WEED BIOLOGY AND CONTROL

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INTECH

Chapter 1

The Role of Weed and Cover Crops on Soil and Water Conservation in a Tropical Region

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Additional information is available at the end of the chapter

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1. Introduction

Weed control is one of the most intensive management practices in different production systems in tropical regions and can influence both agricultural productivity and impact the environment. Despite the importance of this issue, studies reporting the action of different methods of weed control on soil physical properties and their effects on the management and conservation of soil and water are scarce, requiring a greater understanding of the adequacy of management systems. Weeds are considered one of the major constraints in crop production and may substantially reduce yields when not controlled properly. Potential yield reductions caused by uncontrolled weeds are estimated at 45 % to 95 % depending on the crop, ecological and climatic conditions [1].

A key to effectiveness weed management is a holistic approach regarding the scenario considered and must include a combination of tactics and practices in order to successfully and economically reduce the potentially negative impacts inherent to weeds incidence [2]. There are numerous methods of mechanical control of weeds including mowing, cultivation, hoeing, flaming, mulching, and hand weeding. Chemical control of weeds mainly consists of using pre and post-emergence herbicides and soil fumigants [2]. Herbicides and tillage are the dominant practices in many production systems due to efficiency and facilities for weed control [3]. However, these methods may be inadequate for weed control in tropical conditions and may have negative impacts on soil and to the environment most of these impacts are related to hydric erosion [4-7] and soil compaction, which affect soil quality [8-11]. Weed management and cover crops also affects micropedological [6], biological [12-13], chemical soil properties [12, 14-17].

Given the complexity and limitations inherent to each of these methods, integrated weed management systems is an alternative to traditional methods and can be useful for soil and water conservation in Tropical conditions. One of the goals of the integrated weed management systems is to develop methods that provide better use of resources. In addition, to optimize crop production and growth yield through the concerted use of preventive tactics, scientific knowledge, management skills, monitoring procedures, and efficient use of control practices [1]. It is known that, weed control and cover crops management has several impact on soil properties and effects soil and water conservation due changes on soil structure in the row and interrow crop.

The alternative weed control in a newly developed orchard through three years with mowing in Spring, Summer and Fall and tillage in winter improved soil biological and fertility properties compared to conventional weed control methods (chemical and tillage control) [12]. The authors observed that this alternative weed control method improved microbial biomass carbon, phosphorus-solubilizing microbial activity, mycorrhizal fungal spores numbers and soil organic matter.

At Analândia, State of São Paulo, Brazil in a coffee plantation, the constant use of the mechanical mower between coffee rows caused reduction in the coffee plants yield due to weed infestation. However, at Autumn / Winter seasons, when weed management is performed by herbicide applications, such effect is not observed. [5]. Soil compaction is the main ongoing degradation process and concerns in mechanical weed control. Soils under weed control with rotary shredder may experience detrimental effects, such as increased soil strength, measured by a portable recording penetrometer [8], and soil load bearing capacity [18].

Integrated weed management systems and cover crops used as a green manure can be useful in Tropical region, since it may protect soil against degradation processes, such as compaction and erosion. The integrated weed management systems consists in selection and use of the different weed control based on cost-benefit analysis, taking into account the benefits to the production system and the environment as important strategies in Conservation Agriculture.

Conservation Agriculture (CA) involves three basic practices: (i) significant reduction of soil tillage and disturbance, (ii) permanent, or at least semi-permanent, soil protection by using crop residues or selected cover crops, and (iii) diversification of crop rotations and intercropping [19]. CA practices often enhance and utilize soil and crop microenvironments to inhibit germination, growth, and spread of weeds while minimizing the use of synthetic herbicides. Examples of conservation tillage that may fit into a weed management control/suppression program include reduced tillage, cover crops, crop rotation, variable row spacing, and timing of crop planting [20].

Cover crops and cropping residues used in Conservation Agriculture systems serve as a protection for the soil surface against weather aggressions and water erosion, to maintain soil moisture, to suppress weed growth and to provide shelter and food for the soil biota [21]. Also, under Conservation Agriculture regime, the use of crop rotations or intercropping is considered essential, as it offers an option for pest/ weed management that is no longer realized through soil tillage [22].

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In perennial crops (such as coffee and apples), cover crops species and weed between rows of the crops may be helpful on nutrient cycling. Results from six trials conducted in Inceptisol and Oxisol by Chaves et al. [17] denoted that the total amount of plant nutrient accumulated in the above ground dry matter varied from 31 to over 400 kg ha^{-1} of nitrogen, from 20.6 to more 273 kg ha^{-1} of calcium, from 4 to over 40 kg ha^{-1} of magnesium, from 22 to over 224 kg ha^{-1} of potassium, and from 2.2 to over 26 kg ha^{-1} for phosphorus. In addition, the plant residues were found to decrease soil acidity [17]. The authors concluded that in Tropical conditions, cover crops are recommended as an important management strategy for coffee and apple production because they provide large quantities of dry matter and plant nutrients to improve soil fertility of the degraded acid soils.

Also, perennial crops like coffee crop, eucalyptus plantations and orange orchard are good examples for row-interrow management concept developed by Larson [23] *apud* Pierce and Lal [24]. In this concept, row area is managed to provide a good soil structure for plant germination, emergence, appropriate temperature, moisture, fertility, mechanical strength and weed control for the growth and development of the crop [24].

A well-established, living green manure crop can potentially inhibit the germination and establishment of weeds more effectively than desiccated cover crop residues or areas with natural plant residues [25]. Additional positive benefits to physical and chemical soil properties are gained if the cover crop is a legume [26]. Leguminous and other species used as cover crop can release and add chemicals to the system. These substances, known as allelochemicals, can cause beneficial or detrimental effect on other species. This phenomenon is known as allelopathy [27] and is important to be observed when a cover crop is inserted, since there is a species-specific effect, which can inhibit both weeds and crop [28].

According to Meschede, [29], besides the allelopathic effects, a proper use of living mulch/ cover crop can provide control of weed plants by altering of several system features, such as: thermal regimes, incidence of light and physical barriers to emergence, and also increase of rain water retention, soil humidity, organic matter content, microbial activity, predation and overcoming of seed dormancy [29]. Nevertheless, the species cultivated for living mulching/ cover crops must be compatible with the demands of the agricultural system [30].

2. Effects of weed on soil chemical properties in tropical regions

Many studies done in Tropical conditions have shown the effects of weed control by different methods on soil chemical attributes. A long-term study conducted in a clayey Dystropherric Red Latosol at São Sebastião do Paraíso (Latitude 20°55'00'' S and longitude 47°07'10'' W Greenwich at an altitude of 885 m), State of Minas Gerais, Brazil, showed that different weed control methods in a coffee crop (18 years) affected the components of soil acidity, such as pH, potential acidity (H+Al), exchangeable aluminum (Al) and the saturation aluminum (% m), in both soil layers 0–15 cm and 15–30 cm [31]. The authors observed that no-weed control between coffee rows tends to alkalize soil, on the other hand, the constant use of pre-emergence herbicide acidified it. This increase in pH was attributed to the greater increment of organic matter in areas without weed control/suppression methods [9]. Nevertheless, their results showed that other weed control methods (mechanical mower, disk harrow, rotary tiller, post-emergence herbicide and hand weeding) presented intermediate behavior between no-weed control and pre-emergence herbicide.

Other important study was done to determine the effects of weed extracts in the efficiency of lime applied on the soil surface [32]. Their results showed that weed extracts increased soil pH and cycling nutrients, reducing Al up to 20 cm of depth in acid subsoil. The chemical composition of the plant material varies with the weeds species. High contents of nitrogen, potassium and calcium were obtained for *Synedrellopsis gresebachii*. The extracts of the plant materials obtained from *Galinsoga parviflora* and *Commelina benghalensis* were the most efficiency for increases pH followed by *Amaranthus hybridus*, *Ricinus communis* and *Parthenium hysterophorus.*

The improvement of the soil fertility proportioned by integrated weed control might be useful to make the plants grow faster and produce higher amount of shoot and root dry mass as well, providing improvements in physical quality of the soil and protecting the soil against physical agents of soil degradation. Also, integrated weed management might be useful to soil and water conservation. In different production systems, many studies done in different regions of Brazil have been shown the improvement in soil organic matter content provided by weeds [14;9;33;18].

Cover crop used as a green manure is other important strategy to management tropical soils and their residues have been reported to negatively affect germination and establishment of weed seeds. For example, as cited before, species that contain a high level of allelochemicals seem well-suited for residue mediated weed suppression. Still, in addition to allelopathic effects, crop residues can exert an effect on weed germination and establishment through other mechanisms, such as competition among crop/weed species for the nutrients released [34].

Besides acting as a tool on weed management, crop residues may also affect the physical properties of the soil. Residue-amended soil may for instance better conserve moisture. Residues left on the soil surface can lead to decreased soil temperature fluctuations and reduced light penetration, which both have been shown to inhibit weed germination [35].

Nevertheless, although there are clear indications about conservation agriculture biophysical and agronomical positive impacts, many unknowns remain about the continuous and complete trades-off in reducing tillage versus soil erosion or weeds control efficiency, or about exporting biomass versus soil protection, soil C storage or nutrient balance [36].

Therefore, there is a continuous need for new approaches and experimental research regarding the application of conservational tillage systems for weed controlling and suppression, the correct choice of cover crops, without causing any deleterious and harmful effects on crop yield and soil properties – whether chemical, physical or biological.

With this chapter, we describe some results of the trials done in Tropical regions related to weed control and cover crops management and its effects on soil and water conservation.

3. Field characterization

Some of studies to assess the effects of weed control and cover crops management in coffee plantations have been conducted at the Agronomic Institute of Paraná-IAPAR at Londrina County (Latitude 23 ° 21'30 "S and longitude 51 ° 10'17" W Greenwich), Northern of the Paraná State, Brazil at an average altitude of 550 m.

The soilfrom the Experimental Farm is basalt derived and is classified as a Dystroferric Red Latosol according to the Brazilian Soil Classification System; Typic Haplorthox according to Soil Taxonomy and Ferralsol according to FAO classification. More details about soil characterization, such as mineralogical composition can be found in Castro Filho and Logan [42].

Between 2008 and 2011, the study area had been planted with common beans and with black oat in the Autumn / Winter. In February 2012, for the establishment of the coffee crop, the preparation was carried out with a furrow plow with 40 cm wide and 30 cm deep. Inside the furrow, 250 g of sedimentary phosphate rock with 10–12 % P_2O_5 in neutral ammonium citrate solubility and total P_2O_5 content of 28-30 % was applied per meter. A subsoiling was held within the furrow to a depth of 25 cm to incorporate reactive phosphate. After subsoiling the furrow, 200 g of dolomitic limestone with total neutralizing power-PRNT ot the 75 %, 5 L of poultry litter and 100 g of the fertilizer 04-30-10 N, P_2O_5 e K_2O were applied. Seedlings of coffee cultivar IPR 106 were transplanting at a spacing of 2.5 m (narrower spacing) x 1.0 m (between plants). After eight months, since planting in October 2012, infiltration rates were measured in the newly developed coffee plantation at the rows and between rows.

4. Weed management post planting coffee seedlings

The weed control methods used in two areas (row and interrow) of coffee plantations during the year 2012 are shown in Table 1. Hand weeding (HAWE): performed with the aid of a hoe, when the weed reached 45 cm height. Between March 2012 and November 2012 it was accomplished five times in the coffee rows and one time in the interrow. Pre-emergence herbicides (HERB): oxyfluorfen at a rate 4.0 L ha^{-1} of commercial product at 240 g L^{-1} (0.96 kg active ingredient ha^{-1}), applied three times in the coffee row during the year of 2012. Brush cutting: accomplished with brush cutter model 2300 Jan® rotor speed 1,750 rpm, equipped with 64 curved knives, swing and reversible, static mass of 735 kg pulled by a tractor model TL 75 New Holland®. Coffee tandem disk harrow (CTDH): the equipment is composed by two sections in tandem; each section is equipped with seven flat disks with cut width of 1.3 m and static mass 300 kg. It's worked at 7 cm depth. Mechanical mowing: accomplished with mower model Rotter TDP 180 Jan® with two knifes with dimensions 1.95 m width and static mass 460 kg.

In August 2014, thirty months after seedling transplantation disturbed soil samples were obtained in two sampling positions of the coffee plantation to assessment the variability of soil chemical properties inside the coffee crop. Soil sampler was a hand gouge auger at four depths:

0–5 cm, 5–10 cm, 10–20 cm, 20–40 cm. In each plot and sampling position, fifteen sample point were taken and to make composite sample. The soil samples were stored in plastics bags and transported to the laboratory. The soil samples were air dried at room temperature in the laboratory and sieved at 2 mm.

DATE	COFFEE ROW	INTERROW
20/03/2012	Hand weeding and pre-emergence herbicide	Hand weeding
08/05/2012		Brush cutting-1
10/06/2012	Hand weeding	
15/06/2012		Disk harrow - CTDH
14/08/2012	Hand weeding	Mechanical mowing
09/10/2012	Hand weeding	
22/10/2012	Pre-emergence herbicide	
22/11/2012		Brush cutting-2
27/11/2012	Hand weeding	
06/12/2012	Pre-emergence herbicide	
26/12/2012		Brush cutting-2

Brush cutting-1: brush cutter model 2300 Jan®; Brush cutting-2: central brush cutter model TPPC 0.90 m cutting width;

SOIL SAMPLING

Table 1. Management of weed in the row and between coffee rows post-planting coffee Cultivar IPR 106 in 2012.

5. Soil analysis

Chemical analysis of soil (pH in $CaCl_2$, Ca, Mg, K, Al, Cation Exchange Capacity and Total Organic Carbon) were performed on air dried soil-TFSA described in Pavan et al. [38]. Briefly, in an air dried soil samples the pH was determined in a calcium chloride ($CaCl_2$ 0.01 mol L^{-1}) at a 1:2.5 ratio (10 cm^3 TFSA and 25 mL of H_2O). The Ca and Mg content were determined after extraction with potassium chloride (KCl, 1.0 mol L^{-1}) at a ratio of 10 cm^3 TFSA to 100 mL extractor, stirring for fifteen minutes and settling for 16 h. Measurements of calcium and magnesium were performed by atomic absorption spectrophotometry-EAA. The K content was determined by flame spectrophotometer after extraction with Mehlich-1 solution (HCl 0.05 mol L^{-1} H_2SO_4+0.0125 mol L^{-1}), at a ratio of 10 cm^3 TFSA to 100 mL extractor shaking for five minutes and decanted for 16 h.

Extraction H+Al was carried out with Ca (OAc) 2 0.5 mol L^{-1}, pH 7, at ratio of 5 to 75 cm^3 TFSA mL extractor 10 min stirring and decanting for 16 h. The cation-exchange capacity (CEC at pH 7.0) was obtained by the sum of Ca+Mg+K+(H+Al). The levels of soil organic carbon were obtained by the wet combustion method with organic carbon oxidation with 5 mL of $K_2Cr_2O_7$ (potassium dichromate) 0.167 mol L^{-1} and 10 ml of concentrated H_2SO_4 (sulfuric acid) concentrate [39].

Physical characterization of the soil was performed by the soil particle-size analysis by the pipette method [40] with chemical dispersion with a 5 mL 1 N sodium hydroxide solution in contact with the samples for 24 hours Mechanical dispersion was accomplished by 2 hours, in a reciprocating shaker, which shakes 180 times per minute in a 38 mm amplitude [41]. Water-dispersible clay was determined by shaking in water as discussed above, except that NaOH was excluded [42].

6. Results and discussion

Chemical and physical properties of a very clayey Dystropherric Red Latosol (Typic Haplorthox) at four depths in two sampling of positions of the coffee plantation Cultivar IPR 106 are given in Table 2. Soil pH values observed in the four soil depths in both sampling positions are considered low, providing higher soil acidity. Nevertheless those pH parameters are still lower than recommended for the growth and development of coffee in Paraná [43]. Although, the pH can be found inappropriate for coffee growth and development, these values are typical for the Latosol of this study cultivated with coffee [43; 15]. According to the later authors, in the state of Paraná, Brazil, soil acidity is an ongoing process in soils planted with coffee (*Coffea arabica* L.) because rainfall exceeds evapotranspiration and also, due to soil erosion and leaching [15].

In both sampling position of the coffee crop, the total soil organic carbon decreased with the depth (Table 2). Highest total soil organic carbon was found in the 0–5 cm depth as a result of the weed control and deposition of the straw from weeds. These results are similar to observed by Pavan et al. [15].

Among the sampling position, highest variability was for soil phosphorus. A high rate of this nutrient was added at the row area at the time of the planting coffee seedlings.

In each soil depth, the Al exchangeable increased in the inter row in relation to coffee row.

As can be seen from the data presented in Table 1, the chemical properties of the soil in the coffee row is most suitable for plant growth at all depths, which is assigned to the differential management of the crop rows relative to the lines. Besides the application of mineral fertilizers and non-revolving, the specific soil management of perennial crops which gives the soil a variation both vertically and horizontally [47], the weeds in the interrows were managed with the rotary crusher method mechanical weed control.

In both sampling position, water-dispersible clay are similar in two first soil layers (Table 2). It is important to highlight that for this soil, water-dispersible clay has close relationship in soil pH as demonstrated by Castro Filho and Logan [37]. However, the authors suggested that organic matter content is more important to aggregate stability and soil erodibility than soil pH.

PROPERTIES	SAMPLING POSITION							
	COFFEE ROW				INTERROW			
	0 – 5 cm	5 – 10 cm	10 – 20 cm	20 – 40 cm	0 – 5 cm	5 – 10 cm	10 – 20 cm	20 – 40 cm
pH: CaCl2	4.70	4.20	4.30	4.30	4.40	4.00	3.90	3.90
Al, $cmol_c$ dm^{-3}	0.19	0.83	0.57	0.60	0.49	1.25	1.70	1.56
H + Al, $cmol_c$ dm^{-3}	7.20	9.70	8.35	7.75	8.35	10.45	10.45	9.70
TOC, g dm^{-3}	18.31	17.76	14.76	12.81	17.49	15.19	12.35	10.79
P, mg dm^{-3}	101.5	77.7	110.0	49.1	24.2	12.8	4.1	4.2
Ca, $cmol_c$ dm^{-3}	5.75	3.57	4.25	3.75	2.77	1.47	1.12	1.45
Mg, $cmol_c$ dm^{-3}	1.64	0.94	0.90	0.98	1.52	0.57	0.37	0.53
K, $cmol_c$ dm^{-3}	0.65	0.30	0.27	0.20	1.50	1.05	0.75	0.71
SB, $cmol_c$ dm^{-3}	8.04	4.81	5.42	4.93	5.79	3.09	2.24	2.69
Ratio Ca:Mg	3.51	3.80	4.72	3.83	1.82	2.58	3.03	2.74
Ratio Ca:K	8.85	11.90	15.74	18.75	1.85	1.40	1.49	2.04
Ratio Mg:K	2.52	3.13	3.33	4.90	1.01	0.54	0.49	0.75
CEC, $cmol_c$ dm^{-3}	15.24	14.51	13.77	12.68	14.14	13.54	12.69	12.39
V, %	52.75	33.14	39.36	38.88	40.94	22.82	17.65	21.71
Saturation Al, %	2.30	14.71	9.51	10.84	7.80	28.80	43.14	36.70
Ca / CEC, %	37.73	24.60	30.86	29.57	19.59	10.86	8.83	11.70
Mg / CEC, %	10.76	6.48	6.54	7.73	10.75	4.21	2.92	4.28
K / CEC, %	1.72	1.22	0.87	0.68	7.66	9.67	8.50	6.07
Clay, dag kg^{-1}	80	80	82	81	80	80	82	82
Silt, dag kg^{-1}	15	14	14	15	14	14	13	14
Sand, dag kg^{-1}	5	6	4	4	5	6	5	4
WDC, dag kg^{-1}	68	66	65	5	69	65	2	1

TOC – total organic carbon content; CEC – Cation-exchange capacity; WDC – Water-dispersible clay.

Table 2. Chemical and physical properties of a Dystropherric Red Latosol (Typic Haplorthox) very clayey in the Agronomic Institute of Paraná at Londrina coffee plantation Cultivar IPR 106.

It was observed in the field, that the mechanical weed control with brush cutter instead of mechanical mower promoted homogeneous distributions of the residue of the weed on the soil surface. With the brush cutter, in the interrow area is possible to create a rough surface to maximize infiltration rate and inhibit germination of weed seeds in addition increases on soil load bearing capacity to wheel traffic. This increase on soil load bearing capacity proportioned by brush cutter decreased soil compaction in relation to the soil managed with disk harrow, mechanical mower and cover crop (*Arachis pintoi*) as described by Pais et al. [11].

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7. Rainfall simulations

In tropical regions, infiltration rate and hydraulic conductivity are the most important soil physical properties to understand the hydric erosion. This way, the determination of infiltration rates plays an important role because of the direct interrelation between erosion and infiltrability [45] and water movement to downwards layer of the soil profile.

In the field trial, infiltration rate and water and soil losses were measured using a portable. In this equipment, the drops falls inside the metal frame and the infiltration rate is calculated as the difference between rainfall intensity and runoff [46]. The rain simulator operated with rainfall intensity adjusted to 85 mm h^{-1}, which represent the maximum rainfall intensity to Londrina, State of Paraná, Brazil. Runoff was collected through a spout and measured every minute.

The metal frame from rainfall simulator was installed in two positions in relation to the rows of the coffee plantation and in the interrows; weeds covered 100 % of the soil surface and between coffee plants without weed and bare soil.

As illustrated by Figure 1, the infiltration rate in the interrow area under weed cover was 100 % (85 mm h^{-1}) after 60 minutes. In contrast, the infiltration rate in the coffee row area without weed cover was 7 mm h^{-1}, which represent runoff equal to 78 mm h^{-1}. The highest infiltration rate of water into the soil observed in the interrow after 60 minutes may be due to interception of raindrops provided by shoots of weeds in this area. Furthermore, as mentioned earlier, the soil surface between coffee rows are covered by the residues from the brush cutter which probably increases create a rough surface to maximize infiltration rate and inhibit germination of weed seeds, lower occurrence of surface crusting and soil compaction.

These results demonstrated the importance of maintaining permanent vegetative cover on the soil surface. This technique is especially important during the Spring / Summer season period with high intensity of rainfall in the tropical region and erosivity.

In the interrow area, the soil surface was 100 % of the area covered by weeds. On the other hand, in the row area the weeds were removed to provide the growth and development of the crop the soil was exposure without cover (data not shown). As pointed by Yang et al. [12] in perennial crops, weeds covered bare soil and prevented erosion during the rainy season in summer. Due to that is so important cover the soil surface in all areas included the row inside the coffee crop like shown in the Figure 2. This technique improves the water infiltration rate in the row area, and increases the availability water capacity to the coffee.

The weeds between coffee rows play an important role in water dynamics by intercepting raindrops impacts against soil surface, which probably reduces surface crusting and maintains a constant infiltration of water for one hour. On the other hand, in the coffee rows, weeds are controlled to provide the maximum growth and development of the coffee plants. By exclusion of the weeds there is a direct impact of raindrops on the soil surface, which reduces infiltration sharply due to the formation of surface crusting. Thus, a strategy to minimize soil loss and water after planting of perennial crops is to make mulch using waste weed (Figure 2).

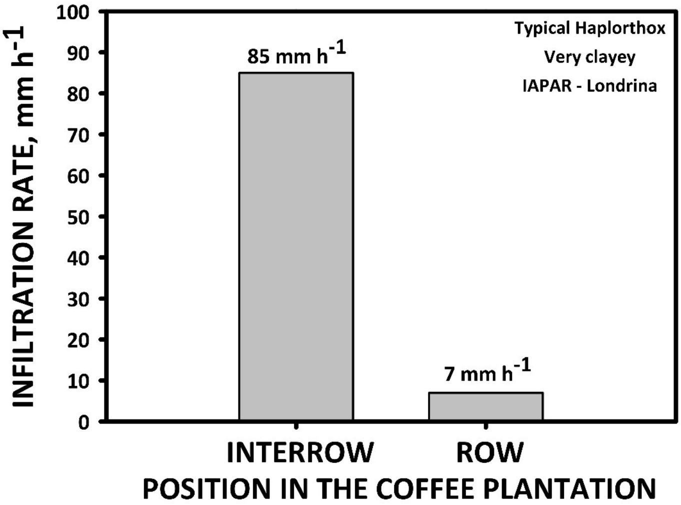

Figure 1. Water infiltration rates in two positions of the coffee plantation after 60 minutes of rainfall intensity of the 85 mm h^{-1}.

As mentioned earlier in the row area, weeds are controlled to provide the maximum growth and development of the coffee plants. In this region, the infiltration rate decreased to 7 mm h^{-1} at the 60 minutes (Figure 1) and the runoff began seven minutes after rainfall (Figure 3 and Figure 4). On the other hand, the infiltration rate in the interrow area between coffee rows where the weeds protect the soil surface, the infiltration rate was 85 mm h^{-1} at the 60 minutes of the rainfall intensity. In this region, there is a great influence of the brush cutting for weed control which promoted homogeneous distributions of the residue of the weed on the soil surface and protect the soil surface against raindrop impact.

By evaluating the effects of no-tillage on infiltration rate in the same soil analyzed in this study, Roth et al. [45] observed the constant infiltration rate to 10 min with rainfall intensity of the 68 mm h^{-1}. The authors highlighted that in no-tillage plot the infiltration rate decreased to about 5 mm h^{-1} after 60 minutes. Also, they observed that runoff usually starter about 4-6 minutes after the began of rainfall. The data from present study showed that runoff starter 7 minutes after the rainfall began.

Thus, the weeds have great influence on water dynamics in this agrosystem and higher impacts on erosion due rainfall intensity will occur in the row area without soil cover (Figure 1). In this context, weed and cover crops between rows of the perennial crops helps to protect the soil against physical degradation processes.

The rainfall simulation time explain 75 % of the variation of the runoff (Figure 4) significant at 1 % probability level, by t-Student test.

Conservation Agriculture include reduced runoff, improved nutrient cycling, reduced soil degradation, reduced soil and water pollution, and enhanced activities of soil biota [47].

Figure 2. Straw from weed used as mulch applied post-planting coffee seedlings for protection of the coffee row area against the direct impact of raindrops and surface crusting.

Our results showed that integrate weed control using the managing zones (row and interrow area) within the coffee crop in Tropical conditions are essentials for soil and water conservation and help the basic principle for Conservation Agriculture. This may suggest that, weed control has a high influence on soil chemical properties, water infiltration rate and runoff.

It is still a challenge to set a suitable weed control in terms of cover crops and soil quality maintenance. Weed control methods can lead to significant changes on soil organic matter which affects soil quality. Nevertheless, taking into account the dynamic character, the response to different weed control systems and the urgency on environmentally safe solutions there is a continuous need on ongoing soil science research in order to achieve suitable conservational practices.

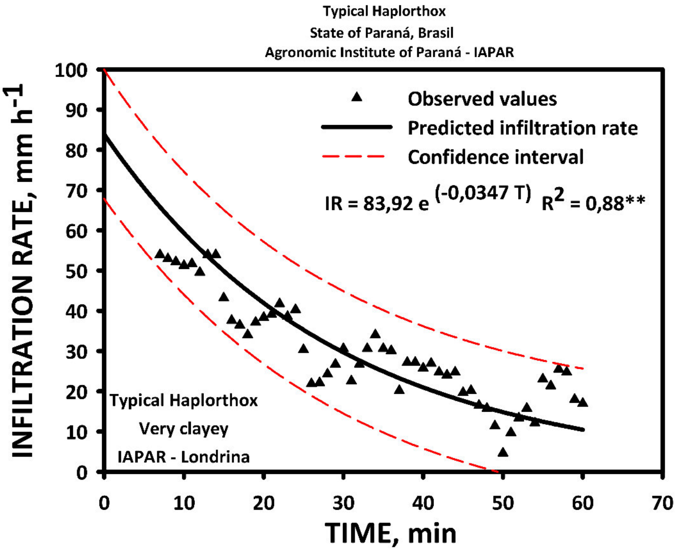

Figure 3. Water infiltration rate in the coffee row area without weed, on a very clayey (80 dag kg^{-1} clay) Typical Haplorthox, at the Agronomic Institute of Paraná – IAPAR, Experimental Station in Londrina, State of Paraná, Brazil. Rainfall intensity 85 mm h^{-1}.

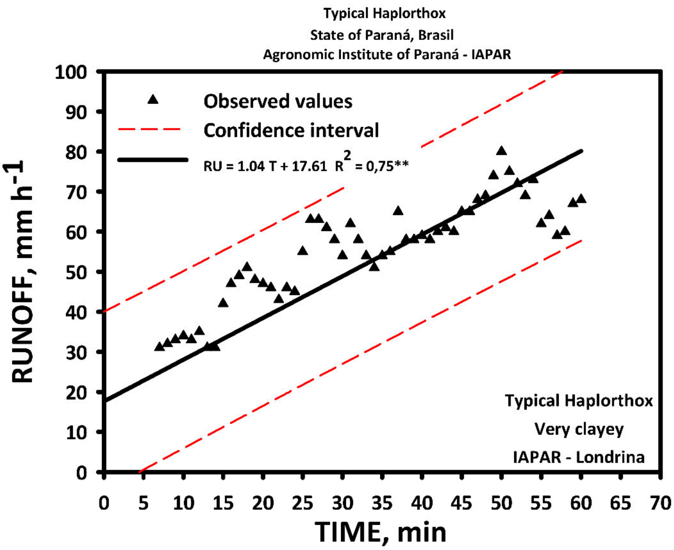

Figure 4. Runoff in the coffee row area without weed, on a very clayey (80 dag kg^{-1} clay) Typical Haplorthox, at the Agronomic Institute of Paraná – IAPAR, Experimental Station in Londrina, State of Paraná, Brazil. Rainfall intensity 85 mm h^{-1}.

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Chapter 2

Weed Control by Chemical and Mechanical Means

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Additional information is available at the end of the chapter

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1. Introduction

Crop production is one of the most important agriculture industries in an agricultural country. It involves not only the land, as the primary means of agricultural production, with all the biological processes taking place in it, but also the surrounding environment, the sun, living nature, the plants and the wide variety of techniques, instruments, tools and implements that are used. People are the main, active participants in the production process, involved in implementing and promoting it, as well as in educating others about it. Generally, there is a closely interacting complex of production factors determining the final outcome of the process, its quantitative and qualitative indicators.

In any case, when planning to perform one or other plant operation, tillage, sowing or crop care activity, one first of all needs to choose the proper, complete, correct technical equipment (machines, tools, operational parts), so that the negative impact on the living environment of the technological operations is minimal: the soil, the activity of microorganisms, the plants and environment, and the quality of work should all be maintained to the highest degree. By knowing the characteristics of the material, we can properly select the technical measure or construction for the intended job; this choice will affect the quality of the work's performance. Performing technological research, implementing and applying the prospective agriculture production technology and increasing production volume, the technology engineering professional has to not only know the engineering issues, but also absorb the agronomic and economic aspects of agricultural production.

An important link in the chain of technological crop supervision is weed control. In order to perform this technological operation properly, it is important to know the characteristics of weeds and properly select technical-technological measures to destroy them. The most commonly used and the most effective plant care and weed control methods are chemical (using loose and liquid chemical products) and mechanical (using agricultural implements, cultivators and harrows). These basic weed control techniques will be analysed in this educational book.

The book *Weed* Biology and Control is intended for researchers and students of institutions of higher education and universities. We also believe that this educational book will interest not only the target groups of students, but also specialists in agricultural companies and farmers.

The authors of this educational work express their sincere gratitude to the reviewers for their valuable comments and suggestions that have helped improve the quality of the book.

2. Weed control by chemical means

Plant protection machines using chemical products are classified into the following groups:

- Sprayers, spraying the soil or plants with small poisonous liquid droplets;
- Powder distributors, spreading toxic powder on trees and plants which are infested with pests;
- Fumigators used for the injection of fast-steaming toxic liquid into the soil;
- Pickling machines used for dry or wet seed pickling.

2.1. Requirements for sprayers and distribution techniques of plant protection products

Modern plant protection is more than just the use of appropriate agents. Liquid droplets of a working liquid should cover the tillable surfaces as evenly as possible. Only then can we expect the optimal result. Apart from this, when protecting the environment, no loss should arise due to drift of liquid droplets downwind, dripping or evaporation. For these reasons, very high demands are made on modern plant protection products, especially sprayers. The accuracy requirements for nozzles that are made today were simply impossible to fulfil several years ago.

The success of plant protection depends not only on the proper selection of a preparation and its optimal usage time, but also on the use of technology.

2.1.1. Requirements for sprayers

Sprayer pace should be free of defects. Pump capacity and the formed pressure should meet the technical characteristics of the sprayer. Performance deviations should not exceed 10 %. Measurements should be carried out having reached the nominal performance of 0.5 MPa (5 bar) pressure. Pump pressure pulsation levelling equipment should work properly. The safety valve has to work reliably. The pump must be sealed.

When the pump is running at nominal speed, the movement of the mixing solution in the tank should be clearly visible. The reservoir and the lid of the filling hole should be sealed; a sieve should be present in the filling hole, and the solution level scale should be clearly visible. There

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should be the possibility to collect all solution that is drained in the reservoir. Sprayer filling and devices for washing packages of preparations should operate. The filling device should have a non-return valve.

All pressure measurement, control and monitoring devices should be *operating and sealed*. In the control board of a garden sprayer, a switch-off button on the right and left sections should be present. Manometer scale must be greater than the maximum pressure developed by the spray. Manometer scale limits should be higher than the maximal pressure of the sprayer. If the working pressure is up to 0.5 MPa (5 bar), the value of a manometer scale division should not exceed 0.02 MPa (0.2 bar). The minimal frame diameter of a manometer is 63 mm; the measuring error should not exceed ± 0.02 MPa (0.2 bar).

The pipe system should be leak-proof, hoses should not be bent *or* broken, and should be well-fitted; they should not interfere with the spray gun parts or be sprayed.

At least one filter should be present in suction and pressure lines, and its net size should comply with the indications of sprayer producers. Filters should be *sealed* and undamaged.

The sprayer beam should be straight and stable in all directions. A beam longer than 10 m should be associated with a device allowing it to swing back *when meeting* the barrier. *Equal* spacing should be obtained between the nozzles and from the nozzle to *the treated* plants. The sprayer parts cannot be sprayed over. Beams longer than 10 m should have protections at the ends. If the length of a beam section is longer than 6 m, a folding device should be present. Beam lifting and damping devices should function properly.

All nozzles, filters and their instant shut-off valves should be compatible with each other; their types and sizes should *not* differ. Upon termination of spraying, there should be no dripping through the nozzles. Spreading uniformity of the sprayed solution droplets is described by a coefficient of the variation of transverse distribution, which is measured by an electronic bench with gutters, and should not exceed 15 %. While measuring transverse distribution by the manual tray with gutters and indicators showing the average meaning, no more than 15 % of cups should indicate a ± 15 % deviation from the average meaning. In the absence of measurement stands with gutters, smoothness of spraying may be temporarily established by special flow meters. They are used to measure performance of all nozzles located on a beam. The error of each nozzle performance should not exceed ± 5 %, compared to the average, or 15 % compared with the performance data of new nozzles indicated in the manufacturer's instructions. Spraying uniformity for pneumohydraulic garden sprayers is determined by measuring the performance of each nozzle. Their indication accuracy should not exceed ± 10 % compared to the average, or 15 % compared with the performance data of new nozzles indicated in manufacturer's instructions. The difference between inputs delivered to the left and right *side* cannot exceed 10 %. Spraying nozzles on the left and right sides of the garden sprayer should be identical. The maximum pressure difference in the nozzle should not exceed 15 %. The fan in the garden sprayer should have a separate switch; the air diversion device should operate *properly*; the sprayer parts cannot be sprayed over.

Sprayers must be designed in such a way that they are used to avoid downwind drift of a dangerous solution (fan with air intake channels, special nozzles reducing drift downwind, and so on).

2.1.2. Application techniques of plant protection products

Powder or granules of plant protection products may be simply scattered on the ground. The main point in this case is that there is no need for water, a low norm of preparation and high performance. Scattered plant protection products work for a long time; active substances excrete continuously. Work expenses for spreading the preparations are low. The biggest problem here is choosing the exact dosage and evenly spreading the plant protection products.

Liquid products, or those dissolved in water or mixed with water may be evenly sprayed on the plants or the soil surface and spread in the form of mist or spray.

The spray method is widely used because of the low risk to the user and the low danger of preparation drifting downwind. However, spraying of plant protection products requires a great deal of water, and is marked by high expenses and labour costs compared to relatively low productivity. The size of sprayed drops varies from 100 to 1000 μm.

Spreading plant protection products in the form of mist requires less water, and work efficiency is higher; expenses and labour costs also reduce. In addition, drops of preparation penetrate into the foliage. However, in this case, much power is needed to turn the fan; due to the higher concentration and drift of drops downwind, a higher risk to the user, the sprayed plants and the growing crop arises. The size of sprayed drops varies from 50 to 150 μm.

The most efficient work is achieved when spreading plant protection products in the form of mist. In this case, the need for water is very little, or water is not needed at all. Expenses and labour costs are also very low. Apart from this, plant protection products penetrate to hard-to-reach places, and they are not washed away by the rain. However, in this case, we are very dependent on natural conditions; users must wear personal protection equipment since the drift of drops presents a serious risk to plants and environment. The size of the sprayed drops is less than 50 μm.

The quality of spraying of plant protection products depends on many factors. They may be divided into four groups:

- Technical requirements for the sprayer, droplet formation and movement;
- Physical and technical properties of a product and solution (product + water);
- The sprayed plant;
- Climatic conditions.

The most important technical *requirements* for the sprayer are as follows: spray norm; running speed of a spray aggregate; operating pressure; spray height; nozzle type and spray angle; and the lateral distribution of the sprayed solution. Droplet formation and movement are affected by their size, speed, flight path and attack angle when reaching the pattern surface.

The pattern coverage ratio depends on the physical and chemical properties of the plant protection product or solution: concentration, viscosity, etc. The quality of spraying of plant protection products also depends on the size of leaves of a treated plant, hairiness, veininess, wax layer, crops density and height. The pattern coverage ratio also depends on the wind speed, relative humidity, temperature, and processes of thermals.

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2.2. Sprayers

2.2.1. Sprayer classification

Sprayers are classified according to a variety of features: power source, destination and spraying method (Table 1).

Sprayer classification according to:			
Power source		Destination	Spraying method
Manual	Automotive	Field	Hydraulic
Motor	Self-propelled	Garden	Pneumohydraulic
Tractor	Aviation	Universal	Aerosol

Table 1. Sprayer classification

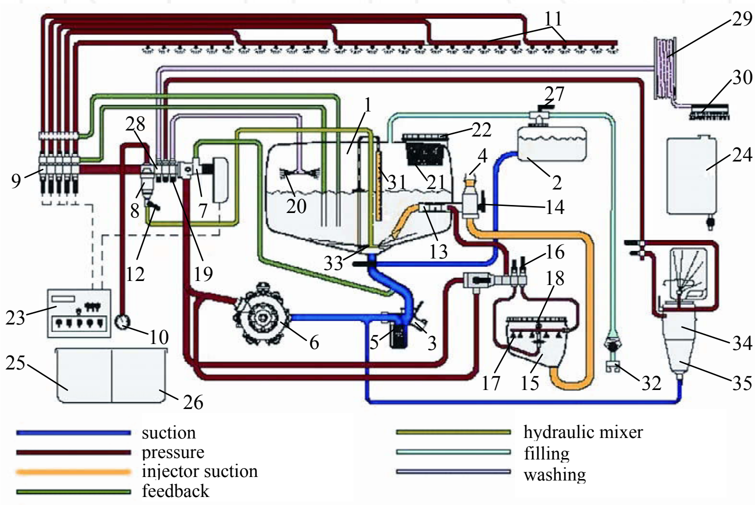
Tractor sprayers may be suspended, tractor-drawn and put-on. Aerosol sprayers are also classified into cold and hot smoke. Powered sprayers may be carried on the back or transported. Powered sprayers carried on the back are usually pneumohydraulic, and transported ones hydraulic. Manual sprayers may be carried on the back or held in the hands. Portable hand-held sprayers may be equipped with a pump, with a spray pipe or without it. Back-carried sprayers may have either a piston or a diaphragm pump. Hand-held sprayers are usually hydraulic.

2.2.2. Structure of tractor-mounted hydraulic field sprayers

Tractor-mounted hydraulic field sprayers are usually used for spraying plant protection products on the plants. The main parts of a tractor-mounted hydraulic field sprayer are the spray tank, pump, control equipment, filters, beam, injectors, equipment to pour agents into the tank, and equipment to wash the exterior of the sprayers and the frame.

The tractor-mounted hydraulic field sprayer works as follows (Figure 1): connector 32 is connected to a hydrant fill hose, and, having opened valve 27, three-quarters of the capacity of spray tank 1 is filled with water. Plant protection products are added to the preparation tank 34, and, having opened valve 35, the required preparation quantity is poured into the spray tank.

Powdered preparation or a higher quantity of carbamide is dissolved in the reservoir 15 by one of the taps 16 having turned on the nozzles 17 that are located in the arch. The tap 12 turns on the hydraulic blender 33. Having turned on the injector 13 by the tap 14, the dissolved products are added to the spray tank. Empty preparation utensils are washed with water three times by the nozzle 18, and the washings are poured into the spray tank. If the fluid does not reach the mark, more water should be added. Fluid mixing intensity may be changed by the tap 12. Having prepared the required quantity of spray liquid, the pump 6 draws solution from the reservoir 1 through the filter 5, and from the self-cleaning pressure line filter 8 delivers it to the control panel. Having set the required pressure by the reducing valve 7, the solution is supplied from the control panel to the hydraulic mixer 33, injector, preparation tanks and sections of spray bar 11 with nozzles. Nozzles spray the liquid on the sprayed surfaces. The surplus of the solution gets back into the tank by reversible lines. Having completed the work, residues of the sprayed liquid should be diluted with water at least 10 times and sprayed in the sprayed field. The empty interior of the sprayer should be twice washed by the rotating spray nozzle 20; some clean water should be added from tank 2 (about 10 % of the tank capacity). After each rinse, the contents of the sprayer tank should be sprayed in the field. The exterior of the sprayer is washed outside or in a special washing area. A small tank 24 for washing hands should be installed in a convenient place.



1 – tank; 2 – clean water tank; 3 – joint to connect suction hose to pump; 4 – joint to connect suction hose to injector; 5 – suction line filter; 6 – pump; 7 – reduction valve; 8 – self-cleaning pressure line filter; 9 – beam sections' control valves; 10 – manometer; 11 – beam section with nozzles; 12 – tap to adjust the intensity of liquid mixing; 13 – injector; 14 – injector control tap; 15 – tank to dissolve the powdered products; 16 – taps; 17 – nozzles located in the arch form; 18 – rotating nozzle; 19 – tap for turning the tank on and off; 20 – rotating tank wash nozzle; 21 – strainer; 22 – filler hole lid; 23 – remote-control box (spraying computer); 24 – clean water tank; 25 and 26 – a storage place; 27 – filling line tap; 28 – tap to turn the washing brush on and off ; 29 – drum for collection of washing hose; 30 – brush for washing the sprayer exterior; 31 – liquid level scale; 32 – filling hose connector to connect to the hydrant; 33 – hydraulic blender; 34 – preparation tank with rotating nozzle; 35 – shut-off valve [1].

Figure 1. Scheme of tractor-mounted hydraulic field sprayer

Suspended field tractor-mounted hydraulic sprayers are mounted on the rear hydraulic lift of a tractor, and their entire weight during operation and transportation falls on the tractor wheels (Figure 2). Their tank capacity ranges from 300 to 1800 l, and operational width ranges from 6 to 24 m.

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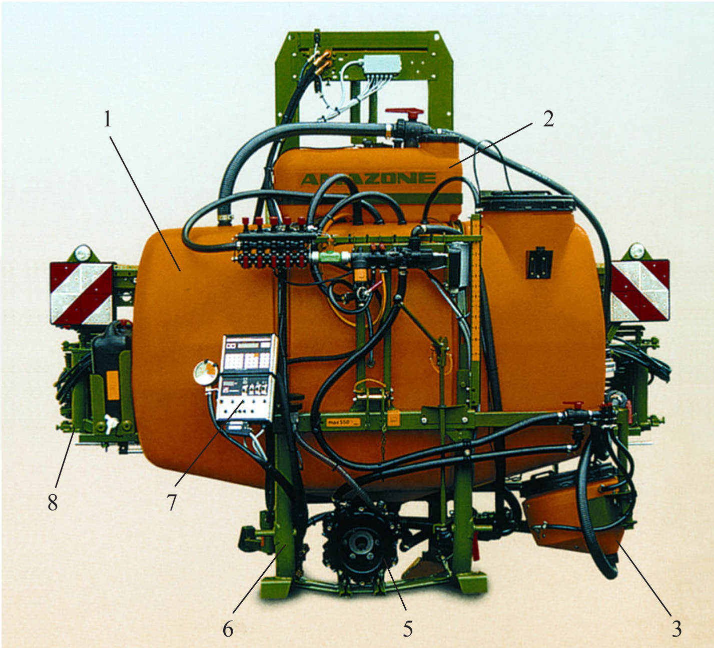


1 – tank for the sprayed fluid; 2 – the tank of clean water; 3 – preparation tank; 4 – three-position (spray-rinse-dilution) tap; 5 – pump; 6 – frame with supports; 7 – remote-control panel with computer; 8 – beam with nozzles [1].

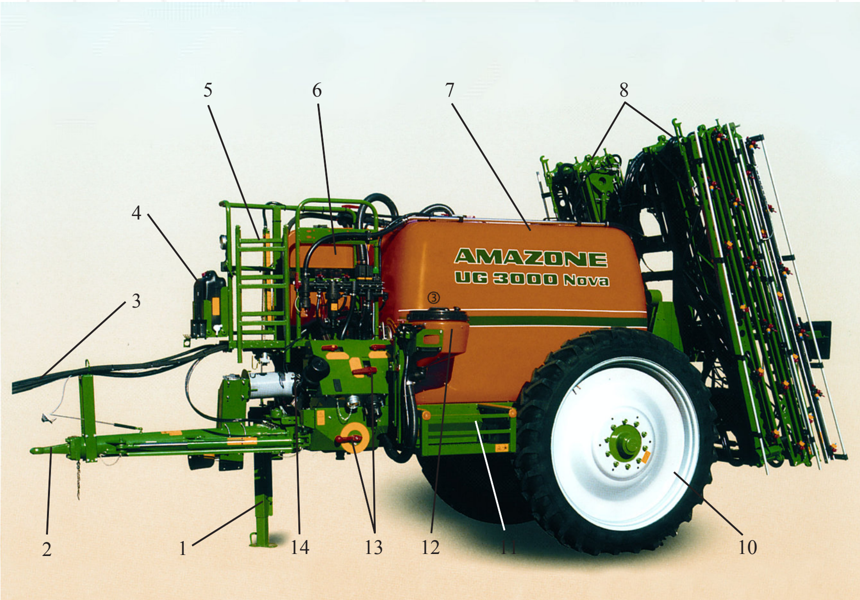
Figure 2. Suspended field tractor-mounted hydraulic sprayer

Suspended field tractor-mounted hydraulic sprayers do not have a chassis. When choosing a suspended field hydraulic sprayer, the following factors should be noted:

- Compactness of the construction, i.e., the gravitational centre of the sprayer should be as close to the tractor as possible, and the distance between the beam and the tank should be minimized;
- Supports should have wheels, which greatly facilitates suspension of the sprayer on the tractor;
- Whether there is sufficient clearance, i.e., it should be at least the same clearance as that of the tractor;
- The location, i.e., in the middle or on the side of the main tank's filler neck (the most convenient place when there are two fillers on either side of the tank);
- Whether there are nozzle protectors, protecting them from contact with soil surface;
- Whether the control panel is easy to reach from the tractor cabin, the advantage of which can be gained by moving the pressure gauge to the front and simply attaching it to the tractor so that the tractor driver can see it better;

- Whether pump performance matches the working width of the sprayer - remember that injection pneumohydraulic nozzles with a long body require higher operational pressure;
- The view of the sprayer, i.e., whether there are marks of corrosion, the state of the painted surfaces and the quality of welds.

The entire weight of the suspended tractor-mounted hydraulic sprayer during operation and transportation falls on its chassis wheels (Figure 3). The modern suspended tractor-mounted hydraulic sprayers meet almost all the requirements of professional users. Their tank capacity ranges from 1,500 to 6,000 l. Larger-capacity tanks increase productivity, but also have some drawbacks: the soil is more burdened, and there is a lack of stability when spraying in hilly areas or on public roads if the speed rises to 50 km h^{-1}. Depending on the tank capacity, the working width of the suspended sprayers is usually between 12 and 36 m; however, there are manufacturers offering 48 m working width beams.



1 – support; 2 – drawbar with eye; 3 – hydraulic hoses; 4 – clean water tank; 5 – ladders; 6 – clean water tank; 7 – tank; 8 – beam sections; 9 – nozzles; 10 – circle; 11 – carriage; 12 – preparations tank; 13 – taps; 14 – pump [1].

Figure 3. Suspended tractor-mounted hydraulic sprayer

When choosing a suspended tractor-mounted hydraulic field sprayer, the following factors should be noted:

- What the sprayer clearance is, i.e., it should not be less than 0.6 m, and preferably from 0.7 to 0.8 m. It should not be greater than the tractor clearance. The lower the sprayer tank is attached, *the more stable the* machine is;
- Whether a tank of more than 3000 l has intermediate walls to suppress liquid splashing;

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- What the design of the drawbar is. If the drawbar with eye is placed on the rear hydraulic hook lift, sprayer clearance is higher; moreover, it is safer when working on slopes. When coupling, if the drawbar is suspended on the lower links of the rear hydraulic lift, the sprayer wheels follow the tractor tracks better. However, in this case the rods are overloaded. It is important that the device tracking the tractor tracks functions well when working in a hilly area;
- Whether the permissible axle load is at least twice as high as the weight of a full tank;
- What the chassis design is. Shock-absorbers decrease the load at higher speed and save the sprayer;
- Whether sprayers of a gross weight more than 3000 kg have pneumatic brakes;
- Whether pump performance matches the working width of the sprayer. This is especially important if pneumohydraulic injector nozzles are used in large working width sprayers. If the second pump is used only for mixing in the liquid tank, its constant concentration is maintained, and there is no formation of sediments;
- Whether it is comfortable for a user to reach the tank;
- Whether the control panel is easily accessible and fastened in a prominent place;
- Whether the spraying computer or other remote-control software works reliably, and is not difficult to manage;
- Whether the sprayer beam has damping devices, and whether they work properly. The beam in the horizontal plane should range minimally;
- Whether nozzle protectors are secured against contact with the soil surface. Sprayers of larger working width should have racks with several different nozzles;
- How the sprayer looks, i.e., whether there are places damaged by corrosion, what the condition of the painted surface is, and what quality the welds are.

It has been estimated that suspended hydraulic sprayers are worth buying if the size of a farm is 150-200 ha. Furthermore, in larger farms (more than 1000 ha), the maintenance costs of suspended sprayers are lower than those of self-propelled or put-on sprayers [2].

Put-on tractor-mounted hydraulic field sprayers are installed on certain types of tractor or self-propelled chassis (e.g., MB-Trac, Unimog, JSB-Fastrac and Fendt-Xylon). The capacity of such sprayers is up to 3.000 l. It is limited by the tire load capacity and maximum permissible axle load. Put-on sprayers are much more manoeuvrable than suspended ones; however, their preparation time for operation is much longer. A fairly high performance is ensured by a beam of 27 m operational width. When choosing a hydraulic put-on sprayer, the following factors should be noted:

- Where the centre of gravity of the spray unit is. It should be a little further than rear axle force of the machine (i.e., the tractor or self-propelled chassis), and the spray beam should also be as close to the power machine as possible;

- Whether spray units can be mounted on the machine and removed from it quickly;
- Whether or not the sprayer is blocked by the coupling parts, since it is convenient to take along a water carrier to the field;
- Whether or not the permissible total weight of the tractor exceeds the weight of a sprayer filled with liquid mineral fertilizers (e.g., urea-ammonium nitrate solution);
- Whether there are enough hydraulic connections on the tractor in case the sprayer pump is rotated by the hydraulic engine;
- Whether the tractor's hydraulic system is cooled sufficiently.

Requirements for sprayer tanks [3]:

- Smooth surface, rounded edges, resistant to corrosion, easily washed;
- Sloping bottom with a solution drain tap and deep drip pan to collect it;
- Solution level scale interval – 50 l (prominent);
- Minimum filler diameter – 200 mm (up to capacity of 600 l) or 300 mm (> 600 l capacity);
- Removable, deep filler strainer;
- 5 % reserve capacity of the reservoir;
- Rotating tank cleaning nozzle for tank washing.

The pump draws solution from the tank and supplies it to distribution pipe with nozzles. It should ensure the desired smooth solution flow rate and constant working pressure, and the flow needed for the hydraulic blender.

The required pump capacity of a tractor or self-propelled hydraulic field sprayer, for the normal course of solution spray rate (up to 600 l ha^{-1}) and maximum allowable operating speed (up to 10 km h^{-1}), is calculated as follows: under 5-10 l min^{-1} for each working metre wide, 10 % of the tank capacity for solution mixture is added if the pressure is 5 bar [3].

Pump capacity of a tractor or self-propelled pneumohydraulic field or garden sprayer: under 10-15 l min^{-1}, 10 % of the tank capacity for solution mixture is added if the pressure is 30 bar [3]. If the existing pump capacity is 15 % less than required, the pump is out of order. Substantial reduction in pump performance worsens the quality of mixing.

Piston pump consists of a frame with a crankshaft on which connecting rods lift the pistons. Pistons slide in cylinders; there is a box with suction and pressure valves and a pressure equalization device over them. Advantages: durable, high pressure range, less wear and tear than with diaphragm pumps; if increasing the pressure, performance is almost unchanged; only a small piston surface area comes into contact with harmful solutions. Disadvantages: expensive, heavy, bulky; cannot be put on the tractor power supply shaft; when spraying suspensions or when there is sand in the water, pistons and cylinders wear out; idling can damage the pistons.

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The main part of a membrane or a piston-diaphragm pump is a membrane which changes the size of the chamber due to its movement. The membrane is made convex by a cam or crank mechanism. Advantages: low weight, low wear, and low cost of maintenance and repair work; may work in idle mode for some time; large pressure range; when increasing operating pressure, performance decreases insignificantly; any formulation may be sprayed with it, since all moving parts are enclosed in a frame and are not in contact with the spray solution. Membrane or piston-diaphragm pump disadvantages: due to their large area, membranes are heavily exposed to mechanical and chemical effects; pump durability largely depends on membrane quality.

In a pinion pump, solution is pumped by two rotating pinions in a frame. On one side of the frame, there is suction, on another, pressure holes. Advantages: inexpensive, lightweight, no need for suction and pressure valves, easy to maintain. Disadvantages: pistons wear heavily if suspensions are sprayed or pollutants get on them; increasing pressure significantly reduces productivity; water quality is essential; not permitted to spray copper-containing products; dangerous to work in idle mode.

Pressure pulsation smoothing devices are required for all piston, membrane and piston-membrane pumps. They are installed in the suction and pressure lines and made of two plastic or metal frames with membranes between them. The device installed in the suction line consists of a plastic frame and a rubber membrane. On the top of the valve the membrane is inflated. Air pressure is indicated in the pump manually. It depends on the spray pressure. When working pressure is 1.5-3 bar, the recommended air pressure in the pulsation smoothing device should be 0-1 bar; when pressure is 3-15 bar, air pressure should be 1-3 bar, and when working with 15-25 bar working pressure, it should be up to 3-4 bar.

A mixer is installed inside the sprayer tank and mixes the toxic solution so that during work the concentration should be the constant. Mixers may be mechanical, *hydraulic* or pneumatic. Mechanical mixers may be bladed or disc type. In hydraulic mixers, the solution gets into the tank through the mixing tube, through injection mixing nozzles or through tube and injection nozzles. Hydraulic mixers are designed so that most of the required flow for solution mixing is sucked through the holes on the injection mixing nozzle. Four litres per minute flow per 100 l tank capacity is needed to stir the solution, while 6 l min^{-1} flow is needed for emulsions, and as much as 8 l min-^{1} for suspensions [3].

In the operation process of a control panel operated sprayer, the usual equipment of the control panel is:

- a precise pressure regulator;
- a gauge;
- a central shut-off valve;
- control valves on distribution pipe sections with pressure equalization devices;
- pressure line filter.

Pressure in sprayers is adjusted by reducing valves. The reducing valve may be closed by an adjustable spring; in this case, pressure depends on tightening the valve springs. When the reduction valve is closed by a screw reducing the hole through which the solution returns to the reservoir, the pressure depends on the opening degree of the hole.

Working width of the sprayer is narrowed by closing the *control valves of* sections. If sprayer sections are turned off, pressure equalization devices maintain constant pressure since the solution is returned to the tank. Having changed the nozzles, the pressure equalization device should be adjusted.

The tractor driver, when working, has to reach the central closing tap, which is controlled by hand, the section taps and the reduction valve; he should also be able to see the gauge very well. This is very comfortable and efficient to control them from the tractor cabin by *electro-magnetic valves.* The most important factors conditioning the spraying of a solution to a hectare are precise and even operational speed, and the spraying norm. It is very important for every user to measure precisely these two indices. There are various devices for measuring driving speed and solution spraying norm.

Spraying computers measure both mentioned indices and maintain the necessary levels. They operate as follows: the desired solution norm is entered into the microprocessor ($l\,ha^{-1}$). A radar sensor measures driving speed and sends data to the processor, which calculates the required spraying pressure to maintain the desired solution spraying norm. A flow meter measures the amount of the sprayed solution ($l\,min^{-1}$) and delivers the data to the processor. The latter compares the present and desired meanings, and sends the necessary control commands to a regulator.

Filters clean solution from small admixtures and secure the sprayer pump against quick wear-out, and the nozzles and sprayers against jamming. The following filters may be present in sprayers: filling-in hole, pump line, centre pressure line, distribution pipe sections and nozzles. It is easier to use the sprayer if one additionally equips distribution pipe sections with filters. Such a filter is made of a frame and equipped with a sieve or plate with 0.1–0.7 mm cells (100–25 cells per inch). It is advisable to choose smaller filters for sections than those for sprayers.

The self-cleaning pressure line filter is made of two plastic frame parts, a sieve, a flow directing stack and a damper. Liquid is supplied from the pump to filter through the pressure line. The stack increases flow speed and directs it to the sieve walls. Cleaned liquid is supplied through the pressure line to the control panel, and admixtures and unmelted preparation particles return to the tank through the damper by the return line. Damper size (from 3 to 6 mm) is chosen according to the model of the pump, the highest operational pressure and highest productivity of all sprayers. If the filter is polluted, solution may return to the tank through the secure valve by the return line.

Sprayer filters may be in cylinder, trapezium or half-circle form; they may be cleft or net. Disadvantages of net, half-circle form filters are as follows: they cannot be used with the hydraulic carrying away of small droplets or injection pneumohydraulic sprayers. Net sprayer filters are made of brass, aluminium or stainless steel, and cleft – from plastic.

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The central pressure line filters should be the smallest; the cell size should be smaller than the area of the cross-section of the used nozzles. The water filling pipe's filter is the biggest. The cell size is up to 20 mm. The cell size of the preparation tank filter is up to 1 mm, and the cell size of the filling hole's sieve is from 0.5 to 2 mm. The recommended number of cells for the various filters is presented in Table 2.

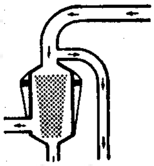
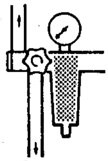
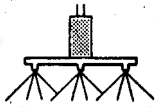
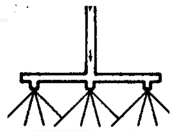
Nozzle size	Pressure line	Cleaning	Pressure line	Sections	Nozzles
					
01, 015, 02	50	100	100	100	100
025, 03	50	80	80	80	80
04, 05, 06, 08	30	80	50	50	50

Table 2. Recommended number of cells for various filters per inch [3].

The purpose of the *sprayer beam* is, during operation, to hold the nozzles parallel to the sprayed surface so that the sprayed solution is distributed evenly. The beam may be metal or plastic, made of several 3-4 mm wide parts connected by joints. Maximum length of the sprayer beam is 6 m [4].

Nozzles are fastened on a sprayer beam or distribution pipe with iron rings 0.5 m apart, one by one, or on heads in threes or fours with various sized holes. In this case, when wishing to change the nozzles and spraying norm, it is sufficient to turn the heads one-third or one-quarter of the circle, and turn on the other nozzles. If the real distance between the nozzles is not 0.5 m, the indicated norm of the sprayed liquid should be multiplied by a certain coefficient: e.g., coefficient 2.5 if the real distance between nozzles is 0.2 m, and likewise 2 (0.25 m), 1.67 (0.3 m), 1.43 (0.35 m), 1.25 (0.4 m), 1.11 (0.45 m), 0.91 (0.55 m), 0.83 (0.6 m) and 0.66 (0.75 m).

Cleft flat-flow nozzles on a hydraulic field sprayer beam should be mounted so that flows sprayed by separate nozzles would cover each other two or three times [5-7]. In order that liquid flows of adjacent nozzles do not interfere with each other, holes of cleft flat-flow nozzles should be turned at 7.5–10° angles in respect of the beam. In older nozzle frames (where nozzles are fastened by screws), this angle is determined by a special key; in new frames with quick-joint screws, nozzles are put into the necessary angle automatically.

Depending on the height of the sprayed plants, the beam may be lifted by one or two hydraulic cylinders or a line winch. There should be the possibility to change the height of the sprayer beam to the sprayed surface from 0.40 to 2 m. The distance of the cleft flat-flow nozzles to the sprayed surface depends on the spraying angle. Thus, using spraying nozzles of 110° or 120°, the optimal distance to the sprayed surface is 0.50 m. It is very important to determine precisely the spraying height, since, if one lifts the sprayer beam 0.10 m higher, *twice as many* drops may drift downwind. If the sprayer beam is wider than 18 m, the optimal spraying height is 0.75 m. In this case, using cleft flat-flow nozzles with an 80° angle, a double interference of flows is created; indeed, when spraying with 110–120° angle nozzles, a triple interference is obtained [6, 8].

In order for the beam not to swing while working in an uneven field, it is held by swing damp devices.

Lengthwise distribution of the sprayed solution mostly depends on the horizontal swinging of the sprayer beam, the driving speed and the field's evenness. Operational width sprayer beams longer than 12 m should be equipped with swinging damp devices and hang freely. In a hilly locality, it is advisable to use a sprayer with a beam position fixation mechanism.

Even distribution of protection preparations mostly depends on *nozzles.* They are also classified into a number of sorts:

- According to operational mode, nozzles are classified into *hydraulic*, *pneumohydraulic* and *rotational*;
- According to the form of the sprayed liquid, hydraulic nozzles are classified into *flat-flow, cone-flow* and *cone-stream,* and pneumohydraulic into *flat-flow* and *cone-flow*;
- According to construction, rotational nozzles are classified into *disc* and *drum,* and pneumohydraulic into *pressure* and *injection*;
- According to construction, flat-flow nozzles are classified into *cleft* and *deflector*;
- According to purpose, flat-flow nozzles are classified into *continuous*, *band spraying* and *washing*;
- According to spraying angle: 25, 40, 60, 65, 80, 90, 110, 120, 130, 150°;
- According to productivity: 01, 015, 02, 025, 03, 04, 05, 06, 08, 09.

Cleft flat-flow and injection nozzles may be of *symmetric* and *asymmetric stream*. Symmetric flow cleft flat-flow and injection nozzles may also be classified into *one-flow* and *two-flow*, and asymmetric into to *short-stream* and *long-stream*. One-symmetric-stream cleft flat-flow nozzles may be *standard*, *universal* and *with dispenser* (fewer drops drift downwind). One-symmetric-stream injection nozzles may be *compound* and *compact.* Compact and injection nozzles may be of *low* and *high pressure.*

Stream nozzles may be *one-hole* and *multi-hole*. Multi-hole stream nozzles may be of *three*, *five*, *six* and *eight holes.*

Cone-stream nozzles may be standard and injection, of double or hollow cone-stream.

Often, the entire junction is called a nozzle; in this case, a nozzle is made of a frame with momentum closing valve, filter, tip and quick connection nut. The cleft sprayer nozzle is

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ceramic, steel, plastic or brass bushing with cleft pressed into a coloured frame. It is advisable to choose the material for bushing depending on usage sphere and volume.

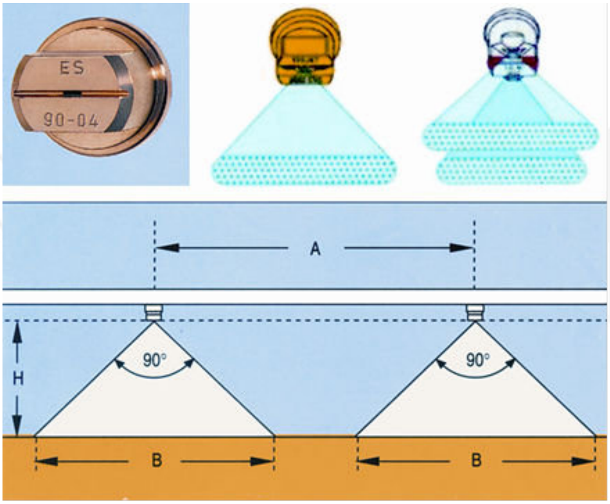
The colour of a nozzle tip and nut indicates the size of a cleft: orange – 01, green – 015, yellow – 02, violet – 025, blue – 03, red – 04, brown – 05, grey – 06, white – 08. The tips are marked according to ISO standard. For instance, *LU 120 – 04S* means: LU – type of a nozzle, in this case – Lechler universal; 120 – nozzle angle, 03 – nozzle productivity, in this case – 0.3 American gallons per minute if the pressure is 40 psi (1 American gallon = 3.7854 l, and 1 psi = 0.0703 bar, in this case 1.136 l min^{-1}, if pressure is 2.81 bar); S – bushing made of special stainless steel (letter "C" means that the bushing is ceramic).

Standard or universal cleft flat-flow nozzles are widely used and are inexpensive. When changing pressure, solution may be sprayed in small, average or large drops. It is possible to spray in windy weather with wind speed up to 3 m s^{-1}. Solution is dosed and sprayed through the cleft [9].

Cleft flat-flow nozzles for band spraying (Figure 4 a and b), due to a special construction, evenly distribute solution drops in the sprayed area; therefore, they spray qualitatively with a pressure of 1 bar. Having duly chosen the spraying height, it is possible to spray very wide (10–25 cm width) stripes. These nozzles are used for field sprayers or mounted on sowing and rowing cultivators. Due to the exact flow limitations, the loss of plant protection preparation is minimal.

In cleft small-drop blow nozzles, there is an additional primary nozzle (dispenser) that forms a flat stream. In this case, the quantity of unwanted small drops which may be blown downwind or steamed is reduced. Drops of the sprayed solution are blown downwind five times less than usual; it is possible to work if the wind speed is up to 5 m s^{-1}. In the primary nozzle (dispenser), when the area of the cross-section of a hole is smaller than the cleft area of the nozzle, it reduces pressure a little; the solution is sprayed in larger drops, and the main cleft of the nozzle wears less. Apart from that, it may be up to 50 % larger than that of the usual cleft nozzles, so it clogs rarely. Nozzles of this type may be fastened not only in the hydraulic field, but also in all pneumohydraulic garden sprayers. The biological effectiveness of plants sprayed by protective products is the same as when sprayed with small drops; however, the sprayed surface is covered evenly, and with the low operational pressure fewer drops are blown downwind. Due to the flat flow, the air stream supply is optimal, and with the higher pressure, the liquid is sprayed by small drops [2]. The company Agrotop was the first to create this type of nozzle, the SD-Servodrop. Later on, similar nozzles were offered by other producers: AD-antidrift (Lechler), LO-drift (Lurmark), ADI (Desmarquest), and DG-drift guard (TeeJet Technical). The special advantage of such nozzles is the possibility to spray smaller liquid amounts in larger drops, i.e., 100–150l ha^{-1} [10, 11].

Two-stream cleft nozzle is a special nozzle for spraying small drops. A double flat-stream is sprayed in the driving direction at 30° forwards and back. When working, good coverage of vertical surfaces is achieved (e.g., stem, eras). *Two-stream nozzles for band spraying* are mostly suitable for spraying of herbicides, fungicides and insecticides in crops with abundant foliage (Figure 4 c),. They are ideal for spraying between rows and rows of plants. TwinJet™ two-stream nozzles spraying at 40° angles should be set at the height of 25 cm for spraying a 20 cm wide stripe (80° spraying angle, 13 cm high); for a 25 cm wide stripe, at the height of 30 cm (80°, 15 cm high), and for a 30 cm wide stripe, at a height of 36 cm (80°, 18 cm).



a – cleft flat-flow Lechler ES; *b* – cleft flat-flow TeeJet® E-type; *c* – two-stream TwinJet™ E-type; *d* – fastening scheme on sprayer beam: A – width between rows, B – area of the sprayed stripe, H – spraying height [7, 9].

Figure 4. Nozzles for band pesticide spraying

TwinSprayCap quick switch-on holders have been created aiming to capture both the advantages of injection pneumohydraulic nozzles, reducing downwind flow of the sprayed drops, and those of two-stream spraying, which ensures better coverage of the sprayed surfaces. The holder is made of two parts. It is easily disassembled by pulling out a fixation, and it is suitable for all nozzles with an external diameter of 8 or 10 mm. Double flat-flow is sprayed with the driving direction of 30° forward and back. Aiming to achieve optimal transverse distribution of the sprayed liquid, the nozzle position is fixed automatically. Usage field:

- Especially suitable for spraying contact, (partly) systematic plant protection preparations;
- For spraying corn ears;
- In gardening;
- For destruction of weeds;
- For band spraying.

Deflector flat-flow sprayer involves a ceramic or plastic tube on one end, which ends with a cut and shield: a deflector. Its spraying angle is up to 140°; it is rarely blocked. Spraying with the pressure of 1–2 bars, few drops are blown downwind. The nozzle is especially suitable for spraying soil herbicides. It is also advisable to use it in tubes spraying liquid mineral fertilizers.

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Separation of liquid dosage and spraying in deflector nozzles helps to spray the liquid in larger drops. In the deflector nozzles Turbo-FloodJet™ and Turbo-TeeJet™ produced by the company TeeJet Technical, liquid is directed to a deflector that is turned by a small angle (about 15° of the vertical) and is very evenly sprayed in a wide and flat stream [12]. These nozzles, especially with an operational pressure of 2–3 bars, spray in larger drops than other flat-flow nozzles [12, 13].

Cleft asymmetric stream nozzles may be hydraulic (e.g., Lechler OC) and pneumohydraulic (e.g., Lechler IS). In hydraulic asymmetric stream nozzles, the cleft is on the side, and the liquid is sprayed at an angle of 90º. They are produced of brass or stainless steel. The recommended operational pressure is 1.5–2.5 bar. According to the width of the sprayed area, these nozzles are classified into short-stream and long-stream. The width of the sprayed flow of short-stream nozzles may vary from 1.2 to 2.5 m; and that of the long-stream may reach as much as 6–8 m. The width of the sprayed flow depends on the nozzle set angle, which may vary from 25 to 45º.

Short-stream asymmetric flow nozzles may be used:

- For spraying of borders and extension of the operational width of pipe nozzles;
- For spraying herbicides in bands in gardens and wineries;
- For spraying herbicides under foliage (e.g., beets, asparagus).

Long-stream asymmetric flow nozzles are used for overhead irrigation and irrigation of riding halls. They are fastened at the ends of the beam. Liquid is supplied to the nozzles by separate or already existing pipe-lines forming T-form branches. It is important that a sprayer should obtain a pump of a sufficient productivity, since two long-stream nozzles need an additional flow of about 80 l min^{-1}.

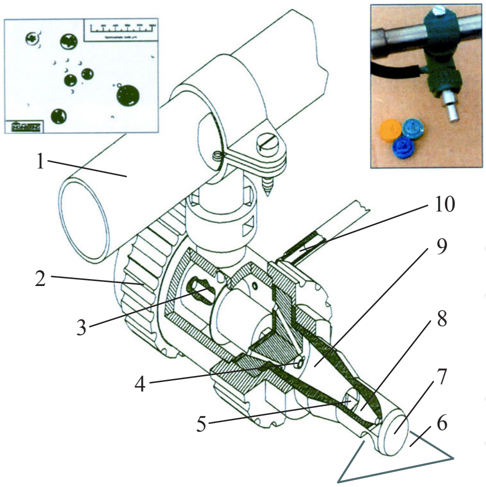
Hydraulic cone-stream nozzles may be full cone-flow and hollow cone-flow. In hollow cone-flow, due to a special insert, liquid flow starts to turn and flows in the borders of the hole. The insert may be a cylinder with slantwise cut or a plate with slantwise holes or slantwise surfaces.

Cone-flow nozzles are often used in pneumohydraulic garden sprayers. Their spraying angle may be from 20° to 120° (usually 65° or 80°). Cone-flow nozzles spray liquid in smaller drops than flat-flow nozzles, and their size spectrum is narrower. However, slantwise liquid distribution (that is measured by a special stand with gutters) by cone-flow nozzles mounted on a hydraulic field sprayer beam is worse.

Operational pressure of cone-flow nozzles is between 3 and 20 bar [7, 9].

Even though marking of cone-flow nozzles is not standardized, a number of producers use the same colours as in flat-flow nozzles. Some producers of cone-flow nozzles indicate the diameter (in mm) of dosage plate holes and liquid flow holes.

Pneumohydraulic nozzles used for field sprayers were created more than 25 years ago. The aim was to reduce water and expenditure of plant protection products downwind.



1 – distribution pipe; 2 – moment closing valve; 3 – liquid channel; 4 – liquid dispenser; 5 – plate; 6 – flow of sprayed liquid; 7 – deflector tip; 8 – branch; 9 – mixing camera; 10 – tip for connection of air hose; top left – range of the sprayed drops (bubbles); bottom left – view of the sprayer mounted on the beam with dispensers of various size [1].

Figure 5. Pressure pneumohydraulic nozzle by Airtec

In pressure pneumohydraulic nozzles the liquid and air mix are supplied by separate channels and are sprayed with higher speed, so that smaller drops are not blown downwind.

In injector pneumohydraulic nozzles, the air taken in from the side holes mixes with the liquid and is sprayed by larger air-filled drops which are also blown less downwind.

Airtec pressure pneumohydraulic nozzles were created in the middle of the 1980s by the company Cleanacres (United Kingdom). In this nozzle, liquid passing through the dispenser (hole diameter 0.9 mm) is firstly sprayed on a plate in the mixing camera. Suppressed air is supplied to a mixing camera from a compressor by a separate line (Figure 5).

One nozzle requires about 60–70 l min^{-1} of air. In a mixing camera, some of the drops are filled with air, i.e., bubbles are formed. This mixture of air and liquid is sprayed through the deflector nozzle. The size of the sprayed drops (bubbles) is regulated by changing the liquid and air ratio. The higher the pressure, the smaller the drops (bubbles). Air flow gives higher initial speed to the drops (bubbles) of the sprayed drops (bubbles), so they may get deeper into the foliage. Due to complicated nozzle construction, there are few drops (bubbles) smaller than 100 μm or larger than 400 μm. The solution is sprayed by drops (bubbles) of the same size; so, more solution is usefully used (70 – 140 l of water to one hectare is enough). The composition of the pneumohydraulic nozzle AirJet produced by the company TeeJet Technical is very similar. Liquid pressure in it may be regulated from 0.7 to 4.0 bar, and air pressure from 0.3 to 2.0 bar. From 12 to 60 l min^{-1} of air may be supplied to one nozzle. Depending on the dosage plates used and air and liquid pressure, it is possible to spray up to one hectare from 10 to 240 l (if driving speed is 6 km h^{-1}). The diameter of dosage plate holes may vary between 0.78, 0.89

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and 1.06 mm. Changing the air pressure, the liquid may be sprayed by very small or very large drops. Productivity of pneumohydraulic nozzles depends on air pressure. If liquid pressure is equal, increasing air pressure productivity of the nozzle reduces. With increasing air pressure, the range of the sprayed drops changes, i.e., they become smaller. Thus, using pressure pneumohydraulic nozzles, it is harder to set the norm of the sprayed liquid [2].

The pressure pneumohydraulic nozzle Eurofoil created by the Danish company Danfoil is meant for field sprayers. In this nozzle, liquid from the side is supplied to a plastic plate of streamline form which is located in the middle of the rubber air nozzle (Figure 6). Air flow supplied from the top disperses the liquid in small drops which are sprayed with a high speed through the wide air nozzle hole, so only a few drops may be blown downwind. Liquid is dosed by a plate with a 0.7 mm diameter hole. Liquid and air mix swirls, so vertical surfaces are covered very well, as well as upper and lower sides of leaves. With these nozzles, up to a hectare may be sprayed from 20 to 100 l liquid. The size range of drops sprayed by Eurofoil nozzle is very wide: from the smallest 100 μm to 800 μm. The size of the sprayed drops may be regulated by changing the quantity of the air supplied to a nozzle. Even if in this case there are more drops smaller than 100 or 200 μm than when spraying by the usual flat-flow hydraulic nozzle, e.g., XR 110-04, due to higher movement speed, fewer drops are still blown downwind. The optimal spraying height of Eurofoil pressure pneumohydraulic nozzles is 0.6–0.7 m, and the recommended driving speed of the spraying machine varies from 4 to 8 km h^{-1}. Smaller drops cover the sprayed surfaces better; so using Eurofoil pressure pneumohydraulic nozzles, the norms of plant protection products and liquid mineral fertilizers may be reduced to 50 % [1].

The first confidently operating complex injector pneumohydraulic nozzle, TurboDrop®, was created by the company Agrotop in the beginning of the 1990s. A little later, the company Lechler created a simpler, compact injector pneumohydraulic nozzle. Later on, similar nozzles started to be produced by the companies TeeJet Technical, BfS (Billericay Farm Services Ltd.), Agrotop and Hardi.

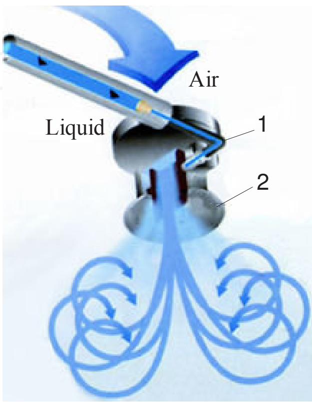
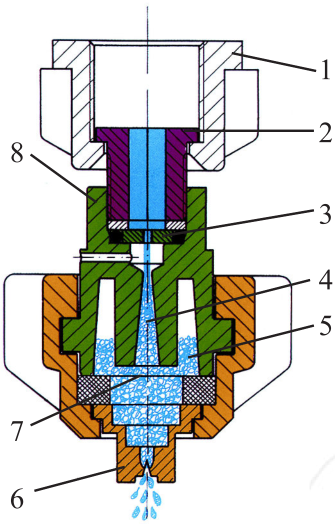


Figure 6. Eurofoil pressure pneumohydraulic nozzle: 1 – rubber air nozzle, 2 – plate [1].

A complex injector pneumohydraulic nozzle called TurboDrop® (Figure 7) is made of an adaptor, quick connection nut, dosage plate, injector, mixing and pulsing damp camera, rubber tight and tip. Using the adaptor, it is possible to connect these two nozzles to any quick connection nuts 1. Round flow is sprayed to injector 8 through dosage plate 3. Air is pumped through holes present on injector sides. Air and liquid are mixed in camera 4. Liquid swirl is reduced in the widest zone of the mixing camera, and pulsing is damped in ring camera 5. Homogeneous liquid and air mixture is sprayed through the nozzle tip 6. While flowing, air suppressed in the nozzle earlier becomes very wide; it increases movement speed of drops (bubbles) and possibilities to get into foliage. Larger and heavier bubbles are less sensitive to blowing downwind, so they reach the sprayed surface quickly and cover it well while blowing upward. Productivity of the nozzle depends only on the dosage plates. In this case, the tip is not important. Cleft, hole or deflector tips may be used in a complex injector nozzle. After mixing with air, the volume of liquid increases; so the area of the diameter of the hole of the nozzle tip may be bigger than the area of the injector hole (at least twice as large).



1 – quick connection nut; 2 – adaptor; 3 – dosage plate; 4 – mixing camera; 5 – liquid pulsing damp camera; 6 – tip; 7 – rubber seal; 8 – injector [13].

Figure 7. Complex injector pneumohydraulic nozzle TurboDrop®

Additional advantages of complex pneumohydraulic nozzles:

- *Two-part (injector and tip) module construction*, theoretically allowing any flow form and drop size to be reached. The bigger the hole of a tip is, the larger the liquid drops sprayed. The patented dosage plate ensures secure operation of a nozzle when the tip hole is much bigger than the injector hole;

- *Very wide operational pressure range (1–35 bar)*, so there are many chances to regulate the productivity of nozzles and liquid spraying norm. Due to patented dosage plates and ring liquid pulsing damp camera, the spectrum of drops in the entire pressure range is more constant than when sprayed by compact injector nozzles;

- *Wide usage possibilities.* Aiming to optimize the flow of the sprayed liquid or the spraying characteristics, i.e., the size of drops, any tip may be fastened to the same injector. For instance, when spraying grain against ear diseases, it is possible to change tips of universal cleft flat-flow nozzles for more suitable hole cone-flow ones. The injector remains the same, so nozzle productivity and operational pressure do not change;

- *Universality.* Due to the quick connection nut, the injector may be mounted in any type of nozzle holder, and tips may be used separately, i.e., as simple nozzles;

- *Easy maintenance.* Complex injector nozzles are bigger and more massive than compact ones, so it is easier to disassemble them without any tools;

- *Long life.* In production of complex injector nozzles, wear-proof plastic POM and especially hard pink aluminium oxide ceramics are used.

Compact injector pneumohydraulic nozzles (Figure 8) operate by a principle of the spout pump. In the inlet hole of the nozzle, the pressure reaches 8 bar; the solution gets into the injector with high speed and pumps air through holes on the sides. Differently from other nozzles, solution is sprayed not in drops but bubbles, because the air pumped into the nozzle frame mixes with the solution. Through the nozzle tip, the solution is sprayed with the pressure of only about 2 bar by larger and heavier bubbles; the danger of blowing drops downwind reduces, and it is possible to operate if the wind speed reaches up to 7 m s^{-1}. Not infringing the wax layer, bubbles adhere to a leaf surface and only when the surface strain is too great do they explode. The surface sprayed in such a manner is covered better. Injector nozzles are almost universal: they are suitable for herbicides, fungicides, insecticides and acaricides, as well as for spraying growth activators and liquid mineral fertilizers. Using injector nozzles, the usage time of a sprayer increases, since it is possible to operate with a higher wind speed, to spray preparation mixes or preparations and liquid mineral fertilizers. Apart from that, less investment is needed if compared to pneumohydraulic nozzles, fewer drops are blown downwind, less depreciation occurs, and it may operate with a pressure of 2–20 bar (optimal operational pressure – 5–8 bar). In compact high-pressure injector nozzles, air is pumped through holes on the sides of the frame (Figure 8 a), and with low pressure ones from the bottom (Figure 8 b).

Advantages of compact low-pressure injector cleft flat-flow nozzles:

- Shorter and more solid frame;

- Possible to easily disassemble the injector (with fixed position) without any tools;

- Optimal operational pressure is much lower (1.5–3 bar);

- Inexpensive.

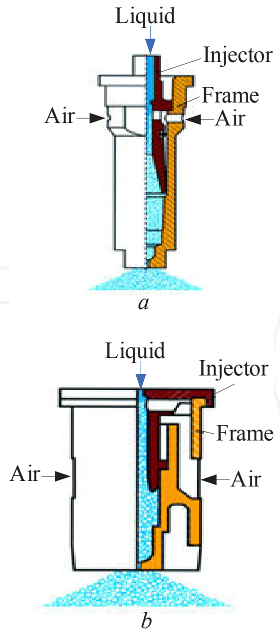


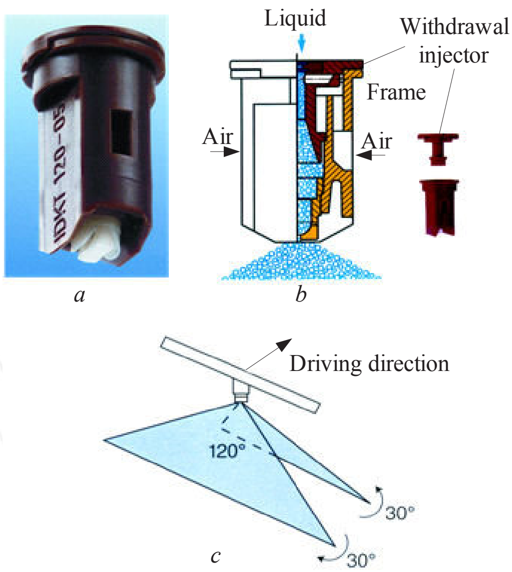
Figure 8. Nozzles of compact injector cleft flat-flow tips: a – high pressure; b – low pressure [9].

With injector pneumohydraulic asymmetric flow nozzles, liquid is sprayed at an 80º angle, i.e., 20º from the symmetric axis to one side and 60º to the other side. They are made of plastic in sizes 02 to 06. The recommended operational pressure for herbicide spraying is from 3 to 8 bar. Injector asymmetric flow nozzles may be used:

- For spraying lines and plant rows and continuous spraying with ID nozzles equipped on the beam ends;
- For spraying continuously along protective bands of open water ponds or field borders;
- For protection of sensitive, closely growing plants;
- For spraying herbicides under the leaves of accumulative plants;
- For spraying herbicides in gardens, vineries and arboretums;
- For limitation of flat-flow in ventilator sprayers (the first and last nozzles).

Injector pneumohydraulic asymmetric flow nozzles IS 80 produced by the company Lechler are acknowledged by the German Federal Biology Service (BBA) as a spraying means that reduces 90 % of losses.

Two-flow injector compact pneumohydraulic nozzles (e.g., Lechler IDKT) obtain a spraying angle of 120°, and liquid flow is sprayed 30° forward and back (Figure 9). Nozzle inlet and dosage



a – general view; b – section: 1 – withdrawal injector, 2 – frame; c – distribution scheme of liquid flows [9].

Figure 9. Two-flow injector compact pneumohydraulic nozzle

plate are made of chemicals and wear-proof ceramics. The range of the sprayed drops is from large to average. If spraying with the pressure up to 3 bars, few drops are blown downwind.

Nozzles are very compact (length 22 mm), and they satisfy the requirements of the German Federal Biology Service (BBA).

They are especially suitable for:

- Spraying contact and (partly) systemic plant protection products;
- Spraying preparations against leaf decay and defoliants;
- Spraying of grain ears;
- Spraying herbicides in beetroot crops and in gardening.

Advantages of the two-flow injector compact pneumohydraulic nozzles Lechler IDKT:

- Suitable for all sprayers' beams, they do not stumble over beams parts when turning in nozzle holders;
- Injector may be easily removed by hand (without tools); its position is fixed;
- If compared with general two-flow nozzles, significantly fewer liquid drops are blown downwind;

- If compared to "normal", i.e., one-flow injector nozzle, there are more drops in the flows of the sprayed liquid; so, better coverage of the sprayed surfaces is reached;
- Leaves and vertical surfaces (stems, ears);
- Prolonged lateral walls optimally secure nozzle inlet from damage;
- Little probability of blockage since air pump holes are on the tip sides.

Asymmetric two-flow complex injector pneumohydraulic nozzles by Agrotop called TurboDrop® HiSpeed are meant for operation with higher speed (> 8 km h^{-1}). The liquid flow is sprayed 10° forward and 50° back. They feature compact construction, optimal coverage of the sprayed surfaces, and few drops drifting downwind. They are very suitable for spraying fungicides, insecticides and herbicides (after sprouting of cultivated plants). Vertical (e.g., stems, ears) and slantwise located (e.g., leaves) surfaces are covered better. Optimal operational pressure is 4–8 bar. The nozzle inlet is made of wear-proof ceramics. It is easy to clean because the system of quick connection nuts is used. Plant protection products sprayed with the TurboDrop® HiSpeed nozzles cover plants optimally because, due to driving speed (> 8 km h^{-1}), the attack angle in respect to a plant of both flows changes, i.e., back-directed flow reduces, and forward spraying flow increases.

Rotation nozzles distribute liquid with centrifugal force. According to operational position, *poppet rotation nozzles* may be divided into those spraying *horizontally*, *vertically* and *slantwise.* Usually, poppet rotation nozzles spray horizontally or slantwise. Only Girojet poppet rotation nozzles produced by Tecnoma spray vertically. Apart from that, plate diameter and rotation frequency of rotation nozzles produced by different producers vary. Usually, poppet rotation nozzles are turned by electric engines. Rotation poppet nozzles disperse liquid in small drops, the size range of which is very narrow. The size of the sprayed liquid drops depends on the plate rotation frequency, nozzle efficiency, viscosity of the sprayed liquid and surface tension. It is possible to change rotation frequency in nozzles through a wide range, from 800 to 8000 min^{-1}. Depending on the construction, plate rotation frequency may be regulated by the electric stream rheostat (from Tecnoma and Spraying Systems) if changing pulleys of the tough transmission (from Micron and Krobath) or by regulation valves if changing the quantity of oil supplied to hydraulic engines (UTS Corp.). Productivity of poppet rotation nozzles is regulated by dosage plates. Depending on the pressure before the dosage plate (from 1.0 to 3.5 bar), productivity of these nozzles may range from 0.1 to 3.5 l min^{-1}. The distance between poppet rotation nozzles mounted on the beam may be from 0.75 to 1.5 m. Optimal spraying height for Air Cone nozzles is 0.45 m, for RotoJet, 0.75 m, and for Girojet, 0.8 m. If the spraying aggregate drives at the speed of 6 km h^{-1}, from 10 to 50 l of liquid are sprayed to one hectare [2].

The *rotation drum nozzle* is made of cylindrical metal mesh which turns around the hollow axle. The air transition screw turns the mesh. Solution is supplied to a hollow axle, and through a sphere closing valve it is supplied on a turning mesh. The turning mesh disperses solution by small drops, the size of which depends on the size of mesh holes and turning frequency. Frequency of mesh turning depends on the diameter of air transition screw, the form of blade, nozzle set angle and mounting place, flying speed, solution spraying norm and the type of flying apparatus.

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The *preparation pouring system* integrated in nozzles is made of a preparation reservoir with washing and mixing nozzles, control taps and injector with control tap; in some cases (e.g., in hydraulic field sprayers produced by the company Amazone), there is a separate reservoir for mixing of flour-form plant protection products. It distributes plant protection products quickly and evenly in a sprayer reservoir and ensures secure work. The calibrated preparation reservoir is mounted in a comfortable place; thus, no additional measuring vessel is needed. It is convenient to wash the preparation vessel by a rotating the washing nozzle mounted in a reservoir. Flour-form preparations or larger quantities of carbamate are dissolved after turning on the effective mixing nozzles. Holding it by a handle, it is possible to lift and fix the preparation reservoir in a transportation position, and when preparing a sprayed solution, it is possible to lower it down.

The *tow-bar* of a suspended hydraulic field sprayer may be mounted higher or lower to the tractor power supply axle or to the lower pullers of a rear hydraulic lift. It may have one or two coupling points, and may be stiff or with a changing turning angle. If a tow-bar with a handle is mounted to a rear hook of a tractor hydraulic lift, the air gap of a sprayer is bigger; moreover, it may be safer when working on slopes. If a tow-bar is mounted to the lower rods of a rear tractor hydraulic lift, the wheels of the sprayer follow the tractor tracks; however, in this case, the rods are overloaded.

Modern suspended field sprayers with tractor-track tracing devices beat crop less; they are more manoeuvrable, and they need less power for pulling as their resistance is smaller. It is important that tractor-track tracing devices work well in a hilly area.

Usually, the chassis of a suspended field sprayer has a stiff or amortizing suspension (e.g., spring or pneumatic). Pneumatic suspension of suspended field sprayers is simple, secure and tough; also, it does not require maintenance. The chassis of suspended field sprayers may be without brakes or with pneumatic or hydraulic brakes.

2.2.3. Peculiarities of self-propelled hydraulic field sprayer construction

A sprayer is called self-propelled if it obtains a chassis and engine (Figure 10 a).

These nozzles differ from the put-on nozzles because their separate knots are not removed. Arguments for the self-propelled pesticide spraying machinery are:

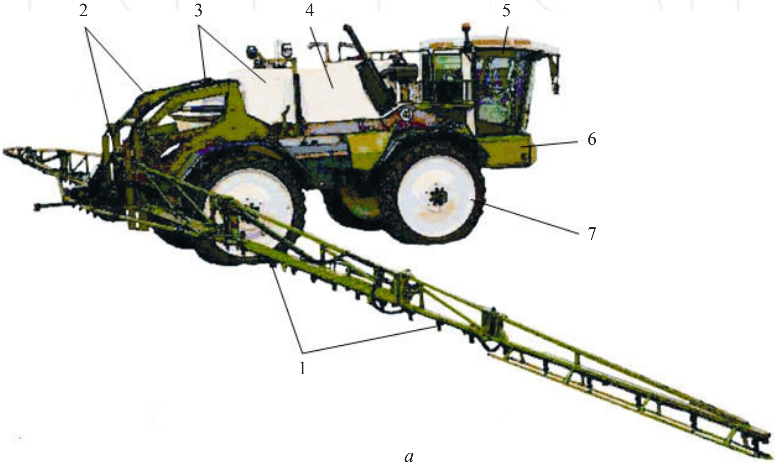
- Always ready for work – it is not necessary to suspend or unhook it;
- Large clearance – it is possible to spray rapeseed during blossom;
- Due to special chassis construction, the position of a beam is more stable - tandem axes, air pillow (Figure 10 b);
- Higher productivity because it is possible to transport a water carrier to the field;
- Hydraulic regulation of track – important for sugar beet, corn, potatoes;
- No-degree gear, even distribution of mass on four wheels, higher operational speed.

Content of self-propelled nozzles' reservoir is usually from 2000 to 4000 l, and in some cases even 6000 l. Engine power reaches from 100 to 200 AG.

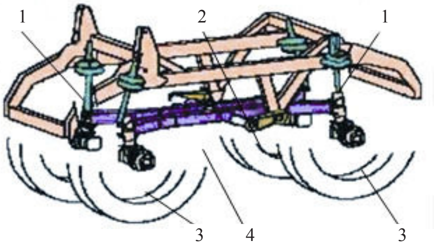
All wheels of a self-propelled sprayer are motive. Their gear is hydrostatic. High wheels ensure about 0.8 m clearance, and in some cases it may even reach 2.0 m (e.g., in sprayers of the company Dammann). In some models of self-propelled sprayers, it is possible to control them separately. Usually, operational width of self-propelled sprayers is from 24 to 36 m, and they may reach 51 m.

Depending on operational width, in self-propelled sprayers there may be one or two pumps the productivity of which is 200–300 l min^{-1}. They obtain productive filling devices.

In self-propelled sprayers, the cabin of the operator is usually in front, and the beam with nozzles on the back. Only in France are self-propelled sprayers with the beam in front popular. It is thought that it is easier to control the beam when equipped in front of the sprayer.



a



b

a – general view: 1 – beam with nozzles, 2 – beam lifting and swing damp devices, 3 – clean water reservoir, 4 – main reservoir, 5 – cabin, 6 – frame, 7 – chassis
b – chassis: 1 – airy amortizes, 2 – pendulous fork, 3 – hydraulic engines, 4 – pendulous frame [1].

Figure 10. Self-propelled hydraulic field sprayer

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Work with a self-propelled sprayer is safe and comfortable. Such sprayers are expensive, so the minimal annual volume of spraying works should be about 2000 ha. If 4000 ha are sprayed annually, only then do the maintenance costs of self-propelled and suspended sprayers become equal [2].

When choosing a self-propelled sprayer, their technical indices, economy and usage possibilities are most important.

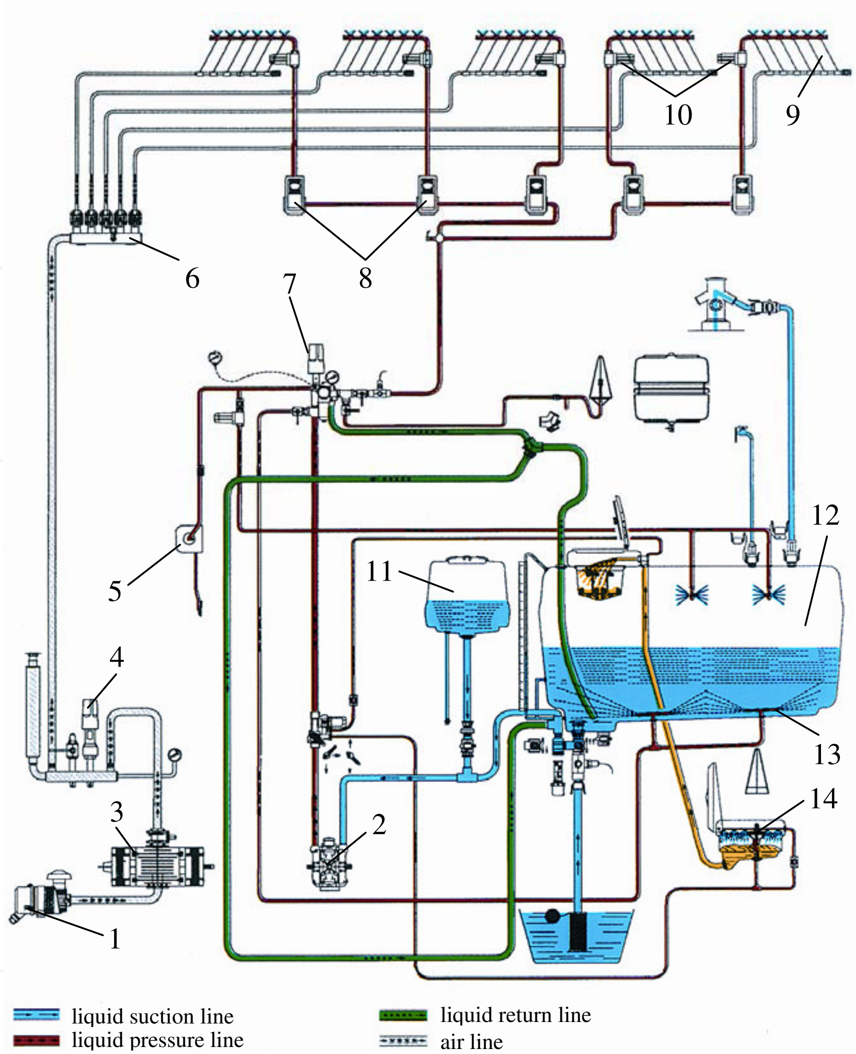
2.2.4. Peculiarities of the frame of pneumohydraulic field sprayers

The pneumohydraulic field sprayer is a sprayer which contains a ventilator or compressor that blows air to pneumohydraulic nozzles attached to a beam or to air distribution channels that are mounted above the sprayer beam. Air flow divides the solution sprayed through the nozzles into small drops and carries them to the sprayed surfaces. Having reached the sprayed crops, air flow stops and starts to swirl. Small drops of the sprayed liquid also settle down on rarely reached surfaces, e.g., the lower part of a leaf and stems. These sprayers are produced by a number of companies. It is possible to separate two conceptions of pneumohydraulic field sprayers. The companies Knight, Danfoil and John Deere produce sprayers with pneumohydraulic nozzles (Airtec, Twin-Fluid, Danfoil), in which solution is mixed with air. In pneumohydraulic field sprayers produced by the companies Rau, Dammann, Hardi and Kyndestoft, additional air flow is used; this air flow helps the sprayed liquid drops to reach the sprayed surface.

The construction of pneumohydraulic field sprayers produced by the companies Knight and John Deere is similar. Air is supplied to pneumohydraulic nozzles by a compressor (Figure 11). The sprayer by John Deere has a special device, the Twin-Fluid Controller, which may automatically regulate the size of the sprayed drops by changing the air pressure depending on wind speed and liquid pressure.

In a pneumohydraulic sprayer by Danfoil, air is blown at a high speed (which may be changed depending on working conditions) from the top to the bottom through a special pneumohydraulic nozzle (Eurofoil) that disperses the solution supplied from the side onto crop. Movement speed of drops is high, so few drops drift downwind, and plants are sprayed more precisely. Solution drops settle down on the rear part of a leaf since air flow swirls intensively. When spraying with these sprayers, it is possible to reduce water quantity to 30 l ha^{-1}.

In pneumohydraulic field sprayers, air flow is created by one or two axial ventilators; usually, they are driven hydraulically. It is distributed by flexible fabric hoses or channels of light metal. Various producers offer air distribution hoses of various forms and holes for their flow, e.g., in the pneumohydraulic field sprayers Rau, Douven (Kyndestoft) and Degania, air flows through 38 mm holes, though the distance between them may vary from 80 to 125 mm. In the first pneumohydraulic field sprayers of the company Hardi, air was blown through the entire length of the distribution hose. In the first pneumohydraulic field sprayers of the company Dammann, air was distributed through 1500 mm diameter aluminium pipes. From a pipe, air flew through holes, the measurements of which were 3 x 150 mm.



1 – air filter; 2 – pump; 3 – compressor; 4 – air line control panel; 5 – cleaning brush; 6 – control taps of air line sections; 7 – control panel of pressure line; 8 – control taps of pressure sections; 9 – pneumohydraulic nozzles; 10 – section filters of pressure line; 11 – clean water tank; 12 – reservoir; 13 – mixer; 14 – preparation tank [14].

Figure 11. The scheme of a pneumohydraulic field sprayer

In the newest pneumohydraulic field sprayers of the company Dammann, various cleft flat-flow nozzles are used, and the sprayed drops are secured from wind effect by two air flows (in front of the spraying beam and behind it, Figure 12). Air is distributed through light metal pipes. This system creates an injector effect, i.e., it pumps drops to crop. Advantages: better effect of pesticides, lower expenditure, fewer drops blown downwind of the sprayed crops.

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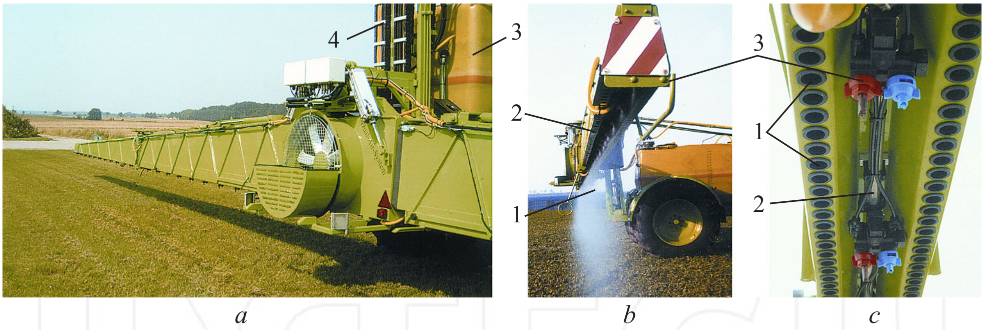


a – view of sprayer beams with integrated ventilator: 1 – air channel, 2 – ventilator, 3 – sprayer reservoir, 4 – beam lifting device;
b – view of sprayed liquid drops: 1 – flow of drops, 2 – nozzles, 3 – beam with air distribution channel; c – scheme of location of nozzles and air flow holes: 1 – holes for air flow, 2 – distribution pipe, 3 – nozzles [15].

Figure 12. Pneumohydraulic field sprayer of the company Dammann

In the opinion of some producers (e.g., Kyndestoft and Douven), it would be enough to direct the trail of small drops to the crop. The smaller air quantity is needed for settling down liquid drops on the sprayed surfaces.

In Airsprayer sprayers of the company Kyndestoft, a ventilator supplies air by a round fabric channel that is mounted above the spraying beam. This air flow (the vertical angle of which may be modified from 0 to 40°) protects sprayed solution drops from downwind blow. If a vacuum is formed, the trail of drops is prolonged (to 1.20 m), and plants are covered more evenly and better (small drops); fewer drops are settled down on the ground. Preparations work better and more reliably; apart from this, productivity doubles since it is possible to reduce by up to 50 % expenditures on preparations and water. Usually, productivity of the ventilator in pneumohydraulic sprayers is regulated.

According to conception of the companies Degania and Rau, the fact that air flow directs all drops of the sprayed liquid to the crop is an advantage. In Rau AirPlus sprayers, additional air flow is supplied vertically downwards, and the solution is sprayed by small drops (as narrow a drop range as possible) using cleft cone-flow nozzles; spraying direction versus the vertical of these nozzles may be changed. Using sprayers of this company, it is possible to reduce expenditures on preparations by 25–30 %; 100 l ha^{-1} of water is enough. Apart from this, it is possible to almost double working speed and to spray if wind speed is up to 8 m s^{-1}.

In pneumohydraulic field sprayers of the company Hardi, only cleft flat-flow nozzles are used; the angle between liquid and air flows remains constant, but it may be changed in respect to the vertical ± 30°. In this case, 100 l ha^{-1} of water is enough, and it is possible to use 25–30 % less pesticides and spray with wind speed up to 9 m s^{-1}.

If spraying with pneumohydraulic field sprayers (e.g., Hardi Twin, Dammann DAS or Kyndestoft AirSprayer), a larger amount of air opens crops widely; however, too strong air flow may reduce the spraying angle of the cleft flat-flow nozzles, and, due to this, slantwise distribution of the sprayed liquid worsens. When crops are opened widely, drops of average size may also reach the lower part of a plant. In any case, spraying with pneumohydraulic sprayers, there should be as few large drops as possible because swirling air flow does not affect their flying trajectory. Additional air flow increases movement speed of these drops, so the possibility that they would spring back or roll down the sprayed surfaces increases significantly [16].

In pneumohydraulic field sprayers using cleft flat-flow nozzles, productivity may vary from 0.3 to 1.2 l min^{-1} (if operational pressure is 3 bar). Spraying height varies from 0.4 to 0.6 m. For one hectare, from 50 to 400 l of liquid may be sprayed [16, 17].

Usually, cone-flow nozzles for small drops are mounted on the sprayer beam at the distance of 0.25 m. Their optimal spraying height is 0.6–0.7 m, and operational pressure about 4.0 bar. It is not recommended to spray with cone-flow nozzles with the pressure less than 3 bar since spraying angle reduces and slantwise distribution of the sprayed liquid worsens. From 50 to 600 l may be sprayed for one hectare [18].

Many authors recommend a norm sprayed by pneumohydraulic field sprayers between 100 and 200 l ha^{-1} [10, 19]. The amount of air is determined depending on wind strength, type of sprayed cultivated plants, their height and density.

When spraying crops in their early growth periods, by pneumohydraulic field sprayers, amount of air should be minimal or the ventilator should be turned off. When plants are small, and the drops in the crop are not stopped, additional air flow increases drift of small liquid drops [20].

On the whole, farmers in Western Europe have a positive opinion of this complex and rather expensive machinery; however, the promised effect is not always achieved. For instance, using pneumohydraulic field sprayers, it is not always possible to reduce 30 % of expenditures on plant protection products. It depends on protection preparations and sprayed plants. The sprayed surfaces are covered very well; so, it is possible to reduce expenditures on contact preparations. However, it is not advisable to reduce norms of systemic plant protection products. Good results are obtained by spraying the reduced norms of herbicides when eliminating weeds in potato and sugar beet crops; however, it is not advisable to reduce norms of soil herbicides. Depending on the sprayed plants, insecticide effectiveness problems may appear because a higher water amount to each hectare is needed.

Using pneumohydraulic field sprayers, it is very important to appropriately set air pressure. If it is too high, solution may be sprayed by small drops that may be blown downwind or evaporate. If air pressure is too low, due to large drops, preparation activity may worsen. Using this spraying technique, solution concentration is very high; so it is important that its remains are small. Let us remember that 50 l of solution is enough to spray 0.5–1.0 ha. The diameter of the sprayer hoses should not exceed 10 mm, so that sediments are not formed.

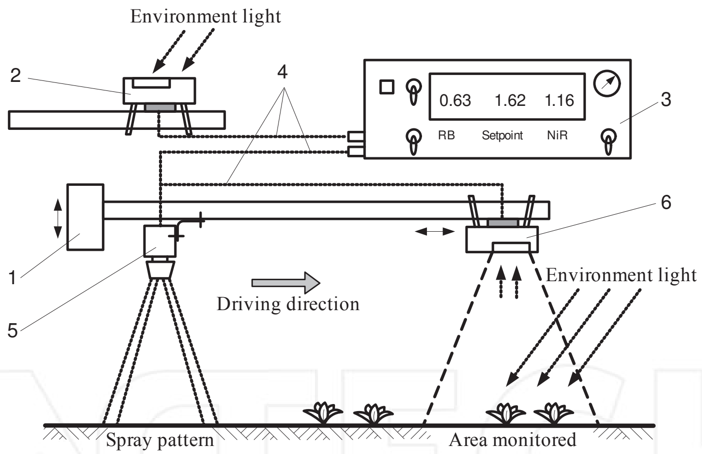
Specialists advise checking new sprayers with pneumohydraulic nozzles in special workshops, since it is rather difficult to determine the optimal liquid slantwise distribution. Nozzles of this type should be washed very well because even insignificant sediments on a deflector may considerably affect the evenness of liquid slantwise distribution.

2.3. Automatic weed recognition systems

In recent years, automatic recognition of weeds has been attempted in two ways. Some try to recognize weeds by optical-electronic sensors measuring their reflecting light spectrum, and others try to use digital video cameras and handling systems for the filmed views.

In the first approach, it is possible to separate only green plants from the soil surface. Using optical-electronic sensors, the daylight spectrum reflecting from green plants and the soil surface is measured; the obtained data are processed, and the nozzles are controlled accordingly. The weed recognition system Detectspay® (Figure 13) operates by this principle. This system is meant to spray herbicides in the mould humus or till sprouting of cultivated plants. According to Biller, if compared to general spraying, usage of the weed recognition system Detectspay® may reduce expenditures on plant protection products by an average of 52 %. As various research shows, under favourable conditions, it is possible to reduce expenditures on plant protection products by 33–68 %, and under unfavourable conditions by only 10–30 % [21, 22].

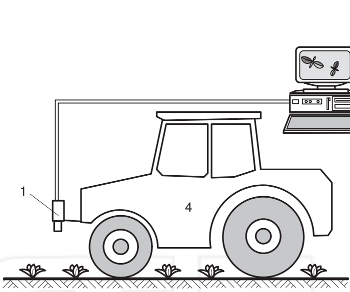
Wartemberg used optical-electronic sensors with DGPS equipment, and recognized weeds comparatively well and fixed their place in the field [23].



1 – sprayer beam; 2 – environment light sensor; 3 – spraying computer; 4 – wires; 5 – magnetic valve; 6 – spraying sensor [23].

Figure 13. Distribution scheme of optical-electronic sensors using weed recognition system Detectspay®

Kühbauch offered a totally different way to recognize weeds, i.e., by analysing images filmed by a video camera. Using GPS devices too, the location of the filmed views is determined very precisely (Figure 14). Analysing the filmed images by special programmes, types of weed and their distribution on the field are determined. The received data are transferred to digital weed maps (Figure 15). When using computers of the older generation, recognition of one sort weed took two seconds; thus, it was quite complicated to control the nozzles at the same time [2].



1 – video camera; 2 – computer; 3 – DGPS receiver; 4 – means of transportation [2].

Figure 14. Location scheme of equipment when filmed by the video camera used for weed recognition

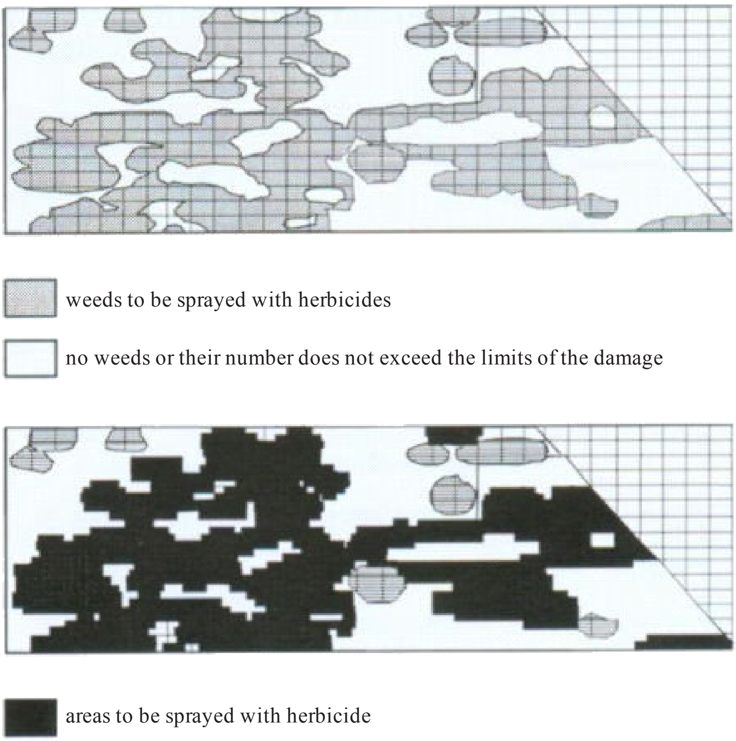
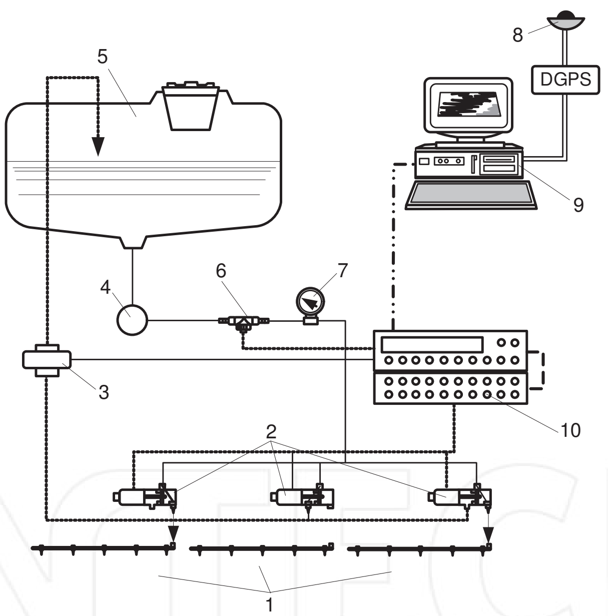


Figure 15. Maps of crop weeding (a) and spraying (b) [2].

With a speed of 25 frames per second, the computer determines the weed outline by analysing the saved images. According to the photos of weed outline and certain proportions, specific parameters are calculated, e.g., the ratio between the outline of each weed and photo. These specific parameters are used for weed recognition. The performed research shows that the accuracy of weed recognition using view analysis equipment may range from 60 to 90 %. Such precision is sufficient for making maps for crop weeding and spraying [2].

Since weed dispersion is related to a certain location, it is possible to use maps of crop weeding in subsequent years to make new maps of crop weeding and spraying. Using DGPS equipment, the place of spraying aggregate in the field is determined accurately, and the computer controls the spraying process according to a crop spraying map (Figure 16). Magnetic valves open the nozzles in exactly the place where the weeds were noticed while making a crop weeding map. It is thought that using this precise farming method, it is possible to save from 30 to 50 % of herbicides [2].



1 – sprayer's beam sections with nozzles; 2 – magnetic valves; 3 – valve for pressure regulation; 4 – pump; 5 – reservoir; 6 – flow meter; 7 – pressure gauge; 8 – DGPS receiver; 9 – computer with installed maps of crop weeding and spraying; 10 – spraying computer with control switches of beam sections [2].

Figure 16. Sprayer control scheme according to a crop spraying map

At this point, for a wider usage of the means of precise farming, some technical details and high prices have become an obstacle; however, in the future, positive economic and environmental protection aspects should help to achieve a breakthrough in this field.

Special sensors for plant protection are offered (Figure 17). The inexpensive and solid ultrasound sensor P3 may determine the state of a crop irrespective of time, i.e., it is possible to work even at night. This sensor may determine the height of crops, the number and position of plant leaves, and the amount of biomass. Using agronomic algorithms with the information supplied by a sensor, it is possible to evaluate the present situation and spray separate field places by different norms of plant protection products. According to the state, it is possible to choose the appropriate aggregate driving speed, working pressure and norm of liquid spraying. Since the equipment quickly reacts to changes in crop state, the ultrasound sensor may be fastened directly on the sprayer beam. So far, these sensors have been mostly used for spraying growth regulators; however, their usage in other areas is very likely.

Figure 17. Ultrasound sensor P3 is attached to a field sprayer's beam for precise plant protection [24].

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OptRx sensors (Ag Leader® Technology, USA) are used to research optical peculiarities of the cultivated plants (Figure 18). These sensors measure the reflected rays in ranges of infrared and red spectra (Figure 19):

R_{760} – reflected 760 nm wavelength infrared rays,

R_{670} – reflected 670 nm wavelength red light rays.

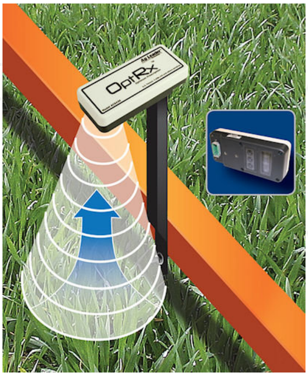


Figure 18. General view of a sensor for plant optical analysis, OptRx [25].

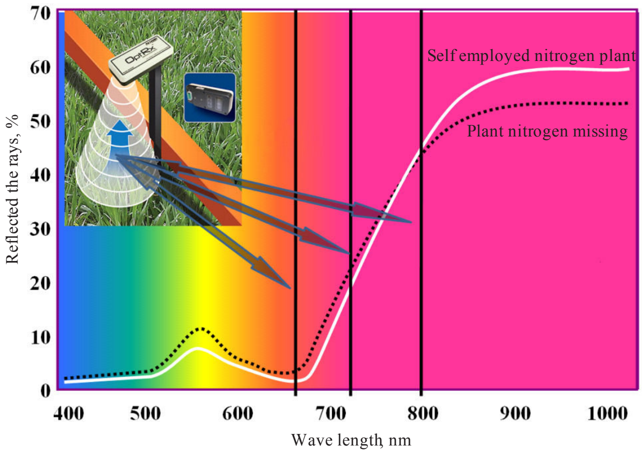


Figure 19. Part of reflected rays depending on the length of a wave [25].

NDVI index is recommended for use until the 32nd wheat growth stage, and in the later stages *NDRE* is offered:

R_{760} – reflected 760 nm wave length infrared rays,

R_{730} – reflected 730 nm wave length red light rays.

3. Weed control by mechanical means

3.1. Cultivators

3.1.1. Purpose and requirements of cultivation agromachinery

Cultivators of continuous operation moulder soil, insert mineral fertilizers into the soil, exterminate weeds and prepare soil for growth.

Row-spacing cultivators cut grass, locally insert mineral fertilizers into soil, moulder row-spacing and moulder up plants.

Requirements of agromachinery for continuous cultivation. Soil is constantly cultivated by observing mould humus and mouldering soil before sowing. Unevenness of soil mouldering is allowed at no more than ± 1 cm. The surface of the cultivated soil should be of a small grain structure, and weeds should be totally destroyed. Soil surface waviness of no more than 3–4 cm is allowed; so often the soil is cultivated and harrowed.

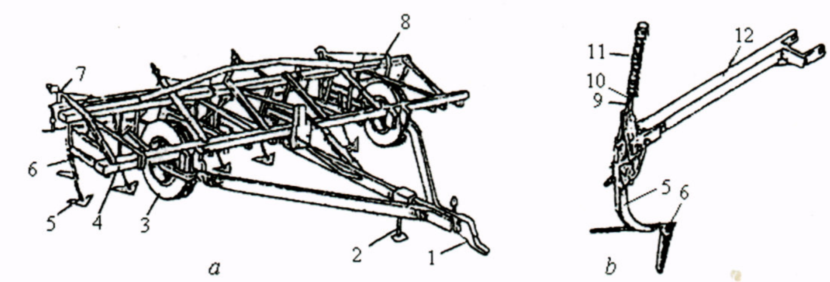
Requirements of agromachinery for row-spacing cultivation. Row-spacing is mouldered at the depth of 4–12 cm. The allowed deviation from the set mouldering depth is not more than ± 1 cm, and deviation from the insert norm of fertilizers is ± 10 %. For the first time, row-spacing is mouldered in the depth of 6-8 cm leaving protection zone for 10–12 cm; for the second time, row-spacing is mouldered in the depth of 8–10 cm leaving protection zone not less than 12 cm, and for the third time, it is mouldered not shallower than 10 cm leaving protection zone 12–18 cm. Driving speed of row-spacing machinery is 5–6 km h^{-1}. When loosening row-spacing, not less than 95 % of weed should be destroyed.

3.1.2. Classification

Cultivators are classified as continuous soil operation, hard and row-spacing. They may have passive or rotating operational parts. Operational parts may be rotated by force (rotor cultivators); operational parts may be rotated by force (rotor cultivators) or may rotate when operational parts are in contact with soil (rotation). Both types of cultivators may rotate around the vertical and horizontal axle. According to their connection with energetic source, cultivators are classified into suspended and put-on.

3.1.3. Construction and operational parts

Continuous operation cultivators with passive operational parts (Figure 20). These cultivators are made of a frame 4, to which operational parts are attached – ploughshares, support wheels 3, suspension or hanging device and harrow hanging device 7. Ploughshare is made of handle 6 and tip 5. A handle may be stiff, made stiff with a spring protector or spring. The ploughshare with spring handle is the most widespread, and it is called a spring ploughshare. Spring handles may be of S or C form. Handles of S form are suitable to work in stony soil since they are elastic and do not break when caught by an obstacle. When working with a cultivator with spring handles, the driving speed is 9–12 km h^{-1}; when they vibrate, soil is not stuck around them, and the soil is well loosened.



a – general view; *b* – joint equipment of ploughshare; 1 – hanging device; 2 – support; 3 – support wheel; 4 – frame; 5 – tip; 6 – handle; 7 – harrow hanging device; 8 – hydraulic cylinder; 9 – pivot; 10 – plug; 11 – spring; 12 – carrier [26].

Figure 20. Continuous operation cultivator

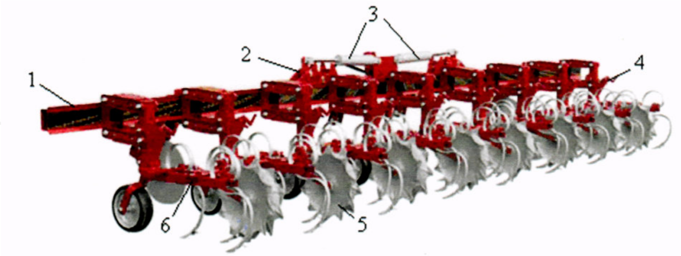
Tips of a ploughshare may be spear, forged or universal arrow 5. Spear and forged tips may be tippled and one-side. If one end of a tippled tip is worn out, it may be turned over to another end. Universal arrow tips are used for weed cutting and soil mouldering. The main parameters of the arrow tips are operational width, attack angle and blade angle. Attack angle is formed by a tip surface with a horizontal surface, and it influences mouldering intensity. The attack angle of a universal arrow tip is 28–30°. The blade angle that is made by the tip blade with the axial line has influence when cutting weeds. The angle is chosen in such a way that weed would be cut when sliding on the tip blade; it may be 30–32.5°, and the angle's operational width may be 145–330 mm.

The ploughshare is attached to a cultivator frame jointly (Figure 20 b) or stiffly. The jointly attached ploughshare copies the soil surface better and cultivates soil more evenly. When attaching ploughshares jointly, they are fastened to the frame by a carrier 12; also, pivots 9 with pressed springs 11 are inserted. If changing position of a plug 10 in the holes of a pivot 9, pressing force of the spring is regulated.

Continuous operation cultivators, ploughshares which have stiff handles, may have spring protectors. Meeting an obstacle, the spring deforms, and the ploughshare straightens. After the ploughshare passes the obstacle, it is returned to the initial position by the spring.

In order that the ploughshares are not stuffed with plant remains, they are located in two or three rows, at the distance of 400–500 mm. Ploughshares with arrow tips are usually located in two rows with an overlap of 40–60 mm, so that on turns no uncultivated soil zones remained. Spring ploughshares are usually located in three rows. Distance between furrows is 6–10 times larger than the width of the ploughshare itself. Ploughshares located in such a way loosen the soil constantly, since the soil is deformed more widely than the width of a ploughshare.

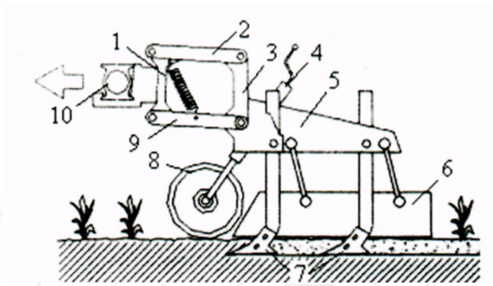
Row-spacing cultivators with passive operational parts. The row-spacing cultivator (Figure 21) is made up of: frame 1; hanging device 2; hydraulic cylinders 3, by which lateral sections are lifted during transportation; regulation device for loosening depth 4; protective disc 5; and section of ploughshares 6. The operational parts of such cultivators are ploughshares. Ploughshares are fastened in sections for operation in one row-spacing.



1 – frame; 2 – hanging device; 3 – hydraulic cylinders; 4 – regulation device for loosening depth; 5 – protective disc; 6 – section of ploughshares [27].

Figure 21. Row-spacing cultivator

Sections (Figure 22) are attached to the frame 10 by a parallelogram device so that their bending angle does not change when ploughshares are lifted or settled down. The parallelogram fastening device is made of two brackets 1 and 3, lower 9 and upper 2 rods. Bending angle of ploughshares is regulated by the upper rod. The section is made of a carrier 5, ploughshares 7 and support wheel 8. Loosening depth is regulated by a screw 4. The support wheel copies soil unevenness well, so ploughshares enter the soil at the determined depth.



1 and 3 – brackets; 2 – upper rod; 4 – screw; 5 – carrier; 6 – protective convex; 7 – ploughshares; 8 – support wheel; 9 – lower rod; 10 – frame [28].

Figure 22. Section of row-spacing cultivator

Row-spacing cultivators have various sets of ploughshares and fertilizing machinery. Fertilizing machinery may have plate or screw fertilizer feeders. Fertilizer feeders are turned by cultivator wheels through chain gears and reducers. In row-spacing cultivators, there are one-side knife *b*, arrow *a*, arrow universal, forged *e*, fertilizing *d*, accumulative *k* and turning ploughshares *g*, protective plates *c*, protective convexes *f* and weeding rotors *h* (Figure 23).

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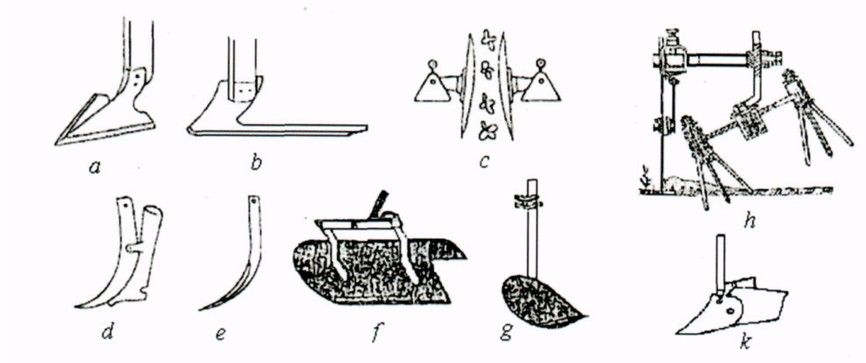
One-side knife ploughshares (Figure 23 b) cut weeds and loosen soil at the depth of 40–60 mm. They are made up of a horizontal knife and a vertical wall. Horizontal knife cuts weed, and vertical wall protects plants against soil heaping up. One-side ploughshares may be left or right side. Their operational width is 80–200 mm.

Arrow ploughshares (Figure 23 a) are in the form of an arrow. They are meant for weed cutting and soil loosening at the depth of 40–60 mm. Blades of these ploughshares make an angle of 60–70°. Blades of arrow universal ploughshares are lifted, so they do not only cut weed, but also loosen soil in the depth of up to 120 mm.

Forged ploughshares (Figure 23 e) are narrow (about 20 mm wide). They loosen row-spacing in the depth of 100–160 mm.

Fertilizing ploughshares (Figure 23 d) are used additionally for local fertilization of plants during vegetation. They are made of a forged ploughshare with a funnel attached to it.



a – arrow ploughshare; *b* – one-side knife; *c* – protective plates; *d* – fertilizing ploughshare; *e* – forged ploughshare; *f* – protective convex; *g* – turning ploughshare; *h* – weeding rotors; *k* – hilling-up ploughshare [26].

Figure 23. Operational parts of a row-spacing cultivator

Potatoes and other hilled-up vegetables are hilled-up by row-spacing cultivators with *hilling-up ploughshares*. These ploughshares are of various constructions. Turning hilling-up ploughshares (Figure 23 k) are made of a handle tip and two tipplers turning soil into both sides of a row. Tipplers may be continuous, rod and complex. When hilling up with ploughshares with rod tipplers, row sides and bottom are pressed less. Turning ploughshares with two ploughshares mounted to spring handles are used less often. Hilling-up ploughshares loosen soil up to the depth of 160 mm, and make the row height up to 250 mm.

Plate hilling-up ploughshares are made of two convex plates mounted in the angle of driving direction; they turn soil in to both sides. When hilling up, plates turn; so, their resistance to gravitation is smaller than that of turning hilling-up ploughshares. Usually, plate hilling-up ploughshares are mounted to potato planters in order to cover sowing potatoes with soil.

Turning ploughshares (Figure 23 g) are made of a handle and a tippler. They may be left- or right-sided, used for operation in row-spacing of potatoes or other hilling-up vegetables. These ploughshares are located at the distance of 250–270 mm on both sides of plants. They cut weed, loosen soil in the depth of 60 mm and cover weeds in the plant protection zone.

Weeding rotors (Figure 23 h) loosen soil and destroy weed in row-spacing. Working with weeding rotors, a narrower protective zone around plant rows is left. They are made of a bend rotor in respect to soil which turns around the axle fastened to the handle. On the sides of a rotor, axles are fastened to which the cultivator is mounted. During operation, cultivators turn around their axles and turn together with a rotor; so weeds are rooted out and covered with soil. If plants are lower than 50 mm, a shield is attached to the handle; the shield protects plants from covering with soil.

Protective convexes (Figure 23 f) are attached above plant rows and protect them from covering with soil. They are used if plants are lower than 50 mm. Protective plates are also used to protect plants from being covered with soil (Figure 23 c).

In modern row-spacing cultivators, *cut discs* 5 (Figure 3.5) are mounted on the sides of sections in order to protect plants from being covered with soil and to shake soil off plants. When rolling, cut discs move ploughshares up and down; in this case, soil is better shaken off the roots of weeds, and weeds are destroyed better.

Rotor row-spacing cultivators. Their operational parts are rotors turning around the horizontal axle in the driving direction; knives of various forms are attached to rotors. Rotors are turned by a tractor operational shaft through gears. Width of rotors is adapted for loosening of row-spacing, the width of which is not narrower than 450 mm. The soil is hilled up by the gear frame by a passive ploughshare.

Row-spacing of potatoes, sugar beet and strawberries is loosened by rotor cultivators. It is not possible to use them in light soil since the structure of the soil is destroyed (many small particles are created; in rainy weather these particles form a crust). When loosening stony soil by rotor row-spacing cultivators, knives break [26].

3.2. Harrow

3.2.1. Purpose of harrow and requirements for agromachinery

Purpose of harrow. The surface of the soil is levelled and loosened, bigger clods are chopped, and soil preparation for sowing is completed. In spring, soil surface is loosened by a harrow; an isolation layer that does not allow dampness to disappear is formed. The harrow destroys springing out weed and cuts the growing ones. The harrow may also be used to insert mineral fertilizers and seeds of perennial grass and other plants. The harrow may be used for harrowing the sprung out crop, aiming to destroy springing weed and chop-forming soil crust.

Requirements for agromachinery. All operational parts of a harrow should loosen soil at equal depth. Harrowed soil surface should be even. During operation, the harrow should move in a direct line; when operating in crops, it should not damage cultivated plants.

3.2.2. Harrow classification and construction

According to the type of operational parts, harrows are classified into rod, spring, mesh, digital, knife and rotation. According to the movement of operational parts, harrows are classified into passive with crawling operational parts, rotational with turning operational parts and active. Active harrows have obligatory flashing to the sides of the operational parts, and a rotor with obligatory turning operational parts.

According to purpose, harrows may be used for pre-sowing and post-sowing harrowing. For pre-sowing harrowing, heavy- or average-weight harrows are used. Cultivation of clay and loamy soil tilled by other equipment is finished by heavy harrows, and average-weight harrows are used to finish cultivation of sandy loam. Light harrows are used for post-sowing harrowing. They are used for harrowing springing beetroot, corn and other agricultural plants. Light harrows loosen soil up to 5 cm, average-weight harrows up to 7–8 cm, and heavy harrows up to 10 cm deep.

According to harrowing direction, they may be lengthwise, transversal, diagonal, or harrowing in a circle, i.e., by the field cut-out. Previously, wooden harrows were used for soil loosening. The first harrow rods were made of wood, and, later on, at the end of the seventeenth century, they became metal [29]. In Eastern Europe and Lithuania, harrows started to be used at the end of the first millennium. The oldest harrows were the top of a cut fir tree or pine tree, with cut branches 50-70 cm long. Such harrows were pulled by a human, and later by a horse or bull. Rod harrows with wooden frame and metal harrow rods started to be used in Lithuania in the end of the nineteenth century, and rod harrows with metal frame at the beginning of the twentieth century.

Rod harrows may be made with stiff or flexible frames. Rod harrows are made of a metal frame and harrow rods. According to the mass falling to one harrow rod, rod harrows are classified into light, average-weight and heavy. Light harrows' mass to one rod is 0.6–1.0 kg, average-weight harrows, 1.0–1.5 kg, and heavy harrows, 1.5–2.0 kg. Frames of rod harrows may be zigzag, rhombus, or more rarely S form.

Spring harrows are made of a stiff frame and spring rods. They are often used for pre-sowing soil cultivation. Spring rods lift couch-grass to the soil surface. It is possible to use this harrow in stony soil. Spring rods (Figure 24) are similar to the ploughshares of a continuous operation cultivator; but they are smaller, located more densely and cultivate soil more shallowly.

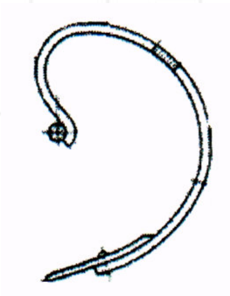


Figure 24. Spring harrow rod [26].

The *mesh harrow* (Figure 25 a) is a flexible rod harrow. It is made of separate meshes net among themselves. Meshes together with the harrow rod are bent from 8-10 mm diameter round steel wire. Rods may be 120–180 mm long, their ends pointed or obtuse. Rods of harrows meant for harrowing light soil are obtuse; for average-weight soil, flat; for heavy soil, pointed. These harrows destroy weeds, and the soil crust on crops is broken.

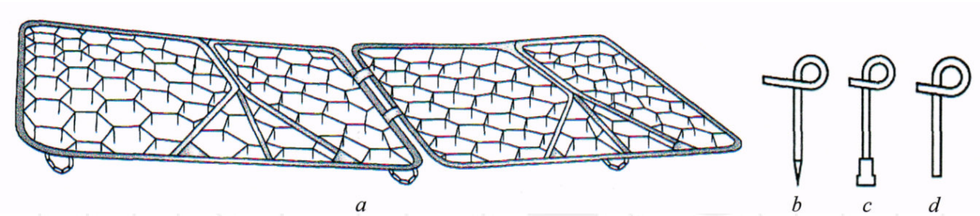
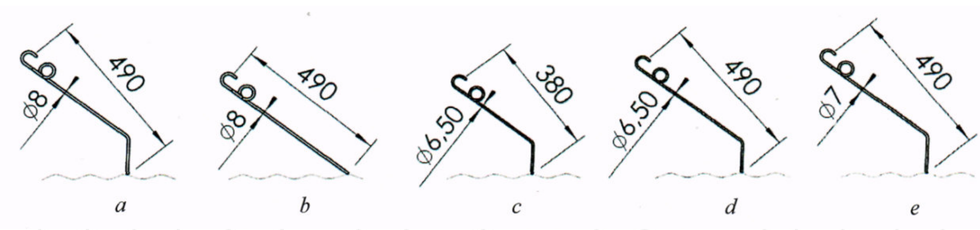


Figure 25. Mesh harrow (*a*) and harrow rods: *b* – pointed, *c* – flat; *d* – obtuse [30, 31].

Articulated harrows do not have a stiff frame. Separate chains of articulated harrow are flexibly connected among themselves and make an articulated net. This harrow adapts well to soil unevenness. An articulated harrow with blade rods is used for the care of meadows and pastures.

Digital harrow is a light harrow used for crop care. Sometimes it is used in a set with a continuous operation cultivator and seeding machines. It is made of long springing rods located in several rows. With this harrow, soil is loosened at the depth of 0.10–030 m.

Depending on soil characteristics, harrow rods may be chosen for crop harrowing accordingly (Figure 27). Thicker rods are used for heavier soils, thinner for lighter; in very stony soils, straight rods are used, and in less stony soils, bent rods are used.



a – for heavy soil; *b* – for stony soil; *c* – for average weight soil; *d* – for light soil; *e* – for various soils (universal) [32].

Figure 26. Harrow rods

Rotation harrow is made of rotors with rods turning around the horizontal (Figure 28) or vertical axle. They destroy weeds and rip the soil crust in row-spacing. A rotation harrow with a horizontal rotor is usually mounted in row-spacing cultivators. A rotation harrow with a rotor turning around the vertical axle is used for the cultivation of stony soil.

Figure 27. Rotation harrow [26]

For mechanical post-sowing weed destruction (when chemical methods are not allowed) in ecological farms, a harrow made of many sections with a flexible frame, called an ***ecological harrow***, may be used (Figure 26).

Figure 28. Ecological harrow: a means for post-sowing crop harrowing [32].

Such a harrow is light, it copies soil surface well and destroys weeds without damaging the crop. Short-age weeds are the most sensitive to harrowing by such a harrow: *Chenopodium album*, *Sinapis arvensis*, *Galeopsis tetrahit*, *Polygonum lapathifolia*, *Polygonum aviculare*, *Capsella bursa-pastoris*, *Euphorbia helioscopia,* et al. It is advisable to harrow on a clear day when the sun is shining because in such weather weeds are destroyed better. The harrow's effectiveness depends on the composition of weeds, harrow time and meteorological conditions.

4. Conclusions

Weed control is an important link in the chain of technological crop supervision. In order to perform this technological operation properly, it is important to know the characteristics of weeds and properly select technical-technological measures to destroy them. The most commonly used and most effective plant care and weed control methods are chemical (using loose and liquid chemical products) and mechanical (using agricultural implements, cultivators and harrows). These basic weed control techniques and technologies are analysed in this educational book.

Technical-technological measures for effective plant weed control methods – chemical and mechanical – are presented. Plant protection machines using chemical products are classified into the following groups: sprayers, powder distributors, fumigators and pickling machines. Sprayers are classified according to a variety of features: power source, destination and spraying method. An important part of sprayers is the sprayer beam, which during operation has to hold the nozzles parallel to the sprayed surface so that the sprayed solution is distributed evenly. Different types of nozzles are fastened on a sprayer beam, and they are classified into a number of types: according to operational mode, nozzles are classified into hydraulic, pneumohydraulic and rotational; according to the form of the sprayed liquid, hydraulic nozzles are classified into flat-flow, cone-flow and stream, and pneumohydraulic into to flat-flow and cone-flow; according to construction, rotational nozzles are classified into disc and drum, and pneumohydraulic into pressure and injection, etc. The particularities of self-propelled hydraulic field sprayer construction and operation are described in this book, too.

Weeds may be automatically recognized in two ways: by optical-electronic sensors measuring the reflecting light spectrum, and by using digital video cameras and handling systems for the filmed views. Some schemes are presented and discussed: the weed distribution scheme of optical-electronic sensors using the weed recognition system Detectspay®; an equipment scheme in which views filmed by the video camera are used for weed recognition; maps of crop weeding and spraying and a sprayer control scheme according to a crop spraying map; the ultrasound sensor P3, attached to a field sprayer's beam for precise plant protection, and the OptRx sensors for plant optical analysis, which are used to research the optical peculiarities of the cultivated plants. These sensors measure the reflected rays in the infrared and red spectra ranges.

For weed control by mechanical means, two groups of machinery can be used – cultivators and harrows. Cultivators are classified as continuous soil operation, hard and row-spacing. They may have passive or rotating operational parts. Constructions and operational parts of continuous operation and row-spacing cultivators are presented and described. Harrows can be classified according to the type of operational parts – into rod, spring, mesh, digital, knife and rotation; according to purpose, harrows may be used for pre-sowing and post-sowing harrowing; according to harrowing direction, they may be classified as lengthwise, transversal, diagonal and harrowing in a circle, i.e., by the field cut-out. Various constructions and operational parts of harrows can be used for weed control: rod harrows, spring harrows, mesh harrows and harrow rods, articulated, digital and rotation harrows, and ecological harrows for post-sowing crop harrowing.

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Chapter 3

Weed Control by Organic Mulch in Organic Farming System

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Darija Jodaugienė and Kristina Bajorienė

Additional information is available at the end of the chapter

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1. Introduction

Weeds are one of the most significant agronomic problems in organic farming [1] and they are an important factor limiting the spreading of organic farming system in the world [2]. Mulching reduces weed incidence in crops [3–7] and is increasingly used as a weed control measure, which is of special relevance in an organic cropping system when growing high quality and safe plant raw materials for food production [8]. Mulching of plant residues is applied in agricultural crop production and exerts many-sided effects on the agroecosystem [9]. [4], [6], [10], estimated that mulches (straw, grass and others) provide weed control. Mulches can control weeds by several ways: as physical barrier and by associated changes in the microclimate, pH, C:N ratio of the soil, immobilization of nutrients, inhibition by allelopatic compounds, less amount of visible light reaching the soil surface. Organic mulches maintain a more stable soil temperature and optimal moisture content, which results in more favourable conditions for living organisms' activity in the soil [11]. Organic mulches enhance soil enzyme activity [12, 13], amount and diversity of soil biota [14–16]. Soil biological properties largely determine crop productivity in organic farming system. Mulching often is used for the influence on soil physical properties. Mulching helps to reduce moisture evaporation from the soil, diminish and maintain a more constant soil temperature [17–19], and this is also very important for the crop growth and yield. Natural organic mulch eventually breaks down and adds organic material back into the soil. Slow nutrient release during mulch decomposition process is more synchronized with plant needs [20, 21]. It was found that straw mulch [22] and grass mulch [23] tended to increase available phosphorus and potassium contents in the soil. Quickly decomposing organic mulch serves as an important source of nutrients for plants. Significantly higher crop yields were obtained in grass mulched plots not only due to weed smothering but due to higher plant nutrient content in the soil and better soil physical properties [24]. Better growing plants have higher ability to suppress weeds.

Some research evidence suggests that mulching reduces the occurrence of annual weeds; however, it does not exert any effect on perennial weeds [25–27]. Plant residues (straw and others) used as mulch have been found to suppress weed emergence and growth due to the phytotoxins released during the breakdown process [28–30]. Many authors [25, 26, 31] observed a reduction in the number of annual weeds using crop residues for soil mulching. A reduction of weed density was established as the level of soil cover increased [3]. Mulching reduces soil bulk density and shear strength and increases air filled porosity [32–34]. The growth of some perennial weeds depends on those soil properties [35].

Some organic mulches are good for using in large scale farms –over-ground mass of catch crops, peat, sawdust, straw and other residues of agricultural crops. In small scale farms and gardens we can use still varied organic residues for mulching: grass regularly cut from grass-plots, hulls of sunflower seeds, nuts, coffee beans and others.

The aim of the investigation was to evaluate the influence and the residual effect of different organic mulches and different thickness of mulch layer on weed emergence.

2. The investigation of organic mulches for weed control

The two factor stationary field experiment was carried out at the Experimental Station of Aleksandras Stulginskis University (previously Lithuanian University of Agriculture) (54°53'N, 23°50'E). The soil type – *Calc(ar)i – Endohypogleyic Luvisol.* The influence of organic mulches and different thickness of mulch layer on weed density was investigated in 2004–2009, in 2010–2012 the residual effect of the mulches and mulch layer was studied. Treatments of the experiment: Factor A – mulch: 1) without mulch; 2) straw mulch (chopped wheat straw); 3) peat mulch (medium decomposed fen peat); 4) sawdust mulch (from various tree species); 5) grass mulch (regularly cut from grass-plots). Factor B – thickness of mulch layer: 1) 5 cm; 2) 10 cm.

Randomised design was used (Fig.1.). Individual plot size was 2 x 6 m. The experiment involved 4 replications.

In 2004 in each plot common bean *Phaseolus vulgaris* L. cultivar *Baltija*, 2005 – common onion *Allium cepa* L. cultivar *Stuttgarter Riesen*, 2006 – red beet *Beta vulgaries* subsp. *vulgaris* convar. *vulgaris* var. *vulgaris* L. cultivar *Cylindra*, 2007 – white cabbage *Brassica oleracea* var. *capitata* f. *alba* L. cultivar *Kamennaja golovka* in raws with interlinears 0.5 m, 2008 – potatoes *Solanum tuberosum* L. cultivar *Anabela* in raws with interlinears 0.7 m, in – 2009 – *Phaseolus vulgaris* L. cultivar *Igoloneska* in raws with interlinears 0.5 m were grown. In 2010, common onion *Allium cepa* L. cultivar *Stuttgarter Riesen*, in 2011 – red beet *Beta vulgaris* subsp. *vulgaris* convar. *vulgaris* var. *vulgaris* cultivar *Kamuoliai,* and in 2012 – white cabbage *Brassica oleracea* var. *capitata* f. *alba* L. cultivar *Kamennaja golovka* was grown.

Figure 1. Field experiment

In 2004–2009 mulch was spread manually in a 5 cm and 10 cm thick layer shortly after sowing (planting). Remains of mulch were inserted into the soil by ploughing. The soil was ploughed after crop harvest in the autumn. In 2010—2012 in all experimental plots crops were grown without mulch, the residual effect of organic mulches was investigated. During all period of experiment the crops were grown employing common organic crop production technologies. The plots without mulching were weeded 2–3 times per vegetation. No chemical plant protection products and fertilizers were used when investigating the influence and residual effects of mulches. The C:N ratio in the mulches used was as follows: in straw 51:1; in peat 40:1; in sawdust 133:1; in grass 11:1.

Weed emergence dynamics. Weed seedlings were counted in each plot in four permanent 0.2 × 0.5 m sites. Assessments were done every 10 days from May to October. During each assessment, the weeds were pulled out, counted and their species composition was determined. The number of weeds was re-calculated into weeds m^{-2}.

Number of weed seeds in the soil. Soil samples were taken by a sampling auger from the 0-25 cm layer after harvesting of agricultural crops. The number of weed seeds was determined by [36] method. The number of weed seeds found in the arable layer (0-25 cm) was re-calculated into thousand seeds m^{-2}.

The means were compared using Fisher's protected LSD test at $P_{(level)}$ <0.05 with ANOVA procedure with SYSTAT 10 [37]. Data transformations lg(x+1) were used as necessary to achieve statistical normality [38]. Pearson's correlation coefficient was used to evaluate the relationships between indices. Probability level: *– 95 %, ** – 99 %, *** – 99.9 %.

3. The dynamics of weed emergence in plots mulched with organic mulches and different thickness of mulch layer

The carried out investigations show that mulching of soil with various organic mulches is particularly important in the first part of summer. In the second part of summer and at the beginning of autumn weed emergence is weaker in comparison with that in the period of spring and early summer, therefore, lower influence of mulch is established.

In 2004 common bean crop was damaged by spring frost for two times, particularly in plots mulched with sawdust. As crop was thin, intensive weed emergence in plots without mulching was lengthen out. According to the data of 2004, sawdust had the longest impeding effect on weed germination (Table 1). Though crop in plots mulched with sawdust was weak, weed emergence was not intensive: at the beginning of summer weed density was established to be by 5.4-11.4 times lower than that in the plots without mulching. The allelopatic effect of sawdust could be a reason of such results.

Peat, straw and grass provide different reducing impact on weed germination. Straw mulch has the most obvious reducing impact (3.5-14.1 times) on weed emergence in June. Later, however, after abundant appearance of *Tripleurospermum perforatum* (Merat.) M. Lainz, which seeds have infected the mulch, the weediness is higher than that in the soil without mulch (July 20). After most of seeds of *Tripleurospermum perforatum* have germinated, the positive influence of mulch comes out again.

Sampling time	Weeds units m^{-2}				
	Without mulching	**Straw**	**Peat**	**Sawdust**	**Grass**
10 06	440.6	31.2***	62.6***	38.8***	24.7***
20 06	204.4	58.1***	44.1***	38.1***	26.2***
30 06	233.4	45.9***	46.6***	25.9***	25.9***
10 07	144.0	85.6***	34.1	20.9***	52.5***
20 07	54.7	113.1	38.1	30.0**	66.2
30 07	50.6	33.1	22.2*	11.6***	45.3
10 08	67.5	40.9**	30.9*	23.4**	44.4**
20 08	54.7	33.4*	20.6*	23.4**	38.4
30 08	34.4	20.3*	18.1*	16.9**	32.2
10 09	25.0	13.4	10.3	14.1	23.1
20 09	5.3	5.3	7.5	6.2	18.1
30 09	25.3	15.0	5.3***	15.0*	29.4
10 10	25.6	20.6	5.0***	16.6	31.6
20 10	13.4	6.6*	2.8***	8.1***	12.5

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 1. The influence of different organic mulches on weed emergence dynamics in common bean crop, 2004

At the beginning of summer peat has slightly weaker impeding effect on weed emergence (4.2-7.0 times), which, however, is uniform during the entire investigational period. Positive effect of grass mulch is manifested at the beginning of the investigations and reduces weed germination from 17.8 to 2.7 times. Later, after decomposition of grass has started, this mulch has no significant influence. Experiments conducted in Hungary indicated that mulching with straw, grass and other materials showed good results in weed control [4].

Even stronger positive influence of mulches on the decrease of weed emergence was determined in 2005. Weed control means in common onion crop are very important because common onion crop hasn't good smothering effect on weeds. In contrast to that in previous years, straw mulch was the best to reduce weed germination, as the mulch itself was not infected with weed seeds (Table 2). A number of studies have documented that straw mulch is a good mean decreasing weed emergence [5, 6]. Though [39] stated that there was no significant effect of straw mulch on number of weeds, but they explain it was mainly attributed to the low amounts of straw applied.

The number of weeds that germinated in the beginning of summer in mulched soils was by 30.9-50.6 times lower than that in the soils without mulch. Later this positive influence weakened but remained for the entire vegetation period. Peat had the influence similar to that in the previous years of investigations.

Sampling time	**Weeds units m^{-2}**				
	Without mulching	**Straw**	**Peat**	**Sawdust**	**Grass**
10 06	207.5	4.1***	65.6***	43.5***	6.3***
20 06	436.3	14.1***	65,9***	56.0***	23.4***
30 06	95.6	22.8***	36.6***	45.9***	16.6***
10 07	76.3	22.5***	18.1***	38.4**	8.8***
20 07	25.6	15.6	24.7	29.0	5.3**
30 07	41.3	13.4***	5.6***	18.4***	16.7***
10 08	30.0	10.1***	6.3***	11.6***	7.8***
20 08	43.8	6.6***	5.3***	7.5***	40.3
30 08	66.3	11.9***	14.0***	11.6***	56.3
10 09	31.0	6.6**	11.0**	4.7***	30.0
20 09	77.5	26.3**	17.8***	20.3***	84.7
30 09	126.3	19.1*	82.2	9.4**	209.4
10 10	95.6	22.8	31.3	7.5	158.1

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 2. The influence of different organic mulches on weed emergence dynamics in common onion crop, 2005

The effect of chopped grass remained until the first decade of August, the number of germinated weeds was significantly lower (by 2.0-32.9 times) than that in the plots without mulch. However, later the weed emergence became equal and even started increasing as rapid germination of *Poa annua* L., which might have got into together with the used mulch, started. During the entire vegetation period grass mulch decreased the germination of weeds by 2.0 times in comparison to that in the soil without mulch.

In 2006 mulches were spread late – after the red beet sprouting (Table 3). The first weed sampling time was before mulching. No significant differences in weed number between plots without mulching and plots mulched with different organic mulches were obtained. Though the highest number of weeds was estimated in plots where grass mulch in previous year was used, the grass mulch smothered weeds significantly till the end of September. Weed germination and re-growth decreased on July 30, and the influence of straw, peat and sawdust mulches on weed number at this sampling time was not significant. In 2006 al examined organic mulches suppressed weeds in red beet crop very well.

Sampling time	Weeds units m^{-2}				
	Without mulching	Straw	Peat	Sawdust	Grass
10 06•	457.7	496.9	525.9	438.5	592.1
30 06	286.6	49.4***	70.3***	54.1***	29.1***
10 07	62.2	31.3**	22.8***	37.8	12.8***
20 07	114.1	27.2***	21.3***	31.6**	10.0***
30 07	53.1	40.3	30.3	39.4	12.2***
10 08	58.4	16.6***	19.1***	21.6**	10.0***
20 08	234.7	36.6***	50.9***	53.1***	47.8***
30 08	104.4	35.3***	33.4***	20.9***	31.9***
10 09	93.4	34.7***	30.6***	30.0***	33.1***
20 09	56.9	21.9*	14.4*	18.8**	22.2*
30 09	38.1	22.2*	54.7	24.4	16.6***
10 10	38.4	15.9***	17.8*	19.4**	23.4

● – before mulching

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 3. The influence of different organic mulches on weed emergence dynamics in red beet crop, 2006

All examined organic mulches significantly suppressed weed emergence during the most intensive weed germination period in May 30 (by 11.7-32.6 times) and June 10 (by 7.5-19.4 times) in 2007 (Table 4). The suppressing effect of organic mulches weakened when weakened weed germination (June 20). The significant suppressing grass mulch effect on weed emergence persisted till the August 10. In 2007 the grass mulch was the best means for weed control till the end of summer (August 30). During the first part of summer grass mulch effectively smothered weeds, and during the second part of summer white cabbage crop smothered weeds very well.

Sampling time	Weeds units m^{-2}				
	Without mulching	**Straw**	**Peat**	**Sawdust**	**Grass**
30 05	293.6	11.3***	25.0***	24.5***	9.0***
10 06	324.5	21.1***	31.5***	43.1***	16.7***
20 06	57.0	47.3	43.1	63.5	19.3**
30 06	93.1	35.6***	34.3***	46,7**	18.1***
10 07	60.0	43.3	28.5	44.6	23.8*
20 07	65.5	33.0*	32,5*	41.1	9.9***
30 07	32.5	36.8	17.3	34.8	17.3*
10 08	40.8	25.4	16.4	31.8	12.3*
20 08	28.1	31.8	13.5	24.1	7.4
30 08	25.9	25.1	12.4	22.0	11.8
10 09	45.3	46.9	13.1*	21.0	22.4
20 09	31.6	22.0	14.3	14.4	18.4
30 09	35.3	28.4	19.8	16.9	29.0

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 4. The influence of different organic mulches on weed emergence dynamics in white cabbage crop, 2007

In 2008, potatoes after planting were harrowed, were hilled after sprouting and then mulches were spread. Spring in 2008 was very dry, without rainfall till the second half of June. Because of lack of humidity we had no grass mulch at the beginning of June. The grass mulch was polluted with matured weed seeds. The lowest number of weeds emerged at the first sampling date in June 20. Late weed germination and re-growth was intensive: weed number in plots without mulch at different sampling times varied from 109.7 to 651.6 units m^{-2} (Table 5). All examined organic mulches significantly suppressed weed emergence till the end of July. From that date the effect of grass mulch weakened, and the number of weeds in grass mulched plots exceeded the number of weeds in plots without mulch.

In 2009 straw and sawdust mulch significantly decreased weed emergence during all experimental period (Table 6). The significant suppressing effect of grass mulch ended at the end of July.

Sampling time	Weeds units m^{-2}				
	Without mulching	Straw	Peat	Sawdust	Grass
20 06	22.2	0.6**	5.3*	10.3	1.9*
30 06	651.6	28.4***	145.9***	43.1***	183.8***
10 07	133.8	37.2*	59.1	36.9*	81.9*
20 07	157.8	37.8***	61.3**	38.4***	796.3**
30 07	181.9	19.4***	28.1***	26.6***	65.0***
10 08	241.9	100.0	40.3***	60.0**	156.3
20 08	214.7	25.9***	21.9***	34.4***	320.6
30 08	118.4	49.1	98.4	71.3	1947.2***
10 09	109.7	60.6*	27.8***	19.4***	438.8**

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 5. The influence of different organic mulches on weed emergence dynamics in potatoes crop, 2008

Sampling time	Weeds units m^{-2}				
	Without mulching	Straw	Peat	Sawdust	Grass
10 06	313.4	27.8***	199.4	20.9***	46.9***
20 06	293.4	14.1***	106.9***	36.3***	20.9***
30 06	205.4	14.4***	50.9***	20.6***	47.7***
10 07	150.0	17.1***	22.3***	17.2***	25.7***
20 07	82.2	5.2***	14.5***	11.1***	10.4***
30 07	66.1	5.6***	9.1***	13.3***	15.6**
10 08	45.6	8.4*	12.5	23.4	48.1
20 08	47.8	14.4**	9.1***	14.7**	50.6
30 08	37.9	8.8**	4.4***	10.3*	72.2
10 09	22.5	11.6**	9.2***	12.8*	104.5

*- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

Table 6. The influence of different organic mulches on weed emergence dynamics in common bean crop, 2009

Perennial weeds. The results of the experiments carried out in Lithuania showed that straw mulch suppressed emergence of annual weeds but not perennial [27]. By the data of our experiments, the effect of organic mulches on the germination and re-growth of perennial weeds is weaker than the effect of organic mulches on germination of annual weeds [7]. In 2007 at the end of spring (May 30) and at the beginning of summer (June 10) the higher amount of perennial weeds was established in experimental plots without mulching. Grass mulch well suppressed perennial weeds during all vegetation period (Fig. 2).

Contrary results were obtained in 2008: the germination and re-growth of perennial weeds was more intensive in unmulched plots during all sampling time. The lowest amount of perennial weeds was obtained in plots mulched with straw and grass mulches.

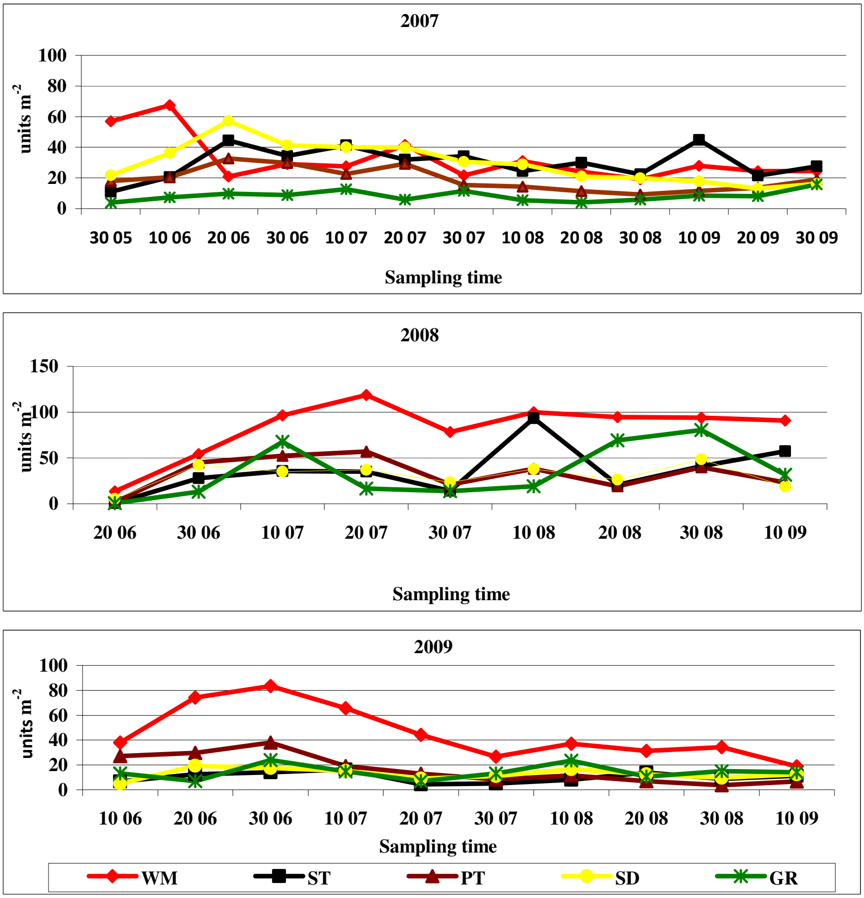

Figure 2. The influence of organic mulches on perennial weed emergence dynamics, 2007–2009. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass.

In 2009 the highest number of perennial weeds germinated and re-grew in plots without mulching during all vegetation period. Significant differences between the number of perennial weeds in unmulched plots and plots mulched with different organic mulches were established at many sampling dates.

Annual weeds. The period of more intensive germination of annual weeds is from the middle of May to the middle of June [40]. In 2007 all examined organic mulches well suppressed annual weed germination. The mulching as annual weed control means was particularly important at the first part of summer (Fig.3).

The contrary results were obtained in 2008 when *Poa annua* L. germination in plots mulched with grass mulch prolonged during all vegetation period. Grass mulch has been infected with seeds of *Poa annua*. The number of germinated annual weeds in grass mulched plots exceeded the number of annual weeds in unmulched plots during almost sampling dates from the 20 of July.

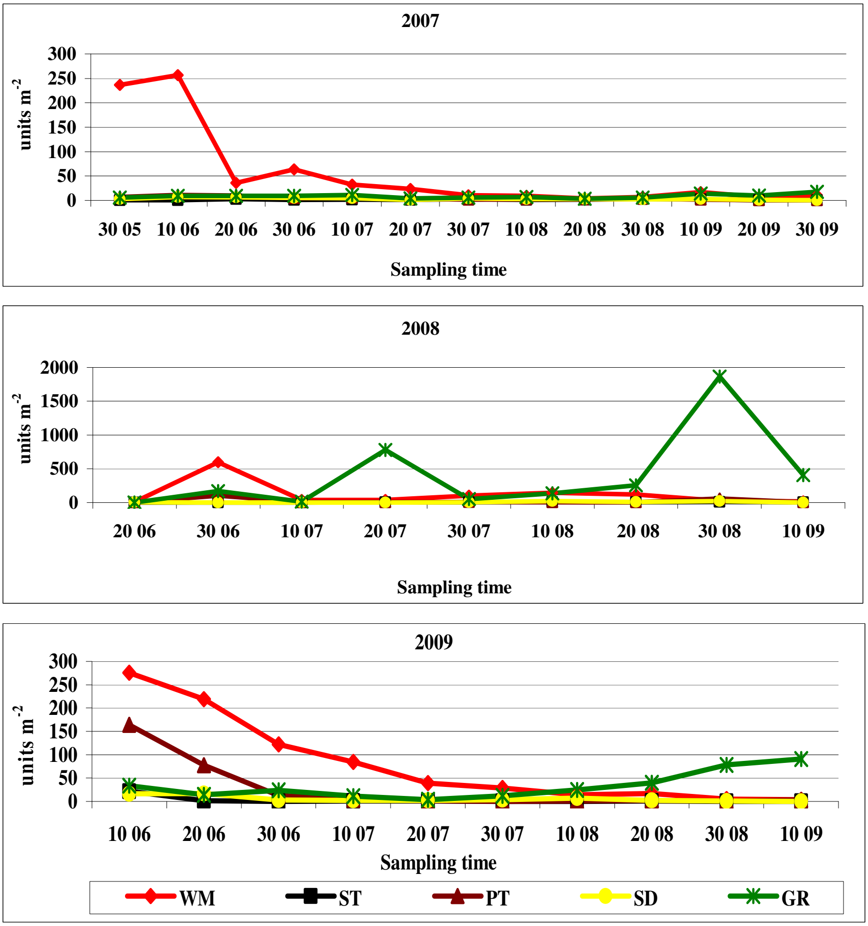

Figure 3. The influence of organic mulches on annual weed emergence dynamics, 2007–2009. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass.

In 2009 the germination of annual weeds in unmulched plots was significantly more intensive till July 30 compared with germination of annual weeds in plots mulched with all examined organic mulches (Fig. 3). From the beginning of August the suppressive effect of grass mulch on annual weed germination disappeared. During this period the suppressive effect on annual weeds of straw, peat and sawdust mulches persisted.

4. The total weed amount influenced by mulching

Mulching decreased weed density (Fig. 4). By the data of our experiments, the best for weed control is straw mulch. In plots with straw mulch weed density was established for 2.6-10.0 times lower compared with weed density in plots without mulch. Significant differences between weed density in plots mulched with peat and sawdust compared to weed density in plots without mulch were estimated.

The influence of grass mulch on weed emergence is not equal. In 2004-2009 (except 2008) grass mulch significantly decreased weed number – by 2.6-5.4 times compared with weed number in unmulched plots. In 2008 weed density in plots mulched with grass was established higher that is in plots mulched with straw, peat and sawdust due to rapid emergence of *Poa annua* at the second part of summer. In 2008 number *of Poa annua* formed a big part – 79.5% of total weed number, as in 2005 – 11.3%, 2006 – 4.9%, and 2007 – 5.1%.

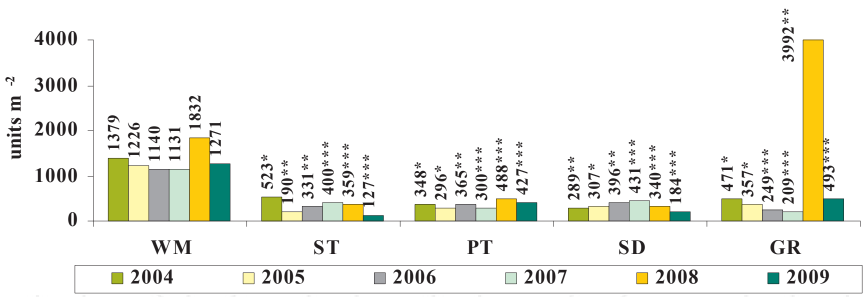

Figure 4. The influence of organic mulches on weed density, 2004-2009. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass. *- 95 % probability level, ** - 99 % probability level, *** - 99.9 % probability level

The influence of peat and sawdust mulch on weed density was significant during all experiment period in 2004–2009. Weed density in peat mulched plots was lower by 3.0-5.4 times compared with this in plots without mulch and weed density in sawdust mulched plots was lower (by 2.6-6.9 times) compared with this in plots without mulch. The growth of agricultural crops in plots with sawdust mulch was poor and the yield obtained was the lowest (Fig.5.).

Weed density in plots mulched with 10 cm mulch layer was lower compared with plots mulched with 5 cm mulch layer (Fig. 6). Differences were significant in 2004, 2006, 2008 and

2009. The thickness of mulch layer is important for weed control. Thick enough layer of organic mulch can serve as physical barrier for weeds.

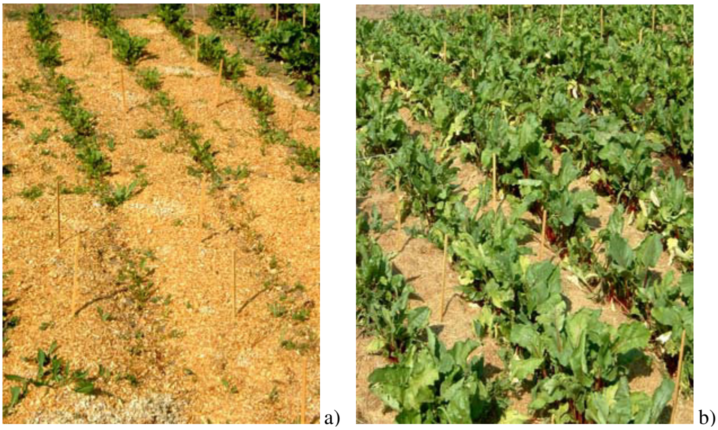

Figure 5. Red beet crop in plots mulched with sawdust (a) and mulched with grass (b)

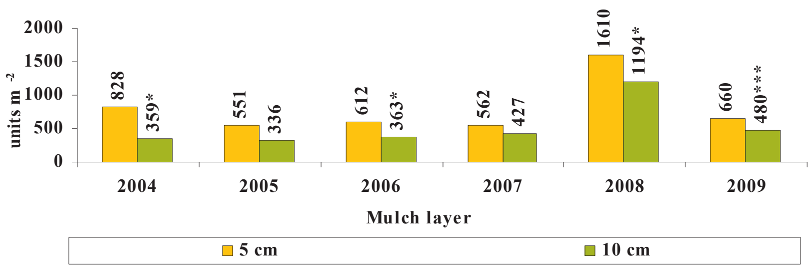

Figure 6. The influence of different thickness of mulch layer on weed density, 2004-2009 yers. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass. * – 95% probability level, *** – 99,9% probability level

5. Mulching effect on weed seed bank

The formation of weed seed bank is multiplex process, belonging on various factors. Weed seed bank in the soil in unmulched plots and plots mulched with different layer of organic mulches was studied in 2007-2009, after three years from the beginning of the experiment. There was no significant influence of mulching on weed seed bank during all experimental period.

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The tendency of lower amount of weed seeds in the soil in plots mulched with straw, peat and sawdust was investigated. Only grass mulch increased the total amount of weed seeds in the soil. We used the grass regularly cut from grass-plots for mulching, but sometimes it could be polluted with weed seeds. Moreover, the grass mulch quickly decomposes and its effect on weed control is shorter compared with other studied mulches. Some matured weeds seeds in grass mulched plots can supplement weed seed bank in the soil. It is very important to use the grass for mulching from plots which are cut every few days (4–7) if we are concerning about weed seed bank.

Seeds of *Chenopodium album* L., *Echinochloa crus-galli* L. (Beuv.) and *Stelaria media* L. dominated in the weed seed bank of all experimental plots (Fig.7). It is known that seeds of *Chenopodium album* amount about 90% of weed seed bank [41].

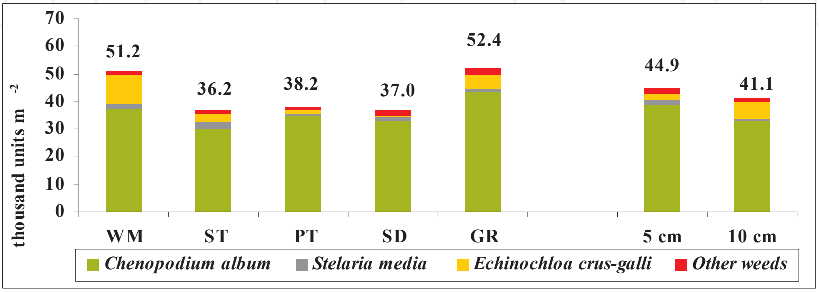

Figure 7. The influence of organic mulches and different thickness of mulch layer on weed seedbank, 2007. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass. $P > 0.05$

The tendency of higher number of *Chenopodium album* seeds in the soil of grass mulched plots was observed in 2007 and 2008. The part of *Echinochloa crus-galli* seeds increased in 2008, especially in plots without mulch and plots mulched with peat (Fig.8).

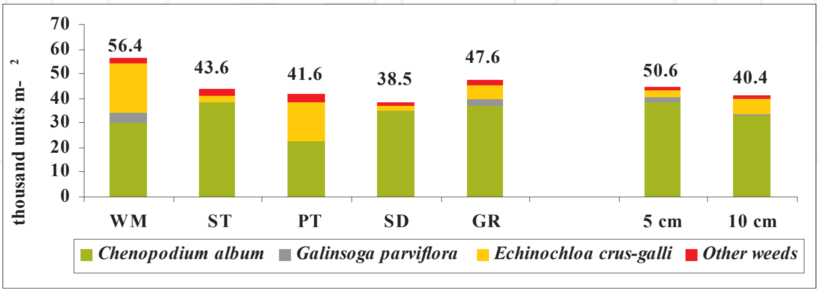

Figure 8. The influence of organic mulches and different thickness of mulch layer on weed seedbank, 2008. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass. $P > 0.05$

In 2009 the lower total amount of weed seeds in the soil was evaluated in mulched and unmulched plots (Fig. 9). The number of seeds of *Echinochloa crus-galli* in unmulched plots and plots mulched with peat decreased, but in plots mulched with straw, sawdust and grass increased.

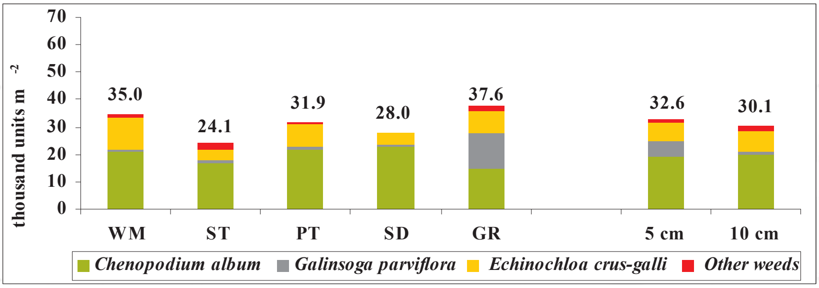

Figure 9. The influence of organic mulches and different thickness of mulch layer on weed seedbank, 2009. WM – without mulch, ST – straw, PT – peat, SD – sawdust, GR – grass. $P > 0.05$

The tendency of the lower amount of weed seeds in the soil was established in plots mulched with thicker (10 cm) mulch layer compared with this in plots mulched with thinner (5 cm) mulch layer during all experiment period 2007–2009.

No significant correlation between the amount of sprouted weeds and weed seeds in the soil was established in 2007. Very strong or strong significant correlation between the amount of sprouted weeds and weed seeds in the soil was established in 2008 ($r = 0.96$; $P < 0.05$) and in 2009 ($r = 0.92$; $P < 0.05$). *Chenopodium album* L. was the dominant weed in crops and *Chenopodium album* seeds dominated in weed seed bank and influenced correlations.

6. The residual effect of organic mulches on weed incidence in crop stands

Soil coverage with any organic mulch inhibits weed emergence at first due to the shortage of light and changed moisture and warmth regime [25]. The previously six year used and incorporated organic mulches did not significantly decreased total weed amount in 2010–2012 because they do not mechanically suppress weed emergence (Fig. 10). Total weed number in experimental plots during 2010–2012 was influenced by weed smothering ability of crops. The lowest total weed number was evaluated in 2012 when white cabbage was grown, and the highest – in 2010, when the common onion was grown.

The tendency of lower amount of weeds in plots previously mulched with sawdust was established in 2011–2012. Due to allelophatic effect the decrease of growth and yield of agricultural crops in plots mulched with sawdust was evaluated in 2004-2012. Decreased weed density in plots mulched with sawdust was significantly lower in 2004-2009. Weeds could be

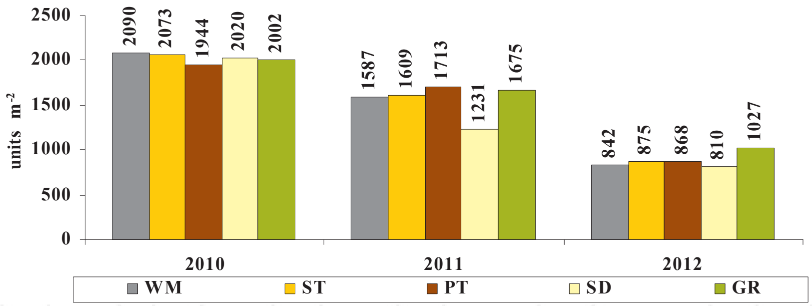

Figure 10. The residual effect of organic mulches on the weed emergence, 2010–2012; $P > 0.050$

affected by the allelophaty too. But the strongest effect on weed emergence and re-growth was the effect of organic mulches as physical barrier.

In 2010 and 2012 the higher weed emergence was established in plots previously mulched with thicker (10 cm) mulch layer (Fig. 11). But in 2011 significantly lower amount of emerged weeds was evaluated in mentioned plots.

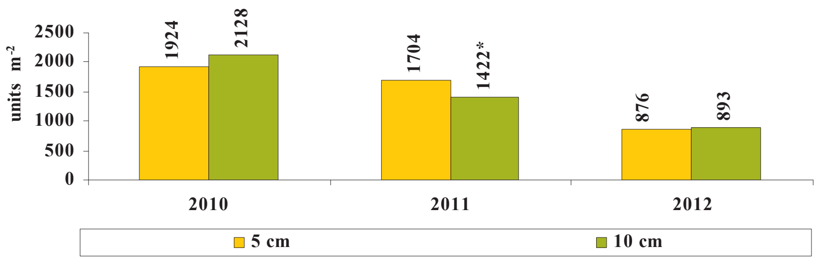

Figure 11. The residual effect of the thickness of mulch layer on the weed emergence, 2010–2012; $P > 0.050$

The residual effect of organic mulches on the emergence of annual weeds was not significant (except plots with peat mulch in 2011), but not the same that on perennial weeds. In 2010, the first year after the use of organic mulches all of the previously used and incorporated organic mulches reduced the abundance of annual weeds during the entire vegetation period (Fig. 12). The residual effect of straw, peat and grass was weaker and tended to reduce (by 6.2–11.4 %) the abundance of annual weeds during vegetation. In 2011, when studying grass and peat residual effect a trend towards increasing (by 4.8–11.2 %) of abundance of annual weeds during the whole vegetation was established.

In 2012, the previously used and incorporated grass mulch significantly (by 1.3 times) increased emergence of annual weeds. The previously incorporated sawdust mulch reduced the abundance of annual weeds most markedly in all experimental years.

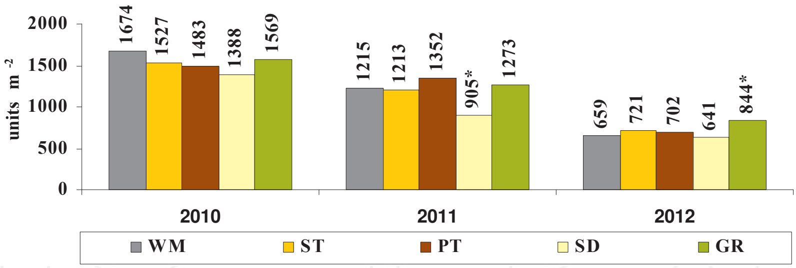

Figure 12. Residual effect of organic mulches on the emergence of annual weeds in 2010-2012; * - 95.0% probability level

Species composition of annual weeds was determined during the 2010–2012. Out of annual weeds the most abundant emergence was exhibited by *Echinochloa crus–galli* (L.), *Galinsoga parviflora* and *Poa annua* L. The residual effect of organic mulches on the emergence of annual weeds was irregular. The previously incorporated thicker mulch layer tended to diminish *Galinsoga parviflora* and *Poa annua* L. emergence, and exhibited uneven effect on *Echinochloa crus–galli* (L.) emergence, compared with the thinner mulch layer.

Perennial weeds. In 2010, the previously used and incorporated straw, peat and sawdust mulches tended to increase (by 11.3–31.5 %) the abundance of perennial weeds during vegetation period; however, the increase was insignificant (Fig. 13). When investigating residual effect of grass mulch, we established a trend towards reduction (by 12.4 %) of re-growth of perennial weeds. In 2011, the previously used and incorporated straw and grass mulches tended to increase (by 7.9–30.1 %) re-growth of perennial weeds, while peat and sawdust mulches tended to reduce it (by 8.3–12.4 %); however, insignificantly. In 2012, no significant differences in the abundance of perennial weeds were established.

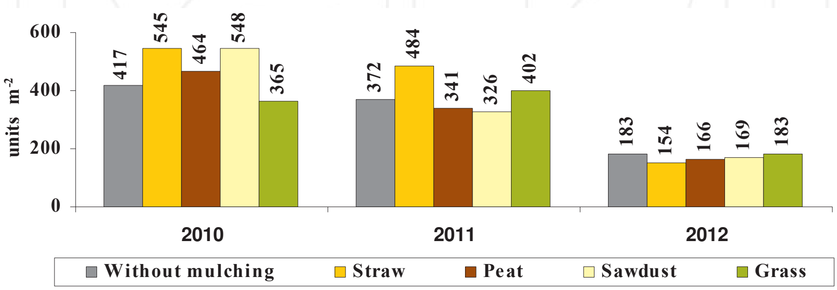

Figure 13. Residual effect of organic mulches on the emergence of perennial weeds in 2010-2012; there are no significant differences: $P > 0.050$

In 2010 and 2012, the previously incorporated thicker (10 cm) mulch layer tended to increase (by 5.8 %) the abundance of annual weeds, and in 2011 it significantly (by 13.8 %) reduced annual weed abundance, compared with the incorporated thinner mulch layer (Fig. 14).

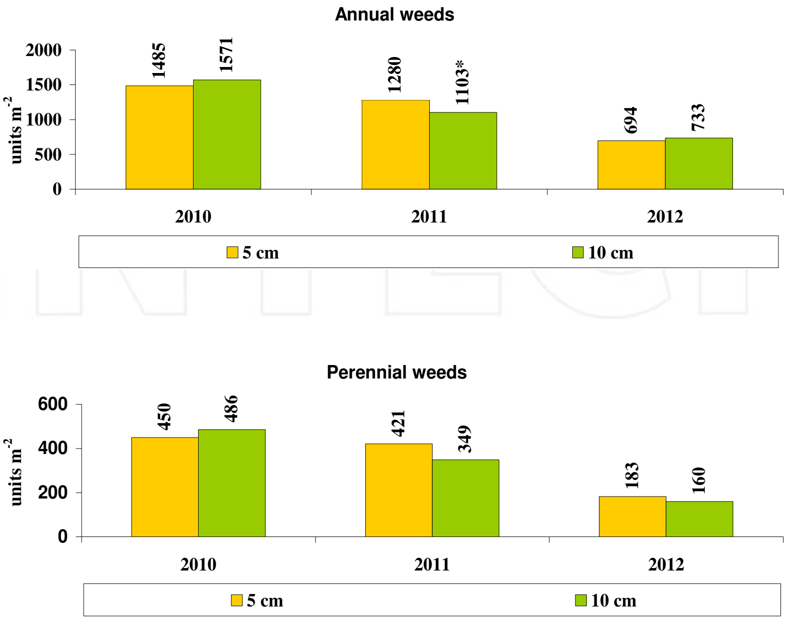

Figure 14. Residual effect of the thickness of organic mulch layer on the emergence of annual and perennial weeds in 2010–2012; there are no significant differences: $P > 0.050$

In 2010, the previously used and incorporated thicker 10 cm mulch layer tended to increase (by 8.0 %) re-growth of perennial weeds, and in 2011–2012 to decrease it (by 12.5–17.1 %), compared with the thinner 5 cm mulch layer; however, insignificantly.

Species composition of perennial weeds was determined. Of the perennial weeds the most prevalent were: *Sonchus arvensis* L., *Rorippa palustris* (L.) Besser., *Mentha arvensis* L., *Cirsium arvense* (L.) Scop., *Elytrigia repens* (L.) Nevski and *Taraxacum officinale* F. H. Wigg.). The residual effect of organic mulches on the re-growth of perennial weeds was unequal. The six year used and incorporated thicker mulch layer tended to reduce the re-growth of *Mentha arvensis*, *Rorippa palustris*, *Elytrigia repens* and *Taraxacum officinale* and tended to increase the re-growth of *Cirsium arvense*. The better re-growth of *Cirsium arvense* in plots mulched with straw, peat and sawdust was investigated in 2004–2007 [35]. The reasons for better *Cirsium arvense* emergence in mentioned plots can be various. As remains of mulch after harvesting were inserted into the soil by ploughing, soil shear strength decreased. Regression analysis of experiment data confirmed relationship between number of *Cirsium arvense* sprouts and soil shear strength.

7. Conclusions

1. All investigated organic mulches reduced weed emergence. Positive effect of mulches was particularly obvious in the period of intensive germination of weeds. Straw, peat and sawdust had the strongest influence on the decrease of weed germination and re-growth. Grass mulch quickly decomposed and its effect on weed density was shorter.

2. Germination of annual weeds was significantly reduced by all organic mulches applied. Re-growth of perennial weeds was significantly reduced by straw (up to 4.5 times), peat (up to 3.0 times), sawdust (up to 3.5 times) and grass (up to 3.9 times) mulches, however, they had a diverse effect on species composition of perennial weeds.

3. The residual effect of organic mulches on weed emergence was not significant. When the physical barrier – organic mulches – disappeared, the amount of weeds in the crop increased. The tendency of lower annual weed density in plots previously mulched with sawdust was established during 2010-2012. The re-growth of perennial weeds changed differently: *Rorippa palustris*, *Elytrigia repens* was significantly reduced by straw and peat mulches (by up to 1.9 times), while the re-growth of *Sonchus arvensis* was significantly increased by straw and sawdust mulches (by up to 2.9 times) and that of *Cirsium arvense* by sawdust mulch (by up to 16.8 times).

4. The influence of organic mulches and thickness of mulch layer on weed seedbank was not significant. The tendency of reduction of weed seedbank density was established in plots mulched with straw, peat and sawdust compared with plots without mulch and in plots with 10 cm mulch layer compared with plots with 5 cm mulch layer. Declining weed density in mulched plots decreased amount of weed seeds in the soil. But the amount of weed seeds in the soil may even increase when organic mulches are used. It is very important to make sure that mulches are not polluted with weed seeds. Dominant weed species in weed seedbank were: *Chenopodium album*, *Stellaria media* and *Echinochloa crus-galli*.

5. Organic mulches have different effects on agrocenosis, they suppress weeds by different ways, therefore a good knowledge of the characteristics of mulching materials and their proper choice are essential.

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Chapter 4

Weed Control by Soil Tillage and Living Mulch

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Dovilė Avižienytė and Aida Adamavičienė

Additional information is available at the end of the chapter

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1. Introduction

Reduced soil tillage can be classified as minimum, sustainable, conservation, ploughless or zero tillage. For example, in the United Kingdom, such tillage systems are commonly referred to as non-inversion tillage. These different types of non-reversible soil tillage methods maintain at least 30% residue coverage on the soil surface [1]. In reduced soil tillage practices, residue coverage leads to lower moisture evapotranspiration, higher soil water content and soil structural stability, and more effective prevention of soil erosion [2-4]. Compared to conventional annual deep soil ploughing, reduced tillage may decrease technological production costs and improve the economic effectiveness of agricultural practices [5]. However, weed control in such soil tillage systems is more complex. Reduced soil tillage leads to different weed seed bank distributions in the soil and occasionally lower herbicide effectiveness, which delays the time of weed seed germination because of crop residue coverage [6] and other indices.

How much do different soil tillage systems influence the weed infestation of crops? First, weed stand density depends on the competition ability of the crop. Cereals generally have higher competitiveness than do cultivated crops (beet, maize, and potato). For example, Vakali et al. [7] showed that in deeply cultivated plots, the barley crop weed shoot biomass was 65–88% higher than that in reversibly tilled plots, but in rye no clear influence was found. Ozpinar and Ozpinar [8] established that shallow soil rototilling (compared with mouldboard ploughing) increased the total weed density by 72 and 58% in maize and vetch crops, while the differences in wheat were low. Similar results were found by Mashingaidze et al. [9]. In crop rotations with maize, the highest weed stand differences were obtained between mouldboard ploughing and no tillage technologies. Occasionally, no tillage resulted in up to 20 times more weed infestation [10]. The spread of perennial weeds was typically more evident [11]. However, Streit et al. [12] showed that for no tillage technologies without herbicides, the weed density was lower than that in conventional or minimum tillage.

Different soil tillage intensities may slightly change the diversity of weed species in crops. In a 23-year experiment by Plaza et al. [13], in minimally tilled plots there were more weed species than in not tilled or traditionally ploughed plots. In a 14-year experiment by Carter and Ivany [14], the weed species diversity was slightly lower in ploughed soil than in shallowly or not tilled soil. In addition, high weed infestation resulted in substantial reductions in maize yield [15].

Worldwide experiments of reduced soil tillage have been widely and well documented, but investigations with maize crops (especially using the no-tillage system) are quite new in lands with low level of herbicide practice.

In chemicalless (ecological, organic, biological or similar) farming systems common problem is high risk of weed infestation. Weeds rival with crops for space, light, water and nutrients. Lazauskas [16] formulated the law of crop productivity, "...crop performance, expressed by the total mass of crops and weeds, is relatively constant and may be defined by the equation: $Y = A - bx$; Y – crop yield, A – maximum crop productivity, x – weed mass and b – yield depression coefficient". According to this law, the crop yield is inversely proportional to the crop weed mass. Rusu et al. [17] found similar results and concluded that maize green mass production losses could be considered equal to the mass of green weeds.

Living mulches (additional component of agrocenosis) can be useful for effective weed control [18]. According to the Lazauskas law, interseeded living mulch occupies part of total bio-production and may decrease weed infestation. Nakamoto and Tsukamoto [19] found that "living mulches are cover crops that are maintained as a living ground cover throughout the growing season of the main crop". The winter rye (*Secale cereale* L.), ryegrasses (*Lolium* spp.) and subterranean clover (*Trifolium subterraneum* L.) might be used to suppres weeds in corn crop (*Zea mays* L.) [20]. However, living mulches can compete for nutrients and water with the main crop and yields of crop could decrease [21, 22]. As a result, living mulch plants often must be mechanically or chemically controlled [23, 24].

2. Impact of different primary soil tillage methods on weed infestation

Soil tillage is the main method to control weeds. The most valuable is primary soil tillage. For answer how effective primary soil tillage methods are, the long-term stationary field experiment is being conducted at Aleksandras Stulginskis University's (up to 2011 Lithuanian University of Agriculture) Experimental Station. The field experiment was set up in 1988 in the then Lithuanian Academy of Agriculture's Experimental Station. The soil of the experimental field is *Endohypogleyic-Eutric Planosol – PLe-gln-w*. The thickness of the soil ploughlayer is 23–27 cm. Soil texture – loam on heavy loam. The upper part of the ploughlayer (0–15 cm) contained: pH_{KCL} – 6.6–7.0, available phosphorus – 131.1–206.7 mg kg^{-1}, available potassium – 72.0–126.9 mg kg^{-1}. Primary tillage methods investigated: 1. Conventional ploughing at 23–

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25 cm depth (CP) (control treatment); 2. Shallow ploughing at 12–15 cm depth (SP); 3. Deep cultivation at 23–25 cm depth (DC); 4. Shallow cultivation at 12–15 cm depth (SC); 5. Not tilled soil (direct sowing) (NT). Crop rotation in the experiment: 1) spring rape; 2) winter wheat; 3) maize; 4) spring barley. The experiment involved 4 replications. Each crop was cultivated in 20 plots. The initial size of plots was 126 m^2 (14 x 9 m), and the size of record plots was 70 m^2 (10 x 7 m). The plots of the experimental treatments were laid out in a randomised order. The protection band of the plot was of 1 m width and that between replications of 9 m width. After crop harvesting, all experimental plots (except for treatment 5) were cultivated by a disc stubble cultivator Väderstad CARRIER 300 at the 12–15 cm depth. JOHN DEERE 6620 tractor was used in the experiment. According to the experimental design, primary tillage was performed in August–September (for winter wheat) or in October (for spring crops). The soil was ploughed with a conventional plough Gamega PP-3-43 with semi-helical mouldboards at the 23–25 cm depth (treatment 1) or at the 12–15 cm depth (treatment 2). Deep cultivation was carried out by a ploughlayer's cultivator (chisel) KRG-3.6 at the 23–25 cm depth (treatment 3). The plots of treatment 4 were additionally cultivated by a disc stubble cultivator Väderstad CARRIER 300 at the 12–15 cm depth. The plots of treatment 5 were not tilled.

In spring, after the soil had reached maturity stage, it was shallow-cultivated by a cultivator Laumetris KLG-3.6 (except for the plots of treatment 5), fertilizers were applied by a fertilizer spreader AMAZONE-ZA-M-1201. Pre-sowing, the soil was cultivated at a seed placement depth. The crops were sown by the following sowing machines: Väderstad Super Rapid 400C in 2010, Väderstad Rapid 300C Super XL in 2011 and in 2012. Herbicides and insecticides were sprayed by a sprayer AMAZONE UF-901. Spring rape and winter wheat plots were harvested by a small plot combine harvester "Sampo-500'' in 2010 and 2011 and by "Wintersteiger Delta'' in 2012. Spring barley was harvested by a small plot combine harvester "Sampo-500'' in 2010 and by "Wintersteiger Delta'' in 2011 and 2012.

Spring rape. Cultivars 'Hunter' in 2010, 'SW Landmark' in 2011 and 'Fenja' in 2012 were sown at a rate of 2–2.3 million seeds ha^{-1} at the 2–3 cm depth. Fertilizers were incorporated at the 2.5 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Winter wheat. Cultivar 'Ada' in 2010–2012 was sown at a seed rate of 4.5–5 million seeds ha^{-1} at the 4–5 cm depth. Fertilizers were incorporated at the 6 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Maize. Hybrids 'Pioneer P 8000 (x6T584)' in 2010, 'Pioneer P 8000 (x027)' in 2011 and 'Es capris' in 2012 were sown at a seed rate of 100 thousand seeds ha^{-1} at the 6 cm depth. Fertilizers were incorporated at the 6.5 cm depth. Sowing was performed by a continuous band wide-row method with 50 cm wide inter-rows (between bands), 12.5 cm wide inter-rows between rows.

Spring barley. Cultivars 'Simba' in 2010 and 2012, 'Tokada' in 2011 were sown at a seed rate of 5–6 million seeds ha^{-1} at the 3.5 cm depth. Fertilizers were applied by placement method at the 4–4.5 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Weed seed bank in the soil was determined in treatments 0–5 (1 and 5 treatments) at the 0–15, 15–25 cm depths after primary tillage in 20 spots of a record plot in 2010 and 2012. The samples were taken with an auger, and a composite sample was formed. Sampling at the 0–5 cm depth was done to compare the weed seed bank in the upper ploughlayer of the conventionally tilled and not tilled plots. A 100 g dry soil sample was placed on a sieve with 0.25 mm mesh diameter and washed with running water until small soil particles washed out. Weed seeds and the remaining mineral soil fraction were separated from the organic soil fraction using saturated salt (or potash) solution [25].

Crop weed incidence was assessed by identifying weed species composition, weed number at the beginning of vegetation or at resumption of vegetation (winter wheat) during intensive weed growth. Dry weed weight was determined at the end of crops vegetation. Weed incidence was assessed in 10 spots of a record plot in 0.06 m^2 area. At the beginning of vegetation, weed seedlings were counted (weed seedlings m^{-2}), and at the end of vegetation weed number (weeds m^{-2}) and dry matter weight (g m^{-2}) were established. The weeds were pulled out, dried to air-dry weight, and analysis of their botanical species composition was conducted [26].

The research data were statistically processed by the analysis of variance and correlation-regression analysis methods. Software ANOVA was used when estimating the least significant difference LSD_{05} and LSD_{01}. The correlation-regression analysis of the research data was conducted using software STAT and SIGMA PLOT. In the case of significant difference between the specific treatment and the control (reference treatment), the probability level was marked as:

* – differences significant at 95 % probability level;

** – differences significant at 99 % probability level.

2.1. Weed seed-bank in the soil

The effectiveness of weed control mainly depends on the ability to sweep out weed seed-bank and to prevent the addition with newer ones [27].

Analysis of the data on the effects of different primary tillage on weed seed bank in the soil revealed that nearly in all cases both in not tilled plots and conventionally deep-ploughed plots weed seed bank in the upper ploughlayer (0–5 cm depth) did not differ significantly (data are not presented). In deeper layer (0–15 cm depth) weed seed bank in reduced tillage treatments generally increased, except for not tilled plots, where weed seed bank was less abundant. Only single significant differences were established (Tables 1-4). In the samples taken from the 15–25 cm depth, the weed seed bank was generally smaller. The seeds of annual weeds prevailed in the soil. In many cases, having reduced tillage, the ploughlayer differentiated into upper layer characterized by more abundant weed seed bank (60.1 % of the total weed seed bank) and bottom layer characterized by less abundant weed seed bank (39.9 %). Weed seeds found in conventionally ploughed soil, at the 0–15 cm depth, in different crops accounted for 51.3 to 52.9 % of the total weed seed bank, and in the 15–25 cm depth – from 47.1 to 48.5 %, in shallow-ploughed soil – 55.9–68.6 and 31.4–44.1 %, respectively, in deep-cultivated soil – 50.0–75.9 and 24.1–50.0 %, in shallow-cultivated soil – 50.0–70.8 and 29.2–50.0 %, in not tilled soil – 56.0-64.3 and 35.7–44.0 %.

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The most widespread were annual weed's seeds: Chenopodium album, *Polygonum lapathifolia*, *Echinochloa crus-galli* and *Sinapis arvensis* L.

Soil tillage method	**Years**	**Sampling depth cm**	
		0–15	15–25
Conventional ploughing	2010	22	23
	2012	12	9
Shallow ploughing	2010	30	23
	2012	16	5
Deep cultivation	2010	34*	20
	2012	12	5
Shallow cultivation	2010	29	24
	2012	16	10
No-tillage	2010	20	10*
	2012	10	8

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 1. The impact of different primary tillage on the number of weed seeds per 100 g of soil in spring oilseed-rape cultivation

Soil tillage method	**Years**	**Sampling depth cm**	
		0–15	15–25
Conventional ploughing	2010	25	16
	2012	16	22
Shallow ploughing	2010	32	16
	2012	17	6**
Deep cultivation	2010	16	7
	2012	24	8**
Shallow cultivation	2010	12	9**
	2012	16	19
No-tillage	2010	14	8
	2012	13	14*

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 2. The impact of different primary tillage on the number of weed seeds per 100 g of soil in winter wheat cultivation

Soil tillage method	Years	Sampling depth cm	
		0–15	15–25
Conventional ploughing	2010	30	26
	2012	13	15
Shallow ploughing	2010	49	25
	2012	14	16
Deep cultivation	2010	71*	15
	2012	17	12
Shallow cultivation	2010	52	17
	2012	15	12
No-tillage	2010	21	12
	2012	13	12

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 3. The impact of different primary tillage on the number of weed seeds per 100 g of soil in maize cultivation

Soil tillage method	Years	Sampling depth cm	
		0–15	15–25
Conventional ploughing	2010	23	13
	2012	14	20
Shallow ploughing	2010	26	15
	2012	12	15
Deep cultivation	2010	27	28*
	2012	14	12
Shallow cultivation	2010	24	14
	2012	19	9
No-tillage	2010	20	8
	2012	17	11

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 4. The impact of different primary tillage on the number of weed seeds per 100 g of soil in spring barley cultivation

According to the K. S. Torresen et al. [28] investigations, in top layer of minimally tilled soil there was found higher number of weed seeds than in 10-20 cm depth. Our investigations partlyš comfirms that findings, arable layer devited into upper one with higher number of weed seeds (60.1 % of total number) and deeper layer with less quantity of seeds (Table 5).

Soil tillage method	Sampling depth cm	Crops			
		spring oilseed-rape	winter wheat	maize	spring barley
CP	0–15	51.5	51.3	52.4	52.9
	15–25	48.5	48.7	47.6	47.1
SP	0–15	62.2	68.6	61.5	55.9
	15–25	37.8	31.4	38.5	44.1
DC	0–15	65.7	71.4	75.9	50.0
	15–25	34.3	28.6	24.1	50.0
SC	0–15	56.4	50.0	70.8	64.7
	15–25	43.6	50.0	29.2	35.3
NT	0–15	62.5	56.0	58.6	64.3
	15–25	37.5	44.0	41.4	35.7

Table 5. The impact of different primary tillage on quantity of weed seeds after primary soil tillage, %, data averaged over 2010 and 2012.

2.2. Weed spread

Analysis of the data on the effect of different primary tillage on the weed incidence in the crops at the beginning of vegetation revealed that almost in all the cases of reduced tillage or direct drilling into not tilled plots, the number of weeds increased; however, significant difference was estimated only for not tilled winter wheat plots (Tables 6-9). In conventional ploughing treatment, the spread of annual weeds was more intensive. Having replaced conventional ploughing by shallow ploughing, deep and shallow cultivation and direct drilling, the number of annual weeds tended to decrease, while that of perennial weeds tended to increase.

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	41.3	17.5	58.8
	2011	264.6	23.4	288.0
	2012	529.7	15.8	545.5
SP	2010	33.4	20.4	53.8
	2011	203.8	49.6	253.4
	2012	533.4	50.8	584.2
DC	2010	31.7	14.6	46.3
	2011	166.3	268.3**	434.6
	2012	675.5	28.3	703.8
SC	2010	17.2	20.8	38.0*
	2011	190.5	91.2	281.7

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
	2012	523.3	42.5	565.8
NT	2010	29.2	12.5	41.7
	2011	147.9	124.6	272.5
	2012	320.4	225.8*	546.2

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 6. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of spring oilseed rape vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	113.3	3.8	117.1
	2011	109.2	0.0	109.2
SP	2010	108.8	5.4	114.2
	2011	106.3	3.7	110.0
DC	2010	317.5**	6.7	324.2**
	2011	99.6	15.4*	115.0
SC	2010	201.2	6.7	207.9
	2011	102.5	17.5**	120.0
NT	2010	123.8	1.7	125.5
	2011	47.1*	0.8	47.9*

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 7. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of winter wheat vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	445.9	18.4	464.3
	2011	305.4	13.4	318.8
	2012	188.4	47.9	236.3
SP	2010	616.3	24.2	640.5*
	2011	395.4	11.3	406.7

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
	2012	193.7	115.0	308.7
DP	2010	625.8	65.4	691.2*
	2011	314.6	40.0*	354.6
	2012	165.0	90.0	255.0
SP	2010	520.8	83.8*	604.6
	2011	286.7	35.8*	322.5
	2012	152.1	155.4**	307.5
NT	2010	515.5	35.9	551.4
	2011	167.9	22.1	190.0
	2012	107.2	82.9	190.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 8. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of maize vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
IA	2010	262.8	16.7	279.5
	2011	205.8	29.6	235.4
	2012	198.3	10.4	208.7
SA	2010	243.7	8.8	252.5
	2011	307.1	10.4	317.5
	2012	234.6	25.8	260.4
GP	2010	428.8	11.2	440.0
	2011	299.6	12.1	311.7
	2012	214.1	39.2*	253.3
SP	2010	327.5	26.7	354.2
	2011	359.6*	22.1	381.7*
	2012	265.4	34.6	300.0
ND	2010	516.3*	38.3*	554.6*
	2011	281.3	21.6	302.9
	2012	135.9	11.3	147.2

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 9. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of spring barley vegetation

At the end of vegetation, the weed incidence in reduced-tillage or not tilled plots increased in all cases compared with the control; however, the difference was not significant. Reduced tillage and direct drilling generally tended to increase the number of both annual and perennial weeds (Tables 10-13).

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}
CP	2010	80.4	77.2	9.6	6.6	90.0	83.8
	2011	172.9	139.8	15.4	45.6	188.3	185.4
	2012	483.4	335.7	11.6	5.5	495.0	241.2
SP	2010	125.0	127.8	13.3	21.4	138.3	149.2
	2011	140.8	110.3	19.6	32.2	160.4	142.5
	2012	487.9	355.9	19.2	19.4	507.1	375.3
DC	2010	256.2**	123.3	18.8	21.6	275.0**	144.9
	2011	210.8	76.5	40.4*	167.7*	251.2	244.2
	2012	552.1	227.8	22.5	42.7	574.6	270.5
SC	2010	219.5*	157.4*	13.8	48.2*	233.3**	205.6*
	2011	190.8	93.8	38.3	91.0	229.1	184.8
	2012	605.0	340.2	20.0	12.3	625.0	352.5
NT	2010	304.6**	54.6	15.8	8.0	320.4**	62.6
	2011	275.0	106.1	6.2	4.6	281.2	110.7
	2012	408.8	215.7	40.0*	16.9	448.8	232.6

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 10. The impact of different primary tillage on weed spread at the end of spring oilseed-rape vegetation

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}
CP	2010	33.8	2.9	21.2	2.3	55.0	5.2
	2011	57.9	3.6	15.8	10.8	73.7	14.4
	2012	81.7	20.6	60.8	100.2	142.5	120.8
SP	2010	32.5	3.2	20.8	2.2	53.3	5.4
	2011	90.0	3.5	25.8	44.9*	115.8	48.4*
	2012	43.7	9.6	73.8	292.2*	117.5	301.8

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Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}
DP	2010	47.1	3.0	19.2	3.4	66.3	6.4
	2011	167.1	5.8	30.8*	42.5*	197.9	48.3*
	2012	34.2	3.3	129.1*	267.1*	163.3	270.4
SP	2010	66.2*	6.3	15.4	1.6	81.6	7.9
	2011	41.7	1.4	39.6**	44.6*	81.3	46.0*
	2012	132.5	226.1	124.6*	193.5	257.1	419.6*
NT	2010	69.6*	8.9*	27.1	6.6	96.7**	15.5*
	2011	249.2*	4.7	17.9	0.6	267.1*	5.3
	2012	87.9	13.8	31.7	16.3	119.6	30.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 11. The impact of different primary tillage on weed spread at the end of winter wheat vegetation

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}
CP	2010	304.6	199.9	16.6	8.6	321.2	208.5
	2011	40.8	93.0	6.7	16.7	47.5	109.7
	2012	109.9	193.7	33.4	70.3	143.3	264.0
SP	2010	467.9*	283.2	15.4	11.4	483.3*	294.6*
	2011	48.3	119.0	18.3	66.9	66.6	185.9
	2012	150.0	165.2	47.1	111.1	197.1	276.3
DC	2010	396.3	304.6*	42.5	31.7	438.8	336.3**
	2011	51.2	122.3	23.8	79.3	75.0	201.6*
	2012	168.7	105.7	34.6	66.1	203.3	171.8
SC	2010	367.9	317.7*	59.2	42.8	427.1	360.5**
	2011	49.6	103.9	12.1	13.3	61.7	117.2
	2012	122.1	111.8	55.8	206.8*	177.9	318.6
NT	2010	272.1	260.2	75.8*	52.4*	347.9	312.6*
	2011	43.3	104.5	21.3	10.1	64.6	114.6
	2012	145.4	198.7	34.6	57.3	180.0	256.0

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 12. The impact of different primary tillage on weed spread at the end of maize vegetation

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}
CP	2010	231. 6	109.6	16.7	5.2	248.3	114.8
	2011	167.1	11.4	8.3	4.9	175.4	16.3
	2012	31.6	7.3	21.7	13.8	53.3	21.1
SP	2010	386.7	135.0	17.1	6.3	403.8	141.3
	2011	263.8	23.9	13.3	15.0	277.1	38.9
	2012	37.5	2.9	22.5	7.2	60.0	10.1
DC	2010	785.0*	173.2	23.8	26.8	808.8*	200.0
	2011	289.6	34.6*	5.4	2.0	295.0	36.6
	2012	71.2	9.2	39.6	17.9	110.8	27.1
SC	2010	384.6	110.5	16.7	13.4	401.3	123.9
	2011	371.2	30.4	10.0	5.6	381.2	36.0
	2012	184.6**	20.1*	40.0	30.2	224.6**	50.3*
NT	2010	778.3*	156.5	10.0	6.4	788.3*	162.9
	2011	193.3	27.8	31.7*	80.0*	225.0	107.8**
	2012	35.0	9.1	24.2	3.0	59.2	12.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 13. The impact of different primary tillage on weed spread at the end of spring barley vegetation

There were found 21-22 species of weeds in experiment. The most widespread were: *Chenopodium album* L., *Echinochloa crus-galli* L., *Polygonum lapathifolia* L., *Sonchus arvensis* L., *Cirsium arvense* L. Scop. and *Elytrigia repens* L. Nevski.

The correlation-regression analysis of the experimental data revealed that the spread of weeds partly depended on the soil structure and its stability, penetration resistance of deeper soil layers (35–50 cm), moisture content in the upper ploughlayer, soil phosphorus and potassium status, pH, crop stand density, amount of plant residues in the soil surface and weed seed bank in the ploughlayer.

3. Impact of living mulch on weed infestation

Numerous research and observations have been conducted aiming to establish weed spread methods and reasons and weed-crop competition peculiarities. Enhancement of the competitive ability of agricultural crops is one of the principal tools to increase the productivity of agricultural crops. Sowing living mulches between the rows of a main crop is a weed control method that does not employ herbicide application. Living mulches result in reduced field weed infestation and an increase in crop yield. From the ecological viewpoint, this technology is promising and beneficial. The study was aimed to establish the competitive peculiarities of the multi-component agrocenosis (maize, living mulches, weeds) and its effects on soil properties under sustainable farming conditions. Experimental object – different species of living mulch plants and maize monocrop. Research was conducted during 2009–2011 at the Lithuanian University of Agriculture (since 2011 Aleksandras Stulginskis University), Experimental Station. The soil of the experimental field was *Calc(ar)i-Epihypogleyic Luvisol LVg-p-w-cc* [29] with a texture of silty light loam on heavy loam. The soil pH_{KCl} measured 7.1, available phosphorus 134.83 mg kg^{-1}, available potassium 74.66 mg kg^{-1}. The soil in this territory has formed on a bottom morain or bottom glacial formations, covered by glacial lacustrine sedimentary rock and is a continuation of the Lithuanian Middle Plain. The layer of the sedimentary rock is of different thickness.

A one-factor, stationary field experiment was conducted. Different living mulches inter-seeded in maize inter-rows were tested.

1. Without a living mulch (control – reference treatment);
2. Spring rape (*Brassica napus* L.);
3. White mustard (*Sinapis alba* L.);
4. Spring barley (*Hordeum vulgare* L.);
5. Italian ryegrass (*Lolium multiflorum* Lam.);
6. Black medic (*Medicago lupulina* L.);
7. Persian clover (*Trifolium resupinatum* L.);
8. Red clover (*Trifolium pratense* L.).

In all experimental years, the same living mulches were inter-seeded in the inter-rows of maize monocrop. The plots of the control treatment were weeded out twice. The experiment was replicated four times. The plots were laid out in a randomised design. The total area of an experimental plot was 24 m^2, and the area of a record plot was 20 m^2. In 2009, black fallow preceded maize and in 2010–2011 maize was monocropped.

Maize monocrop inter-seeded with living mulches was grown without chemical pest control under arable agriculture conditions. In spring, when the soil had reached physical maturity, complex NPK 16:16:16 fertilizer at a rate of 300 kg ha^{-1} was applied, and later the soil was loosened at 4–5 cm depth. Maize was sown by a pneumatic-mechanical drill Köngskilde PRECI – SEM with 50 cm-wide inter-rows and 16–17 cm distance between seeds. Post-emergence of maize, inter-rows were loosened and living mulches were sown with a 7-row manually-operated greenhouse seeder. The marginal rows of the inter-seeded living mulches were at 1–2 cm distance from maize. In each experimental year, living mulches were inter-seeded in the plots in the same places. Living mulches were cut and chopped 2–3 times at maize growth stages BBCH 15–16, 31–32 and 63–65. BBCH 15–16 is leaf development stage when average maize height is 10–12 cm (Photo 1). BBCH 31–32 is stem elongation stage when 1–2 nodes are visible and maize height is 56–63 cm. BBCH 63–65 is maize flowering stage when the plant height is 70–215 cm. At flowering stage, the living mulch was cut only in 2009.

Photo 1. After first cut of living mulch. 2009.

Later the practice was abandoned since tractor-hitched implement would not be able to do this. Mulches were cut with a hand-operated brush cutter "Stihl" FS – 550, using a designed and manufactured trolley, reducing the operator's load, with a protection hood, which evenly spreads the mulch in the inter-row and protects the crop from mechanical damage. Living mulches were cut after they had reached a height of up to 20–25 cm. Green mass of the living mulches was spread in maize inter-rows. At stem elongation stage (BBCH 31–32), the maize crop was additionally fertilized with nitrogen (N_{60}). When fertilizing at 250 kg N ha^{-1} rate, no significant differences were observed between maize cultivation systems. The objective of our experiment was to determine the competition among living mulches, maize and weeds; therefore the total nitrogen rate selected was as low as 108 kg N ha^{-1}. Maize samples for the determination of productivity were hand-cut at the end of September – middle of October (BBCH 87–88) at maize physiological maturity stage. After harvesting, the remaining plant residues were ploughed in by a reversible plough with semi-helical mouldboards at the 20–22 cm depth.

A hybrid maize cultivar 'Silvestre' was used in our experiment. Gul et al. [30] have reported that a denser maize crop increased competition between maize and weeds. As a result, the seed rate of maize in our experiment was 130–138 thousand seeds ha^{-1} or (20–23 kg ha^{-1}). Spring rape (cv. 'Sponsor'), white mustard (cv. 'Braco'), Italian ryegrass (cv. 'Avance'), black medic

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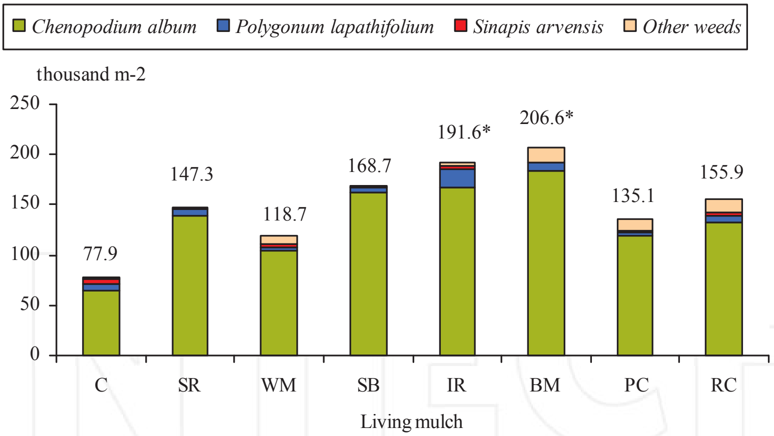
(cv. 'Arka'), Persian clover (cv. 'Gorby'), red clover (cv. 'Nemuniai') (Photo 2) were sown at a seed rate of 10 kg ha^{-1}, and spring barley (cv. 'Simba') was sown at a rate of 200 kg ha^{-1}.

The first assessment of weed infestation in maize crop was made post emergence of crop and weeds. Weeds were counted in 5 randomly selected record plots 0.06 m^2 in size, analysis of weed botanical composition was done, the weeds were dried up to a dry weight and weighed [26]. Weed number was re-calculated into weeds m^{-2}, dry matter weight into g m^{-2}. Such assessment was conducted before each cut of living mulches and before maize harvesting. Soil contamination with weed seeds was estimated after maize harvesting. Soil samples were taken with a sampling auger in 10 places of the record plot from the 0–20 cm depth of the ploughlayer. The number of weed seeds found was re-calculated into thousand seeds m^{-2} [25]. The tests were done in 2009 and 2011.

Photo 2. Inter-seeded red clover.

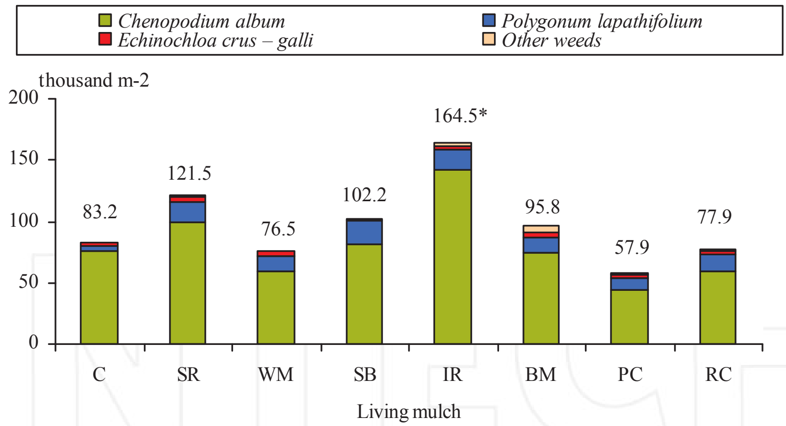
3.1. Weed seed-bank in the soil

Weed seed bank in the ploughlayer was established at the beginning of the experiment in 2009 and at the end in 2011 (Fig. 1-2). The seeds of *Chenopodium album* L. accounted for the largest share in the total weed seed bank. Analysis of the change in weed seed bank over the three experimental years suggested that living mulches reduced weed seed bank in the ploughlayer by 14.1 to 57.1 %. In 2011, compared with the control treatment, the lowest number of weeds was established when growing white mustard (8.0 %) and Persian clover (30.4 %) living mulches. Although weed suppressive capacity of Italian ryegrass was high, contrary to expectations, it gave only a small reduction in weed seed bank and the weeds were significantly, nearly twice as big as those in maize crop without living mulch.



Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Figure 1. The impact of living mulch on weed seed-bank in the soil, 2009



Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Figure 2. The impact of living mulch on weed seed-bank in the soil, 2011

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3.2. The abundance of weeds and living mulch

At early development stages of maize, more intensive growth was exhibited by spring rape, barley and white mustard living mulches (Table 14). However, living mulches of Italian ryegrass, black medic, Persian and red clover up to the first cut (maize BBCH 15–16) were only at seedling stage and therefore competed weakly with weeds. An especially rapid growth rate was shown by white mustard and until the first cut its dry mass was the highest. However, spring rape, barley and white mustard intercrops were sensitive to mulching and their re-growth after cut was poor, and in the second half of the summer they completely rotted away, the cut mass rapidly decomposed, therefore at later development stages of maize weed number and mass increased. Irrespective of this, these living mulches served their major purpose – competed with weeds at the time when maize competitive ability was low. The *Fabaceae* living mulches grown in maize inter-rows developed slowly; however, in the second half of the summer their growth rate increased and after cutting continued until the end of maize growing season. Moreover, they produced the largest mass. Compared with other *Fabaceae* family plants, black medic exhibited a slower development rate. Its mass was lower than that of other *Fabaceae* plants and it suppressed weeds more poorly; however, better than spring rape, barley and white mustard living mulches that had rotted away by the end of the summer. Italian ryegrass living mulch also produced large mass and exhibited a good weed suppressive ability. Its vegetation also continued until maize harvesting.

Living mulch	Weeds						Living mulch g m^{-2}
	annual		perennial		total		
	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	
2009							
C	859.4	202.5	11.5	1.74	870.9	204.2	–
SR	984.3	327.6*	24.0	5.64	1008.3	332.4	104.4
WM	1015.5	297.5	20.9	4.82	1036.4	302.3*	52.2*
SB	951.4	256.9	30.2*	8.31*	981.6	265.2	126.2
IR	535.4*	95.7*	8.3	0.97	543.7*	96.6*	473.2*
BM	915.7	260.1	11.5	1.24	927.2	261.3	131.0
PC	477.0*	135.6	1.1*	0.10*	478.1*	135.7	451.6*
RC	691.6	158.6	1.0*	0.01*	692.6	158.6	236.2
2010							
C	381.0	136.2	13.6	10.4	394.6	146.6	–
SR	571.7*	258.3	51.7*	18.8	623.4*	277.1	6.0*
WM	548.9	245.8	31.3*	12.0	580.0*	257.8	43.5*
SB	495.0	261.3*	33.3*	60.9*	528.3*	322.2*	3.0*
IR	549.2*	195.7	16.6	9.9	511.3	205.6	193.1
BM	552.1*	325.9*	24.0	8.8	596.0*	334.7*	120.6
PC	459.2	226.4	12.4	3.9	471.6	230.3	213.4

Living mulch	Weeds						Living mulch g m^{-2}
	annual		perennial		total		
	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	
RC	409.5	174.3	6.2	4.0	415.7	178.3	272.2
			2011				
C	579.3	109.7	18.8	8.7	598.1	118.4	–
SR	567.1	238.6*	21.9	20.3*	589.0	258.9	37.9*
WM	654.2	266.0*	42.8*	37.6*	697.0*	303.6*	41.1*
SB	597.9	248.3*	27.1	29.8*	625.0	278.1*	37.6
IR	437.6*	126.0	9.4	2.2	447.0	148.2	220.9
BM	578.2	195.7	17.7	8.0	595.9	203.7	78.1*
PC	483.3	155.8	10.4	12.0	493.7	167.8	226.0
RC	443.3	203.3	2.1*	0.9*	445.4*	204.2	166.8

Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Table 14. The abundance of weeds and living mulch plants over the whole growing season of maize, 2009–2011

The correlation-regression analysis of the data from 2009 revealed statistically significant relationships between dry mass of living mulches and weed number and dry mass (Table 15).

Growing season	Weeds, Y					
	annual		perennial		total	
	number m^{-2}	g m^{-2}	number m^{-2}	g m^{-2}	number m^{-2}	g m^{-2}
2009	0.916**	–0.797*	n	n	–0.908**	–0.796*
2010	–0.762*	–0.948**	–0.909**	–0.850**	–0.820*	–0.956**
2011	–0.802*	–0.778*	–0.949**	–0.731*	–0.802*	–0.726*

Note: n–non-significant or weak relationship. * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 15. The relationships between dry mass of living mulches (*x*) and weed number and dry mass (*Y*) over the whole growing season of maize 2009–2011

4. Conclusions

1. In most cases, different tillage did not have significant impact on weed seed bank in the ploughlayer and weed abundance in the agricultural crops tested. The ploughlayer differentiated into the upper layer with a greater weed seed bank (60.1 % of the total weed seed bank) and bottom layer with a less abundant weed seed bank (39.9 %). In spring

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crops, weed mass in shallow-ploughed plots was by on average 28.6 %, in deep-cultivated plots by 41.5 %, in shallow-cultivated plots by 39.9 % and in not tilled crops by 16.1 % higher than that in conventionally ploughed plots, and in winter wheat crop by respectively 2.5; 2.3; 3.4 times higher, and in not tilled plots by 2.8 times lower.

2. Non-regrowing living mulches (white mustard, spring barley and rape) competed with weeds at early development stages when maize competitive ability was poor. Living mulches whose vegetation was longer exhibited better weed suppressive ability and produced more biomass; however, they competed more for nutrients with maize. The correlation regression analysis of the experimental data indicated that at more advanced growth stages of maize, the number and mass of weeds mostly depended on the biomass of living mulches. Living mulches reduced weed seed bank in the ploughlayer by 14.1 to 57.1 %. The greatest change was established when growing Persian clover (57.1 %) and black medic (53.6 %).

3. Most of the *Poaceae and Brassicaceae* living mulches competed more with weeds for space at the beginning of maize vegetation, while *Fabaceae* plants and Italian ryegrass – already after the first mulching of the inter-rows. In most cases, a strong correlation was determined between the surface area covered by weeds and living mulches.

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Chapter 5

Current and Potential Use of Phytophagous Mites as Biological Control Agent of Weeds

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Additional information is available at the end of the chapter

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1. Introduction

Biological control of weeds by using phytophagous mites may help to contain infestations and reduce their spread in time. Although, eradication is not the goal due to the vastness of the areas, the most desirable scenario is achieved when weeds are no longer a concern and no other control is necessary. However, biological control should not be considered the unique strategy to face weed problems, thus commonly; other methods are still required to attain the desired level of control.

There is an increasingly interest in using mites for biological control of weeds, primarily those belonging to Eriophyidae because of they are host-specific and often weaken the host plant affecting plant growth and reproduction. Although eriophyid mite species impact the fitness of their host plant, it is not clear how much they have contributed to reduction of the population of the target weed. In some cases, natural enemies, resistant plant genotypes, and adverse abiotic conditions have reduced the ability of eriophyid mites to control target weed populations. Besides, susceptibility of eriophyids to predators and pathogens may also prevent them from achieving population densities necessary to reduce host plant populations.

In addition to eriophyid mites, tetranychid mites are also being considered as an alternative for weed control. The gorse spider mite, *Tetranychus lintearius* Dufour, has shown to reduce shoot growth on gorse (*Ulex europaeus* L.) by around 36% in impact studies conducted over 2.5 years in Tasmania. New colonies expand rapidly and cause severe damage to gorse plants, but often do not persist in large numbers.

Since the use of phytophagous mite species is a safe alternative for controlling weeds, in this chapter we will review some examples of biological control programs using eriophyid and tetranychid mites worldwide.

2. The problem with weeds

Weeds can be defined as plants growing out of place. For example, water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is widely planted as a water ornamental but when environmental conditions are suitable it spreads rapidly obstructing lakes, rivers and rice paddy fields, affecting adversely human activities (fishing, water transport) and biodiversity [1]. Similarly, morning glory is beautiful in the garden, but also it can cause 30% yield loss [2].

Invasive non-native plants are a serious threat to native species, communities, and ecosystems since they can compete with and displace native plants, animals, and other organisms that depend on them, alter ecosystem functions and cycles significantly, hybridize with native species, and promote other invaders [3]. However, according to these authors, reversion, halting or slowing of plant invasion and even restoring badly infested areas to healthy systems dominated by native species is possible but actions to control and manage those invasive plants are required.

Details of weed management approaches will obviously vary from crop to crop. For instance, although weed control remains a major concern in organic agriculture, producers have limited tools for managing weeds [4].

3. Weed control techniques

Weed control techniques can be grouped in the following categories:

1. Prevention: it consists in avoiding introduction of weeds within an area based on cultural and mechanical practices (such as clean seed use, sanitation of mechanical implements) that ensure sanitary conditions and minimize weed introduction.

   a. Cultural: cultural practices promoting vigorous, dense crops are the most important and least recognized means of preventing weed establishment and encroachment. Also soil fertility, humidity and chemical properties (pH, electrical conductivity, etc.) may favor one plant species over another. Other cultural means of control involve covering a weed infested area with mulches to exclude light.

   b. Mechanical (physical): mechanical control of weeds involves hand pulling or various types of tractor-powered tillage operations.

2. Chemical: One of the major contributing factors to the advancement of man's way of life during the 20th century has been the development of chemical compounds for pest control. The first major selective pest controlling compound used was a lime-coppersulfur mixture known as the Bordeaux mixture, which also was used for broadleaf weed control.

3. Biological: Biological methods use weeds' natural antagonists as control agents. The objective of biological control is not weed eradication, but rather the reduction of the population below a level of economic or aesthetic injury.

4. Biological control: A weed management approach

Definition: Weed biocontrol strategies are based on the use of natural enemies to suppress the growth of a weed or to reduce its population [5].

Main strategies of Biological Control: There are two basic strategies for implementing the biological control of weeds:

- The classical biological control which involves the introduction of foreign biological control organisms, and
- Non classical biological control including augmentative strategies, where the biological control agent is already present (native or introduced) and their population is increased by mass rearing [6] and also inundative strategies which includes releasing of large number of the agent to control the target weed. Ex. mycoherbicides [7].

The classical biological control has three disadvantages, such as: high initial costs, limited number of natural enemies for each target weed species and inability to control the biological control agent dissemination after being released in nature [8]. In addition, successful weed control is strongly dependent on favorable conditions promoting biological control agent population increasing, thus stimulating the establishment of epiphytotics to reduce the target weed population [6].

5. Classical biological control of weeds: The beginning

The first intent of classical biological control of a weed species is documented in southern India in 1863 and in Sri Lanka in 1865 with introduction of a cochineal mealybug *Dactylopius ceylonicus* Green against the cactus *Opuntia vulgaris* Mill. [9]. Although it failed, it was followed by the release in 1914 of another strain which resulted in the successful control of *O. vulgaris* [10]. After that, introduction of up to 30 separate insect species rendered in the successful control of common pest pear *Opuntia stricta* (Haw.) Haw. by the moth *Cactoblastis cactorum* (Berg), and of other cacti by this moth and different *Dactylopius* species [10]. Later, the first significant program of classical biological control, involving the import of agents following a search in the country of origin of the weed, was the program against *Lantana camara* L. in Hawaii. For this, 23 different insect species from Mexico were shipped to Hawaii, of which 14 were released and eight of these established to give adequate control of lantana in most areas [11].

6. Mites as biological control agents of weeds

Insects and, in lesser extent, pathogens have long been considered as the main agents of weed control. Specialized literature lists most of the successful using one of these organisms. For example, the search for biological agents to control water hyacinth began in the early 1960s resulting in six arthropod species released around the world including five insect species [*Neochetina bruchi* (Hustache), *N. eichhorniae* (Warner), *Niphograpta albiguttalis* Warren, *Xubida infusellus* (Walker) and *Eccritotarsus catarinensis* (Carvalho)] and only one mite species [*Orthogalumna terebrantis*Wallwork] [12]. As result, the mite and *X. infusellus* have not contributed to control and only *N. bruchi*, *N. eichhorniae* and *N. albiguttalis* have been released in numerous infestations since the 1970s and have contributed to successful control of the weed in many locations [12]. Other classical example of predominance of insects as bio control agent is referred to *L. camara*. First attempts were made with importation of 23 insect species to Hawaii from Mexico. After that, thirty-nine insect species have been deliberately or unintentionally released as biocontrol agents or otherwise associated to lantana worldwide and only 27 of them have established in at least one country or island [13] (see table 1). In contrast, only three fungus species have been used, such as: *Mycovellosiella lantanae* var. *lantanae* (Chupp) Deighton (Mycosphaerellaceae), *Prospodium tuberculatum* (Spegazzini) Arthur (Pucciniaceae) and *Septoria* sp. (Sphaeriopsidaceae) released in South Africa, Australia and Hawaii, respectively [13]. In turn, only one eriophyid species, so called *Aceria lantanae* (Cook) have been reported on lantana [14] (Fig 1).

Biological control agent	Country released
LEPIDOPTERA	
Autoplusia illustrata Guenée	Australia, South Africa
Cremastobombycia lantanella Busck	Hawaii
Diastema tigris Guenée	Zambia, Australia, Micronesia, Fiji, Ghana, Hawaii, St. Helena, Tanzania, Uganda
Ectaga garcia Becker	Australia
Epinotia lantana Busck	Micronesia, Hawaii, Marshall Islands, South Africa, Australia
Hepialus sp.	Hawaii
Hypena laceratalis Walker	Micronesia, Hawaii, South Africa, Fiji, Australia, Guam
Lantanophaga pusillidactyla (Walker)	Micronesia, Hawaii, Hong Kong, Palau, South Africa
Leptostalis sp.	Jamaica
Oxyptilus sp.	Jamaica
Neogalea sunia (Guenée)	Australia, Micronesia, Hawaii, South Africa
Pseudopyrausta santatalis (Barnes and McDunnough)	Micronesia, Fiji, Hawaii
Salbia haemorrhoidalis Guenée	Kenya, Zambia, Uganda, Tanzania
Strymon bazochii (Godart)	Australia, Fiji, Hawaii
Tmolus echion (L.)	Hawaii, Fiji

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Biological control agent	Country released
Coleoptera	
Aerenicopsis championi Bates	Australia, Hawaii
Alagoasa parana Samuelson	Australia, South Africa
Apion sp1	Hawaii
Apion sp2	Hawaii
Charidotis pygmaea Klug	Australia, Fiji
Longitarsus spp.	Jamaica
Octotoma championi Baly	Fiji, South Africa, Hawaii, Australia
Octotoma scabripennis Guérin-Méneville	Guam, South Africa, Niue, New Caledonia, India, Solomon Islands, Hawaii, Ghana,Fiji, Cook Islands, Australia
Omophoita albicollis Fabricius	Jamaica
Parevander xanthomelas (Guérin-Méneville)	Hawaii
Plagiohammus spinipennis (Thomson)	Palau, Australia, Hawaii, South Africa, Guam
Uroplata fulvopustulata Baly	Fiji, Australia, South Africa
Uroplata girardi Pic	Trinidad, South Africa, Samoa, Solomon Islands, St.Helena, Tanzania, Ghana, Palau, Uganda, Vanuata, Zambia, Tonga, India, Australia, Cook Islands, Micronesia, Hawaii, Guam, Philippines, Mauritius, New Caledonia, Niue, Northern Mariana Islands, Papua New Guinea, Fiji
Uroplata lantanae Buzzi and Winder	Australia, South Africa
HEMIPTERA	
Aconophora compressa Walker	Australia
Falconia intermedia (Distant)	Australia
Leptobyrsa decora Drake	Guam, Zambia, South Africa, Palau, Hawaii, Fiji, Australia, Cook Islands, Ghana
Orthezia insignis Browne	Hawaii
Phenacoccus parvus Morrison	
Teleonemia bifasciata Champion	Hawaii
Teleonemia elata Drake	Uganda, Australia, Zambia, Cook Islands, South Africa
Teleonemia harleyi Froeschner	Australia
Teleonemia prolixa (Stål)	Australia
Teleonemia scrupulosa Stål	Tonga, Palau, Papua New Guinea Zimbabwe, South Africa, Samoa, Solomon Islands, Tanzania, Northern Mariana Islands, Uganda Vanuata, Zambia, Zanzibar, St. Helena, Hawaii, Niue, Australia, Micronesia, Fiji, Ghana, Guam, Ascension Island, India, Indonesia, Kenya, Madagascar, New Caledonia.
DIPTERA	
Calycomyza lantanae (Frick)	South Africa, Australia, Fiji

Biological control agent	Country released
Eutreta xanthochaeta Aldrich	Australia, South Africa, Hawaii
Ophiomyia camarae Spencer	South Africa
Ophiomyia lantanae Froggatt	Cook Islands, South Africa, New Caledonia, Kenya, India, Hong Kong, Hawaii, Guam, Micronesia, Australia, Fiji
Aceria lantanae Cook	South Africa, Australia

Based on [13, 15-16].

Table 1. List of biological control agents associated to *L. camara* worldwide

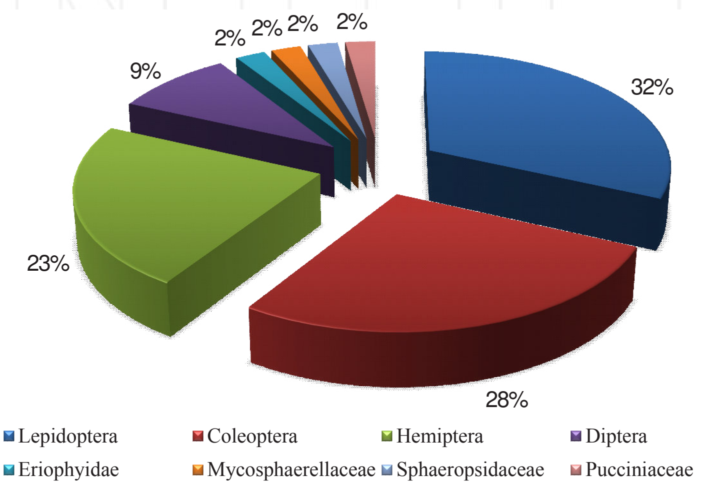

Figure 1. Percentage of different groups of biological control agents used against *L. camara*.

In regard to pathogens, Australia led the world with the first deliberate introduction of a plant pathogen as a biocontrol agent, i.e. the rust *Puccinia chondrillina* Bubak & Syd., released in 1971 to control skeleton weed *Chondrilla juncea* L. [10]. Furthermore, several fungal pathogens with mycoherbicide potential (*Sclerotinia sclerotiorum* (Lib.) de Bary in Hyakill™ and *Cercospora rodmanii* Conway, named ABG-5003) have been discovered on diseased water hyacinth plants, but none has become commercially available in the market [8].

7. Eriophyoid as biological agents of weed control

Eriophyoid mites have long been thought to have a high potential as a source for biological control agents of weeds [17-20] because of their typically high degree of host plant specificity [21]. Also, eriophyoid mites can substantially damage vegetative and reproductive plant parts, thus reduce fitness of the target weed, have high reproductive rates, and disperse widely by wind, which all favor their potential to be effective biological control agents [18, 22-23]. Despite those desirable features exhibited by eriophyoid mites, relatively few species have been introduced as classical biological control agents [19]. This could be account for the fact that relatively few species of Eriophyoidea are considered economic pests [23], which suggests that the impact of most species would be limited by host plant resistance or tolerance, natural enemies, and adverse abiotic conditions, affecting the efficacy of biological control agents [24].

There are about 4,000 recognized eriophyoid mite species, and about 80% of currently known species have been recorded in association with a single species of host plant [21], suggesting that there should be a large number of prospective agents available to discover. By far, species from the genus *Aceria* have been widely used in biological control of weeds (Fig 2), probably due to together with *Eriophyes* include about one-third of the known Eriophyoidea revealing high species diversity.

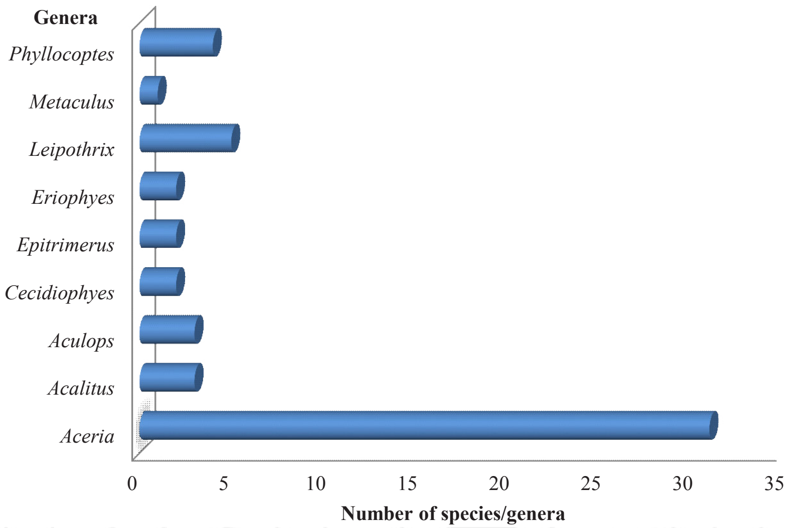

Figure 2. Number of Eriophyidae species used as biological control agents of weeds.

The oldest cases of attempts to use eriophyid mites for biological control include *Aceria chondrillae* Canestrini, *A. malherbae* Nuzzaci and *Aculus hyperici* Liro. *Aceria chondrillae* is native to Europe and has been introduced to control *C. juncea* (rush skeletonweed, Asteraceae) in Australia, USA and Argentina [25] and it is considered to be the most effective of the three biological control agents that were released [26].

Aceria malherbae is native to Europe and forms galls on developing leaves and stems of *Convolvulus arvensis* L. (Convolvulaceae) [27]. *Aceria malherbae* has been released in the USA in 1989 [17], in Canada in 1989 [28] and in South Africa in 1995 [29].

Aculus hyperici, native to Europe, was introduced to control *Hypericum perforatum* L. (Clusiaceae) in Australia [18]. By mid 1994, a total of 245 releases of *A. hyperici* had been made throughout New South Wales and Victoria, being mite populations confirmed at 108 sites. Although the mite significantly reduced shoot and root biomass, field weed populations has not been significantly impacted [18, 30].

As related by [19], since Rosenthal's review in 1996, 13 species have undergone some degree of pre-release, so named: *Aceria genistae* (Nalepa), *A. lantanae*, *Aceria* sp. [boneseed leaf buckle mite, BLBM], *A. salsolae* De Lillo & Sobhian, *A. sobhiani Sukhareva*, *A. solstitialis* de Lillo et al., *A. tamaricis* (Trotter), *A. thalgi Knihinicki et al.*, *A. thessalonicae* Castagnoli, *Cecidophyies rouhollahi* Craemer, *Floracarus perrepae* Knihinicki & Boczek, *Leipothrix dipsacivagus* Petanović & Rector and *L. knautiae* (Liro), but only four of them have been authorized for introduction (*A. genistae*, *Aceria* sp., *C. rouhollahi* and *F. perrepae*). However, there are much more species have been considered for biological control of weeds [19] (Table 2).

Biological control agent	Target plant	Country
Aceria species		
A. acacifloris Meyer	*Acacia saligna* (Labill. Wend. (Fabaceae)	Australia
A. angustifoliae Denizhan et al.	*Elaeagnus angustifolia*	Turkey
A. artemisiae (Canestrini)	*Artemisia vulgaris* L. (Asteraceae)	Italy
A. bicornis (Trotter)	*Solanum elaeagnifolium* Cav. (Solanaceae)	Argentina
A. boycei (Keifer)	*Ambrosia artemisiifolia* L. (Asteraceae)	U.SA.
A. burnleya Keifer	*A. saligna*	Australia
A. sobhiani Sukhareva	*Acroptilon repens* (L.) DC. (Asteraceae)	Uzbekistan
A. centaureae (Nalepa)	*Centaurea diffusa*, *C. stoebe* L. (Asteraceae)	Austria (presumed)
Aceria chondrillae Canestrini	*Chondrilla juncea* L. (Asteraceae)	USA and Argentina
A. convolvuli (Nalepa)	*Convolvulus arvensis* L. (Convolvulaceae)	Austria
A. cynodoniensis Sayed	*Cynodon dactylon* (L.) Pers. (Poaceae)	Egypt
A. dissecti Petanović	*Geranium dissectum* L. (Geraniaceae)	Serbia
A. drabae (Nalepa)	*Cardaria draba* (L.) Desv. (Brassicaceae)	Austria
A. eleagnicola Farkas	*Elaeagnus angustifolia* L. (Elaeagnaceae)	Hungary
A. galiobia (Canestrini)	*Galium mollugo* L., *G. verum* L. (Rubiaceae)	Italy
A. geranii (Canestrini)	*Geranium dissectum*	Italy
A. imperata (Zaher & Abou-Awad)	*Imperata cylindrica* (L.) Beauv.	Egypt
A. jovanovici Petanović	*Lythrum salicaria* L. (Lythraceae)	Serbia
A. meliae (Dong & Xin)	*Melia azedarach* L. (Meliaceae)	China
A. mississippiensis Chandrapatya & Baker	*Geranium carolinianum* L. (Geraniaceae)	Mississippi
A. salsolae de Lillo & Sobhian	*Salsola tragus* L. (Chenopodiaceae)	Turkey
A. salviae (Nalepa)	*Salvia pratensis* L., *S. verticillata* L. (Lamiaceae)	Austria

Biological control agent	Target plant	Country
A. solcentaureae de Lillo et al.	*Centaurea solstitialis* L. and *C. virgata* ssp. squarrosa Lam. (Willd.) Gugler (Asteraceae)	Turkey
A. solstitialis de Lillo, Cristofaro & Kashefi	*Centaurea solstitialis* and *C. virgata* ssp. Squarrosa	Turkey
A. spartii (Canestrini)	*Spartium junceum* L. (Fabaceae)	Italy
A. squarrosae de Lillo et al.	*Centaurea virgata* ssp. Squarrosa	Turkey
A. striata (Nalepa)	*Chromolaena odorata* (L.) King & H. Robinson (Asteraceae)	Barbados
A. tamaricis (Trotter)	*Tamarix gallica* L. and *T. ramosissima* Ledeb. (Tamaricaceae)	Turkey
A. thalgi Knihinicki et al.	*Sonchus oleraceus* L., *S. asper* (L.) Hill, *S. hydrophilus* Boulos (Asteraceae)	West Australia
A. thessalonicae Castagnoli	*Centaurea diffusa* Lam. (Asteraceae)	Greece
A. tribuli (Keifer)	*Tribulus terrestris* L. (Zygophyllaceae)	Sudan
A. vitalbae (Canestrini)	*Clematis vitalba* L. (Ranunculaceae)	Italy
Acalitus species		
A. essigi (Hassan)	*Rubus* sp. (Rosaceae)	California (USA)
A. mikaniae Keifer	*Mikania micrantha* Kunth (Asteraceae)	Florida (USA)
A. osmia (Cromroy)	*Chromolaena odorata*	Puerto Rico
Aculops species		
A. euphorbiae (Petanović)	*Euphorbia seguierana* Neck. And *Euphorbia* spp. (Euphorbiaceae)	Serbia
A. toxicophagus (Ewing) (=*Aculops rhois*) (Stebbins)	*Toxicodendron radicans* (L.) Kuntze (Anacardiaceae)	Florida (USA)
Aculus species		
Aculus hyperici Liro	*Hypericum perforatum* L. (Clusiaceae)	Australia
Cecidophyes species		
C. caroliniani Chandrapatya & Baker	*Geranium carolinianum*	Mississippi (USA)
C. galii (Karpelles)	*Galium aparine* L. (Rubiaceae)	Austria (presumed)
Epitrimerus species		
E. heterogaster (Nalepa)	*Clematis vitalba*	Austria (presumed)
E. lythri Petanović	*Lythrum salicaria*	Serbia
Eriophyes species		
E. cuscutae (Molliard)	*Cuscuta epithymum* (L.) L. (Cuscutaceae)	France
E. rubicolens (Canestrini)	*Rubus fruticosus* L. (Rosaceae)	Italy
Leipothrix species		
L. coactus (Nalepa)	*Plantago* spp. (Plantaginaceae)	Germany
L. dipsacivagus Petanović & Rector	*Dipsacus fullonum*, *D. laciniatus*	Serbia

Biological control agent	Target plant	Country
L. eichhorniae (Keifer)	*Eichhornia crassipes* (Mart.) Solms (Pontederiaceae)	Brazil
L. knautiae (Liro)	*Dipsacus fullonum* L., *D. laciniatus* L. (Dipsacaceae)	Finland
L. taraxaci (Liro)	*Taraxacum officinale* F. H. Wigg. (Asteraceae)	Finland
Metaculus species		
M. lepidifolii Monfredo & de Lillo	*Lepidium latifolium* L.	Turkey
Phyllocoptes species		
P. cruttwellae Keifer	*Chromolaena odorata*	Trinidad
P. euphorbiae Farkas	*Euphorbia cyparissias* L. (Euphorbiaceae)	Hungary
P. gracilis (Nalepa)	*Rubus tomentosus* Borkh. (Rosaceae)	Germany (presumed)
P. nevadensis Roivainen	*Euphorbia esula* L., *E. cyparissias* (Euphorbiaceae)	Spain

Table 2. Eriophyid mites species used in biological control worldwide.

8. *Aceria lantanae* vs. *Lantana camara*

The lantana flower gall mite, *A. lantanae* is native to the Gulf of Mexico and it causes to its host plant to produce vegetative galls instead flowers. This tiny mite is about 0.15 mm long, beige and white in color. Mite feeding induces the flower bud develop into a 20-mm-diameter green gall and in high population levels mites form a mildew-like swarm on the surface of the gall. These galls act as nutrient sinks, which causes stunt vegetative growth and up to 90% reduction in seed production in susceptible varieties [31].

Also, two leaf vagrant eriophyid mites, *Shevtchenkella stefneseri* Craemer and *Paraphytoptus magdalenae* Craemer, were described from *L. camara* in Paraguay and Jamaica, however, so far only *A. lantanae* has shown to cause symptoms that could be used to control this plant [32].

9. *Floracarus perrepae* vs. *Lygodium microphyllum*

The Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Br. (Lygodiaceae) is native to wet tropical and subtropical regions of Africa, Asia, Australia, and Oceania [33] and over recent decades has become a hugely problematic and rapidly spreading invasive weed of natural areas across much of southern Florida in the United States [34].

Management of *L. microphyllum* using fire or mechanical control have been ineffective, meanwhile chemical control is expensive, and not economically sustainable over the large areas already infested [35]. Thus, biocontrol is thought to be a more promising strategy for long-term management [33] and *Neomusotima conspurcatalis* Warren (Lepidoptera: Crambidae) has successfully established in Florida as a biological control of *L. microphyllum* [36-37].

Also, the leaf galling mite, *Floracarus perrepae* Knihinicki & Boczek (Eriophyidae) has been commonly found causing damage to this fern species during extensive foreign exploration within its native range [38]. Since then, several studies have been conducted to evaluate potentiality of this eriophyid mite to effectively control fern. Although *F. perrepae* successful colonized *L. microphyllum* field populations in Florida, the observed incidence was unexpectedly low [37]. According to these authors, only 10% of *L. microphyllum* plants showed mite-induced leaf galls, and mite populations died out resulting in only 3% of infested plots after 12-14 months. However, the low rate of *F. perrepae* establishment was not due to failure of mites to transfer onto field plants but a variety of factors such as:

a. *Propagule*: introductions of biocontrol agents can fail to result in establishment if too few individuals are released.

b. *Environmental conditions*: climatic dissimilarity between source areas and areas of introduction can result in the failure of biocontrol agents to establish. Moreover, persistent and heavy rainfall has shown to be the most important factor dislodging the dispersing *F. perrepae* as they attempted to settle and induce leaf rolls [38].

c. *Plant phenology*: a lack of host plants of the appropriate phenological stage can also hamper agent establishment.

d. *Nutritional status of the plant*: nitrogen limitation can affect establishment of biocontrol agents against invasive weeds.

e. *Biotic interference*: predators or pathogens cause mortality or interfere with introduced weed biocontrol agents.

f. *Plant susceptibility*: differences in susceptibility to eriophyid mite pests exist among different varieties of the same crop species and among eriophyid weed biocontrol agents to biotypes or geographic races of their target weeds.

Distinct haplotypes of *L. microphyllum* and *F. perrepae* from populations across Southeast Asia and Australasia have been revealed from genetic testing of the fern and mite and these different genetic strains of mite and genetic forms of *L. microphyllum* mapped out together according to their geographic origin [39]. Thus, bioassays indicated that strains of *F. perrepae* performed best (were most able to induce leaf galls) on the local forms of *L. microphyllum* from which they were collected and presumably were best adapted [39].

High specificity and variations in mite performance and host plant resistance could make eriophyid agents may have difficulty suppressing all forms of a weed throughout its adventive range when both resistant and susceptible weed genotypes are present [25].

Limited broader establishment of *F. perrepae* strains would appear related to the apparent role of fern resistant genotypes, reflecting difficulties in weed biocontrol programs using this eriophyid mite. Hence it seems unlikely that *F. perrepae* will contribute substantially to suppression of *L. microphyllum* in Florida [36].

10. Could *Aceria solstitialis* be a prospective biological control agent versus *Centaurea solstitialis*?

Yellow starthistle, *Centaurea solstitialis* L. (Asteraceae), is native to the northern half of the Mediterranean and currently it has invaded the western USA displacing native plant communities, reducing plant diversity and forage production for livestock and wildlife [40]. The origin site of this plant species has been explored for prospective biological control agents. Recently an eriophyid mite, *Aceria solstitialis* de Lillo, Cristofaro & Kashefi was discovered damaging *C. solstitialis* in Turkey [41]. However, it is still unclear if *A. solstitialis* could be an effective biological control agent of yellow starthistle, since field and laboratory studies did not yield conclusive results on host specificity and damage level on this host plant [42]. According to these authors, mites remained live on *C. solstitialis*, *Centaurea cyanus* L., *Centaurea diffusa* Lam., *Carthamus tinctorius* L., and *Cynara scolymus* L. 60 days after the start of the experiment. This fact would suggest that *A. solstitialis* is not specific to feed on *C. solstitialis*. Moreover, although young and old *Ce. solstitialis* infested plants became yellow and withered, most of them produced flowers and seeds. Also, damage symptoms by mite feeding was verified on *C. scolymus*, a cultivated species thus hindering possibility of use this eriophyid mite in biological weed control programs. However more detailed studies should be addressed to determine the relationship of mite population size and time of infestation to damage host plants.

11. Other mite groups used in biological control of weeds

Tetranychid mites: Gorse, *Ulex europaeus* L. (Fabaceae), is a thorny shrub native to the temperate Atlantic coast of Europe. Gorse has proven to be an aggressive invader, forming impenetrable, largely monotypic stands that reduce access of grazing animals to fodder, modify native ecosystems and ecosystem processes, and outcompete trees in developing forests [43], mainly in Australia, Chile, New Zealand and the USA [44-46].

The gorse spider mite, *Tetranychus lintearius* (Dufour) is one of the few tetranychid mite species being used for the biological control of gorse in Australia and it is now widespread in Tasmania and Victoria and has become well established in South Australia and Western Australia [47]. Mite populations have shown rapidly increases in the countries where it was released, with colonies forming massive webs over gorse and causing severe bronzing of the foliage. However, populations of the gorse spider mite rarely cause severe damage to the target weed [48]. As previously discussed, natural control mechanisms can interfere with the establishment and development of high population densities that are considered desirable for classical biological control agents [49]. Probably, predators are the main contributors to biotic resistance of spider mites [50]. In this regard, although presence of mite colonies on gorse bushes over a period of 2.5 years from the time of release reduced foliage dry weight by around 36% in Tasmania [51], predation of *T. lintearius* colonies by *Stethorus* sp. and *Phytoseiulus persimilis* Athias Henriot [52], has limited efficacy of control of *T. lintearius* on gorse.

Oribatid mites: The water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), is native of the Amazon basin [53] and whose capacity for growth and propagation causes major conservation problems with considerable socioeconomic repercussion [54]. Also, it has invaded fresh water bodies causing significant economic and ecological losses, being considered to be the worst aquatic weed in South Africa [55]. Several biocontol agents have been used to diminish ecological impact of the plant species, being *Orthogalumna terebrantis* Wallwork (Acari: Oribatida) one of seven biocontrol agents used against the water hyacinth in South Africa and it is currently established at 17 out of the 66 recorded water hyacinth infestation sites across the country [56]. Field observations in South Africa indicate that during summer certain water hyacinth infestations may have more than 50% of the leaf surface area damaged by mite herbivory [56]. Feeding by the nymphs of this mite forms galleries between the parallel veins of the lamina which cause leaf discoloration and desiccation when high mite populations are reached, however it has not contributed to control of the weed [12].

12. Conclusions

Various studies dealing with effectiveness of mites as biological agents of weed have shown variable results; however some of them clearly have the potential to play a significant role in the classical biological control. Field and laboratory observations have shown the debilitating effect of some mite species on its target plant, opening a gate to be explored in the future. Furthermore, additional aspects as plant genotype interaction with those biological control agents and also interaction with other biological control agents such as pathogens should be addressed to complement the action of the mite agents currently established on susceptible weedy varieties in order to improve biological control programs.

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