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Weed Control by Chemical and Mechanical Means

Algirdas Jasinskas, Dainius Steponavičius,
Povilas Šniauka and Remigijus Zinkevičius

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 pump 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

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.

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.

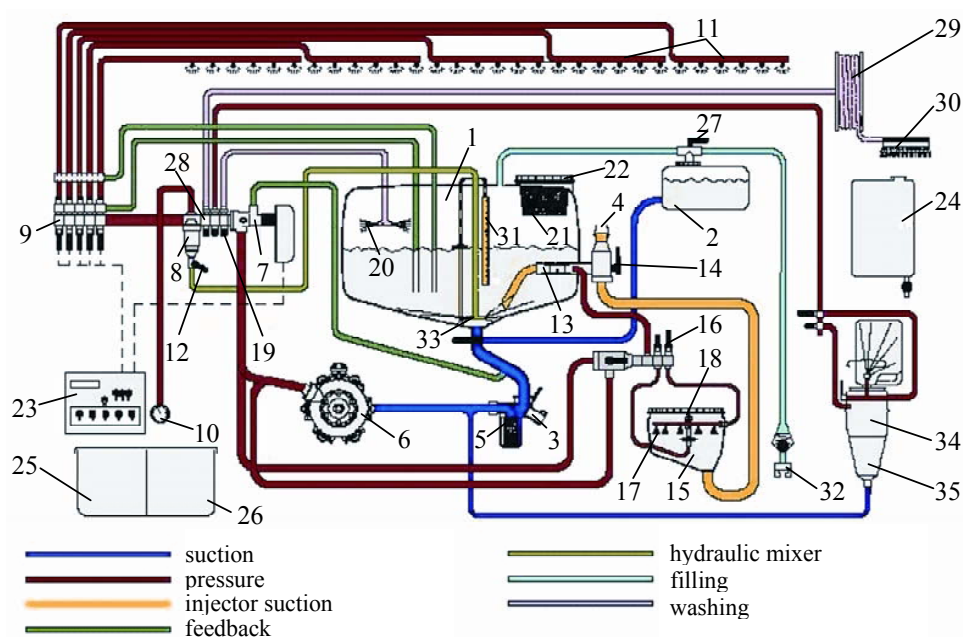
2.2.2. Structure of tractor-mounted hydraulic field sprayers

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

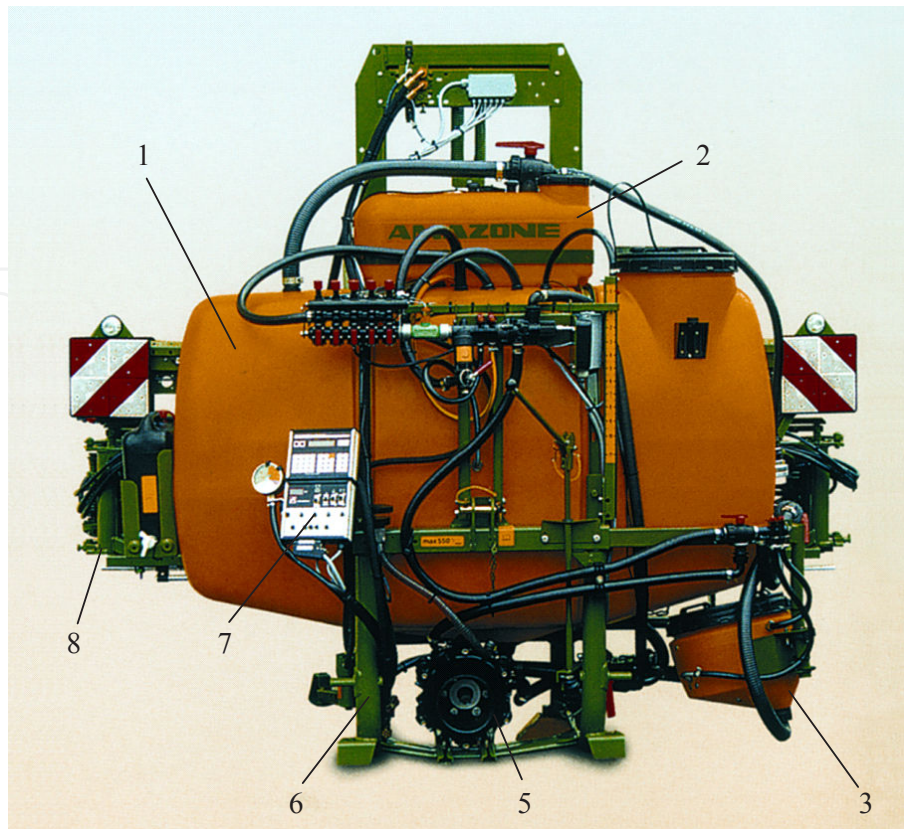
to the control panel. Having set the required pressure by the reducing valve 7, the solution is supplied from the control panel to the hydraulic mixer 33, injector, preparation tanks and sections of spray bar 11 with nozzles. Nozzles spray the liquid on the sprayed surfaces. The surplus of the solution 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.



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].

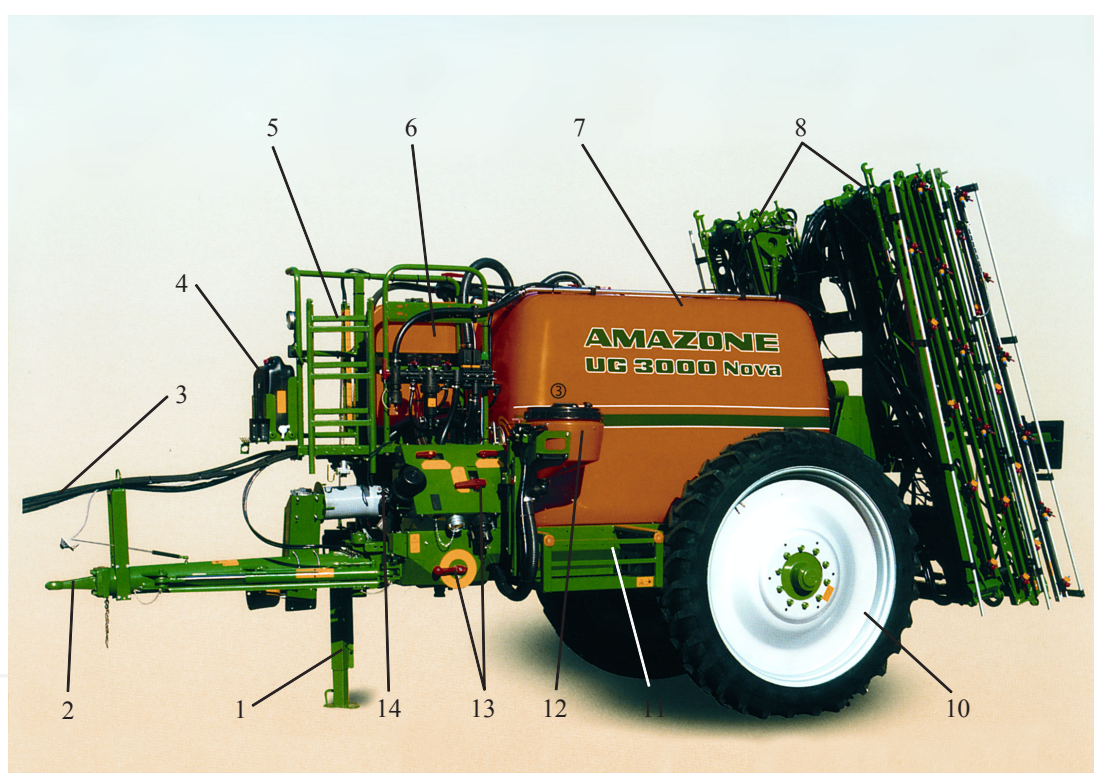
Figure 2. Suspended field tractor-mounted hydraulic sprayer

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;

- 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 $5\text{-}10 \text{ l min}^{-1}$ 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 $10\text{-}15 \text{ l min}^{-1}$, 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.

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 *electromagnetic 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.

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 *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

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).

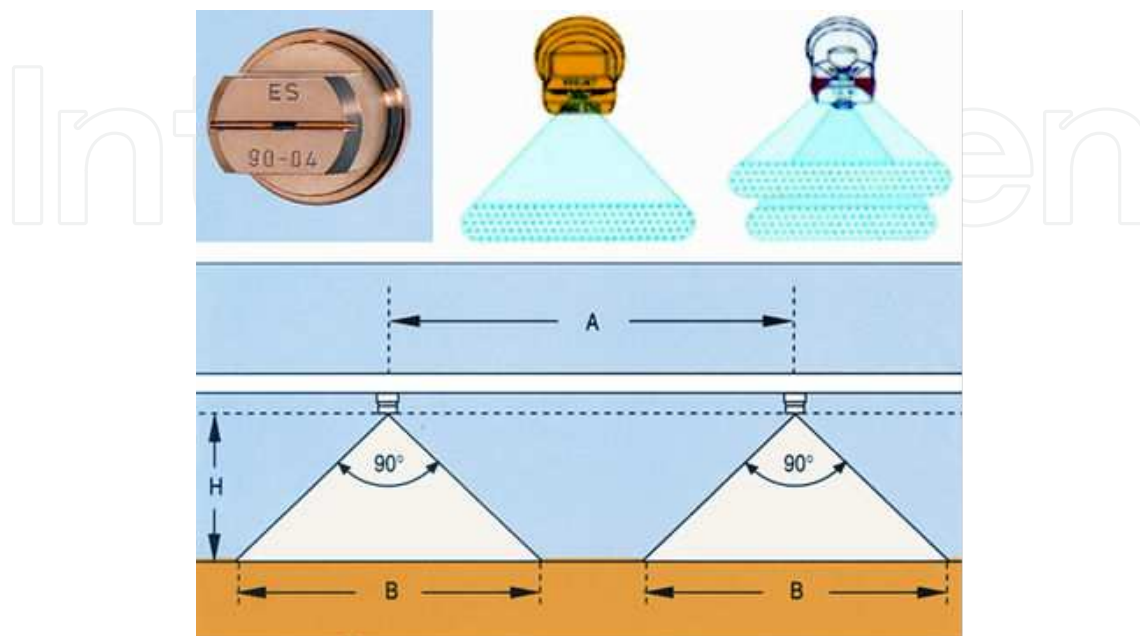
Standard or universal cleft flat-flow nozzles are widely used and are inexpensive. When changing pressure, solution may be sprayed in small, average or large drops. It is possible to spray in windy weather with wind speed up to 3 m s⁻¹. Solution is dosed and sprayed through the cleft [9].

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., 100–150 l 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.

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 90°. 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 45°.

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.

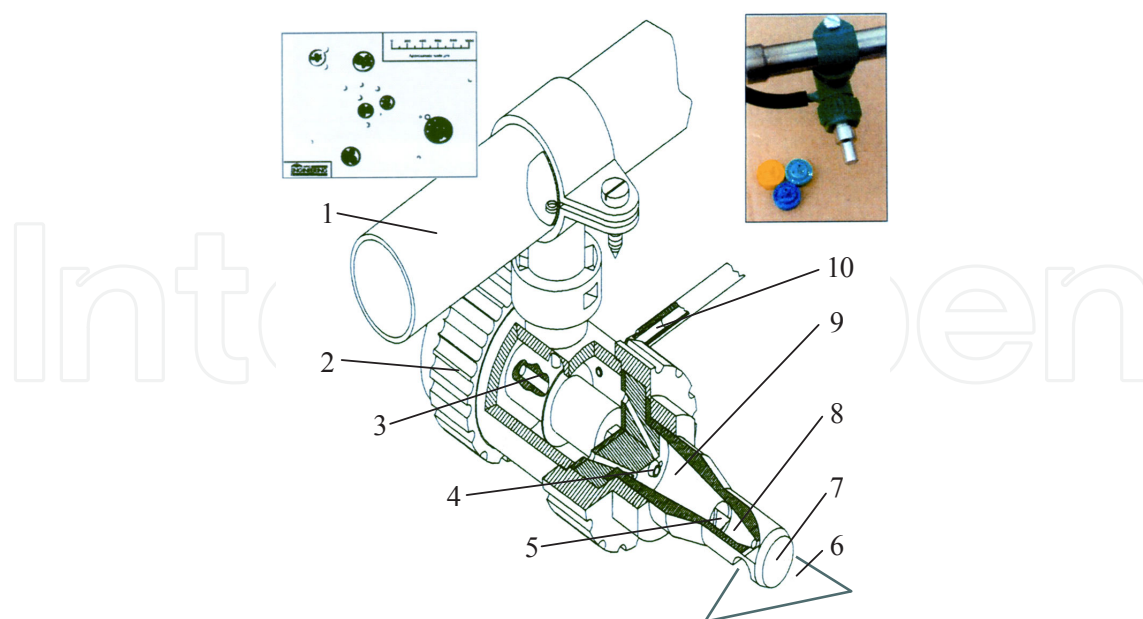
Hydraulic cone-stream nozzles may be full cone-flow and hollow cone-flow. In hollow cone-flow, due to a special insert, liquid flow starts to turn and flows in the borders of the hole. The insert may be a cylinder with slantwise cut or a plate with slantwise holes or slantwise surfaces.

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

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.

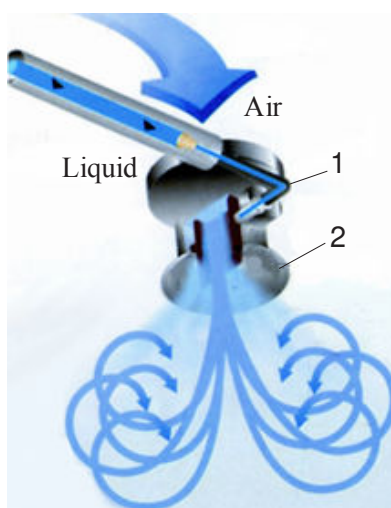
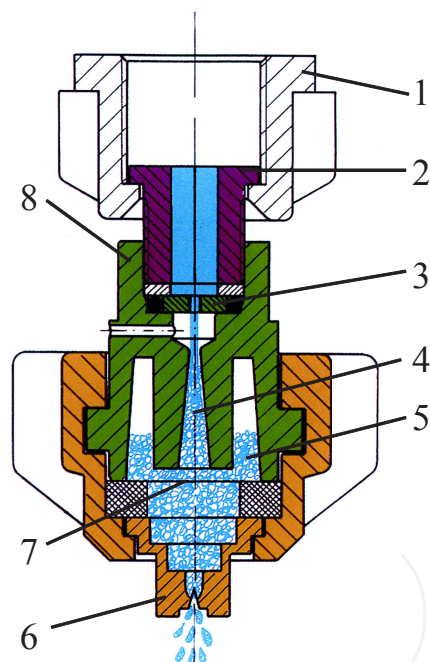


Figure 6. Eurofoil pressure pneumohydraulic nozzle: 1 – rubber air nozzle, 2 – plate [1].

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.

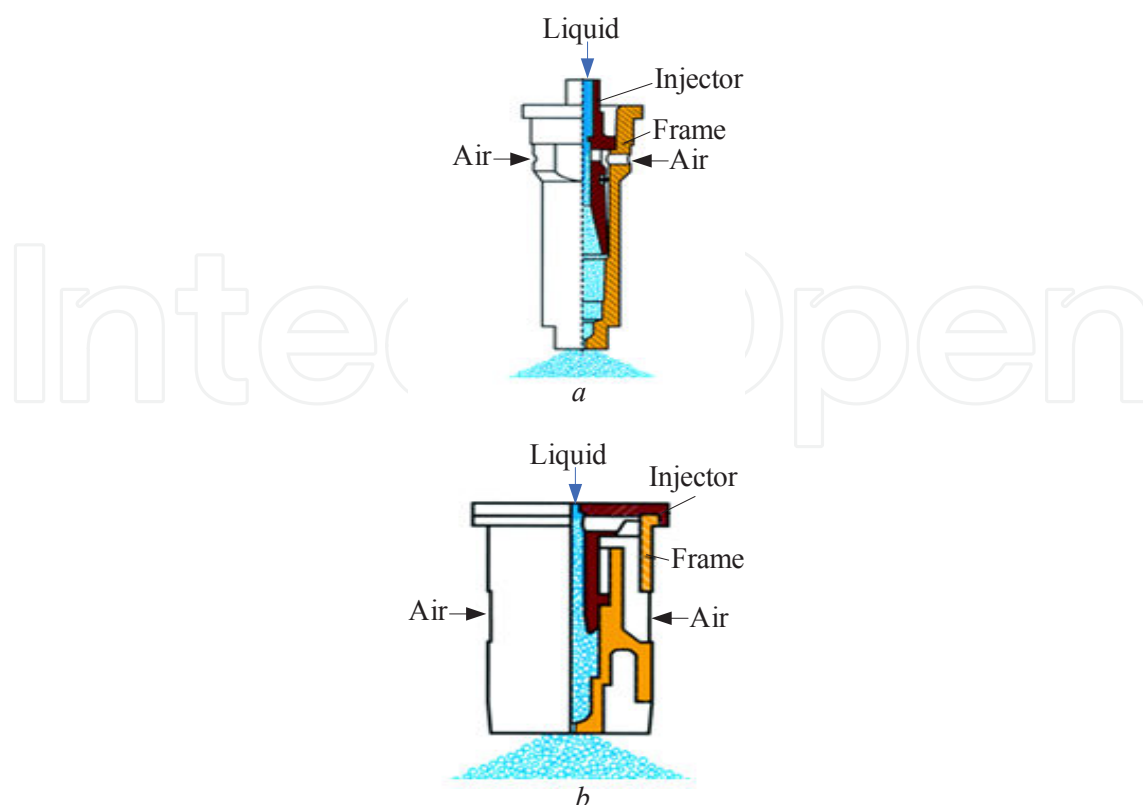


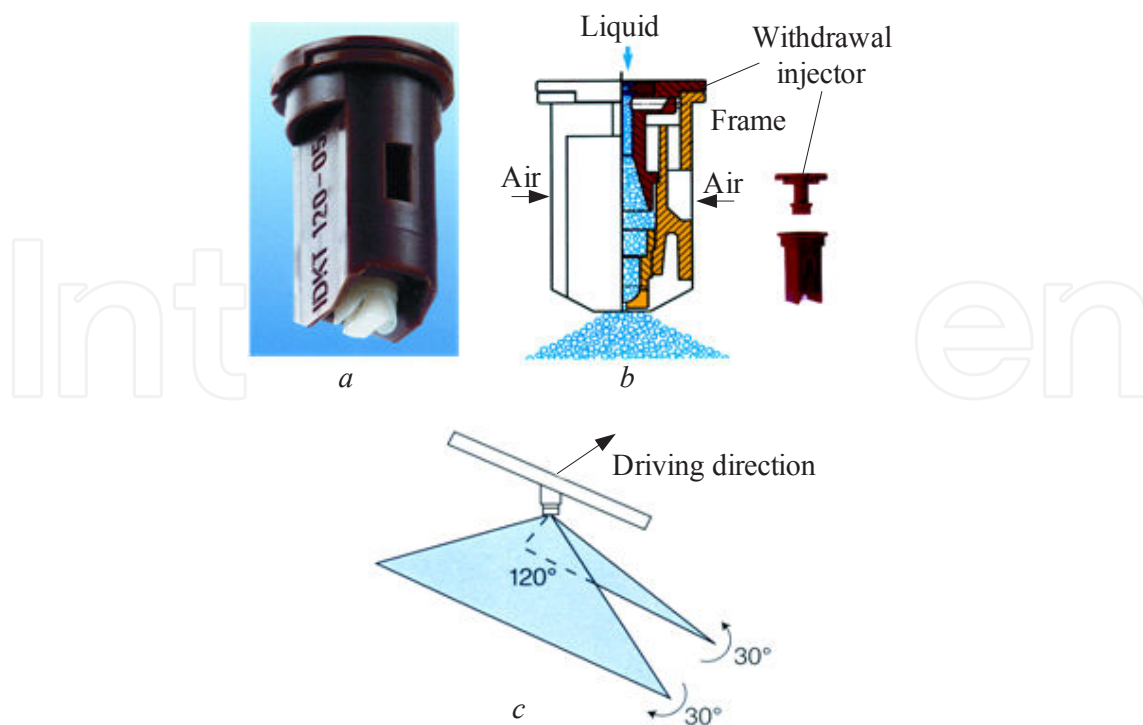
Figure 8. Nozzles of compact injector cleft flat-flow tips: a – high pressure; b – low pressure [9].

With injector pneumohydraulic asymmetric flow nozzles, liquid is sprayed at an 80° angle, i.e., 20° from the symmetric axis to one side and 60° 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 ($> 8 \text{ km h}^{-1}$). 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 ($> 8 \text{ km h}^{-1}$), 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 Tecnomat 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 Tecnomat 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.

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:

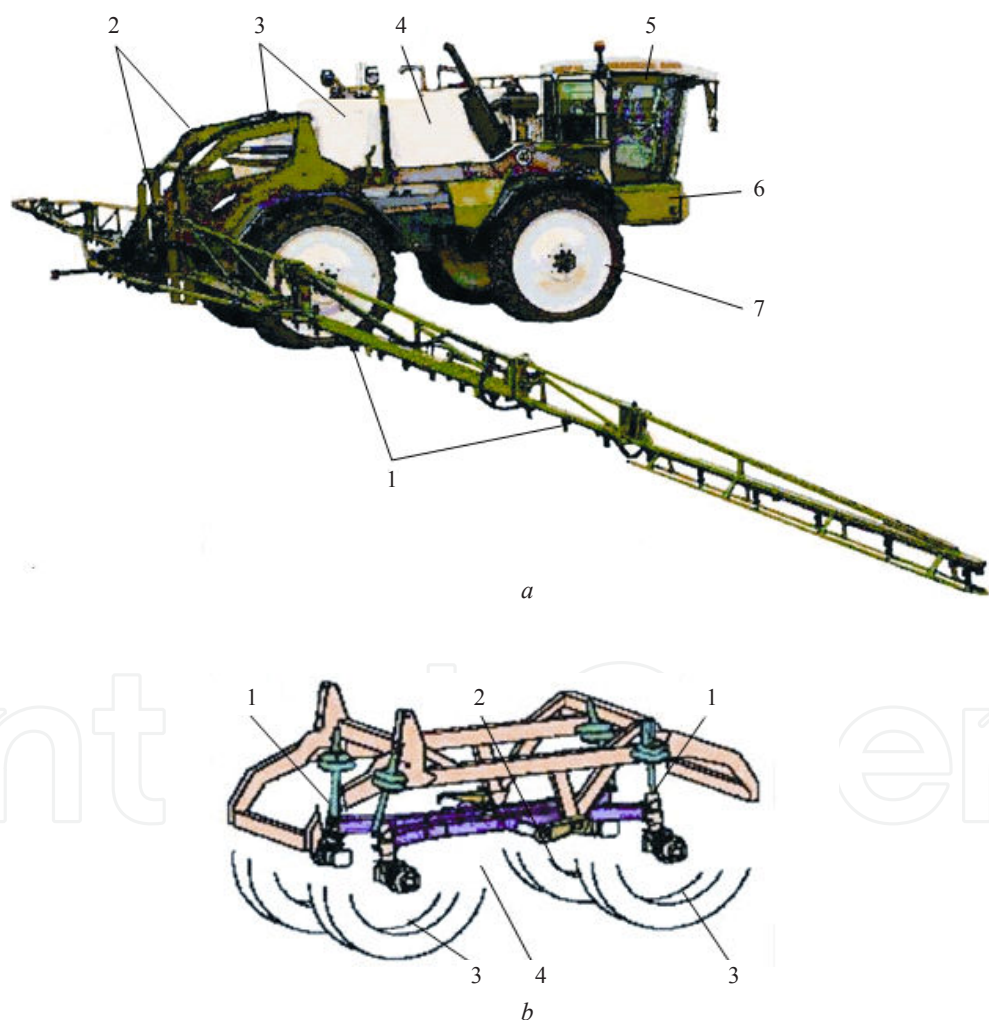
- Always ready for work – it is not necessary to suspend or unhook it;
- Large clearance – it is possible to spray rapeseed during blossom;
- Due to special chassis construction, the position of a beam is more stable - tandem axes, air pillow (Figure 10 b);
- Higher productivity because it is possible 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 – 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 – air amortizers, 2 – pendulous fork, 3 – hydraulic engines, 4 – pendulous frame [1].

Figure 10. Self-propelled hydraulic field sprayer

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.

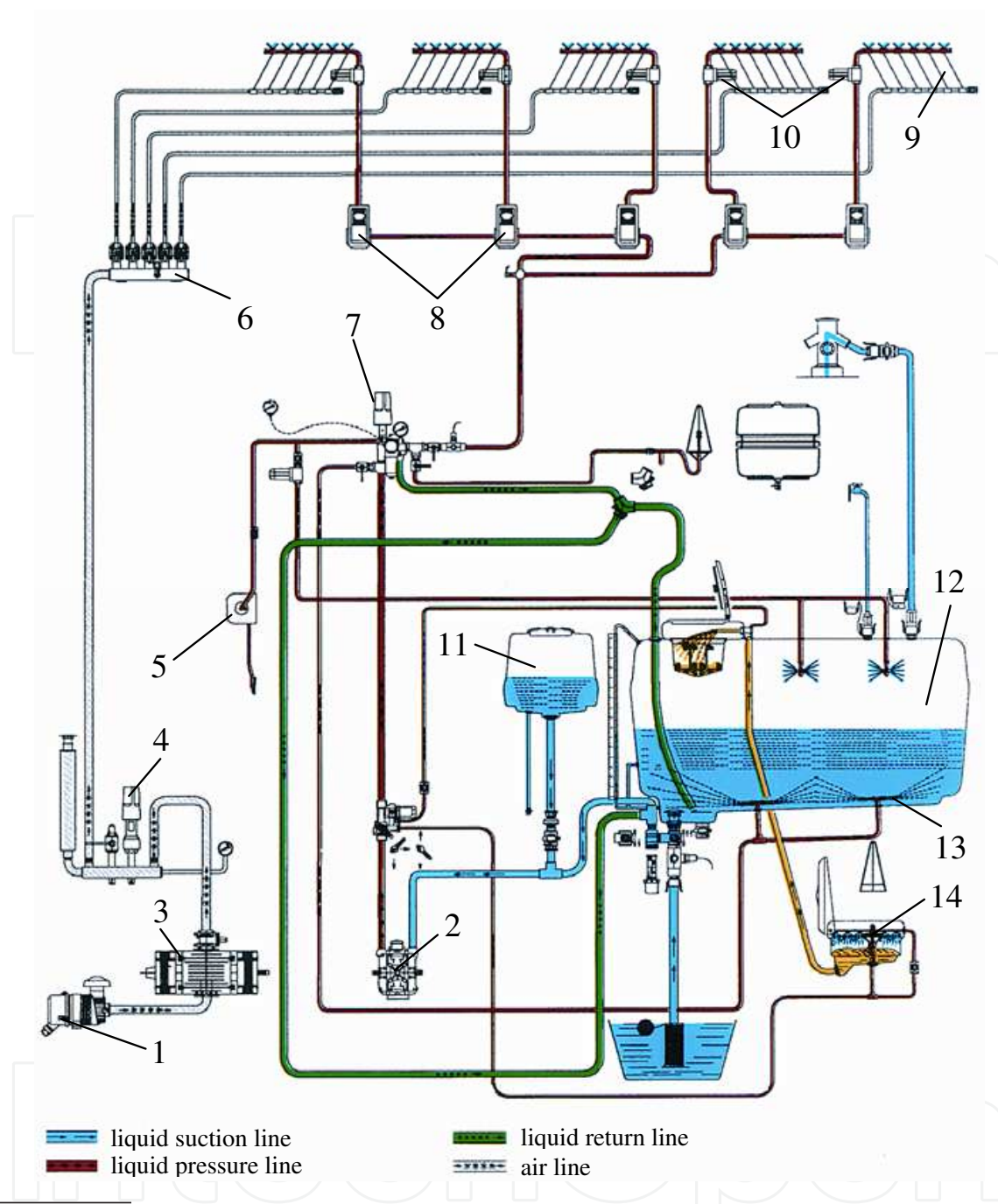
2.2.4. Peculiarities of the frame of pneumohydraulic field sprayers

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.

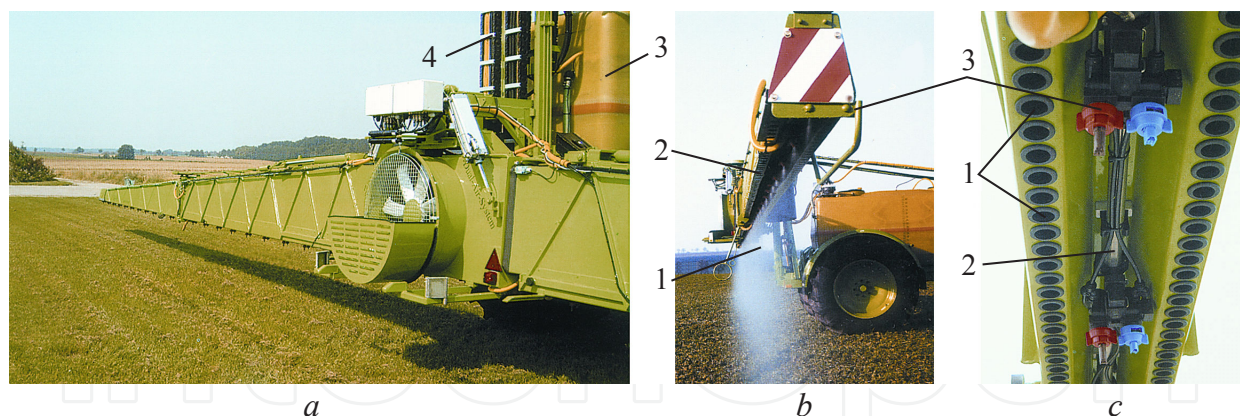
In pneumohydraulic field sprayers, air flow is created by one or two axial ventilators; usually, they are driven hydraulically. It is distributed by flexible fabric hoses or channels of light metal. Various producers offer air distribution hoses of various forms and holes for their flow, e.g., in the 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.



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 $\pm 30^\circ$. 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.

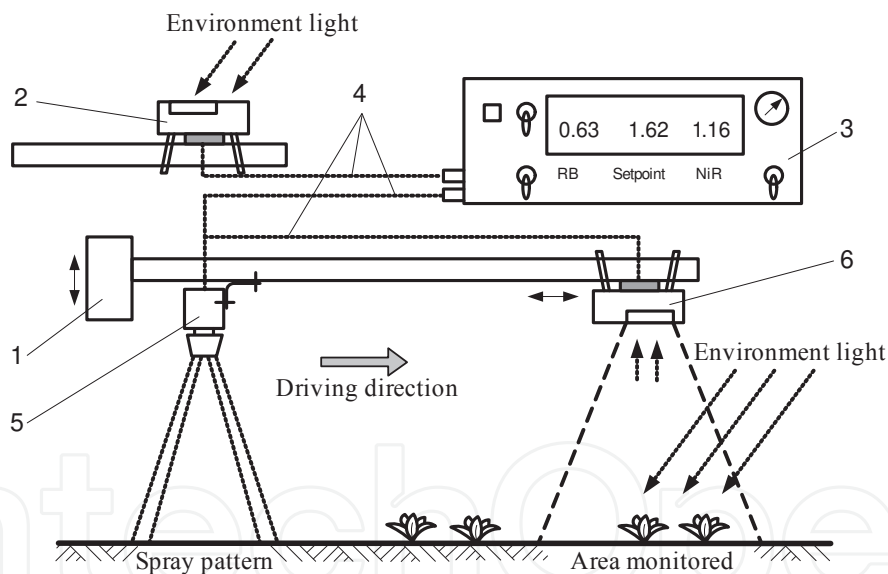
Specialists advise checking new sprayers with pneumohydraulic nozzles in special workshops, since it is rather difficult to determine the optimal liquid slantwise distribution. Nozzles of this type should be washed very well because even insignificant sediments on a deflector may considerably affect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

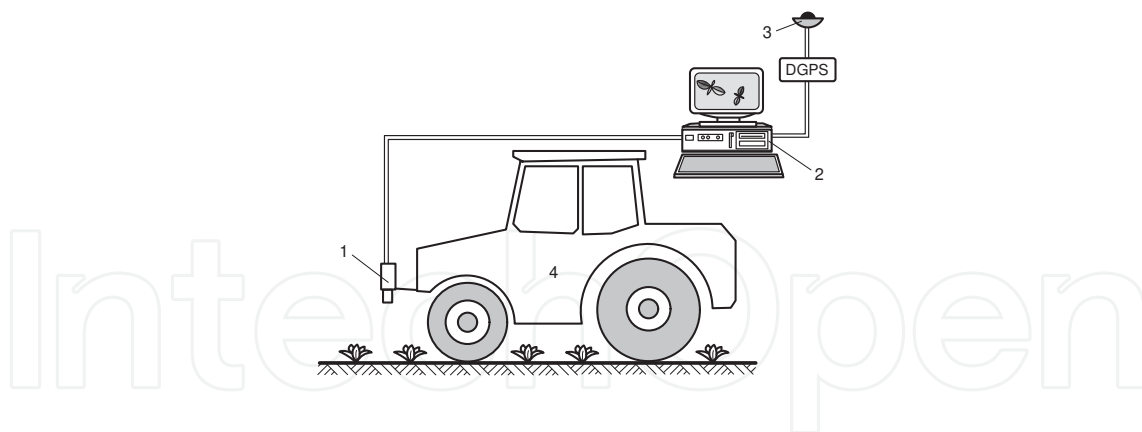
Wartemberg used optical-electronic sensors with DGPS equipment, and recognized weeds comparatively well and fixed their place in the field [23].



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].

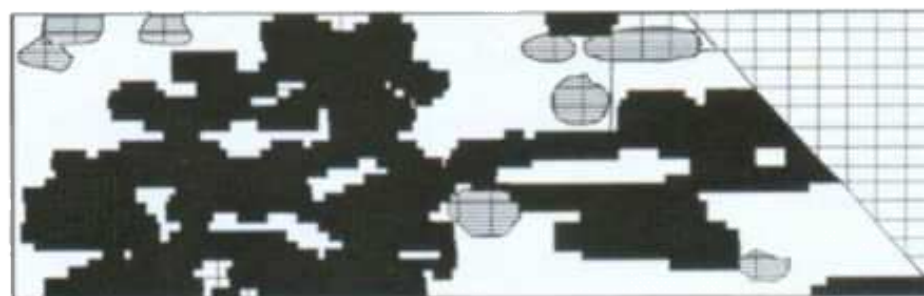


1 – video camera; 2 – computer; 3 – DGPS receiver; 4 – means of transportation [2].

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



-  weeds to be sprayed with herbicides
-  no weeds or their number does not exceed the limits of the damage

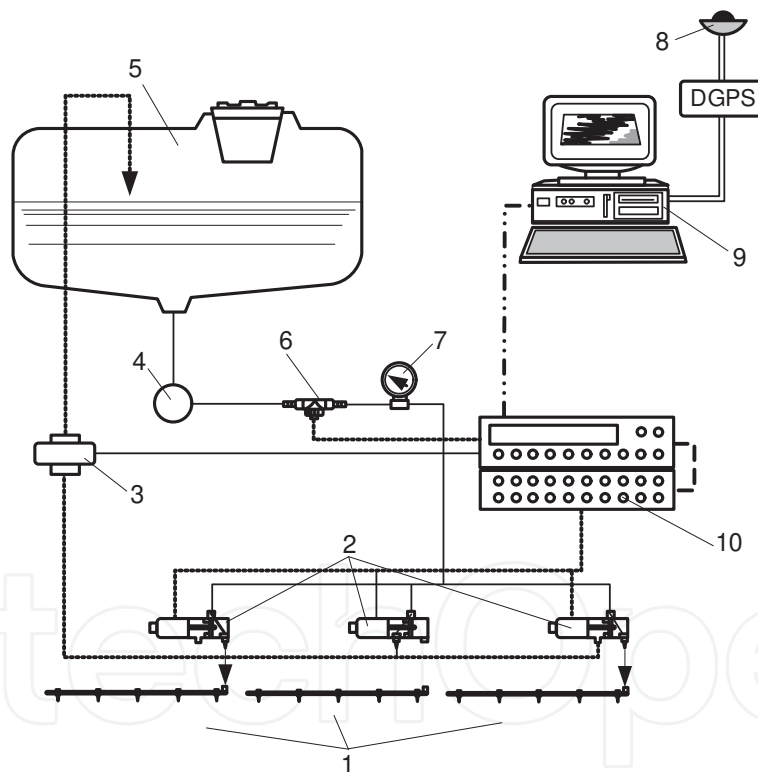


-  areas to be sprayed with herbicide

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].

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].

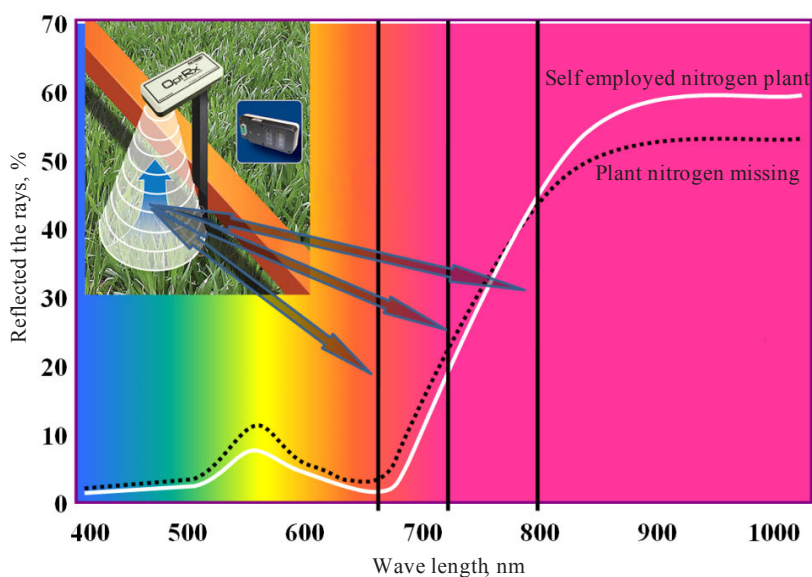


Figure 19. Part of reflected rays depending on the length of a wave [25].

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.

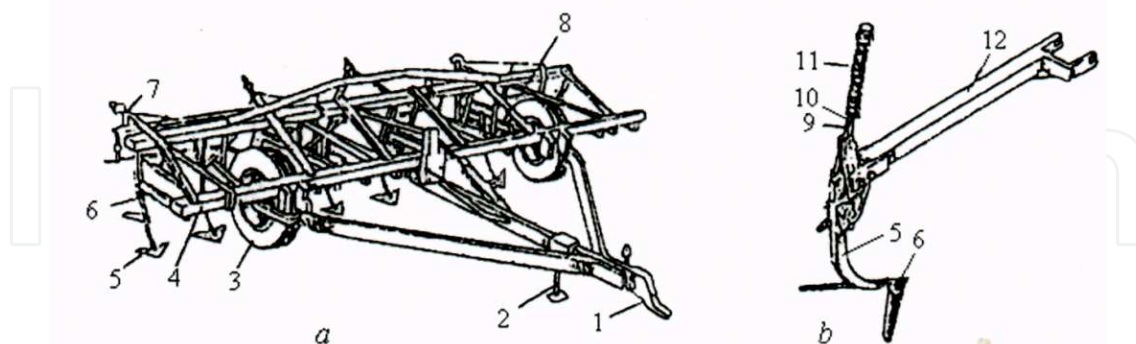
3.1.2. Classification

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.

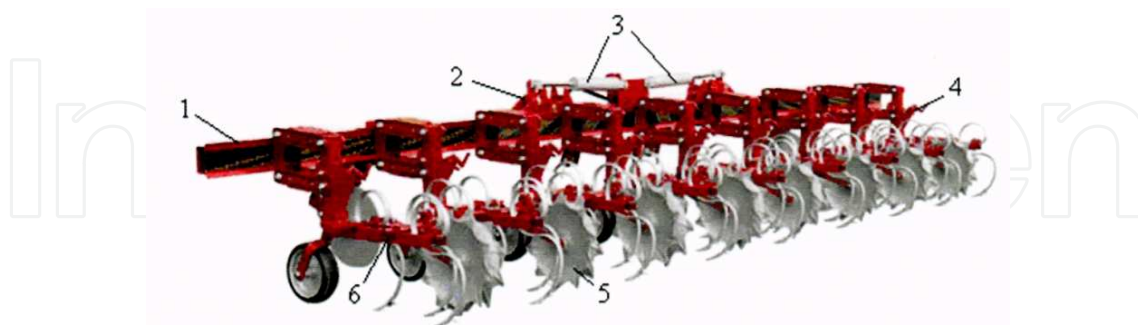
The ploughshare is attached to a cultivator frame jointly (Figure 20 b) or stiffly. The jointly attached ploughshare copies the soil surface better and cultivates soil more evenly. When attaching ploughshares jointly, they are fastened to the frame by a carrier 12; also, pivots 9 with pressed springs 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

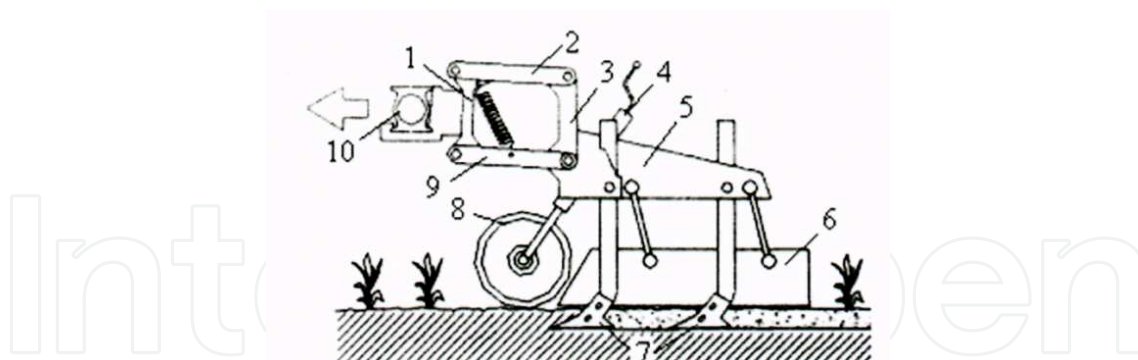
are lifted during transportation; regulation device for loosening depth 4; protective disc 5; and section of ploughshares 6. The operational parts of such cultivators are ploughshares. Ploughshares are fastened in sections for operation in one row-spacing.



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

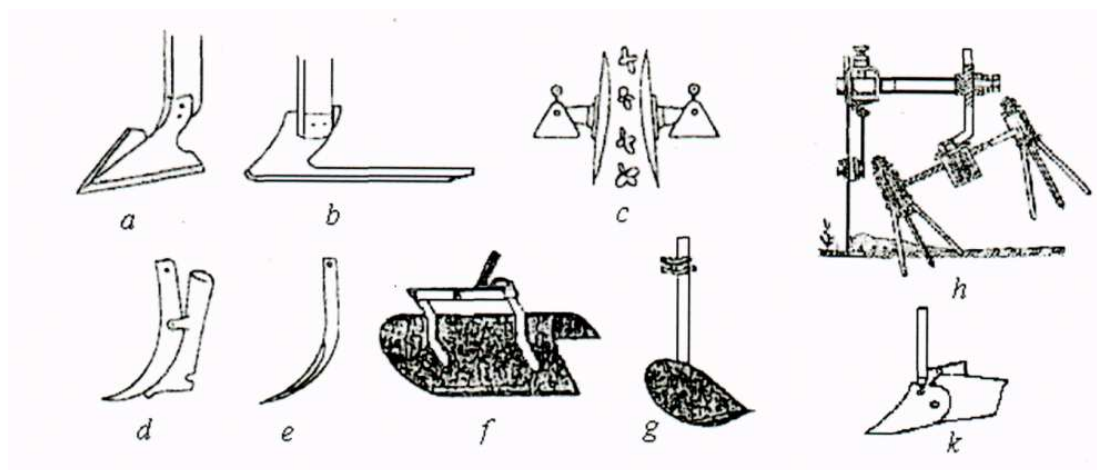
Row-spacing cultivators have various sets of ploughshares and fertilizing machinery. Fertilizing machinery may have plate or screw fertilizer feeders. Fertilizer feeders are turned by cultivator wheels through chain gears and reducers. In row-spacing cultivators, there are one-side knife *b*, arrow *a*,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

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.

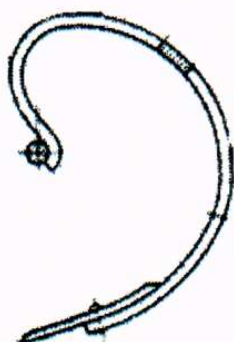


Figure 24. Spring harrow rod [26].

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.

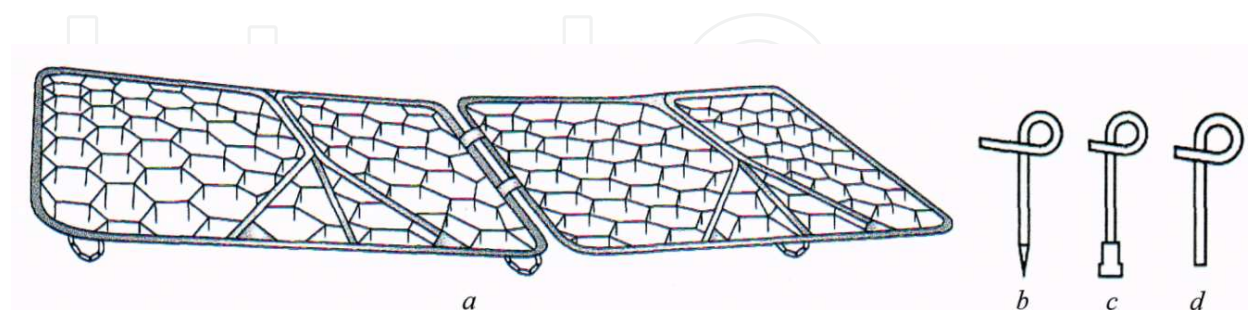
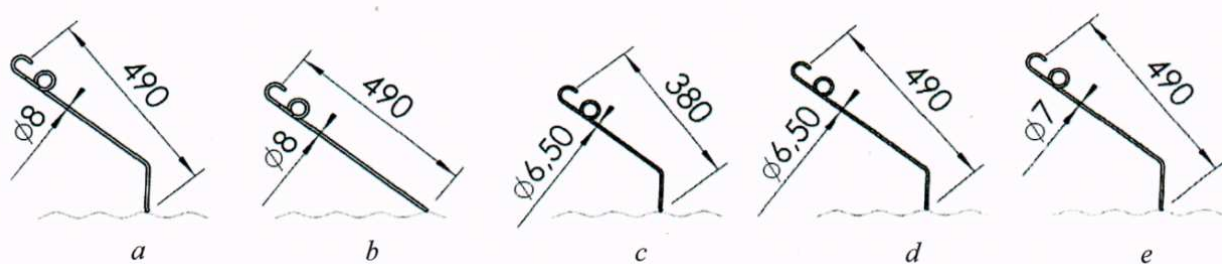


Figure 25. Mesh harrow (a) and harrow rods: b – pointed, c – flat; d – obtuse [30, 31].

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 0.10–0.30 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 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.

Author details

Algirdas Jasinskas*, Dainius Steponavičius, Povilas Šniauka and Remigijus Zinkevičius

*Address all correspondence to: algirdas.jasinskas@asu.lt

Institute of Agricultural Engineering and Safety, Faculty of Agricultural Engineering,
Aleksandras Stulginskis University, Kaunas-Akademija, Lithuania

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