octyl phenol ethoxylate	A special purpose non-ionic surfactant for use with the Roundup family of herbicides.
	SACOA WETTA 1000 non-ionic ethoxylates	For use as a **bio-degradable** wetting and spreading agent**.** A spray for use with knockdown and residual **herbicides.**
Petroleum oils	**D-C-TRATE, TRYCOL, VARIOUS** petroleum oil	Used on a range of crops with **insecticides and herbicides**.
	TALISMAN, TRIBUTE, petroleum oil/non-ionic polyethylated surfactants	To enhance the performance of certain **herbicides**.
Paraffinic oils	**BIOPEST** paraffinic oils	May be used with certain fungicides, insecticides, herbicides to improve wetting and penetration.
Botanical oils, vegetable oils	**SYNERTROL OILS** botanical oils/vegetable oils	For addition to most agrochemical, horticultural, foliar fertilizer and micro-nutrient sprays to **increase** chemical wetting, spread, penetration and rainfastness and to **reduce** spray drift and leaching of soil chemicals.
	CODACIDE rape seed oil (canola)	Can maximize the performance of many plant protection products; enhances the activity of some **insecticides**.
STICKING AGENTS	**SPRAYFAST** di-1-p-menthane	For use as a **tank mix** with some agricultural chemicals to **improve their performance**, ie penetration, wetting and adhesion, can also be used as an **anti-transpirant.**
ANTI-DRIFT AGENTS	**DRIFTEX, VARIOUS** refined canola oil	For addition to turf pesticides sprays to reduce spray drift and improve rainfastness. An adjuvant added to a spray mixture to **reduce drift**.
ANTI-EVAPORANTS	**ANTIEVAP, RULVAPRON** petroleum oil	**Anti-evaporant** and winter spray oil. Used with insecticides, fungicides, herbicides.
BUFFERING AGENTS	**SPRAYBUFF, PROBUFF** soyal phospholipids acid/propionic acid	Acidifying and penetrating surfactant, reduces alkaline hydrolysis of dimethoate, assists with uptake of foliar fertilizers, assist in management of spray droplet size.
SPREADING AGENTS	**HYGRO-STIC STICKER SPREADER** di-1-p-menthene	Used as a sticker/spreader for agricultural chemicals.
CLEANING AGENTS	**KOMPLETE KLEEN** 4% available chlorine	Multipurpose cleaning concentrate for spray equipment.
	TANK & EQUIPMENT CLEANER sodium triolyphosate + detergents	For **cleaning** spraying equipment, for **decontamination** when changing from one agricultural chemical group to another, for **end of season cleaning** before storage.
COMPATIBILITY	**STEADFAST** alkylaryl polyoxyethylene glycol phosphate ester	A compatibility, acidifying and surfactant agent
	FLOWRIGHT COMPATIBILITY AGENT blend of fatty acid triglycerides	Used when **tank mixing** certain herbicides.
DEFOAMERS	**ACTIVATOR** non-ionic surfactants	Rainfast wetting agent with **low foaming qualities**, **reduces drift** by producing a thick foam. Used to reduce foaming of a spray mixture due to agitation.
PENETRANTS	**PULSE, BREAK-THRU GOLD PENETRANT** polyether modified polysiloxane	Spray additive for improved penetration of **glyphosate** and/or **metsulfuron methyl** herbicides when treating certain brush and woody weeds, eg bracken.
SYNERGISTS	**LIASE, VARIOUS** ammonium sulphate	For use with **glyphosate-based** herbicides to minimize antagonism when tank mixing with **flowable** herbicides and improve performance under adverse environmental conditions.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

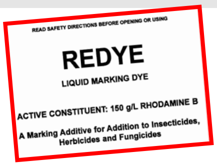
ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Marking systems

To ensure uniform pesticide coverage over target areas, some system of temporarily **marking** the treated area is needed to prevent/indicate overlapping, unsprayed areas, spray drift onto non-target areas, blocked nozzles. etc.

- **Overlapping** increases pesticide usage, time taken, cost of spraying operations and may hasten development of herbicide resistance in overlapped areas or cause environmental contamination.
- **Unsprayed areas** can decrease crop yields, increase seed set of weeds, increasing the future weed burden.
- May indicate blocked nozzles, equipment malfunction.
- Different colours, eg blue is regarded as being more aesthetically acceptable on sportsgrounds/turf.
- Some are not for use on edible crops.
- Some are formulated for use on turf only, others for horticulture and turf.
- Some are for use only with herbicides, others with insecticides, herbicides, fungicides, PGRs, fertilizers.
- Some only for herbicides and smaller areas, eg rhodamine Kendocide
- Some breakdown in hours, eg Blazon®, others remain for several days; foam remains for several hours.
- They contain a range of ingredients, eg rhodamine, etc.
- Plants accidentally sprayed can be immediately treated to minimize damage. Some do not stain fingers.
- Markers are listed under product type on **PubCris** on the **APVMA** website www.**apvma**.gov.au/

Table 75. Marking systems – some examples.

THE PRODUCT	SOME USES
Trade name **Active constituent**	**Read label, obtain advice from company**
DYES **RED** 	**REDYE Liquid Marking Dye** (rhodamine B) use with **herbicides** (high water volume applications) for marking sprayed areas in horticulture, turf. • Use with both liquid and powder herbicide spray products, foam colouring agent. • Colour on sprayed areas remains for several days. • Use in areas which are not too large, shrub beds, spot spraying, boom spraying small areas where other markers cannot be used. • Use where stock are grazing, as a warning to owners. • Indicates contamination of operator's personal protective equipment. Can be difficult to wash out. • Use **low** rates on **light coloured** vegetation situations**,** eg concrete edges, kerbs and gutters, granite areas and pine mulch. Use **high** rates on **dark** vegetation. **ENVIRODYE Red Liquid marking Dye** can be used with pesticide sprays; good compatibility with glyphosate, 2,4-D, MCPA and dicamba.
BLUE 	**BIG FOOT liquid** (sulphonated aromatic acid dye) is a highly concentrated blue spray pattern indicator in **horticulture and turf**. **BLAZON Blue Spray Pattern Indicator** (proprietary colorant) for use with pesticide, fertilizer and PGR solutions, to temporarily identify treated areas. Not intended for use on edible corps. **ENVIRODYE** Blue Liquid Marking Dye (sulphonated aromatic acid dye) a colorant for **turf** and a marker for use with pesticides and marking foam. **TurfMark Blue** (blue colorant) is a spray marker for turf use.
GREEN	**RE-GREEN** is used on dormant turf, pale coloured grasses or dying turf.
FOAM MARKERS	Foam generators on the end of the spray boom drop blobs of foam to mark the edge of the treated area. Foam may be white, pink or blue. **Uses.** Broadacre agriculture.
MECHANICAL SCRATCHERS	Mechanical scratchers, eg plough shares or discs, trailed from the end of a spray boom will leave a mark for the next spray. Not recommended for areas with stumps or large stones, hard soil, dust may inactivate chemical. **Uses.** Broadacre agriculture.
TRAMLINES	Very accurate. Strips of paddock/crop are left unsown and "tramlines" are used to guide the sprayer. Seeder width is matched so that the sprayer is a multiple of the seeder widths. **Uses.** Broadacre agriculture.
HUMAN MARKERS	The Aerial Agricultural Association of Australia has prepared a list of procedures for human markers to follow to ensure operational safety and uniform application. **Uses.** Broadacre agriculture, aerial applications.
FIXED SIGHT MARKERS	Fixed sight markers, preferably colour-coded to prevent confusion, are placed on fences. Some are radio-controlled that move themselves along fence lines. **Uses.** Broadacre agriculture, aerial applications
GPS (Global Positioning Systems)	Satellite navigation on aircraft, and within tractors, are becoming common with spray contractors. They enable accurate spraying limited only by the accuracy of the particular GPS equipment in use and the ability of the tractor driver or steering equipment to follow navigational lines. **Uses.** Broadacre agriculture, aerial applic.
TREE MARKING PAINTS	Special paints available as aerosols are used to mark individual trees for treatment. Resists weathering.
SPRAY DEPOSITS ON PLANTS various dyes	Various dyes and systems are used to check droplet coverage and spray patterns on leaves.
SPRAY OPERATORS various dyes	Various dyes, some of which can only be seen under fluorescent lights are available for checking spray deposits on **personal protective equipment** of operators.

Post-emergent, pre-emergent, soil residual herbicides

Weed types

Annual and perennial herbaceous grass and broad leaved weeds.

Herbicides

For effective herbicide application and to avoid poor herbicide performance:

- **Select a registered herbicide to** control the **weeds** in the **crop** or **situation** in which the weeds occur. Apply at **right stage of crop and weed.**
- **Apply the herbicide at the correct time,** eg
  - To control winter annual weeds apply March/April.
  - To control summer annual weeds apply Sept/Oct.
- **Length of time between treatments** can be manipulated by careful attention to herbicide selection for weed spectrum, application rates, weed populations, uniform coverage and use of various non-chemical methods, eg hand weeding.
- **Use appropriate application equipment**, techniques and rates, eg correct nozzles, distance between nozzles, boom height, pressure and speed, calibrate application equipment.
- **Add a wetting agent or other spray additive** if label recommendations indicate.
- **Apply during the correct weather** before, during and after application.
  - **Apply during favourable temperature and moisture** conditions that enable the herbicide to work.
  - **Temperature** must not be too hot or too cold. Avoid applications when weeds are stressed, eg hot weather.
  - **Irrigation and rainfall** affects both post and pre-emergents. **Drought reduces weed growth** and so reduces post-emergence herbicide performance. Rain following application results in herbicide being washed of treated target weeds.
  - **Moist leaves** absorb herbicide better than dry ones so **good soil moisture** which leads to moist leaves is paramount. If the foliage is not moist the product fails to penetrate leaf hairs.
- **Plant injury** (phytotoxicity).
  - **Many young plantings and new crops** are very sensitive to herbicides, eg new turf and roses < 2-3 years of age.
  - **With hormone herbicides** select least volatile formulations, ie sodium salts or amines of 2,4-D instead of esters (page 460).
  - **Observe plant back times** on the label.
- **Do not mow, graze or cultivate** until after the recommended time on the label. Allow time for post-emergent herbicides to be absorbed by the plant.

Table 76. Near desired plants. Some examples, the following is a guide only.

What to use?	When and how to apply?
NO RESIDUAL WEED CONTROL	
• Post-emergents are used for controlling **emerged weeds only**, often described as knockdown herbicides. • Can be used around trees and shrubs, domestic paths and fencelines. Follow label directions for application around newly planted trees and shrubs. • Can be used as a directed spray. **Post-emergent** (foliage-applied) **Non-selective post-emergents**, eg	Apply most post-emergents when weeds are young, weeds are easier to kill and landscapes look better. For perennial weeds the aim is to kill the plant's underground parts. Systemic herbicides move from foliage to roots.
Group M, eg Glypho®, Roundup® (glyphosate)	**Systemic foliage absorbed**. Kills emerged weeds only, kills roots. Do not disturb treated weeds by cultivation, grazing or sowing for at least 1 day after treatment of annual weeds and 7 days for perennial weeds (check label for variations).
Group N, eg Basta®, Finale® (glufosinate-ammonium)	**Contact (minor translocation) foliage herbicide**. Burns off parts of green plants contacted by spray. Many annual and perennial broadleaved weeds and grasses, some perennial weeds may regrow from roots.
Group L, eg SpraySeed®, Tryquat® (diquat + paraquat) **DANGEROUS POISON**	**Contact foliage herbicide**. Kills emerged weeds only, does not kill roots. Do not sow or cultivate for 1 hour after spraying (check label for variations).



Fig. 251. Examples of herbicide damage. ***Left:*** Glyphosate injury to honeysuckle. ***Centre:*** Glyphosate injury to roses. ***Right:*** Tryquat injury to tulip leaves. Photo©CIT, Canberra (P.W.Unger).

Table 76. Near desired plants. *(contd)*

What to use?	When and how to apply?

RESIDUAL WEED CONTROL--------- 3-6 MONTHS

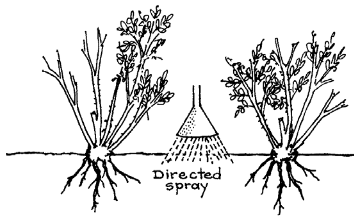
- Shrub beds, around trees, roses, along domestic fencelines. Care should be taken when spraying around newly planted trees and shrubs.
- Annual beds, containers (pages 463, 464).

PRE-EMERGENT RESIDUAL HERBICIDES

- **Existing emerged weeds** should be controlled either by hand weeding, spot spraying or combining a pre-emergent with a post-emergent knockdown herbicide, eg Glypho®, Roundup® (glyphosate) (pages 453, 457).
- **Residual activity** is the length of time a herbicide provides control. Most pre-emergent herbicides are effective for 3-4 months (some up to 6 months), depending on the uniformity of coverage, weed pressure, reintroduction of seed to the area and amount of hand weeding carried out.
- **Pre-emergent herbicides kill germinating seeds** of both target weeds and non-target plants (herbicide must contact germinating seeds; seedlings may emerge before they die).
- **Registered uses**. The pre-emergent **must be** registered for the particular **weed** in the **crop** to which it is to be applied otherwise apply for a permit.
- **Weed type.** Most pre-emergents are more effective against the germinating seeds of some weed species than others, eg broadleaved weeds or grass weeds.
- **Spectrum of activity.** Formulations combining herbicides, eg Rout® (oryzalin + oxyfluorfen), are useful as they can increase the weed control spectrum and the residual activity of a herbicide application, thereby reducing the number of applications required.
- **Timing of application.** Apply pre-emergents before time of maximum weed seed germination or very soon after, eg Surflan® (oryzalin), simazine (low rates).
- **Apply at correct rate** and at the correct frequency.
- **Even application, incorporation and activation are essential:**
  - **Evenness of application**. Uniform coverage of soil surfaces outdoors and in containers, ensures that the effectiveness of pre-emergent herbicides is maximized and cost savings achieved.
  - **Incorporation into the soil** may be required to prevent loss of activity through volatility or prevent later crop damage. Many pre-emergents need rainfall or irrigation for incorporation but too much causes them to decompose too rapidly, with too little rain the herbicide stays on the surface and volatilizes, degraded by sunlight. **Poor soil moisture conditions** probably cause more failures with soil-applied herbicides than anything else. A few pre-emergents are incorporated by mechanical means (page 447). Later cultivation may enhance **or** decrease herbicide activity.
  - **Activation.** Pre-emergents, need to be **activated** by rain or irrigation. Pre-emergent herbicides **act** when weed seeds germinate as a result of moisture.
  - **Soil disturbance** can dramatically reduce the effectiveness of pre-emergents.

For effective application of pre-emergents:

- **Weather**. Check weather, rainfall, temperature, wind, volatilization, photo-degradation.
- **Seedbeds** should be clump-free, ie free of weeds, trash and clods at time of application.
- **Formulations.** Pre-emergent herbicides may be applied as a directed spray or as granules and either before or after planting the crop.
- **Plant injury** (phytotoxicity). All pre-emergents may damage some species of plants. Some pre-emergent herbicides at higher concentrations damage established plants, eg simazine at **low** concentrations is a pre-emergent while at **high** concentrations it can kill established plants. Others, eg Surflan® (oryzalin) have a much wider margin of plant safety. Pre-emergents may be sprayed over the top, or as a directed spray before or after planting, so there is scope for injury.
  - The crop or the emerging crop must be tolerant.
  - Know which species may be injured, check label.
  - Injury can occur with woody plants but is more likely with soft-foliaged annuals and herbaceous perennials.
  - The use of pre-emergent herbicides on **annual and herbaceous perennial flower crops** has been slower to develop and are frequently not quite as effective as those used around woody trees and shrubs, fruit trees, vines and in turf areas. This is mainly because annual and herbaceous perennial crops are more susceptible to injury due to:
    - Roots being more superficial in the soil.
    - Foliage is softer and closer to the ground and more easily damaged by herbicides.
    - Application in polytunnels where the atmosphere is enclosed and temperature is higher, vapour may injure non-tolerant species.
    - Being grown in closed recycling systems.
    - More applications than label recommendations.
- **Season when applied affects effectiveness**. Many pre-emergents are more effective against the same weed species during summer than during winter.
- **Cost of herbicide.** Some pre-emergent herbicides, eg Ronstar® (oxadiazon) are much more expensive than others, eg simazine.



COMBINING PRE-EMERGENTS AND POST-EMERGENTS

Always check mixtures are compatible	Labels supply compatibility information.
Post-emergent (knockdown) eg **Group M**, eg Roundup (glyphosate)	**Systemic**, foliage absorbed, non-selective herbicide translocated down into roots, kills emerged weeds.
+	
Pre-emergent (kills germinating weed seeds), eg **Group D**, eg Surflan® (oryzalin)	**Soil residuals** Some broadleaved and grass weeds.
OR	
Group C, eg Gesatop® (simazine) (low rate only)	Some broadleaved and grass weeds.
Post-emergent (knockdown), eg **Group L**, eg Spray.Seed®, Tryquat® (diquat + paraquat) **DANGEROUS POISON**	**Non-systemic**, contact, non-selective foliage herbicide, kills foliage on contact, does not kill roots.
+	
Pre-emergent (kills germinating weed seeds), eg **Group G**, eg Goal® (oxyfluorfen)	**Soil residual** Grasses and some broadleaved weeds

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 77. Total vegetation control.

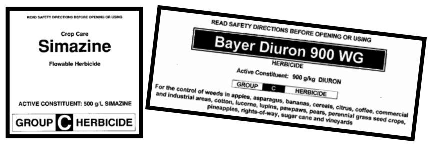
What to use?	**When and how to apply?**
RESIDUAL WEED CONTROL---------- 6-12 MONTHS	
• **Not for use near desired plants** or on areas where their roots may extend, or water catchments areas. They are only suitable for relatively flat areas where there is no chance the chemicals can wash down slopes to garden beds or lawns and leave lasting damage. • These chemicals are suitable for use along log barriers, crash rails, drain headwalls and fencelines, generally **not** in domestic or residential areas. • Soil residuals must be used at **recommended rates** to obtain the desired length of control. Many of these herbicides at higher concentrations provide control for a much longer time so that the area of land to which they are applied is not available for other uses for that period of time.	• For long term weed control there are "once-a-year pathweeders" registered for home gardeners, which have a residual effect for up to 12 months and prevent weeds growing in paths, driveways and paved areas. • Some may be mixed with a post-emergent (knockdown) herbicide, eg Roundup®, Tryquat®. • **Always check the label to see that mixtures are compatible.** • Remember no pre-emergent herbicide will control all germinating weeds.
Post-emergent (knockdown) eg **Group M**, eg Roundup (glyphosate) **+** **Soil residual**, eg **Group C**, eg Gesatop® (simazine)	**Systemic**, foliage absorbed, non-selective herbicide translocated down into roots, kills emerged weeds. **Soil residuals** Residual weed control for **6-12 months**.
RESIDUAL WEED CONTROL---------- 1 YEAR OR LONGER	
• **Not for use near desired plants** or on areas where their roots may extend. • The herbicide must be used at the **recommended rate** to obtain control for this period of time. • May be used in parking areas (not domestic or residential).	
Soil residuals, eg **Group C**, eg Diuron® (diuron) **OR** **Group C**, eg Gesatop® (simazine) **OR** **Group O**, eg Casoron®, Sierraron® (dichlobenil)	Weed control can be obtained for about **1-2 years**. Weed control can be obtained for **several years**. Weed control can be obtained for **several years**.

Fig. 252. Example of herbicide injury. ***Left:*** Soil residual applied to path washed down slope onto turf. ***Centre:*** Pre-emergent simazine injury to *Prunus*, applied just before heavy rain, interveinal yellowing can range from relatively mild to severe depending on the amount of herbicide absorbed. ***Right:*** Leaf veins of citrus turn yellow or white (vein clearing), possibly bromacil or diuron injury; note that vein clearing may also be caused by other agents, eg virus disease, root injury or girdling, or arguably, if normally well fertilized trees are suddenly deprived of nitrogen. Photo©CIT, Canberra (P.W.Unger).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

Broadleaved weeds

Weed types

Annual and perennial broadleaved weeds, eg

- Annual, eg capeweed (*Arctotheca calendula*) and
- Perennial, eg sheep sorrel (*Rumex acetosella*).

Spread

Depending on the species, methods of spread include:

- By wind and water, eg seed, broken plant parts.
- By cultivation, eg oxalis bulbs, root parts.
- By growth of stolons on the soil surface.
- In soil deliveries, manures, compost, containers as seed, rhizomes, cut up root pieces, bulbs etc.

Management (IWM)

1. **Access a plan** that fits your situation.
2. **Crop, region.** There will be variations in activity depending on the situation.
3. **Identification** of the weed(s) must be confirmed. Be able to identify different growth stages of the weeds. Consult a diagnostic service if necessary (page xiv). Know their life cycle, method of spread, etc.
4. **Monitor** weeds and/or their impact, record results (page 429). Know when seeds are going to germinate.
5. **Threshold.** How much weed infestation is acceptable? Have any economic, environmental aesthetic? Do you need to calculate your own threshold? There may be a nil tolerance, eg turf playing fields.
6. **Action.** Take appropriate action when any threshold is reached and follow through a maintenance program.
7. **Evaluation.** Review **IWM** program. Recommend improvements if required.

Control methods

Cultural methods. After 'eradication' from a bed, maintain suitable groundcover of plants, or mulch, to prevent re-establishment of weeds. Consider edging beds to keep out any stolons.

'Tolerant crops'. Some crops have been genetically engineered **(GE)**, eg ornamentals (petunia), vegetables (potato), field crops (canola, cotton, soybean) for tolerance to **non-selective herbicides**, eg Roundup Ready Cotton.

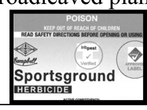
Plant quarantine. After removal from an area avoid re-infestation by not introducing soil, compost or containers infested with broadleaved weed seeds, stolons or rhizomes, corms.

Weed-tested seeds, soil etc. Ensure crop seed is certified weed-free; tubestock and containers should not contain weed seeds, rhizomes, etc.

Physical & mechanical methods. Annual broadleaved weeds may be hand pulled before seed is set. **Perennial** broadleaved weeds may be dug out diligently over time to remove most stolons and roots. Cultivation can spread bulbs and root pieces, etc and there is still a seed bank of weeds seeds in the soil.

Herbicides. Depending on the situation, annual weeds can be controlled before they flower and set seed, by foliar sprays of selective herbicides, or directed sprays of non-selective herbicides. Pre-emergents must be applied **before** seeds germinate (page 458, Table 76). Many broadleaved weeds have developed **resistance** to certain herbicides (page 449).

Table 78. Broadleaved weeds. - Selective control ***(mostly for commercial growers).***

What to use?	When and how to use?
BROADLEAVED WEEDS IN GRASS CROPS.	
Post-emergents Selective post-emergent **hormone herbicides** which do **not** kill grasses have been available for years to control a wide range of broadleaved weeds in turf, pastures and cereal crops. Some are more effective at controlling some broad-leaved weeds than others. Check label directions for the weeds in your crop.	**Hormone herbicide injury** to crops eg cotton and grapes, is not uncommon (Fig. 253). There are restrictions on their use near grapevines. Some formulations are volatile and may damage non-target plants. Hose jar applications to garden lawns may damage surrounding broadleaved plants.
Hormone-type herbicides **Group I**, eg 2,4-D, MCPA, dicamba, clopyralid, mecoprop; often formulated as mixtures, eg dicamba and MCPA	**Systemic**, foliage applied 
Pre-emergents, eg **Group B**, eg Glean® (chlorsulfuron)	**Soil residual**, mainly broadleaved weeds in cereal crops (see also broadleaved weeds in turf, page 462).
BROADLEAVED WEEDS IN BROADLEAVED CROPS	
Post-emergents,	Are available for a few crops.
Pre-emergents, eg **Group D**, eg Dacthal® (chlorthal), Surflan® (oryzalin) **Group G**, eg Ronstar® (oxadiazon)	**Soil residuals** Certain broadleaved weeds (and grasses) in ornamentals, eg roses, fruit, vegetables, nursery stock.
SPOT SPRAYING (DIRECTED FOLIAGE SPRAY)	
Post emergent **Group M**, eg Roundup® (glyphosate) – Non-selective	**Systemic**.

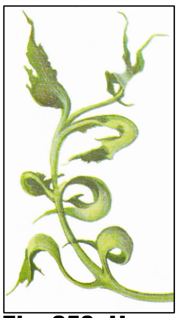



Fig. 253. Hormone herbicide injury. ***Left:*** Spindly tomato leaves. ***Centre and right:*** Parallel leaf veins in plane tree and grape vine. Cotton and grapevines can be severely damaged each year. Photo©NSW Dept of Industry and Investment. Photo©CIT, Canberra (P.W.Unger).

Grass weeds

Weed types

Annuals, eg annual ryegrass in field crops and winter grass (*Poa annua*) in turf are arguably the most written about annual grass weeds. **Perennial grasses** are endless, eg couchgrass (*Cynodon dactylon*), various tussock grasses in pasture and bushland.

Impacts

Water and nutrients are used up. Crop yields are reduced, playing surfaces affected and native bushland invaded by perennial grass weeds. Landscapes may be affected aesthetically. Old clumps of unmown grass weeds are a **fire hazard** in some areas.

Weed biology

- **'Overwintering'** in seed banks, eg **10000 ryegrass seed/m²** and **75000 perennial veldt grass seed/m²** have been found in WA after fire; perennial grasses also as underground roots and other structures. It should be possible to disrupt seed cycles of grass weeds, especially for **annual grasses**, since seeds are not well adapted for long term storage in the soil (up to 4 years). The problem is there are so many seeds.
- **Methods of spread**. Depending on the species, seed may be spread by wind and water. Stolons and rhizomes grow into adjacent areas. Seed, rhizomes, cut up root pieces, bulbs, are spread by cultivation, in soil deliveries, manure, compost, containers, road building materials.
- **Conditions favouring**, depend on species, but seed of some species in some areas will germinate at any time of the year following rainfall. Poor pasture, bare turf. Many grasses prefer open sunny sites and do not establish or compete successfully in shade.

Management (IWM)

Are you a commercial grower or home gardener?

1. **Obtain/prepare a plan** that fits your situation. Assess sites for weed control and soil type; plan a possible program of control and maintenance.
2. **Crop, region.** Recognize variations. List the grass weeds which are a problem.
3. **Identification.** Grasses are more difficult to identify than broadleaved plants, there are many native grasses. Be able to identify different **growth stages** of grass weeds. Identifying and treating grasses at the correct growth stage is essential for successful control. Consult a diagnostic service if necessary (page xiv).
4. **Monitor/map** weeds and/or their impact and record results of any weed management programs (page 429).
5. **Threshold.** Have any thresholds been established? If so, are they economic, fire, aesthetic, environmental?
6. **Action.** Take appropriate action when any threshold is reached.
7. **Evaluation.** Review **IWM** program to see how well it worked. Recommend improvements if needed.

Control methods

Correct timing is fundamental to successful grass weed control - prevent seed set, reduce seed bank and kill emerged weeds. In bush areas have enough resources to control grass weeds following fire.

Cultural methods. After eradication from a flower bed, maintain a suitable groundcover of plants or mulch to prevent re-establishment of grass weeds. Select couchgrass cultivars that do not 'run'.

'Tolerant crops'. Some ornamental crops, eg petunia, have been genetically engineered **(GE)** to be resistant to **non-selective herbicides**, eg glyphosate.

Plant quarantine. After eradication from a bed minimize re-infestation by not introducing soil, compost or containers infested with grass weed seeds, stolons or rhizomes, bulbs.

Weed-tested seeds, soil etc. Ensure crop seed is certified weed-free; tubestock and containers should not contain weed seeds, rhizomes, etc.

Physical & mechanical methods. In small areas, annual grass weeds may be pulled out before seed is set. Perennial grass weeds may be dug out over a long period of time to remove stolons and roots. Garden beds may have an edging to keep out the stolons. A ditch a few centimetres wide may be used in place of an edging. Grass weeds may also be mown, slashed, rolled or grazed before seed set.

Herbicides. Many herbicides are available to control grass weeds, however, some grasses have developed significant resistance to herbicides, eg annual ryegrass (page 449). Slashing without follow-up herbicide treatment may increase seed production of some grasses, eg love grass. Herbicides must be applied at the correct stage of weed growth. Selective control of grass weeds is difficult (Table 79 below).

Table. 79. Grass weeds - Selective control *(commercial growers).*

What to use?	When and how to use?
GRASS WEEDS IN BROADLEAVED CROPS eg perennial borders, vegetable & field crops	
Post-emergents, eg **Group A**, eg Fusilade® (fluazifop-p)	**Systemic**, foliage-applied. Grass weeds in broadleaved crops, garden beds. **Soil residual** for up to 4 months or longer.
Pre-emergents, eg **Group K**, eg Devrinol® (napropamide)	**Soil residual** Most grasses, some broadleaved weeds in tomato, other crops.
GRASS WEEDS IN GRASS CROPS, eg cereal crops, pasture, turf	
Post-emergents, eg **Group C**, eg Tupersan® (siduron) **Group I**, eg Drive® (quinclorac) **Plant growth regulator**, eg SHORTstop® Turf Growth Regulator (paclobutrazol)	Couch, kikuyu and summer grass in bent turf. Summer grass, white clover, suppresses kikuyu in turf. Suppression of winter grass and growth regulation in turf.
Pre-emergents, eg **Group D**, eg Pre-M® (pendimethalin + fertilizer), Dimension® (dithiopyr) **Group J**, eg Tri-allate® (tri-allate) **Group J**, eg Exporsan® (bensulide).	**Soil residuals** Winter grass in many turf species. Winter and summer grass in turf. Wild oats and some broadleaved weeds in wheat, barley, triticale and some broadleaved field crops. Winter grass in certain turf species.
SPOT SPRAYING (DIRECTED SPRAY)	
Post-emergents, eg **Group M**, eg Roundup® (glyphosate) - **non-selective**	**Systemic**, foliage-applied.

Weeds in turf

Commercial turf is an industry in itself.

Weed types

Annual and perennial broadleaved and grass weeds need to be controlled during turf preparation, establishment and maintenance. Winter grass (*Poa annua*) is the most written about weed affecting commercial turf.

Impacts

Weed impacts in turf are well known. In commercial turf water and nutrients are used up. Playing surfaces become uneven. In home gardens, flowering heads tower above the turf, flat growing weeds smother surrounding turf, etc.

Weed biology

- **'Overwintering'.** Weed seed, some of which is in the seedbank in the soil, rhizomes, etc.
- **Spread.** Seed by wind and water. By growth of stolons on the surface of the soil. Bulbs, stem pieces by cultivation. In soil deliveries, manure, compost, containers as seed, rhizomes, cut-up root pieces, bulbs, top dressing products.
- **Conditions favouring.** Weeds may colonize bare areas in turf due to heavy traffic, environmental stress or chemical applications to existing weeds. Commercial contractors in low maintenance areas have a tendency to 'scalp' grassed areas. Poor drainage, hollow coring and scarifying at a time

Management (IWM)

Are you a commercial grower or home gardener?

1. **Prepare a plan.** Access a weed management plan for your turf species involving site preparation, turf establishment and maintenance.
2. **Crop, region**. Recognize variations.
3. **Identification** of existing or likely future weed(s) must be confirmed. Recognize mown weeds, consult a diagnostic service if necessary (page xiv). Understand life cycles, spread, etc. habitat conditions, etc.
4. **Monitor** weed(s) and/or impacts and record results (page 429).
5. **Threshold**. Have any thresholds been established? If so, are they, playing requirements and/or aesthetic?
6. **Action**. Take appropriate action when any threshold is reached.
7. **Evaluation**. Review **IWM** program to see how well it worked. Recommend improvements if needed.

Control methods

Do not introduce weed seeds, rhizomes or cut up root pieces in soil deliveries for turf establishment or top dressing. **If using herbicides always check the label for the type of turf they can be used on**.

- **Site preparation.** Perennial weeds should be controlled either by hand weeding or by spraying, when weeds are actively growing, with Roundup® (glyphosate), at least 2 weeks prior to cultivation to prepare the seed or turf bed. Once the soil is prepared for sowing or turfing, if any weeds germinate during this period they should be destroyed either by hand weeding, shallow cultivation or with herbicides. In commercial turf, sterilization of the seedbed may be warranted, or complete removal of infested soil.
- **Turf maintenance.** Weeds should not be a problem in dense well managed commercial turf or home garden lawn as the competition from grass should not allow weeds to gain a foothold. In a home garden, weeds can be removed by hand or dug out; many broad leaved weeds can be controlled to some extent by **'Lawn Sand'** (page 454) or herbicides. Some weeds in turf may be mowed out, eg chickweed.

Table 80. Weeds in turf – Some herbicides ***(mostly for commercial growers).***

What to use?	When and how to use?
SITE PREPARATION & TURF ESTABLISHMENT	
Site preparation **Group M**, eg Roundup® (glyphosate) **Newly established turf** is sensitive to recommended rates of herbicides**.** Do not apply herbicides to turf < 3 months of age, do not mow for 3 days before or after spraying, or fertilize for 2 weeks before or after spraying, unless label directions state otherwise.	At least 2 weeks prior to cultivation to prepare the seed or turf bed, annual and perennial weeds should be controlled either by hand weeding or by spraying when weeds are actively growing, with glyphosate. Once the soil is prepared for sowing or turfing, if any weeds germinate during this period they can be destroyed either by hand weeding, shallow cultivation or herbicide.
TURF MAINTENANCE	
Broadleaved weeds in turf **Post-emergents**, eg **Group I**, eg Kleenlawn®, various (dicamba + MCPA) – hormone herbicides **Pre-emergents**, eg **Group D**, eg Dacthal® (chlorthal) **Group G**, eg Ronstar® Turf & Ornamental Herbicide (oxadiazon)	 Hormone herbicide injury to ash tree due to drift from a hose-jar application to a home garden lawn
Grass weeds in turf. ***Commercial turf only*** **Post-emergents**, eg **Group A**, eg Hoelawn® (diclofop-methyl) **Group I**, eg Drive® (quinclorac) **Pre-emergents**, eg **Group D**, eg Dacthal® (chlorthal), Pre-M® (pendimethalin/ fertilizer), Dimension® (dithiopyr) **Group G**, eg Ronstar® Turf & Ornamental Herbicide (oxadiazon) **Group J**, eg Tramat® (ethofumesate)	
SPOT SPRAYING, ROPE-WICK, WEEDING BRUSH	
Group M, eg Roundup® (glyphosate) **Non-selective**	Treat weed clumps with a weeding-brush or spot spray.

Weeds in flower plantings

Weed types

Many weed problems in flower beds are the result of poor weed control in seed, seedling or cutting beds prior to planting the crop. A wide range of annual and perennial herbaceous grass and broadleaved weeds must be identified to ensure that any herbicides used will provide effective control. For example, weeds poorly controlled by pre-emergent herbicides such as clover and wireweed need to hand weeded to prevent competition with annuals.

Impacts

Weeds reduce the aesthetic value of a display and compete for water, light and nutrients and thereby reduce plant vigour. Weeds look unsightly and increase the incidence of disease and pests (Forster 2008).

Management (IWM)

Are you a commercial grower or home gardener?

1. **Prepare a management plan** that fits your situation and includes site assessment, source of planting material (plant species selections), site preparation and construction, planting and maintenance, cleaning up the site.
2. **Crop, region.** Recognize variations depending on the site, plants being grown etc. Select plant species suited to site, season and climate, etc.
3. **Identify** likely weed problems **- annual grasses**, eg annual rye grass (ARG), winter grass, wild oats, and **perennial grasses**, eg couchgrass; **annual broadleaves**, eg bitter cress, chickweeds, common cotula, fat hen, **perennial broadleaves**, eg thistles, wireweed, clover, and mustard weed. Obtain a Fact Sheets for each one. Seek advice if unsure (page xiv).
4. **Monitor** weeds and their impact and record results (page 429). Begin by carrying out a weed risk assessment by performing a weed seed germination test on the soil after site preparation. After planting up, monitor flower beds weekly for presence of weeds.
5. **Threshold.** How many weeds are acceptable? Have any thresholds been established? If so, what are they, economic, aesthetic, environmental? Do you need to calculate your own threshold?
6. **Action/Control.** Take appropriate action when any threshold is reached. Be careful in the selection of herbicides.
7. **Evaluation.** Review **IWM** program and flower species selection to see how well it worked. Recommend improvements if needed.

Control methods

Cultural & Physical. Choose areas free of perennial weeds. Beds must be properly prepared, weed seeds allowed to germinate and any weeds which develop must be controlled either by hand weeding, cultivation or by herbicides (see below).
Weed mats or weed-free mulches of various types prevent moisture loss, keep roots cool and discourage annual weeds.

Resistant/tolerant varieties. Some crops have been genetically engineered **(GE)**, ie ornamentals, eg petunia; to tolerate **non-selective herbicides**, eg glyphosate.

Plant quarantine. Avoid introducing **weed-infested** soil, mulch, planting material in tubes, pots, etc. Try to prevent keep weeds in surrounding areas from setting seed.

Disease-test planting material. Use if available and considered necessary.

Physical & mechanical.
Hand weeding during flowering may disturb plantings and damage roots.

Herbicides.

- **Post-emergents**. Existing weeds can be sprayed out with glyphosate after the weed seed germination test has been done. Pedestrian paths can also be sprayed with glyphosate, garden bed edges with glufosinate-ammonium to keep weed free. Continue weekly monitoring for weeds in flower beds – weekly hand weed as required.
- **Pre-emergent herbicides**. Select carefully to ensure their effectiveness and least likelihood of causing damage to plants. No pre-emergent herbicide will control all weeds (page 458, Table 76, Table 81 below).

Table 81. Weeds in flower plantings – Some herbicides

What to use?	When and how to use?
NON-SELECTIVE PRE-PLANT POST-EMERGENTS	
Group M, eg Roundup®, Zero® (glyphosate) (systemic) **Group N**, eg Basta® (glufosinate-ammonium) (partially systemic)	**Non-selective post-emergent** herbicides may be used to kill young emerged annual and perennial weeds in prepared planting sites prior to planting. Check planting times. Where applicable glufosinate-ammonium may be applied as a directed or shielded spray along edges of garden beds and for inter-row weed control after planting.
PRE-EMERGENTS	
Group D, eg Dacthal® (chlorthal-dimethyl), Surflan® (oryzalin) **Others**	Treat immediately after planting out (page 458). Wide range of weeds. Main use is over bulbs and annuals to control broadleaved weeds such as chickweed, capeweed, wireweed, creeping oxalis and fat hen.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Weeds in containers

Weed types

Annual and perennial broadleaved and grass weeds, eg creeping hairy bittercress (*Cardamine hirsutus*), common groundsel (*Senecio vulgaris*), oxalis (*Oxalis corniculata*), winter grass (*Poa annua*), liverwort (*Marchantia polymorpha*), chickweed (*Stellaria media*), willow herb (*Epilobium* sp.). **Some weeds are difficult to control in containers**.

Impact

Weeds in containers may compete for light, water and nutrients, detract from appearance and value of plants, be an unknown purchase in pots which spread to gardens, landscapes, bush areas. They physically hinder workers and are a source of insects such as aphids, thrips, whiteflies and mites and be symptomless reservoirs of virus diseases.

Weed biology

- **'Overwintering'.** Soil acts a primary storage bank for weed seeds and vegetative propagules. Nursery property fence lines and adjacent properties can act as large sources of weed seeds that are blown in by wind.
- **Spread.** Infested crop seed, propagation material, containers. Seed is spread by wind, water, animals, and people. Weed infestations close to a nursery and in the immediate area around containers. Many manufacturers avoid using uncomposted material and soil in potting mixes but they can become contaminated during transport, and by untreated recycled water.
- **Conditions favouring.** Weedy surrounds, poor weed management.

Management (IWM)

Good weed management is important for any nursery business and is one of the most difficult.

1. **Plan** the weed control program well in advance. Have a calendar so you will know what to do when. Include site assessment, source of planting material (plant species selections), potting up, maintenance and preparation for sale. Cleanup between batchs.
2. **Crop, region.** The container species you are growing will determine your weed control options. What information is already available?
3. **Identify** present and predicted weed problems. If necessary seek advice (page xiv). Identify problem weeds, eg bittercress, know source of weed seed, weed life cycles, etc.
4. **Monitor** weeds in the nursery and/or impact and record your findings (page 429). Early detection of weed problems is essential and regular scouting can begin as a first assessment on foot, walking the perimeter of the nursery and then across sections. Create a working system to allow workers to report weed infestations.
5. **Threshold**. How much weed infestation is acceptable? Have any thresholds been established? If so, what are they, eg economic, aesthetic? Do your customers have nil tolerance?
6. **Action/control**. Some weed control options do not apply to container plants. Last minute hand weeding can be used to remove weeds that escape herbicide or other treatments prior to sale. Pre-emergent herbicides will remain economical for the present as a necessary part of many **IWM** programs. However, their use should be minimized.
7. **Evaluation**. How effective was the weed control program? Evaluate a selection of plants **6 weeks after they have been sold and planted out** whether in a garden, bushland, or in a commercial planting. Recommend improvements if required.

Control methods

Weed control is one of the largest cost issues for growers and is the No.1. issue for organic growers.

Cultural methods prevention

- **Use weed-free potting mixes**. Soil-less mixes should be weed-free. Organic materials, if used, may contain large amounts of seed, and must be adequately composted.
- **Pot toppers** (fabric discs) are suited for larger container stock, eg 2-litre size upwards. Weeds readily grow in any gaps, eg around edges, and along any cuts made to assist fitting.
  - **Non-damaging** to plants, stable and resistant to wind, protected situations, control weeds for at least 1 year. Price competitive and easy to fit or apply. Commercially attractive at point of sale.
  - **Disks** must be UV resistant and permeable to fertilizers. Wool material deteriorates too rapidly.
  - **Some pot toppers** are coated with copper. Others contain herbicides and slow-release fertilizers and control weeds longer and better than standard herbicide applications.
- **Loose fill mulches** are suited to perennials grown in small pots. Mulches must be permeable to water and air but exclude light. Seed may germinate on top.
  - **Mulches are best applied** immediately after potting.
  - **Surface must be weed-free**. A weed mat could be used in containers with a weed-free mulch on top.
  - **Recycled paper pellets** applied at 25mm may not be cost effective but may have merit in certain places, enclosed structures where herbicide use is restricted, environmentally sensitive areas, eg water, some plants difficult to weed, eg thorny plants, plants grown in large container where between container loss is great.
  - **Mulches treated with pre-emergent herbicides** are used overseas. They could be added as top layers during pot-filling in assembly-line plantings in commercial production or in landscapes of commercial and non-commercial plantings.
  - **Pre-emergent treated bark nuggets** results in increased and extended herbicide efficacy.

Sanitation prevention

- **Crop-free fallow.** Growers, who have a break in their production cycle, can empty these areas and control weeds. Remove debris well before another cropping cycle, could put down new screenings.
- In enclosed areas, eg in greenhouses and propagating sheds, wash and disinfect containers for re-use.
- Propagation areas should have concrete floors which can be regularly hosed down and disinfected.
- Well-draining blue metal or gravel aggregate in areas where container plants are grown or held for sale prevents water puddling and contact with soil.
- **Sources of weed seed** include:
  - Control weeds in surrounding areas to prevent seeding by mowing, etc and maintain at least **6 metre weed-free area** around greenhouses to eliminate weeds near vents which can be screened to limit introduction of wind-blown seed.
  - Sandbeds must be kept weed-free at all times.
  - Remove weeds before they set seed, place in bag, dispose of **outside** greenhouse or production area.
  - Dispose of unwanted plants promptly before they become a weed seed bank for clean stock.
  - Handle weedy pots **before** weed-free pots.
  - Do not use the same buckets to dispose of hand-pulled weeds and for transporting cuttings.
  - Store mixes in covered bins to keep out wind blown seed.
  - Do not re-use potting mixes.
  - Check overhead baskets, a source of weed seeds.
  - Remove weeds in containers before they flower and produce seed. **One prostate petty spurge weed may produce up to 50,000 seeds per plant**.

Biological control.

- Rarely used in nurseries or container stock.

Plant quarantine.

- Inspect tube stock at the time of purchase or delivery. Do not accept weed-infested plants, tube stock.
- Isolate new stock from existing stock until its weed status is determined.

Weed-tested planting material/soil?

- Only **purchase** tubes from suppliers which produce 'clean' tube and nursery stock in weed-free production areas. Do not accept weed-infested tube stock or other plants in containers.
- Use only **certified** weed-free **seed**.
- **Soil-less mixes** reduce incidence of weeds. Plant in potting mixes which comply with Australian standards to ensure containers are, **at least initially**, **free of weed seeds**.

Physical & mechanical methods.

- **Hand weeding** when weeds are small and before seed is set, can be difficult (Fig. 254) and time consuming. When weeds are larger it may disturb roots of established plants during hot dry weather.
- **Pasteurization** (60°C for 30 minutes) of soil or contaminated potting mix kills some weed seeds. Pasteurised mixes should be kept covered to avoid contamination from windborne seeds (page 438).
- **Solarisation**. Involves stretching a sheet of clear plastic over soil. The trapped heat raises the soil temperature by several degrees and destroys young weeds (page 438).
- **Control** weeds under containers. Isolate pots from direct contact with soil by concrete paths, gravel or blue metal screenings, weed mat over sand. Control weeds in screenings, weed mats and mulches.

Fig. 254. Hand weeding cacti in containers or in closely planted cacti beds is almost impossible.

Herbicides.

Herbicides are still the most economic and quickest.

- **For organic growers** where herbicides are not allowed, weed control is a major issue.
- **The cost** of herbicide applications plus hand weeding is already the highest cost that growers have and far surpasses any other form of pest control.
- **Correct application rate**, uniform coverage. With the use of combination herbicides, the time between treatments can be at least 6 months.
- **Follow strategies** for minimizing resistance.
- **Pre-emergents**.
  - Pre-emergents only kill certain germinating weed seed, check label. They will not kill vegetative growth.
  - **In an optimized weed control program** you choose the most effective pre-emergent herbicide for each species. This provides the best, most cost-effective weed control but is **only** suitable for large nurseries which grow greater numbers of each species. Smaller nurseries may choose to select a **marginally effective pre-emergent** that is safe on the majority of species being grown and supplement with hand weeding.
  - **Apply at correct time**, ie immediately after finishing a quantity of potting up, after plants have been watered and the media settled. Most pre-emergents for use in greenhouses are granular but should not be applied to wet foliage, there may be other restrictions on the label. Further applications depend on weed pressure, the herbicide used and its effectiveness on weeds.
  - **If being applied later**, media surface must be weed-free prior to applying pre-emergent.
  - **Granular herbicides** can be broadcast with a spreader over the top of stock. Jam pots together to avoid non-target herbicide waste, non-target herbicide falling between pots can be as high as 80%.
  - **Fertilizers may be coated** with pre-emergents.
- **Post-emergents**, eg Fusilade® (fluazifop-P-butyl) is registered for the control of certain grass weeds in potted and open grown ornamental trees and shrubs in nurseries. Post-emergence control of broadleaved weeds in containers is limited.
- **Plant injury**.
  - **Chemical control of weeds is difficult** due to the diversity of plant species grown in nurseries.
  - **Injury to some nursery stock** may result from application in enclosed areas, where vapours and high temperatures may damage non-tolerant species. Fans and spray drift from spray applications. Improper calibration.
  - **Herbaceous plants** generally are more likely to suffer damage than others. On some **native plants**, especially Proteaceae and Poaceae, use premergents with caution, also some soft-foliaged plants.
  - **Non-tolerant species** can be isolated into separate untreated blocks.
  - **If using a new herbicide** in containers do a trial run first.
  - **Herbigation/recycling.** Weed control in nurseries is becoming an important issue due to increasing irrigation restrictions/recycling and necessity for re-circulation ponds. The biggest potential contamination in re-circulation ponds is herbicides. If recycling water seek advice. Water solubility should be a strong factor in choosing a herbicide.

Table. 82. Container plants – Some herbicides *(commercial growers).*

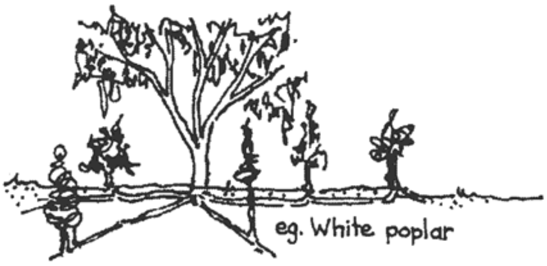
What to use?	When and how to use?
PRE-PLANT FUMIGANTS Basamid® (dazomet) **(page 267)**	
PRE-EMERGENTS **Group G**, eg Ronstar® (oxadiazon) **Group O**, eg Casoron® (dichlobenil), **Group D**, eg Dacthal® (chlorthal-dimethyl), Surflan® (oryzalin) **Groups D/G**, eg Rout® (oryzalin + oxyfluorfen)	Pre-emergents are soil residuals and provide control for varying lengths of time. CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE
POST-EMERGENTS **Group A**, eg Fusilade® (fluazifop-P-butyl) - **selective grass**	ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Tree suckers

A sucker is a shoot growing from adventitious buds at the base of stems or rootstocks of some grafted trees and shrubs, below ground stems, roots of trees, shrubs, climbers, etc. Some trees produce suckers from buds on the tree trunks, eg *Prunus*.

Tree types

Some species are prone to produce suckers from underground roots, eg elm, eucalypt, poplar, black locust, wattles, willow, wisteria.



Impact

Unsightly, may grow into garden beds, turf areas, rose gardens.

Conditions favouring

- Roots of some trees, eg cherry (*Prunus* spp.) may sucker after injury, eg by digging, cultivation.
- Some trees and shrubs sucker after heavy pruning, eg citrus, lilac.
- Drought may cause dieing back of upper portions and suckering at the base and on trunks and branches.
- Fire from control burning or which kills the upper part of the tree.

Management (IWM)

Are you a commercial grower or home gardener?

1. **Prepare a plan** that fits your situation.
2. **Crop, region**. Recognize variations.
3. **Identification** of suckers must be confirmed. Know what species of tree you are dealing with. Consult a diagnostic service if unsure (page xiv).
4. **Monitor** development of suckers during the growing season and their impact (page 429). Record results as recommended.
5. **Threshold**. How much damage can you accept? Have any thresholds been established? If so, what are they, economic, aesthetic, environmental? Do you need to calculate your own threshold?
6. **Action.** Take appropriate action when any threshold is reached.
7. **Evaluation**. Review **IWM** program to see how well it worked. Recommend improvements if required.

Control methods

Physical & mechanical methods.

Tree suckers in a home garden or small orchard can be diligently dug out over a period of time. Cut of cleanly where the base of the sucker arises from the root. Note suckering on the trunks due to drought, etc should also be cut off cleanly allowing sap to go up the stem.

Herbicide treatments.

Herbicides used depends on whether the suckers are still attached to the parent tree or not (Table 83 below).

Table 83. Tree suckers – Some herbicides.

What to use?	When and how to use?
SUCKERS *NOT* ATTACHED TO PARENT TREE **Surrounded by turf**, eg **Group I**, eg Blackberry &Tree Killer®, Garlon® (triclopyr) **Not surrounded by turf**, eg **Group I**, eg Blackberry &Tree Killer®, Garlon® (triclopyr) **Group M**, eg Roundup®, various (glyphosate)	**General procedures.** • Suckers up to 1 metre high may be sprayed directly. • Larger suckers or those growing in close proximity to desired species may be cut off at ground level and the freshly cut surface treated with herbicide. • Care should be taken when spraying with either triclopyr or glyphosate to avoid causing damage to nearby desired broadleaved plants from spray drift. • Triclopyr will damage broadleaved plants during the growing and dormant periods; grasses are normally unaffected and establish quickly after treatment.
SUCKERS *STILL* ATTACHED TO PARENT TREE Usually label rates apply to the control of suckers **not** attached to the parent tree. Rates used to control suckers still attached may be **lower** than label rates	**Systemic herbicides may be translocated through the roots to the parent tree or shrub causing injury.**
Surrounded by turf or desired plants	**A permit may be required for an off-label use.**
Not surrounded by turf or desired plants, eg **Group N**, eg Basta® (glufosinate-ammonium) (partially systemic) is registered for application as a directed spray for sucker control in blackberry, boysenberry, loganberry and raspberry plantations. Contact with non-target plant parts will cause damage.	**Seek professional advice.**

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Brush and woody weeds

Types

Trees and shrubs, introduced and native species have increased to undesirable densities in some areas of Australia. They may be agricultural, noxious weeds or environmental weeds, garden escapes, Weeds of National Significance (**WONS**) or other types of weed.

Impact

In central Australia brush and woody weeds can impact on biodiversity, cause mustering difficulties, harbour vermin, added expense either maintaining or relocating fences, roads and waterways, industrial sites, suppress pasture growth and lower nutritional levels, hence carrying capacity and production.

Management (IWM)

Are you a commercial grower or home gardener? If wood weeds are > 3 metres tall, seek advice.

1. **Prepare a plan** that fits your situation. **Weed Management Systems** are available for some woody weeds, eg bitou bush, and for some situations, eg plantation forestry (Sindel 2000). **Special Taskforces** deal with some woody weeds, eg Aleppo Pine Management Group in SA, Lantana Taskforce in NSW.
2. **Crop, region.** Recognize variations.
3. **Identification** of weed(s) must be confirmed. Consult a diagnostic service if unsure (page xiv).
4. **Monitor** weed(s) and impact and record results (page 429).
5. **Threshold.** How much infestation is acceptable? Have any thresholds been established? If so, what are they, economic, aesthetic, environmental?
6. **Action.** Take appropriate action when any threshold is reached.
7. **Evaluation.** Review **IWM** program to see how well it worked. Recommend improvements if needed.

Control methods

Legislation. Some woody weeds are declared noxious weeds, control may be compulsory and the method of control prescribed by legislation.

Biological control. For some, biological control agents have been released, eg the blackberry rust fungus (*Phragmidium violaceum*). It is hoped that it will provide some economic control of blackberry infestations, avoiding the need for herbicide applications.

Plant quarantine. All plant introductions should be assessed for their potential to be become weeds (Weed Risk Assessment) (page 436).

Physical & mechanical methods.

- **Small infestations** of brush or woody weeds can be dug out diligently over time. Many such weeds may have large seed banks in the soil.
- **Fire** may be economical and provide effective control of some seeds, seedling trees and shrubs, but can only be used occasionally when seasonal conditions have resulted in buildup of sufficient fuel. Local Fire Services **must** be consulted.
- **Chaining** or blade ploughing may increase production but does not justify cost and may not be sound environmentally.
- **Grazing** management, eg by goats.

Herbicides.

- **Local Shires**/Administrations have leaflets and bulletins with recommendations for control. The following should be regarded as a guide only.
- **Not all herbicides work against all woody weeds**. Confirm that the herbicide selected is registered and effective against the problem weed in your situation.
- **Depending on the weed species and herbicide being used**, sprays may be applied using knapsacks or handguns to foliage of young woody weeds evenly wetting all foliage. Sprays are also applied as basal bark or soil treatments using spot guns (page 468). Hack and squirt and stem injection techniques are also used.
- **Timing of application** is critical, follow label **Directions For Use**. Some deciduous woody vines and rhizomatous perennial weeds are controlled by late summer or early fall applications – spring applications may only burn the top of the plants.

Fig. 84. Brush and woody weeds – Some herbicides.

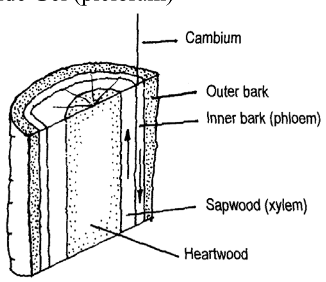
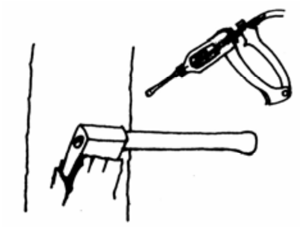
What to use?	When and how to apply?
HERBICIDES **Group M**, eg Roundup® (glyphosate) **Soil residuals – for use in certain situations only, check label Directions For Use:** **Group B**, eg Brush-Off® (metsulfuron-methyl) **Group C**, eg Velpar® (hexazinone) **Groups I/I**, eg Garlon® (triclopyr), Grazon® (triclopyr + picloram), Tordon® Herbicide Gel, Vigilant® Herbicide Gel (picloram)  	• Apply when plants are growing actively, moist soil. • Use a white or other herbicide marker dye. • **Many are soil residuals and should not be applied near desired plants or in areas where their roots might extend, or where chemical may be washed to their roots**. Do not use if rain is likely to fall with 12 hours of application. Follow label Directions For Use. • For stem injection to be successful, the herbicide **must** be injected into the sapwood (see diagram) immediately after the cut is made. • Penetrants may aid uptake by woody weeds. **CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE**

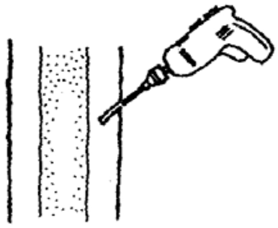
Fig 255. Brush and woody weeds - Stem injection equipment, etc.

AXE AND DRENCH GUN



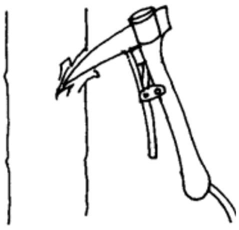
Used for killing trees and shrubs. An axe is used to make a cut into the sapwood and the herbicide is delivered with a drench gun. Frills or notches are cut around the base of the tree by making downward axe cuts through the bark and into the sapwood.

DRILLING



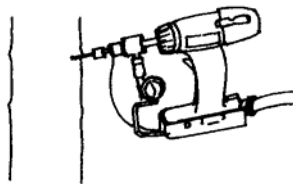
Used for insect control and killing unwanted trees. Holes about 10 cm in diameter are drilled into the sapwood and the pesticide placed in the drilled hole. Generally used when only a few trees require treatment.

WOODYWEEDER



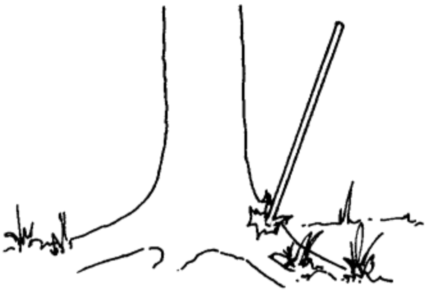
This axe has been used extensively for thinning young forests and controlling woody weeds. A simple single-handed tool that combines cutting and injection, delivering the herbicide directly and immediately into the sap stream in one action.

SIDE WINDER



Used for disease and pest control in avocadoes, eucalypts and other species and for controlling unwanted trees. A tool that delivers varying amounts of pesticide under a range of pressures directly into the sap stream.

BASAL SPEAR

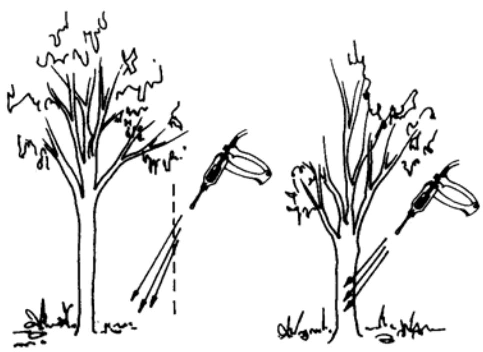


Used for killing trees to improve grazing lands. A 2-handed tool cuts and delivers the herbicide directly into the sapwood at the base of the tree.

CUT & PAINT

Used to kill trees and shrubs. Herbicide is applied to the sapwood immediately after cutting the stem off.

SOIL & BASAL BARK APPLICATIONS



Used to kill suckers and small seedling trees.

Left : The **spotgun** is directed onto the soil around the stem **within the drip line**. The herbicide is moved into the soil by rainfall where it is taken up by the roots. Clear away all vegetative litter from area to be treated.

Right : Often referred to as **basal bark treatment**. The **spotgun** is directed towards the base of young stems and the herbicide is absorbed through the young bark.

The **drip line** is the area covered by the spread of the crown.

Splatter guns deliver a measured dose of herbicide from units which resemble drench guns. The total volume applied is about 1/10th that of a handgun rate. They are used for foliage, basal bark, cut stump treatments

Unwanted individual trees

Management

Seek advice and engage a **qualified arborist** for trees taller than 3 metres.

- Safety is the No. 1 issue. Is the tree defective?
- Be familiar with relevent legislation.
- Identification of the tree must be confirmed.
- Know its height, diameter and whether it suckers.

Control methods

Legislation.

Be aware that there may be **conflicting legislation and opinions** influencing unwanted trees.

- **Tree Preservation Orders** or other legislation may apply. Seek advice if in doubt.
- **Weed legislation**. Contact your State/Territory authority for a copy of the current list of declared weed species which change from time to time as more research is carried out. When a species is discovered to be an environmental weed, what can be done? Such a tree does not necessarily have to be removed it, it may merely have to be prevented from seeding (propagating itself).
- How do you prevent a tree with a 20m diameter canopy covered in seed from propagating itself is not usually defined. Problem arises when local council may not allow removal and owners don't want to pay the cost of annual pruning to remove seeds. Negotiate annual pruning? Who pays?
- Although it is preferable to kill trees prior to removal, in an urban situation this is not usually acceptable.

Physical & mechanical methods.

- Plants which **do not** sucker, eg conifers, can be removed by cutting them off at ground level.
- Trees or shrubs which **do** sucker, eg elm, eucalypt, poplar, black locust, honey locust, tree of heaven, wattles, willow and wisteria can be eradicated by cutting down the tree or shrub and by **diligently** removing the suckers over a period of time, especially in a home garden situation. However, suckers of some species, eg elm, poplar and wisteria, may continue to appear for years after the parent tree or climber has been removed.
- **Tree remains** may be chipped and applied as mulch, occasionally non-parasitic mushroom fungi may grow on them, bio-degrading them.
- **Stumps adjacent to domestic buildings** should be removed as they may attract termites, or wood rotting fungi which may later lift pavers, etc.

Herbicides.

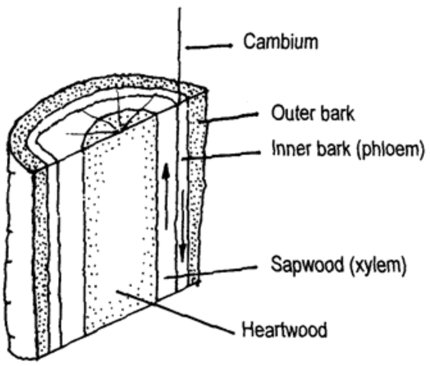
- Trees such as conifers which do **not** sucker after removal do **not** require application of herbicide.
- Cut stumps of trees that **do** sucker can be treated with herbicide immediately after felling.
- **Great care** must be exercised in the use of herbicides to kill woody plants. Some have a long residual life in the soil and so represent a hazard to surrounding plants. **Strictly observe** label recommendations for application methods.
- **Heavy rain** soon after application may cause herbicide to wash from treated stumps onto surrounding plants and areas.
- Although triclopyr is highly toxic to **broadleaved** plants during growing and dormant periods, grasses are normally unaffected and could establish quickly after treatment. Roundup®, Zero® (glyphosate) will kill **both** broadleaved and grass plants.

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

Table 85. Unwanted individual trees – Some herbicides.

What to use?	When and how to use?
ALL TYPES OF TREE POISONING	**BEFORE TREE REMOVAL**
Group M, eg Roundup®) (glyphosate) **OR** **Group I**, eg Garlon® (triclopyr), Tordon® Herbicide Gel, Vigilant® Herbicide Gel (picloram) is applied directly from a container onto cut stumps.	• Preferably apply the herbicide prior to tree removal, but this may not be practical (page 468, Fig. 255). • Follow label Directions For Use. • Trees must be actively growing and not under stress (drought, waterlogging, cold). • Apply herbicide to the freshly cut surface as soon as possible after **frilling or notching**. • **In tree injection**, the herbicide is immediately delivered into the sap stream. • Do not remove the treated tree for at least 4 weeks after treatment. to allow good translocation to the roots.
	AFTER TREE REMOVAL
	• **Cut and paint** stump treatments (for trees which sucker). • Use when circumstances make it impractical to use frilling, notching, tree injection. • Paint sapwood area of the freshly cut stump. • May not be as effective as frilling, notching or tree injection.



Environmental weeds

Weed Types

- **Environmental weeds**, unlike other weeds invade natural plant communities **without the need for disturbance** by human activity, fire, altered drainage, added nutrients, cultivation, grazing, etc (page 415). They are mainly introduced species but some **native species** have spread outside their natural range, eg golden wreath wattle (*Acacia saligna*) from WA is now found in bushland along the NSW coast.
- **Occur as a range** of trees, shrubs, herbs, grasses, creepers or climbers, aquatic plants, but are mostly **garden escapes**, eg privet (*Ligustrum* spp.), lantana (*Lantana camara*), English ivy (*Hedera helix*), pampas grass (*Cortaderia* sp.), periwinkle (*Vinca major*). There are nearly **1,000 species** of environmental weeds in Australia, but only **52 species** have been selected for the national list (page 415). Many are still being grown and promoted by the industry. Each state/territory/region has its own lists of environmental weeds.
- **Environmental weeds** may also be:
  - **Noxious weeds**, eg some willows (page 417).
  - **Agricultural weeds**, eg blackberry (*Rubus fructicosus*) and St John's wort (*Hypericum perforatum*) (page 413).
  - **Weeds of National Significance (WONS),** eg bitou bush (page 415).
  - **Sleeper weeds** that have not yet increased their distribution significantly and could be controlled before numbers explode (page 414).

Impacts

- Weeds threaten indigenous plant and animal bio-diversity by affecting their natural regeneration and survival, ie food sources, shelter and habitat.
- They threaten the existence of already endangered or vulnerable species of flora and fauna. Plants may become extinct (Sindel 2000).
- They are of particular concern in areas dedicated for conservation purposes.
- They impact on public lands, State Forests, National Parks, Botanic Gardens recreational areas, and remnants of native vegetation on private land.
- They can **impede water flow** in wetlands and river systems, alter the habitat for wetland fauna, deplete available nutrients, and alter soil fertility. Impede tourism.
- Some are poisonous or unpalatable to stock.
- Annuals are considered to do less long term ecological damage than woody species.
- Exotic grasses moving into native grassland in poor condition contribute to their decreasing biodiversity, sustainability and are a fire hazard.

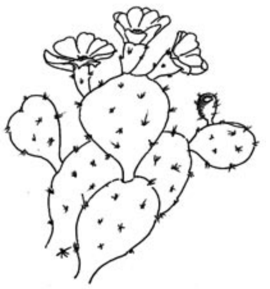


Fig. 256. Environmental weeds. ***Left:*** Blackberry (*Rubus* spp.). ***Right:*** Prickly pear (*Opuntia* spp.) controlled by cactoblastis caterpillars in Qld.

Weed biology

- **Reproduction.** Weeds reach maturity quickly. They produce large amounts of seed or vegetative propagules, and may be able to self–pollinate or pollination is not required.
- **Overseasoning.** Large seed banks, eg 75000 seed/m^2 of perennial veldt grass have been found in WA after fire; also as tubers, rhizomes, deep roots, etc.
- **Spread efficiently.** Birds and flying foxes eat fruit and seed which is carried to nearby bushland. Livestock, pets and people carry seeds from gardens to bush on fur, clothing and shoes. Garden waste is dumped over back fences or in waterways. Wind can blow seeds many kilometers. Seeds and plant parts can wash down drains into waterways where they grow and spread. Some have branches which can break off easily and are washed downstream and take root forming new infestations. Seeds and plants are carried in soil on vehicle tyres, tools, machinery. Floral arrangements. Plants for sale.
- **Conditions favouring.** Rainfall is the most important factor determining the possibility and extent of woody species. Each environmental weed has its own conditions which favor its spread and development. Environmental weeds do not need disturbance but may need several favorable seasons to establish. They tolerate drought, frost, salt, low nutrients. Predicted climate change may favor new weed species, but others may become less important. Plants being bred for drought tolerance may be the next generation of environmental weeds. Tussock grasses invade areas damaged by fire and loss of canopy cover.

Management (IWM)

Many countries have lost their natural biodiversity and most of their flora has come from naturalized species from other areas, and so do not attempt to manage invasive species. Australia is one of the very few countries of the world that try to do so (Thorp 2008) and aims to prevent incursions of new weeds, detect new incursions quickly (making eradication possible), contain spread of existing weeds and re-habilitate disturbed ecosystems.

1. **Planning ahead** and **site assessment** is essential. There are many programs in which you can participate (page 471), training programs are available (page 430).
2. **Crop, region**. Obtain information on environmental weeds and their management in your local area. Contact your local council.
3. **Identify** those present at various stages of development, eg seedlings, flowers, seeds, etc. Some environmental weeds especially grasses, can be difficult to identify. You must be sure it is a weed, many grasses are native to their area. Consult a diagnostic service if necessary (page xiv).
4. **Monitor** environmental weeds to determine their **distribution, spread** and later the effectiveness of control programs (page 429). Methods include using the National Classification System of Mapping for **WONS**, satellite imagery, low altitude aerial photography and hard slog, ie utes, canoes by Weed Warriors, Landcare groups. Willows have been mapped by all these methods.
5. **Threshold.** There may be a **nil** legal threshold for certain weeds in your area, otherwise construct your own, deciding how much invasion you can tolerate, aesthetically, economically or environmentally.
6. **Action**. Environmental weeds are difficult to control. Address the **causes** of weed invasion.
   - **Prioritise weeds for control**. Eradication of most environmental weeds is not possible. New arrivals stand some chance of being eradicated, eg Koster's curse in the NT. Be aware of **potential sleeper weeds**, eg lobed needlegrass.
   - **Prioritize vegetation areas**, eg sensitive areas dominated by native vegetation may be maintained weed-free, in others areas their spread prevented, etc. Lightly infested areas may be treated prior to areas with heavier infestations.
   - **Re-vegetation of sites** is challenging but essential.
   - **Act co-operatively** with local government, land-owners, suburban householders to control and eradicate environmental weeds in local bushlands.
   - **Resources are required.**
7. **Evaluation**. Review your **IWM** program to see how well it worked. Recommend improvements.

Control methods

Weed Management Guides are available for all **WONS** and many other weeds. Most states/territories have Weed Control Handbooks for invasive species plans, eg NSW Invasive Species Plan 2008-2015, UMCCC 2010.

Legislation

Few regulations for environmental weeds are compulsory. Unlike weeds of crops, eg cereals, flowers, turf, environmental weeds occur in all habitats and land use systems, making their management extremely difficult, there is no one body (with commercial interests) to pay for their management. There is pressure for all tiers of government and various public stakeholders to commit to management programs for weeds of national significance and all locally significant invasive species within their formal plantings via the **National Weeds Action** plan. Overseas there are **Voluntary Codes of Conduct** for government, home gardeners, landscape architects, nursery professionals, botanic gardens and arboreta, eg www.centerforplantconservation.org/**invasives**/codesN.html
Also UK Codes of Practice www.**defra**.gov.uk

- **Government**
  - **Commonwealth government** (Weeds Australia) provides access to key weed policies, regulations, extension, and training. **Best Practice Management Guides** are available for **WONS** and other weeds. www.**weeds**.org.au
  - **State governments provide** information on invasive plants but their responsibility is mostly for noxious weeds (some which are environmental weeds).
  - **Regional/Local Councils/Shires** have weed information packs for environmental weeds in their area.
  - **Australian Botanic Garden** network of 70 public gardens, zoos, arboreta has been established to develop/ improve weed management policies and risk assessment www.**rbg**.vic.gov.au/**horticulture**/**weeds**
- **Public Weed programs** include:
  - **Weed Busters** aim to increase public involvement in weed management, education and awareness projects.
  - **Weed warriors** involves children in schools and parents in managing local weed infestations.
  - **Weed Swap** gives you a free Australian Native plant for you local environmental weed.
  - **Weed Spotter Networks** are groups of people who look out for new and emerging weeds in the field, nurseries and garden centres, the media, email discussions groups and the internet. In Northern Australia, **AQIS** officers supported by a network of landholders and government agencies, look for new plant invaders, staff in botanic gardens and others, identify them.
  - **Weed Stop programs** reduce the **transport** of weeds by contractors, service providers and government agencies.
  - **Landcare**, Bushcare, Park Care and Greening Australia have weed control programs.
  - **Weed Alert Rapid Response Plans** identify new and emerging weeds in a region and have in place a plan for their eradication when detected. Enviroweed lists are published on state websites.
  - **World Wetland Day**. WWF www.**wwf**.org.au
- **Horticultural industries, Media**
  - **Gardening/Lifestyle** TV/radio programs, magazines, etc, could be encouraged to recommend appropriate plants www.,**ngia**.com.au www.**lifeisagarden**.com.au
  - **NGIA** (Nursery & Garden Industry Association) promote the **Grow me instead program** which suggests alternatives based on similar hardiness, flowering characteristics and height, eg replace English ivy. *Hedera helix*) with false sasparilla (*Hardenbergia* sp.)
    Sustainable Gardening Australia (SGA) with the support of the NGIA aim to remove from sale, 10 of the worst weed invaders in an area and are encouraged to target other potentially invasive plants.
  - **Other proposals** under consideration include voluntary removal of the **garden escape** list of 52 garden plants from trade around Australia and examination by the **National Weeds Action Plan** of the merits of a mandatory labeling scheme on invasive plants being sold.
    Bushland Friendly Nursery Schemes (BFNS) could establish weed lists for a local area, specifying plants that should not be sold, propagated or knowingly distributed.

Cultural methods.

After environmental weeds have been removed, local native plants can be re-established. Most councils have regeneration and maintenance programs.

- **Problems during re-vegetation.** Native bushland may be invaded by new weed species or re-invaded by pre-existing weed species.
- **Re-vegetation techniques** vary, eg nursery-raised seedlings, direct seeding. The **Bradley method** relies on natural re-vegetation but can only used in sites with a good pre-existing native soil seed bank (Bradley 1988). Repairing riparian zones, cleared of willows is a challenge.

Sanitation.

- Remove environmental weeds from bushland.
- Clean equipment before using in other areas.
- Cover trailers so seeds and cuttings do not escape and invade roadside bushland. Compost garden waste at home or recycle through local collection services or take to local tip.
- Do **not** dump garden waste in bushland or tip aquarium/pond water into drains, ponds, waterways.
- Prevent weeds from flowering to slowly deplete soil seed reserves.

Biological control.

This is the only practical long term control of existing environmental weeds in Australia, eg prickly pear by the cactoblastis moth in Qld. **However, biological control programs are not easy**. Goats and other vertebrate pests eat blackberries and other weeds but damage native plants as well.

Plant quarantine.

- **Commonwealth. AQIS** applies a **WRA** (Weed Risk Assessment) process to all proposed plant imports. This screens out plants with the worst weed potential but is not entirely foolproof. New plants must also be thoroughly trialed and assessed by the importer **prior to release**. Imported plants, bulbs, seeds including those ordered over the internet or by mail order must be cleared **before** coming into the country. Rapid response programs are in place.
- **State/Territory quarantine.** Legislation regulates some environmental weeds (page 437).
- **Local quarantine** might aim to remove the worst weeds from horticultural production each year.

Physical & mechanical methods.

- **Fire** reduces seed banks of weeds such as bitou bush but must only be applied to sites where monitoring indicates that there is a substantial native seed bank. Burning stimulates germination of some native seeds. Consult local Fire Service.
- **Slashing** or cutting may be followed by appropriately timed herbicide applications, eg blackberry.
- Hand pulling, grubbing with mattock reduces weeds that do not sucker.

Herbicides.

- Glyphosate is widely used to control environmental weeds because of its low hazard and short persistence. Biactive® (glyphosate) is a formulation registered for use near waterways.
- Small isolated patches of lowlying weeds could be spots sprayed.
- A small number of other products are registered for some situations where conditions are such that contamination can be avoided. Some products are selective and selectivity may be improved when cut-stem, stem injection, or wiping equipment is used in preference to foliar sprays (page 468).

CHECK CURRENT REGISTRATION STATUS OF PESTICIDES PRIOR TO USE

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS ATTACHED TO THE PESTICIDE CONTAINER AT TIME OF USE

REVIEW QUESTIONS AND ACTIVITIES

By the end of this topic, you should be able to do the following:

1. List the **distinctive features** of weeds.
2. Describe **4 harmful** and **4 beneficial** effects of weeds. Name examples of each.
3. Explain how weeds may be **classified to facilitate control** using **1 local example from the following list**:
   Annual, biennial, perennial
   Growth habit, herbaceous, woody
   Habitat
   Land-use
   Invasive, naturalized
   Introduced, indigenous
   Noxious
   Garden escapes
   WONS
   Environmental weeds
   Botanical groups, eg Asteraceae
   Weed lists
   Target weeds
   Sleeper weeds
4. **Recognize by sight**, **local** **weed species** belonging to the following weed groups and complete the following:

DICOTYLEDONS (broadleaved weeds) ANNUAL & HERBACEOUS WEEDS, eg **Rosette** (some only at certain stages of growth) **Those with SMALL OR FINE leaves** (many are flat or mat forming), eg WOODY WEEDS, eg
MONOCOTYLEDONS (narrowleaved weeds) Grasses (Poaceae), eg Iris family (Iridaceae), eg Lily family (Liliaceae), eg Sedges (Cyperaceae), eg Rushes (Juncaceae), eg
MISCELLANEOUS WEEDS Aquatic weeds, eg Cacti, eg Conifers, eg Cycads, eg Ferns, eg Parasitic plants, eg Riparian weeds, eg

5. Describe 6 ways by which weeds may **reproduce**. Name 1 example of each.
6. Describe 6 ways by which weeds may **overwinter.** Name 1 example of each.
7. Describe 5 ways by which weeds may **spread**. Name 1 example of each.
8. Describe local/Commonwealth **legislation** providing for the control of noxious weeds.
9. Describe **conditions that favour** selected weeds in you area.
10. List **control methods** available for weeds. Name 2 examples of each.
11. Describe the steps in **IWM** (Integrated Weed Management)
12. Explain why weed control can be difficult for **certified organic growers**.
13. Explain **WRA** (Weed Risk Assessment) and how is it used in weed control.
14. Describe the advantages and disadvantages of **red herbicide marking dye**.
15. Explain how you would use herbicides to prevent the development of **resistance.**
16. Name **2 weeds in Australia** that are **resistant** to some herbicides.
17. Explain how the following **types** of herbicides control weeds, name 1 example of each:

POST-EMERGENT HERBICIDES
HORMONE HERBICIDES
PRE-EMERGENT HERBICIDES
SOIL RESIDUAL HERBICIDES
FUMIGANTS

18. Provide the following information for **glyphosate**:
    Herbicide mode of action group
    How it effectively controls weeds
19. Explain the meaning of the **following terms** and give 1 example of each.
    Selective, eg
    Non-selective , eg
    Systemic, eg
    Non-systemic, eg
    Contact, eg
    Knockdown, eg
    Translocated, eg
20. Give **3 reasons** why herbicides may not work.
21. **Provide the following information** for selective control of broadleaved weeds and grass weeds; weeds in containers and annual beds; tree suckers, brush and woody weeds; environmental weeds, and other **local** weed problems and situations:

Types of weeds	'Overwintering'
Common names of weeds	Spread
Description	Conditions favouring
Weed cycle	**IWM** & Control methods

22. Prepare/access an **IWM** program for a weed or weed situation at your work or in your region.
23. Locate **reference material** and know where to obtain advice on the identification and control of weeds.

SELECTED REFERENCES

Weeds in Australia www.weeds.gov.au/
(official website of the Dept of Forests and Fisheries), eg
Alert List for Environmental Weeds and Weed Management Guide
Australian Weeds Strategy, Strategic Plans
Potential Environmental Weeds in Australia : Candidate Species for Preventative Control

Weeds Australia www.weeds.org.au/
(this website is run by a consultant on behalf of the Commonwealth Government and mostly relates to **WONS** weeds but includes other weeds related matters in detail), eg
Australian Weeds Committee
Best Practice Manuals
National Weed Strategy
CRC for AWM (avail online)
Glyphosate sustainability working group
Herbicides: guidelines for use in and around water (2005)
Riparian weeds
Killing us softly - Australia's green stalkers – 2020 vision

BRS (advisory) www.daff.gov.au/brs/land/weeds eg
A field manual for surveying and mapping nationally significant weeds
Current practice in applying CLIMATE for weed risk assessment in Australia
Development of a manual for mapping Weeds of National Significance
Managing green waste to reduce weed spread - for home gardeners
Managing green waste to reduce weed spread - for local councils
Some priority agricultural sleeper weeds for eradication
Science for Decision Makers: Managing the Menace of Agricultural Sleeper Weeds

GRDC Weedlinks www.grdc.com.au/
CSIRO Australia www.csiro.au/science/InvasivePlants.html
Environment www.environment.gov.au
Weed Societies (Australian and state). avail online
Council of Australasian Weed Socs. www.caws.org.au/
Global Compendium of Weeds www.hear.org/gcw
Greening Australia www.greeningaustralia.org.au
Nursery Industry Assoc. of Australia (NIAA) www.niaa.org.au
Nursery Industry Accreditation Scheme of Australia (NIASA) www.ngia.com.au/niasa
Standards Australia www.standards.com.au
Weed Information www.weedinfo.com.au/

Fact Sheets by State/Territory Depts. of Primary Industries/Councils etc are available online, eg
Hormone herbicide injury, woody weeds
Specific weeds – identification & control
Weed Control Handbooks
Grow Me Instead
Specific Weeds - Identification

Ute & Field & Pocket Guides, eg
TOPCROP www.nre.vic.gov.au/farming/topcrop
WEEDeck National Pocket Guides (Sainty & Associates)
The Ute Guide – The Northern Grain Belt.

Keys www.lucidcentral.com/
Ausgrass
Blackberry: An Identification Tool to Introduced and Native Rubus in Australia
Crop Weeds of Australia (educational version)
Declared Plants of Australia
Environmental Weeds of Australia
Families of Flowering Plants of Australia
International Environmental Weed Foundation - Keys to Local Area Weeds
Key to Common Suburban Weeds
Key to Species of Weeds in Turf
Seed Identification Key
Species of Weeds in Turf
Suburban and Environmental Weeds of South East Queensland v1 and v2.
Weed Biocontrol
Weeds of National Significance
A Lucid Key to Common weeds of New Zealand
Weed Management in Woody Cut Flower Plantations
www.uq.edu.au/lcafs/documents/plantationweeds.pdf

Training Courses & Resources
National Competencies for Weed Management www.weeds.org.au/training.htm
CRC for AWM (avail online)
Australian Weed Management:Biocontrol
Northern Australia Quarantine Strategy
Weed and Plant Collection Manual
Introductory Weed Management Manual
Integrated Weed Control Manual
Weed Collectors Manual: Collect, prepare and preserve weed specimens
Various school resources (Misbehaving plants, Ghastly Guests, Weed Wipeout)
Bushfriendly Gardens
What does your garden grow? (Australian Weed Management 2007 for the Nursery Industry).
Also Post grad scholarship
GRDC Weedlinks www.grdc.com.au/ follow links to events and publications, education, training
TAFES, Universities
Weedbuster Week www.weedbusterweek.info.au

Biological control/Organic standards/IPM
AS 6000—2009. *Organic and Biodynamic Products* www.standards.org.au/
CSIRO. Managing Invasive Plants www.csiro.au/science/InvasivePlants.html
Integrated Plant Protection Center www.ipmnet.org/
Organic Federation of Australia www.ofa.org.au/

Davies, G., Turner, B. and Bond, B. 2008. *Weed Management for Organic Farmers, Growers and Smallholders : A Complete Guide*. Crowood Press, UK.

Quarantine
Commonwealth quarantine www.daff.gov.au/aqis
PaDIL - Pests and Diseases Image Library of diagnostic photographs and information on more than 1000 pests and more than 100 diseases www.padil.gov.au
Target lists of weeds, insects, plant and animal pests and diseases. www.daff.gov.au and search for target lists
State websites have information on quarantine restrictions for their states
Lucid keys of DIRECT Relevance to Quarantine, Plant Health and Invasive Species

Herbicides
Pubcris. APVMA. Canberra www.apvma.gov.au
Infopest, Qld www.dpi.qld.gov.au/infopest
Croplife Australia www.cropelifeaustralia.org.au/
MSDS www.msds.com.au/
Company websites provide label and MSDS information
Kondinin Group : Field Crop Herbicide Guide www.kondinin.com.au/
HerbiGuide www.herbiguide.com.au/
GRDC www.grdc.com.au/
WA Herbicide Resistance Initiative (WAHRI) http://wahri.uwa.edu.au/
International Survey of Herbicide Resistant weeds www.weedscience.org/In.asp
Regional Herbicide Guides for particular crops

Ainsworth, N. and Bowcher, A. 2005. *Herbicide Guidelines for Use In and Around Water*. CRC for Australian Weed Management. avail online.
Preston, C. et al. 2010, *Room for Improvement in Herbicide Management.* GRDC. Jan-Feb.

General
Adler, M., Adland Horticultural and Stephens, R. 2001. *The Facts on Hazardous Plants*. The Nursery Papers 2001/14.
Ainsworth, N. and Ede, F. J. 2005. *Understanding and Managing Weed Effects on Establishment of Native Tree Seedlings in Riparian Zones.* Procs. of the 2nd Vic. Weed Conf. Weed Soc. of Vic, Melbourne pp 52-54.
Armitage, A. M. and Laushman, J. M. 2003. *Specialty Cut Flowers: The Production of Annuals, Perennials, Bulbs, and Woody Plants for Fresh and Dried Cut Flowers*. 2nd ed. Timber Press, Portland.
Auld, B. A. and Medd, R. W. 1986. *Weeds : An Illustrated Botanical Guide to the Weeds of Australia.* Inkata Press, Melbourne.
Barker, et al. 2006. *Weeds of the Future: Threats to Australia's Grazing Industry by Garden Plants*. Meat & Livestock Australia/CRC WMS. avail. online
Blood, K. 1999. *Future and Expanding Weeds.* Plant Protection Quarterly Vol.14(3).

Blood, K. 2001. *Environmental Weeds : A Field Guide for South-eastern Australia*. ANCA/NRE, Melbourne.
Bradley, J. 1988. *Bringing Back the Bush*. Lansdowne Pub., Sydney.
Brown, K. and Paczkowska, G. 2005. *The Perennial Tussock Forming Grass Weeds*. CALM, WA.
Csurches, S. and Edwards, R. 1998. *Potential Environmental Weeds in Australia : Candidate Species for Preventative Control*. Environment Australia, GPO Box 636, Canberra.
Dahler, J. 2001. *Non-chemical Weed Control in Container Nurseries* : A Literature Review. Ornamentals Update Vol.16(3), Aug.
Day, M. D., Wiley, C. J.., Playford, J. and Zalucki. M. P. 2003. *Lantana: Current Management Status and Future Prospects.* ACIAR.
Delfosse, E. S. and Scott, R. R. (eds). 1996. *Biological Control of Weeds.* CSIRO, Melbourne.
Dept of Agric. and Food. 2009. *Harmful Garden Plants in Western Australia*. Dept of Agriculture and Food.
Ede, F, J., Ainsworth, N. and Hunt, T. D. 2004. *Assessing Weed Impacts on the Recruitment of Overstory Species*. Proc. of the 14th Aust. Weeds Conf. (eds. B. M. Sindel and S. B. Johnson). Weed Soc. of NSW, Sydney. pp 218-221.
Ede, F. J. and Hunt, T. D. 2008. *Habitat Management Guide – Riparian Weed Management in Riparian Areas : south-eastern Australia.* CRC for Australian Weed Management, Adelaide. avail online
Emaus, D., Hatton, T, Cook, P and Colvin. 2006. *Ecohydrology: Vegetation Function, Water and Resource Management*. CSIRO Pub.
Emert, S. 2001. *Gardener's Companion to Weeds*. 2nd edn. New Holland.
Ensbey, R. and Johnson, A. 2007. *Noxious and Environmental Weed Control Handbook.*: *A Guide to Weed Control in Non-crop, Aquatic and Bushland Situations*. cur edn. NSW DPI. avail online.
Forster, A. 2008. *Weed Management Programs*. Personnel communication.
Harley, K. L. S. and I. W. Forno, 1992. *Biological Control of Weeds : A Handbook for Practitioners and Students*. Inkata Press, Melbourne.
Holm, L. G., Doll., E. Holm, J. Pancho, and J. Herberger. 1997. *World Weeds: Natural Histories and Distribution.* John Wiley and Sons, NY.
Holm, L. G., Plucknett, D.L., Pancho, J.V., Herberger, J.P. 1977. *The World's Worst Weeds: Distribution and Biology*. East-West Center, Honolulu, Hawaii (USA) Univ. Press of Hawaii.
Hussey, B. M. J., Keighery, G. J., et al. 1997. *Western Weeds : A Guide to the Weeds of Western Australia.* Plant Protection Soc. of WA, Perth.
Groves, R. C. H., Shepherd, R. G. and Richardson, R. G. (eds). 1995. *The Biology of Australian Weeds Vol. 1.* RG & FJ Richardson. Vic.
Groves, R. C. H., Shepherd, R. G. & Paretta, F. D. (eds). 1997. *The Biology of Australian Weeds Vol.2.* R. G and F. J Richardson, Vic.
Groves, R. H. 1999a. *Environmental Weeds : Past, Present and Future.* Plant Protection Quarterly. Vol.14(3).
Groves, R. H. 1999b. *Environmental Weed Forum.* Plant Protection Quarterly Vol.14(3).
Groves, R. H., Panetta, F. D. and Virtue, J. G. 2001. *Weed Risk Assessment.* CSIRO, Melbourne.
Jacobs, S. W. L., Whalley, R. D. B. and Wheeler, D. J. B. 2008. *Grasses of New South Wales*. 4th edn. University of New England (Botany).
Jessop, J. 2006. *Grasses of South Australia: An Illustrated Guide to the Native and Naturalised Species.* Wakefield Press.
Julien, M and White, G. 1997. *Biological Control of Weeds*. No, 49, ACIAR, Canberra.
Julien, M. H. (ed.) 1998. *A World Catalogue of Agents and their Target Weeds*. CAB International.
Kleinschmidt, H. E. & Johnson, R. W. 1987. *Weeds of Queensland*. Qld DPI, Brisbane.
Lamp, C. A., Forbes, S. J. and Cade, J. W. 1990. *Grasses of Temperate Australia : A Field Guide.* Inkata Press, Melbourne.
Lamp, C. & Collet, F. 1999. *A Field Guide to Weeds in Australia.* Inkata Press, Melbourne.
Lazarides, M., Cowley, K. and Hohnen, P. 1997. *CSIRO Handbook of Australian Weeds*. CSIRO, Melbourne.
Lewis, P. and Stephens, R. (eds). 2001. *Discovering Alternatives to Garden Escapes*. Proc 3rd Symposium on the Control of Environmental Weeds. The Nursery Papers 2001/12
Lonsdale, G. 2000. *Weeds Threaten Australia's Economy and Biodiversity*. Media Release. CSIRO Entomology 17 August 2000.
Loughrar, A. 2006. *Native Plant or Weed? Pick the Difference.* NSW Department of Primary Industries
Loughrar, A. 2007. *Native Plant or Weed 2. Pick the Difference.* NSW Department of Primary Industries.
Mathers, H. 2000. *Controlling Weeds in Containers.* NMPRO July.
Mathers, H. and Ozkan, E., 2001. *Herbicide-Treated Mulches.* NMPRO Jan.
McNaught, I., Thackway, R., Brown, L. and Parsons, M. 2008. *A Field Manual for Surveying and Mapping Nationally Significant Weeds*. 2nd ed., Bureau of Rural Sciences, Canberra.
Moerkerk, M. and Barret, A. G. 1998. *More Crop Weeds*. R. G and F. J Richardson, Meredith, Vic.
Moss, W. and Walmsley, R. 2005. *Controlling the Sale of Invasive Plants: Why Voluntary Measures Alone Fail*. WWF-Australia, Sydney. Avail online
Muyt, A.C. 2001. *Bush Invaders of South-East Australia : A Guide to the Identification and Control of Environmental Weeds Found in South-East Australia.* R. G. and F. J. Richardson, Meredith, Vic.
Neal, J. C. and Gordon, I. 2004. *Weed Management in Woody Cut Flower Plantations.* The Centre for Native Floriculture, Uni of Qld. avail online
Neylan, J. 2009. *Supers speak out on Poa control*. Australian Turfgrass Management Mar/April.
NIASA (Nursery Industry Assoc. Scheme of Australia). cur. edn. Sydney.
Panetta, F. D., Groves, R. H. and Shepherd, R.C.H. (eds). 1998. *Biology of Australian Weeds. Vol.1*. R.G. and F.J. Richardson, Vic.
Panneta, F. D. (ed.). 2009. *Biology of Australian Weeds. Vol.3*. R.G. and F.J. Richardson, Vic.
Parsons, W. T. and Cuthbertson, E. G. 2001. *Noxious Weeds of Australia*. 2nd edn. CSIRO, Melbourne.
Plant Protection (Quarterly Journal)
www.**weedinfo**.com.au/
Preston, C., Watts, J. H. and Crossman, N. D. (eds). 2006. *15th Australian Weeds Conference Proceedings: Managing Weeds in a Changing Climate.* Weed Management Society of SA Inc.
Primary Industries Report Series 38. 1992. *Register of Releases and Establishment of Agents for Biological Control of Insect Pests and Weeds*. CSIRO Pub./PISC.
Richardson, F. J., Richardson, R. G. and Richardson, R. C. H. 2006. *Weeds of the South-East: An Identification Guide for Australia*. RG and FJ Richardson Pub. Vic
RIRDC. 2001. *National Organic Conference 2001*. Pub.No.01/121, OFA/RIRDC, Barton, ACT.
Roush, et al. 1999. *Garden Plants under the Spotlight (draft) an Australian Strategy for Invasive Garden Plants.* CRC for WMS/Nursery Ind. Assoc., Australia.
Sainty, G., Hosking, J. and Jacobs, S. (eds). 1998. *Alps Invaders : Weeds of the Australian High Country.* Australian Alps Liaison Committee. Sainty and Assocs., Darlinghurst, Australia.
Sainty, G and Jacobs, S. 2003. *Water Plants of Australia*. Sainty and Assocs., Darlinghurst, Australia.
Senate committee Report. *Turning back the tide: The Invasive Species Challenge.* 2004. Commonwealth of Australia.
Sindel, B. M. (ed.). 2000. *Australian Weed Management Systems.* R. G and F. J Richardson, Meredith, Vic.
Spencer, R. 2006. *Environental Weeds, Agricultural Weeds and Garden Plants. Resource and Information Pack with Emphasis on Victoria*. RBGM Board. avail. online
Sweedman, L and Merritt, D. 2006. *Australian Seeds A Guide to Their Collection, Identification and Biology.* CSIRO Pub.
Taylor, U. and Sindel, B. 2000. *Pasture Weeds Management Kit*. CRCWMS, Glen Osmond, SA
Thiele, K. R. and Adams, L. G. (eds). 2002. *Families of Flowering Plants of Australia: An Interactive Identification Guide.* CSIRO Pub./ABRS).
Thorp, J. R. and Lynch, R. 2001 *The Determination of Weeds of National Significance*. AFFA, ACT.
Thorp, J. 2008. *Stemming the Weed Invasion*. DAFF. Avail. online
Thurtell, K. 2001. *When is a Tree a Weed.* The Australian Arbor Age. Vol.5(5). Feb/Mar.
The Weed Society of America. *Herbicide Handbook of the United States of America.* cur. edn. Weed Science Society of America.
UMCCC (Upper Murrumbidgee Catchment Coordinating Committee). 2010. *Willow Management : A Strategy for the Upper Murrumbidgee Catchment*. ACT Environment Advisory Committee.
Wilding, J. L., Barnett, A. G. and Amor, R. L. 1986. *Crop Weeds*. Inkata Press, Melbourne.
Wilson, B. J. Hawton, D. and Duff, A. A. 1995. *Crop Weeds of Northern Australia*. Qld DPI, Brisbane.

GLOSSARY & ACRONYMS

Abiotic Non-living.

Acaricide See Miticide.

Action In relation to **IPM** (Integrated Pest Management), decision-making, control.

Adjuvant A substance added to a pesticide to improve effectiveness or safety, eg wetting agent.

Adventitious Buds and roots arising from unusual places in normal plants.

Aerobic A microorganism that lives, or a process that occurs, in the presence of molecular oxygen.

Aflatoxin A toxin produced by some fungi which is toxic to humans and livestock, eg by *Aspergillus flavus* when it infects peanuts.

Algacide A substance active against algae.

Agricultural biological products
- **Biological chemicals**, eg pheromones, hormones.
- **Plant and other extracts**, eg plant extracts, plant oils.
- **Microbial agents**, eg bacteria, fungi, viruses, protozoa.
- **Other living organisms**, eg microscopic insects, plants and animals plus some organisms that have been genetically modified.

Alien weed An introduced weed.

Allelopathy The beneficial or harmful effects of one plant on another plant by the release of chemicals from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes in both natural and agricultural systems.

Anaerobic A microorganism that lives, or a process that occurs, in the absence of molecular oxygen.

Annual Completes its life cycle in one year.

Ant An insect belonging to the Order Hymenoptera (ants, bees, wasps and sawflies).

Anthracnose A leaf or fruit spot with a sharply defined margin, caused by a group of fungi, eg *Colletotrichum* spp.

Anti-transpirant **1.** A substance applied to a plant to slow transpiration. **2**. Oils that do not evaporate readily maintaining droplet size longer.

Aphid An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerps, scales, mealybugs, whiteflies).

APVMA Australian Pesticides and Veterinary Medicines Authority.

AQIS Australian Quarantine and Inspection Service.

Arachnid A Class within the Phylum Arthropoda (Insects and Allied Pests), eg spiders, ticks and mites.

Armyworm The larva of some moths (Family Noctuidae, Order Lepidoptera).

Arthropoda (Insects and Allied Pests) A Phylum in the Animal Kingdom.

AS Australian standard.

Ascomycota A Phylum of Fungi producing their sexual spores (ascospores) within asci (sac fungi), eg powdery mildews.

Ascospore A sexually produced fungal spore in an ascus.

Ascus A sack-like cell of a hyphae in which meiosis occurs and which contains ascospores, usually 8.

Asexual reproduction Non-sexual reproduction, vegetative reproduction.

Autoecious fungus A parasitic fungus that can complete its entire life cycle on the same host.

Avicide A substance active against birds.

Bactericide Any agent active against bacteria.

Bacterium (pl. bacteria) A single-celled microscopic organism lacking chlorophyll and which multiplies by cell division.

Bag shelter Leaves of plants bound together by silk produced by insects which shelter within (usually moth caterpillars (Order Lepidoptera).

Bait A food or other substance that attracts a pest to a chemical or trap where it is destroyed or captured.

Basidiomycota A Phylum of Fungi producing their sexual spores (basidiospores) on basidia (club fungi), eg rusts, smuts, mushrooms, wood rots.

Basidiospore A sexually produced fungal spore on a basidium.

Basidium A fungal club-shaped reproductive structure on which basidiospores are borne.

Bee An insect belonging to the Order Hymenoptera (ants, bees, wasps, sawflies).

Beetle An insect belonging to the Order Coleoptera (beetles, weevils).

Beneficial insect An insect that is useful or helpful to humans, eg pollinators, parasites and predators of pests.

BFA (Biological Farmers of Australia) The pre-eminent organization for the organic industry and movement (education, trade, promotion, advocacy).

Biennial A plant that completes its life cycle in 2 years. It grows vegetatively for 1 year then flowers, seeds and dies in the 2nd year.

Biochemistry The study of chemical processes that take place in all living things.

Biodegradable Can be broken down by living organisms, eg by bacteria, fungi, nematodes, etc.

Biological control Classical biological control is the deliberate use of a pest, disease or plant's natural enemies to control a particular pest, disease or weed.

Biosecurity Australia Provides science-based quarantine assessments and policy advice that protects Australia's favourable pest and disease status and enhances Australia's access to international animal and plant related markets.

Biotype A race of a species that is genetically different from the rest of the species often caused by geographical isolation, often look the same, only genetic analysis in a laboratory can tell the difference.

Blight A general and extremely rapid browning of leaves, flowers, branches or twigs resulting in their death, caused by fungi, insects, frost or other agents.

Blister Raised area on leaves or fruit, eg grapeleaf blister mite, peach leaf curl (fungus).

Blotch Dead areas on leaves and fruit which may cover most of the plant, be irregular in shape or form patterns other than spots, caused by fungi, bacteria, leafmining insects, sunscorch, or other agents.

BMP (Best Management Practice) Management practices which are environmentally conscious.

Borers Insects usually belonging to the Order Coleoptera, eg longicorn beetles; or the Order Lepidoptera, eg wood moths, which feed internally in trunks, limbs, branches, stems and roots of trees and shrubs. Some feed in fruit.

Breaking Loss of flower color resulting in a variegated flower, usually caused by virus diseases, eg tulip breaking virus, rasping and sucking insects, eg thrips, genetic variegation, or sunscald.

Bud drop A mass dropping of buds before they open, not necessarily a symptom of disease as some plants always drop some buds.

Bug An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerp insects, mealybugs, scales, whiteflies).

Butterfly An insect belonging to the Order Lepidoptera (butterflies and moths).

Cambium Thin layer of longitudinal cells between the xylem and phloem that gives rise to growth.

Canker A localized diseased area resulting in an open wound usually on a woody structure caused by stubs, sunburn, fungi and bacteria), etc.

Capillary action The physical process by which fluid material is drawn upwards from a fluid surface through narrow tube-like structures, either natural (in roots, stems, fibres) or manufactured, eg glass tubing.

Carbon dioxide A significant greenhouse gas which come from natural sources and human activity, eg burning fossil fuels for energy, cattle, etc.

Case moths Caterpillars of moths which live in a case made of silk and leaves/sticks and feed on leaves.

Caterpillar Larva of a moth or butterfly (Order Lepidoptera), has 3 pairs of legs on the thorax and 2-5 pairs of legs on the abdomen.

Certification Scheme Provides seed or vegetative propagation material conforming to cultural characteristics and guaranteed-free from specified pests, diseases and weeds, to the grower.

Chemical group (pesticide) The chemical group to which the active constituent(s) belongs, eg carbamate.

Chewing damage Caused by animals, eg insects or snails, feeding externally or internally on leaves, stems, shoots, fruit, flowers and other plant parts.

Chitin A hard substance forming the outer coat of Insects and Allied Pests.

Chlorosis Yellowing of normal green tissue of the host plant due to partial failure of chlorophyll to develop. Can occur on all parts of the plant, but commonly associated with leaf colour. Caused by virus diseases, natural variegation, deficiencies and toxicities, etc. Chlorosis may precede death of a plant.

Class A division of a plant or animal **Order**.

Cleistothecium (pl. cleistothecia) Closed fruiting body of Ascomycota Fungi, eg powdery mildews.

CLIMEX is a computer software package that predicts the spread of pests, diseases, weeds and beneficial organisms.

Cockroach An insect belonging to the Order Blattodea (Cockroaches).

Cocoon A protective sac, spun by the larvae of many insects in which they pass the pupal stage, eg butterflies (Order Lepidoptera).

Conditions favouring Certain conditions which favour development of a pest, disease or weed.

Conidia Sexual fungal spores.

Conservation tillage (CT) Minimum or reduced tillage, sustainable crop production based on soil preservation.

Contact herbicide A compound active at the point of application (leaves, stems, roots), does not move into plants.

Contact insecticide A compound that causes death or injury to insects upon contact, it does not need to be ingested to kill the insect.

Cornicles Tube-like structures on the dorsal side of the 5th and 6th abdominal segments of aphids.

Crawler The 1st stage nymph of a scale insect, mealybug or whitefly which can crawl a short distance before settling and becoming non-motile.

CRC WMS Co-operative Research Centre for Weed Management Systems

Cricket An insect belonging to the Order Orthoptera (crickets, grasshoppers, locusts).

Critical weed density The minimum number of weeds worth spraying in a crop which will give a return to cover the costs of sprays and application.

CropLife Australia The industry body in Australia, which, through its Resistance Management Strategies, provides a guide for product rotation in crops.

Cross-resistance. A pest, disease or weed which develops resistance to one pesticide will develop resistance to pesticides with similar modes of action.

CT Conservation tillage (see above).

Cultural control The use of ordinary day-to-day horticultural practices and equipment to control pest, diseases and weeds.

Curd The solid part of milk in cheese making.

Cutworm The larva of some moths belonging to the Family Noctuidae, Order Lepidoptera.

Damage. Generally refers to plant damage clearly visible to the naked eye, eg chewing, leafmining, tearing, skeletonizing.

Damping-off A fungal disease that rots seeds and seedlings before or after emergence from the soil. May be caused by fungi, bacteria or other agents.

Damselfly An insect belonging to the Order Odonata (dragonflies, damselflies).

Defoliation The premature fall of leaves caused by many agents.

Desiccant A chemical that promotes drying or loss of moisture from leaves or other plant parts.

Diapause A state of arrested development.

Dicotyledons (dicots) Flowers that have 2 seed leaves (cotyledons).

Dieback Progressive death of shoots and branches beginning at the top of the plant which may be caused by insects, bacteria, fungi, drought or other agents.

Direct drilling Sowing into uncultivated soil after weed control, eg by herbicides or heavy grazing.

Disease Any condition of a plant that interferes with its normal structure, functions, or value.

Disease cycle Describes each stage of the life cycle of a disease (spore, symptom, etc) and where it occurs (on leaves, soil, etc).

Disease-tested planting material Plant material free from specified diseases and pests for which it has been tested.

Disinfectant A substance freeing the surface of plants, organs or tissues from disease organisms.

Distortion Misshapen plant parts including buds, flowers, fruit and trunks.

DNA Deoxyribonucleic acid, a component of the nucleus of all cells.

Downy mildew A fungus belonging to the Phylum Oomycota in which spores appear as white or gray downy growth on leaf undersurfaces, stems, fruit, etc.

Dragonfly An insect belonging to the Order Odonata (damselflies, dragonflies).

Earwig. An insect belonging to the Order Dermaptera (earwigs).

Ectoparasite A parasite living on the outside of the host.

EDTA Ethylene diamine tetra acetate.

ELISA (enzyme-linked immunosorbent assay) A serological test in which one antibody carries with it an enzyme that releases a coloured compound.

Endoparasite A parasite that lives inside the host.

Endophyte A fungus or a bacterium growing systemically in living plants, causing few or no symptoms, but protecting them from diseases and pests, while improving growth and drought tolerance.

Entomopathogen A disease organism that kills insects and mites, eg entopathogenic nematodes **(ENs)** kill insects.

Environmental weed A cultivated plant which invades natural ecosystems threatening indigenous biodiversity.

Etiolation A yellowing of tissue and elongation of stems, usually caused by reduced light or darkness.

Excretion Waste material which is ejected from any living body.

Exotic weed An introduced weed.

Fasciation. A plant abnormality on any part of the plant characterized by a change in the stem of the plant from normal round or bundle-like shape to a flattened, ribbon-shaped organ.

FFEZ Fruit Fly Exclusion Zone.

Filament Thread-like structure.

Fleck A fungal disease of apples, pears (Rosaceae).

Fly An insect belonging to the Order Diptera (flies).

Forbs Wildflowers.

Formulation The technical grade active constituent **(TGAC)** processed by the addition of other materials into a form which is usable by the operator.

Frass The wet or dry sawdust-like excreta of borers, usually evident at their exit holes on trunks, fruit or other plant parts; often used to describe any insect remains, eg pellets of caterpillar excreta, black drops of excreta from thrips feeding on the undersides of leaves, nymph skins of aphids.

Freckle A fungal disease of stone fruit.

Fruiting body A complex fungal structure containing spores, eg a mushroom. Sometimes too small to be seen with the naked eye.

f.sp. (Forma specialis) A group of races or biotypes of a pathogen species that can only infect plants within a certain genus or species.

Fumigant A chemical that forms gases which are toxic to plants, animals and micro-organisms.

Fungicide Any agent active against fungi.

Fungus (pl. fungi) A simple plant with a mycelium as a body, possesses no chlorophyll and reproduces by spores; in a separate kingdom of their own.

Gall A swelling, more or less spherical, of unorganized plant cells occurring on any part of the plant, as a result of infection by fungi, other disease organisms or infestation by insects.

Genetic engineering (GE) Various experimental techniques that manipulate the genes of an organism, eg transfer of genes for drought resistance from wild plants to crop plants.

GPUTS Garden Plants Under The Spotlight.

Grasshopper An insect belonging to the Order Orthoptera (crickets, grasshoppers, locusts).

GRDC (Grain Research & Development Corporation).

Greenhouse effect A process by which carbon dioxide **(CO_2)** and other gases such as chloro-fluorocarbons **(CFCs)**, methane and nitrous oxide in the atmosphere, prevent some of the heat radiation produced by the action of the sun's energy on earth from returning to space.

Greening Floral parts are green, usually caused by a phytoplasma disease (tomato big bud, virescence).

'Grubs' Thick-bodied larvae of beetles and weevils (Coleoptera), butterflies and moths (Lepidoptera).

Gumming, gummosis An obvious secretion of gum which may be caused by bacterial or fungal diseases, insect pests or other agents.

HACCP. Hazard Analysis Critical Control Point.

Haustorium (pl. haustoria) A simple or branched projection of fungal hyphae or cells into host cells which act as food-absorbing organs.

Herbicide A substance active against weeds or unwanted vegetation.

Heteroecious Requiring 2 different kinds of hosts to complete its life cycle, eg some rust fungi.

Honeydew An excretion of some Hemipterous insects (aphids, lerp insects, mealybugs, scales, whiteflies), with a high carbohydrate, sugar and nitrogen content attractive to ants. Black sooty mould fungi grow on it.

Hormone herbicide Belonging to the phenoxy aliphatic acid group of herbicides, eg 2,4-D, MCPA, active against broadleaved weeds. Act in a similar manner to the natural plant hormone auxin. Benzoic acids, eg dicamba, act in a similar way.

Host A plant on, or in which, a pest or parasite lives.

Host range Plants attacked by a pest or disease.

Hydathodes Small pores at the margins of leaves that release small droplets of plant fluid when turgor pressure is high.

Humectant A soil humectant is a compound that attracts and/or retains moisture in the soil.

Hydroponics Growing plants in aerated water containing all the essential nutrients.

Hygiene The practice of keeping a greenhouse or planting area clean by removal of weeds and plant debris, sterilization of growing media and pots, and disinfection procedures. See Sanitation.

Hyperparasite A parasite parasitic on another parasite.

Hyphae Single branches of a fungal mycelium.

Immune. Ability of a plant to remain completely free from attack by specified diseases and pests.

Imperfect Fungi A fungus that is not known to produce sexual spores.

Indexing The transmission of a virus from a diseased to a healthy plant (a variety on which symptoms can be easily seen) by budding, grafting.

Indigenous Plants found naturally in a particular area.

Infection Establishment of a parasite within a host.

Infestation When pests arrive and multiply to a large number causing plant damage. It can also refer to established pest populations.

Insect Arthropod with 3 body segments, 3 pairs of legs on thorax, 1 pair antennae, with or without wings.

Insect growth regulator (IGR) Specific insecticides such as growth hormones that disrupt the normal development of insects.

Insecticide Any agent active against insects and mites, includes pheromones, lures, baits, repellents, biological pesticides.

Insects & allied pests Insects and related animals, eg springtails, mites, spiders, slaters and millipedes, belonging to the Phylum Arthropoda.

Instar One stage of growth between moults from egg to adult.

Integrated pest management (IPM) Systematic management of pests with consideration for the environment. Part of managing crops as a whole, includes Integrated Disease Management **(IDM)** and Integrated Weed Management **(IWM).**

ISO International Standards Organization.

Invasive A pest or plant which colonizes and persists in an ecosystem in which it did not occur before.

Knockdown spray. **1.** An insecticide spray used against flying insects that acts quickly causing sprayed insects to fall. **2.** A contact herbicide that is rapid in action.

Lacewing. A predaceous insect belonging to the Order Neuroptera (antlions, aphidlions, lacewings).

Larva (pl. larvae) The growing worm-like stage of insects with a complete metamorphosis, eg butterflies, moths, flies, beetles, sawflies.

Latent infection A virus that infects but does not induce symptoms in its host.

Leaf blister Raised surface of a leaf caused by many agents, eg blister mites, peach leaf curl (fungal disease).

Leaf curl Distortion and malformation of leaves and shoots caused by insects, eg aphids, peach leaf curl (fungal disease), herbicide injury, other agents.

Leafhopper An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerps, scales, mealybugs, whiteflies).

Leaf insect An insect belonging to the Order Phasmatodea (stick insects, leaf insects, phasmatids).

Leafmining Damage caused by the larvae of insects feeding internally between the lower and upper leaf surfaces, including moths (Lepidoptera), eg wattle leafminer; sawflies (Hymenoptera), eg leafblister sawfly); flies (Diptera), eg cineraria leafminer; sometimes beetles (Coleoptera), eg lantana leafminer.

Leaf rolling Any obvious rolling of leaves, may be caused by a range of agents, eg insects, mites, cold weather, lack of water.

Leaf scorch Dead areas of various shapes on leaves, which may be caused by heat, lack of water or other agents, eg insects, fungal and bacterial diseases.

Leaf spot A self-limiting lesion on a leaf, commonly caused by fungal diseases but also caused by virus and virus-like diseases, bacterial diseases, insects feeding and by a range of non-parasitic problems, eg senescence or contact herbicide injury.

Lenticel A opening on the stem of woody plants, tubers, etc, that allows for the exchange of gases between the plant and the atmosphere.

Lerp An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerps, scales, mealybugs, whiteflies).

Lesion A local spot of diseased tissue on a leaf, fruit, trunk or other plant part.

Lichen A symbiotic relationship of a fungus and an alga in which the two components are interwoven to form what appears to be a single individual.

Life cycle The stages in the growth and development of an organism that occur between the appearance and the re-appearance of the same stage, eg spore, egg.

Line pattern Lines of light coloured tissue on normal coloured leaves caused by some virus diseases.

Locust An insect belonging to the Order Orthoptera (crickets, grasshoppers, locusts).

Looper A caterpillar that loops its body as it moves.

Lure A chemical that attracts a pest to a trap, bait or to a lethal deposit of pesticide.

Maggot. Legless larva of flies (Order Diptera).

Mantid A predaceous insect belonging to the Order Mantodea (mantids, praying mantids).

Marking agent A coloured substance used to ensure uniform coverage of a pesticide over a particular area.

Masked symptoms Absence of symptoms on virus-infected plants under certain environmental conditions, but which appear when the plant is exposed to certain conditions of light and temperature.

Mealybug An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerps, scales, mealybugs, whiteflies).

Mechanical control Use of barriers, traps and operations to control pests, diseases and weeds.

Mechanical injury Physical injury due to insects, wind, vehicles, other agents.

Metamorphosis The process of change from egg to adult.

Microorganism A small organism that cannot be seen without the aid of a microscope, eg bacteria.

Mildew A fungal disease in which the fungus is seen as a growth of mycelium and spores on the host plant surface, eg downy mildews, powdery mildews, sooty mould, rusts. See Mould.

Millipede An animal belonging to the Class Diplopoda, Phylum Arthropoda.

Mite An animal belonging to the Order Acarina, Class Arachnida, Phylum Arthropoda with 8 legs, a body divided into 2 parts, no antennae.

Miticide A substance active against mites, ticks, spiders.

Mode of action group (of a pesticide). The metabolic process in the pest (insect, fungus, weed, etc) affected by the pesticide.

Molluscicide A substance active against snails and slugs.

Monocotyledons (monocots) Flowering plants that have only a single seed leaf (1 cotyledon).

Mosaic Irregular light and dark areas in leaves (mottling effect) caused by many virus and virus-like diseases, eg turnip mosaic virus.

Moth An insect belonging to the Order Lepidoptera (butterflies, moths).

Mottle Irregular light and dark areas in leaves, generally caused by virus and virus-like diseases, eg camellia yellow mottle virus.

Mould A fungus with a conspicuous mycelium or spore mass, eg powdery mildews. See Mildew.

Moult The shedding of skin by insects and mites as they grow.

MSDS Material Safety Data Sheet.

Mutation An abrupt appearance of a new characteristic as the result of an accidental change in a gene or chromosome.

Mycelium The hyphae or mass of hyphae that make up the body of a fungus.

Myco-insecticides Fungi used to control insects.

Mycorrhiza A symbiotic association of a fungus with the roots of a plant.

Myxomycota A Phylum of Fungi which form plasmodia, eg slime moulds.

Nanometer **(nm)** One billionth of a meter.

Nanoparticle. Usually considered to be particles with a radius of ≤ 100 nm.

Natural enemy. A naturally occurring beneficial organism which controls or suppresses a pest.

Naturalised weeds Invading species that have become established and reproduce for several generations in the wild without human assistance.

Necrosis, necrotic Death of plant cells, tissue turns brown, dark colored, and appears sunken.

Needle cast Certain fungal diseases of conifers which result in the copious shedding of needles, eg *Lophodermium* spp. on pines.

Nematicide Any agent active against nematodes.

Nematode An unsegmented generally microscopic round worm belonging to the Class Nematoda.

Non-target organisms Plants and animals directly or indirectly affected accidentally by control measures.

Noxious weed A plant defined by law as being particularly troublesome, undesirable and difficult to control. Also called a declared or proclaimed weed.

NSOBP National Standard for Organic and Bio-Dynamic Produce.

Nutrient charting A means of getting early warning signs of nutritional disorders, a prognosis.

Nymph The growing stage of insects with a gradual metamorphosis, eg grasshoppers.

Obligate parasite. A parasite that in nature can only grow and multiply on or in living organisms.

Oedema Small masses of tissue expand and break out on plant parts (mostly leaf undersurfaces) causing watery swellings or small galls, which may become rusty or scabby. The plant absorbs more water through the roots than it can transpire through the leaves.

Oil sprays Used as spray additives, soil wetting agents and spray oils to control pests and diseases.
- **Botanical/vegetable oil** Derived from the seeds of oil seeds, eg soybean, canola, cottonseed.
- **Paraffin oil** High quality petroleum oil, containing at least 62% paraffinic chains.
- **Spray oil** Oils mixed with water and applied to plants as a spray to manage certain pests and diseases.
- **Dormant/winter oil** Used on woody plants during dormancy (trees without foliage) to control pests.
- **Summer/white oil** Used on plants when foliage is present to control pests and some diseases.
- **Superior oil** Used year-round without phytotoxicity.

Oomycota A Phylum of Fungi which produce thick-walled resting spores called oospores/zygospores, eg downy mildews, *Pythium, Phytophthora*.

Oospore A fungal sexual spore in the Oomycota.

Ooze Liquid discharge from diseased or injured tissue. May occur with bacterial or fungal diseases, some insect infestations, pruning or other injury.

Organic standards Growing crops without synthetic fertilizers and pesticides, and not genetically modified. There are legal obligations (AS 6000–2009).

'Overwintering' How the pest, disease or weed carries over from one season to another.

Ovicide A chemical that destroys eggs.

Ozone A gas within a layer of the upper atmosphere which is spread fairly evenly around the entire globe. It absorbs dangerous **UV** rays from the sun preventing injury to plant, animal and human life.

Parasite. A plant, animal or micro-organism living in, on, or with another living organism for the purpose of obtaining all or part of its food.

Parasitoid A form of parasitism in which the larval stage is specially adapted to live inside the host, eventually killing the host, eg the whitefly parasitoid *Encarsia formosa*.

Parthenogenesis Reproduction takes place without fertilization of the eggs.

Pasteurisation Partial sterilization of foods at a temperature that destroys harmful microorganisms without major changes in the chemistry of the food.

Pathogen An organism that causes disease.

Pathogenicity The capability of a pathogen to cause disease.

Pathovar (p.v.) In bacteria, a subspecies or group of strains that can infect only plants within a certain genus or species.

PCR (polymerase chain reaction) A technique that allows almost infinite multiplications of a segment of **DNA** for which only a short piece of **DNA** is available. .

PDA Personal Data Assistant.

Perennial A plant which lives for 3 years or more and may be short-lived or long-lived. Some may be classified as woody species or herbaceous.

Pest An undesirable organism (bacterium, insect, fungus, nematode, weed, virus, rodent) which is injurious to desirable plants and animals.

Pest cycle Describes each stage of the life cycle (egg, adult, etc) of the pest and where it occurs (on leaves, soil, etc).

Pesticide A chemical or other agent used to kill, control or suppress pests, diseases and weeds.

Pest management See Integrated Pest Management.

Phasmatid An insect belonging to the Order Phasmatodea (stick insects, leaf insects).

Pheromone A substance emitted by an animal that influences the behaviour of other animals of the same species, may be synthetically produced for insect traps.

Phloem Tissues which transport nutrients from leaves which produce them to other plant parts.

Phylum A division of the plant and animal Kingdom.

Physical control Use of certain physical properties of the environment, eg temperature, to control pests, diseases and weeds.

Phytoplasma See Virus & virus-like organism.

Phytotoxity Toxicity of a pesticide or a pesticide component to desired plants

Pigmentation Development of pigments other than chlorophyll in leaves, flowers and fruit. Can occur as a result of insect infestations, disease, weather conditions or other agents.

Plant growth regulator A substance which accelerates, retards or alters the natural development of any vegetation.

Plant quarantine Legislative regulatory control against introduction and dissemination of weeds and pests and diseases of plants into new areas.

Plasmodiophoromycota A Phylum in the Fungi which are obligate endoparasites of plants, eg club root of brassicas (*Plasmodiophora brassicae*).

Poisoning A toxic reaction when touched or eaten.

Post-emergent herbicide A herbicide applied after weeds have appeared through the soil.

Powdery mildew A fungus in the Phylum Ascomycota which produces white, powdery spores on mostly upper leaf surfaces, stems, flowers, fruit.

Praying mantid A predaceous insect belonging to the Order Mantodea (mantids, praying mantids).

Predator An animal that attacks, kills and feeds on other animals, eg assassin bugs.

Pre-emergent herbicide A herbicide applied before the weeds have appeared through the soil.

Protectant A fungicide applied to a plant prior to infection by a disease organism in order to prevent infection of the host plant.

Protocol A negotiated formal procedure drawn up and recorded.

Provenance(s) Populations of a species from different regions, individual trees within regions, and even different branches of one tree.

Pubcris The registered product database of the Australian Pesticide & Veterinary Medicines Authority **(APVMA)**.

Pupa (pl. pupae) The stage during which an insect with a complete metamorphosis transforms from the larval to the adult stage.

Pustule A small blister-like elevation of epidermis created as spores from underneath push outwards.

pv.. See Pathovar.

Quarantine. See Plant Quarantine.

Race. **1.** A genetically and often geographically distinct mating group within a species. **2.** A group of pathogens that infect a given set of plant varieties.

Relative humidity The amount of water vapour in the air compared to the amount required for saturation, stated as a percentage. If air contains only half the amount of water vapour that it can hold when saturated, relative humidity is 50%.

Repellent A compound that keeps insects, rodents, birds or other pests away from plants, domestic animals, buildings or other treated areas.

Resistance 1. The ability of a host plant to suppress or retard the activities of one or more specified disease organisms. **2.** Populations of pests, diseases or weeds that are unaffected by a certain dosage of chemical used to control other populations of the same organisms successfully.

Resistance mode of action groups (of a pesticide) The classification of pesticides by **Croplife Australia** which is displayed on commercial pesticide labels.

Rhizomorph A root-like strand of fungal hyphae, used to spread for long distances through soil or along or under bark of woody plants, eg *Armillaria* spp.

Ringspot Yellowish or chlorotic rings with green tissue in the centre, caused by many virus & virus-like diseases, eg peony ringspot virus.

Risk assessment The process of assessing whether a pest, disease or weed is likely to become a major pest.

Rodenticide A agent active against rodents (vermin).

Roguing The removal of an infested or diseased plant from an otherwise healthy crop to prevent spread to neighbouring plants or through its seeds to future generations. Weeds may also be rogued.

Rot A decay or decomposition of plant tissue which can affect any plant part, eg roots, trunks, fruit, bulbs, seed. It may be caused by bacteria or fungi, water-logging or by other agents.

Russet Development of brown, roughened areas on the skin of fruit due to the formation of cork, caused by mites, virus diseases, powdery mildew, frost, etc.

Rust A fungus in the Phylum Basidiomycota which causes a disease characterized by orange brown spore masses, eg chrysanthemum rust.

Salinity. A concentration of soluble salts in water between soil particles sufficient to restrict plant growth.

Sanitation The elimination or reduction of pest and disease organisms and weeds in a nursery, glasshouse, storage facility or other horticultural situation, to reduce spread to other healthy plants or produce, especially at the beginning of a new season.

Saprophyte An organism using dead plant matter as food.

Sawfly An insect belonging to the Order Hymenoptera (ants, bees, wasps, sawflies).

Scab Localized lesion on plant parts, eg leaves, fruit, corms, usually slightly raised, giving a scabby appearance. It may be caused by bacterial or fungal diseases, eg apple scab or by environmental agents, eg oedema. See Oedema.

Scale An insect belonging to the Order Hemiptera (bugs; hoppers; aphids, lerps, scales, mealybugs, whiteflies).

Sclerotium (pl. sclerotia) A hard compact mass of fungal threads, when dry dark on the outside, can survive unfavourable conditions, eg *Sclerotinia* rot.

Scorch Dead, 'burnt' areas on leaves and fruit, which may cover nearly the entire plant, irregular in shape, or form patterns (other than spots). May be caused by insects, disease, environmental conditions.

Secretions. Substances extracted from plant sap by insects for their use or to be excreted as waste.

Seed banks Existing seed in soil.

Semio-chemical A chemical that modifies pest behaviour.

Shothole Small spots on leaves which fall away to leave small holes. Used to describe types of fungal diseases, eg shothole of stone fruit; bacterial diseases, eg bacterial canker of stone fruit. Insects, eg metallic flea beetles, chew tiny irregular holes in leaves, which enlarge to give the leaves a 'shotholed' appearance.

Sick soil syndrome Often referred to as 'replant disease'. Disease microorganisms are thought to build up in soil during the life time of certain plants, eg roses; when planting roses into old rose beds soil is replaced.

Sign The presence of actual insects, fungi, snails or other agents causing the problem. If signs are present the problem can usually be readily identified.

Signal heading Indicates the hazard level of the product, eg a pesticide.

Silk Produced by caterpillars of butterflies and moths (Order Lepidoptera) from special glands in the mouth, used for constructing cocoons, binding leaves together or lowering themselves for dispersal.

Silvering Leaves become silvery in appearance instead of the normal green colour, most commonly caused by thrips rasping and sucking leaf surfaces, but also caused by senescence and other agents.

Skeletonization Caused by chewing insects feeding externally on the surface of leaves, leaving only veins, eg autumn gum moth and gumleaf skeletonizer (Lepidoptera); elm leaf beetle (Coleoptera); pear and cherry slug and callistemon sawfly (Hymenoptera) and young snails.

Slater An animal belonging to the Class Malacostraca, Phylum Arthropoda.

Sleeper weeds Weeds that appear benign for many years then suddenly spread rapidly.

Slime mould A very simple fungus belonging to the Phylum Myxomycota

Smut A fungus in the Phylum Basidiomycota which causes a disease characterized by the presence of black sooty spore masses in seeds and leaves.

Snail An animal belonging to the Phylum Mollusca, Class Gastropoda.

Sodicity Soil containing levels of sodium that affects its physical properties (stability). Applies to soils rather than media,

Solarisation A process in which heat from the sun may raise the temperature near the surface of soil or potting media to levels high enough to kill or reduce populations of some pests, eg mites, most soilborne disease organisms (bacteria, fungi, nematodes), and some weeds and weed seeds.

Sooty mould The dark hyphae of fungi growing on the honeydew secreted by some Hemipterous insects, eg aphids, lerps, scales, mealybugs, whiteflies.

Speckles, stippling Patterns of dots (feeding sites of sap sucking insects) on leaves and fruits.

Spider An 8-legged animal belonging to the Order Acarina, Class Arachnida, Phylum Arthropoda.

Spittle bug An insect belonging to the Order Hemiptera (bugs) the nymph of which produces a wet, frothy material for protection.

Splitting The cracking of fruit commonly due to rain/too much water and too rapid growth.

Spore The reproductive unit of a fungus consisting of one or more cells.

Spray adjuvant A substance added to a pesticide to improve effectiveness or safety, eg wetting agent.

Springtail An insect belonging to the Class Collembola, Phylum Arthropoda.

Sterile fungi A group of fungi not known to produce any kind of spores.

Stick insect An insect belonging to the Order Phasmatodea (leaf insects, phasmatids).

Stomach poison A pesticide that must be eaten by an animal in order to be effective.

Stomates Small openings on leaves, twigs and other plant parts which regulate the flow of water from the plant into the atmosphere and admit carbon dioxide from the atmosphere for photosynthesis.

Strain Descendants of a single isolate in pure culture, an isolate, a race.

Streaking Dark longitudinal streaks on stems infected with virus diseases, eg symptoms of tomato spotted wilt virus on stems of broad bean.

Stunting Failure of a plant to reach normal size, caused by insect pests, virus diseases, other agents.

Suppressive soils Soils in which certain diseases are suppressed because of the presence in the soil of microorganisms antagonistic to the pathogen.

Surfactant A spray supplement which lowers the surface tension of a pesticide spray enabling it to spread evenly over, and adhere to, the surface of an insect, diseased plant surface or weed, overcoming the repellent nature of the pest, disease or weed.

Susceptible Being prone to attack by a given disease or pest organism.

Symbiosis Mutually beneficial association of 2 or more different kinds of organisms.

Symptom The visible response of the host plant to a disease or pest, eg chlorosis, leaf curl, scab.

Systemic **1.** A chemical that is absorbed and translocated within a plant or animal. **2.** A disease that spreads within a plant.

Target organism. The pest, disease or weed to be controlled.

Termite An insect belonging to the Order Isoptera (termites, 'white ants').

Threshold Levels of pest or damage at which treatment is necessary to manage a pest problem. May be economic, aesthetic or environmental.

Thrips An insect belonging to the Order Thysanoptera (thrips).

Tolerant The property of organisms (including plants), to withstand a certain degree of stress, pest attack, unfavourable weather and other agents.

Toxin A compound produced by plants, animals or microorganisms which is toxic to another.

Translocation A substance taken in through the plant surface and moved throughout the plant.

Uredospores. Rust spores produced by a fruiting structure called a uredium.

Vector. **1.** An insect, nematode, parasitic plant or other parasite which can carry and transmit a disease organism from one host to another. **2.** In genetic engineering the transmission of **DNA** into a host cell.

Vegetative Asexual reproduction of plants.

Veinbanding Regions along the veins of leaves darker or lighter in colour than the tissue between the veins, caused by some virus diseases.

Veinclearing Veins of leaves become translucent, caused by some virus diseases, herbicide injury, etc.

Virescence See Greening.

Virus & virus-like 'organism' A submicroscopic parasite consisting of nucleic acid and protein. A group of related 'organisms', eg phytoplasmas and viroids, have similar properties, ie can only multiply in living cells, can spread from one plant to another and can only be seen with aid of an electron microscope.

Wasp. An insect belonging to the Order Hymenoptera (ants, bees, sawflies, wasps).

Wax A normal secretion of the epidermal glands in insects, eg woolly aphid.

Webbing Fine silk produced from glands in the mouth of 'spider' mites, eg twospotted mites crawl over it and fasten their eggs to it.

Weed A plant that has or has the potential to have, a detrimental effect on economic, social or conservation values.

Weevil An insect belonging to the Order Coleoptera (beetles and weevils).

Wetting agents A substance that reduces the surface tension of a liquid, so it can spread across or penetrate more easily the surface of a plant. May be added to pesticide sprays to allow easier spreading on leaves, or to the soil to aid the rewetting of soils.

Whey Liquid waste from cheese products.

White ant An insect belonging to the Order Isoptera (termites).

Whitefly An insect belonging to the Order Hemiptera, (bugs; hoppers; aphids, lerps, mealybugs, scales, whiteflies).

Wilt A drooping of plants due to an inadequate water supply, excessive transpiration, or a variety of agents. True 'wilt ' diseases are caused by fungi or bacteria blocking the xylem vessels of the host plant, eg *Fusarium* wilt and *Verticillium* wilt of various plants and bacterial wilt of tomato.

Wireworm Larvae of click beetles (Elateridae, Coleoptera).

Witches' broom Broom-like growth or massed proliferation of shoots, caused by insects or mites, other agents, and occasionally by fungal diseases.

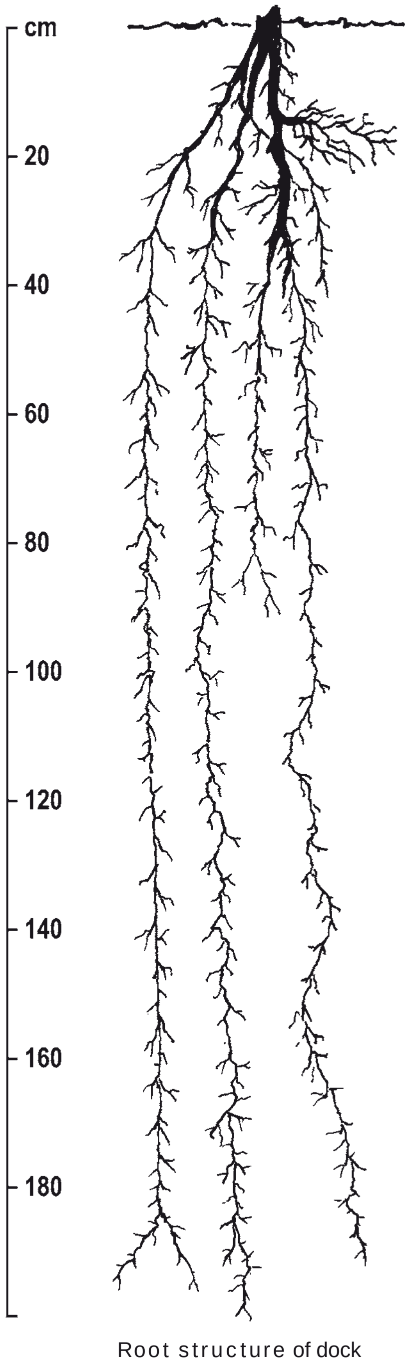
'Worm', 'weevil' damage Damage caused internally to fruit, nuts, seeds by larvae of various insects with a complete metamorphosis, eg caterpillars of moths (Lepidoptera), maggots of flies (Diptera), larvae of beetles and weevils (Coleoptera) and wasps (Hymenoptera).

Xylem. Water conducting tissue in plants.

Zoospore. A fungal spore with flagella capable of moving in water.

Zygomycota A Phylum of Fungi with thick-walled resting zygospores, eg bread moulds (*Mucor, Rhizopus*).

INDEX



Root structure of dock (*Rumex* spp.). After Parsons and Cuthbertson 2001.

The Author's Aim in this series of books is to provide users with the systematic understanding of Plant Protection and Plant Management required of modern horticulture. The books are used to teach Plant Protection throughout Australia and as a reference by people working in the horticulture industry.

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