

Parameters of the herbicide spraying system for oil-bearing rose production

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Abstract

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Chemical weed control is characterized by a significantly lower energy intensity of the technological operation and the less time required for its realization, than the mechanical one.

Based on the morphological characteristics of the rose plant, the agrotechnical requirements for cultivation of the oil-bearing rose and the ways and means for conducting mechanized weed control, the structural parameters of a boom-type spraying system for treatment of the soil surface in the row between and around the rose bushes are defined. By computer simulation the relationship between operating factors influencing the efficiency and spraying quality, including the nozzle position with respect to the soil surface and the outer contour of the oil-bearing rose bush, the spray angle and the type of nozzle for spraying has set for different technological schemes of planting the oil-bearing rose plantations.

Keywords: oil-bearing rose; weed control; herbicide; spraying system; computer modeling; parameters

Introduction

The weed control in oil-bearing rose plantations during vegetation is mainly done mechanically – mechanized in the interrow spaces and by manual weeding and hoeing in the row (Atanasov et al., 2008). The mechanized treatment of the soil inside the row (between plants), in practice, is inapplicable. The use of agricultural implement with automatic deviating sections in young rose plantations (up to three years) is impossible, because for actuating the deviating device its finder must encounter a resistance that could damage the rose plant. Implement with automatic deviating sections can not be used as well in plantations where the space between plants is less than 1 meter (seedlings of oil-bearing rose are planted at a distance of 0.8-1.2 m (Nedkov et al., 2005), which decreases with the growth of the rose bushes.

Weed control also occurs with herbicides. They are applied early in the spring before the vegetation of roses and weeds. The weed control continues against the secondary oc-

currence of weeds (Atanasova & Nedkov, 2004; Atanasov et al., 2008).

The spreading of herbicides into oil-bearing rose plantations is usually preceded by mechanical treatment of the interrow spaces and their subsequent dispersal in the untreated area of the soil surface under the rose bush crowns. A basic requirement is that the herbicidal solution does not fall on the foliage of the spray plant. For this purpose, in the small-size rose-growing farms are used back or chest man-portable sprayers. Sprayers of this type (motor, accumulator or hand-driven) are poorly productive due to the requirement for a large number of unproductive moves for charging. Working conditions are also unfavorable – weighing 25 kg on the operator’s shoulders, climatic conditions of the early spring period, close contact with the spraying system, vibrations, engine noise and many others.

An attempt to mechanize the weed control in the area between plants in oil-bearing rose plantations was made at the Institute of Roses, Essential and Medical Cultures – Kazanlak.

An agricultural implement has been developed, with which granular herbicides are applied only in the untreated strip of the rows (Nedkov et al., 2005). The implement does not reach mass production. There is also no information on its use on the territory of the Republic of Bulgaria at the present moment.

Advantages of chemical weed control are the significantly lower energy consumption of the technological operation and the less time required for its realization. The requirement for the absence of working fluid on the foliage of the oil-bearing rose plants becomes more easily attainable with the increasingly widespread practice of shaping rose bushes with high crowns.

The investigations on the mechanization of technological operations in the cultivation and harvesting of oil-bearing roses has been done in department “mechanization of the agriculture” at the Institute of Soil Science, Agrotechnologies and Plant Protection “Nikola Poushkarov” – Sofia over the last years (Bozhkov et al., 2015; 2017; 2018). The determination of the parameters of a spraying system is a stage of research on creating of a technical means for spread of herbicides into the row of the oil-bearing rose plantation in meeting the requirements ensuring the effective implementation of the plant protection operation, incl. (Kostadinov, 2008):

- reliability in operation and productivity, ensuring timely realization of the event;
- spray quality – the droplet coverage parameters to ensure maximum (biological and economic) effect;
- ecological safety – preventing the spreading of working fluid on other crops adjacent to the oil-bearing rose plantations;
- safe working conditions – no direct contact or inhalation of the preparation by the operator during work.

The conceptual design foresees the possibility that the spraying system for herbicides can be joined to existing plant protection implement or on its basis to develop new constructions of agricultural implement.

Materials and Methods

The determination of the parameters of a spraying system for introducing herbicides into oil-bearing rose plantations required the following tasks to be solved in stages:

- clarification of the possibility of herbicide treatment of the area of the soil surface under the bush crown;
- determining the width of the soil surface under the rose bush that can be treated by nozzles located at the side of the bush;
- determination of the position of the nozzles with respect to the soil surface and the oil-bearing rose bushes, guaranteeing quantitative and qualitative treatment of the spraying area of the soil surface;

- calculation of the angle at the top of the torch (spray angle) which the nozzle has to provide to cover the treatment area of the soil surface at the base of the bush.

Task responses were obtained after experimental and analytical activities.

An analysis of the morphological features of the oil-bearing rose plant and agrotechnical measures in its cultivation (Staykov, 2003; Atanasova & Nedkov, 2004; Nedkov et al., 2005) was made to clarify the possibility of herbicide treatment of the soil surface around the bush root and its approximate width. The experimental tests were carried out, too. The used device in the tests is a semi-professional LADY 10 hand-held sprayer with a single spray flat-jet nozzle through which the liquid comes out in one plane. Tests were carried out with a different orientation of the nozzle relative to the treated surface.

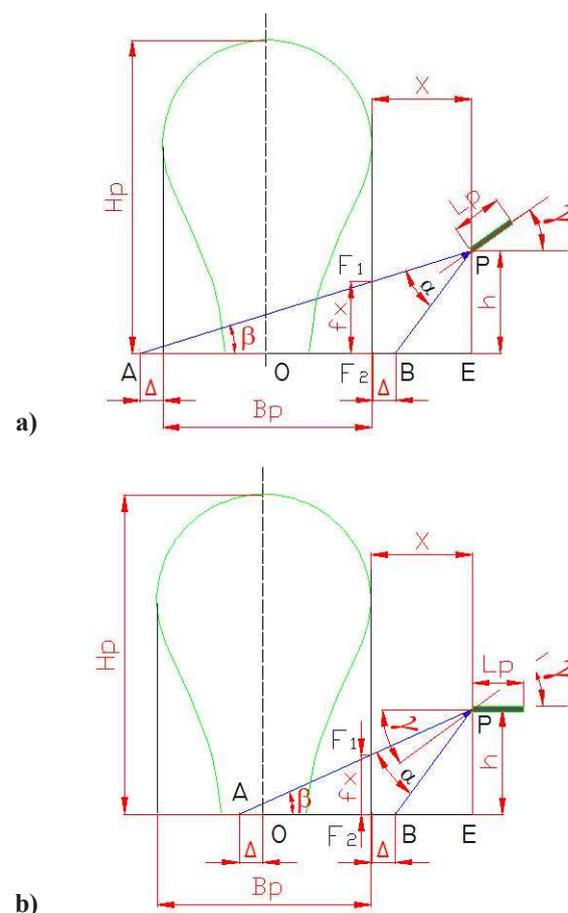


Fig.1 Schemes for determining the position of the herbicide nozzle

- a) spraying the entire undercrown area of the soil surface**
- b) spraying half of undercrown area of the soil surface**

The parameters concerning the positioning of the herbicide nozzles are determined analytically. For this purpose, the schemes of Figure 1 have been developed, using Auto-Cad softwar. Based on them, mathematical formulas giving the relationship between the studied parameters are derived (Table 1). With the help of the Excel software product an application program was created, with which various variants of positioning of the spraying element with respect to the treated soil surface, outside of the rose bushes and spray angle have been simulated. The height of positioning of the nozzles is limited: as a minimum value – from the unevenness of the soil surface; as a maximum value – half the height of the bush in the active stage of development of red oil-bearing rose. The range of distances for nozzle positioning with respect to the oil-bearing rose bush is determined according to the widths of the interrow space, crown of the bush, farm implement to which the spraying system is attached, and the length of the nozzle.

During computer simulation the relationship between (Figure 1) the width of spray area (AB), the nozzle position on the vertical (h) and the horizontal (X), the spray angle (α), the angle of the nozzle slope with respect to the horizontal (γ) and the spray height on the outside of the bush (fx) is searched. Calculations were made for the three used in the agricultural practice schemes for the formation of oil-

Table 1. Mathematical formulas used in computer simulation

Sprayed area under bush crown	
The entire width of the soil surface (Fig. 1 a)	Half of the width of the soil surface (Fig. 1 b)
$X_{max} = (B-Bp-B_M)/2-Lp*\cos(\gamma)$	$X_{max} = (B-Bp-B_M)/2-Lp*\cos(\gamma)$
$\Delta = 10\% * Bp$	$\Delta = 10\% * (Bp/2)$
$AB = Bp+2*\Delta$	$AB = Bp/2+2*\Delta$
$AE = Bp+\Delta+X$	$AE = Bp/2+\Delta +X$
$h = PE$	$h = PE$
$BE = X-\Delta$	$BE = X-\Delta$
$BP = \text{SQR}(BE^2+PE^2)$	$BP = \text{SQR}(BE^2+PE^2)$
$AF_2 = Bp+\Delta$	$AF_2 = Bp/2+\Delta$
$fx = F_1F_2 = AF_2/AE*PE$	$fx = F_1F_2 = AF_2/AE*PE$
$\tan(\beta) = PE/AE$	$\tan(\beta) = PE/AE$
$\beta = \text{arc tan}(\beta)$	$\beta = \text{arc tan}(\beta)$
$\sin(\alpha) = AB/BP*\sin(\beta)$	$\sin(\alpha) = AB/BP*\sin(\beta)$
$\alpha = \text{arc sin}(\alpha)$	$\alpha = \text{arc sin}(\alpha)$
$\gamma = \beta + \alpha /2$	$\gamma = \beta + \alpha /2$

bearing rose plantations with a width (B) between the rows of 2.8 m, 3.0 m and 3.2 m, respectively. As input parameters are used:

- the width of the rose bush in the widest crown area ($Bp = 1000$ mm), determined as average by researchers in the branch (Nedkov et al., 2005);
- the height of the rose bush ($Hp = 1600$ mm) in the active stage of development of red oil-bearing rose (after 4-5 year of planting) (Nedkov et al., 2005);
- the width of the farm implement ($B_M = 1250$ mm) corresponding to the width of the basic module of the oil-bearing rose implement MP-1 (Bozhkov et al., 2015);
- the length of the nozzle ($Lp = 100$ mm), chosen as common for sprayers manufactured by different manufacturers.

With the computer program developed on the basis of the schemes of Figure 1, two options were investigated, one of which was to spray the entire area of the soil surface under the crown of the rose bush (Figure 1a) and the second one to spray the half (Figure 1b). The extension (Δ) of the spraying zone is provided for both sides by 10% of its width, to compensate for the influence of the slope of the terrain and the irregularities on its surface. The following variants for the nozzle location have been simulated:

- on the vertical – through 100 mm within the limits of the accepted minimum 200 mm, determined by the unevenness of the soil surface (including those formed after the plowing of the rose bushes) up to a maximum of 800 mm, representing half of the height of the bush adopted in the study;
- horizontally – through 25 mm within the limits of the minimum distance (X_{min}) from the contour on the outside of the bush (includes the 10% extension of the spraying area) to the maximum distance (X_{max}) that can be provided at a given interrow space, and the accepted input parameters, namely:

Width of interrow space, mm	Limit values, mm	
	X_{min}	X_{max}
2800	100	175
3000	100	275
3200	100	375

The spray angle (α) and the angle of the nozzle slope with respect to the horizontal (γ) are calculated. When the symmetry axis of the torch does not coincide with the nozzle axis (Figure 1b), angle γ represents the angle of inclination of the axis of the torch with respect to the horizontal. To assess the

applicability of nozzles with a certain spray angle at different vegetative development periods of the rose plants, crown shaping and other characteristic parameters and indicators, a sprayed height is calculated on the outside of the bush (f_x).

To visualize the results obtained for the spray angle and the angle of the nozzle slope with respect to the horizontal, the graphs have been built, and for their precise use, the regression mathematical models have been derived using the STATISTICA software.

Results and Discussion

Tests with the experimental device have shown that the droplet coating at the periphery of the stain left by the sloping nozzle is less dense than that in its remaining part. However, the length of the stain (approximately 650 mm at $h = 300$ mm) is commensurate with half the width of the area under the rose bush crown, which have to be treated during the weed control. It has been hypothesized that it is possible to implement a technical solution that would allow covering the entire area of the soil surface under the bush crown, such as using two or more nozzles or nozzles with more than one spray nozzle, optimizing the position of the nozzles with respect to the soil surface and the oil-bearing rose bushes, refine the pressure of the working fluid in the system, the spray angle, etc.

With the accepted input parameters and observing the restrictive conditions by the developed computer program 168 variants were simulated. The results obtained for the two widths of the spraying area in the three planting schemes are systematized with respect to the spray angle (α), the spraying height on the outside of the bush (f_x) and the angle of the nozzle slope to the horizontal (γ).

Analysis of computer simulation results showed that the spray angles, which the nozzles have to provide for spraying the area of the soil surface at the base of the oil-bearing rose bush, in all possible variations are within the range: for entire undercrown area treatment (total spraying area 1200 mm) – from 28.5° to 84.5°; for half of undercrown area treatment (total spraying area – 600 mm) – from 23.6° to 79.0°. Whether it will be spraying half or entire undercrown area and by what kind of nozzle will depend on the planting scheme, the stage of vegetative development of the plant, the type and quality of the pruning performed, the current condition of the plantation and other factors. Larger potentials in choosing the optimal combination of setting parameters for the spraying system is the scheme in which the half of undercrown area are treated with herbicides. The main disadvantage is the lower performance of the technological operation.

The results obtained during the analytical study showed

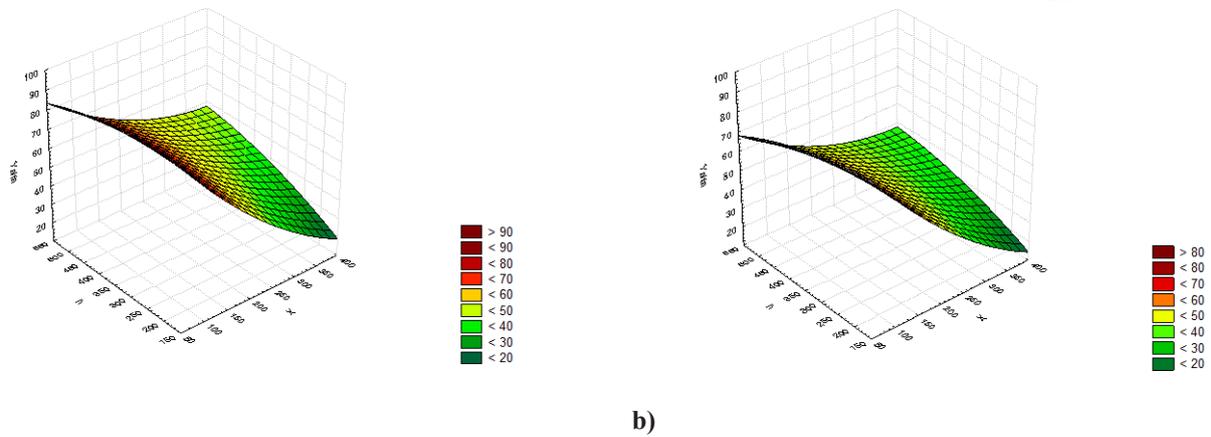
that spraying from farther distances allows the use of nozzles with smaller spray angles. The height at the outer side of the bush on which the herbicide is falling is less, i.e. areas under rose bushes with lower shaped crowns may be sprayed. In the case of spraying from further distances, the areas with uniform droplet density at the periphery of the torch are wider, which degrades the spraying quality. Higher working fluid pressure is required for spraying.

When spraying from closer distances to cover the areas for herbicide treatment, it is necessary to use nozzles that provide larger angles at the top of the torch. In this scheme, the spray height on the outside of the bush increases and in certain cases may cause herbicide to fall on the foliage of the rose plant.

The results of computer simulation unambiguously confirm the fact that the position of the nozzle directly affects the sprayed height on the outside of the bush. For the accepted test range of 200 to 800 mm, the sprayed height is when treating the entire undercrown area from 149 to 733 mm and half of undercrown area from 123 to 686 mm. To prevent the spreading of working fluid at a height above 400-450 mm (where the dense foliage of crown of maintained oil-bearing rose plantation starts) the positioning of the nozzles in a vertical direction shall not exceed 500 mm, regardless of the spray pattern adopted (half or entire undercrown area). If the condition for covering the treatment area under the bush is fulfilled, the nozzles should be positioned as low as possible to the soil surface, taking into account the specific features of its profile. Considering the introduced limitation with respect to the position of the nozzle, the ranges in which the angle of the nozzle slope to the horizontal at the two spraying patterns will vary within the range: for spraying the entire undercrown area from 22.0° to 62.0°, and for spraying half of undercrown area from 24.9° to 79.1°.

Based on the results of the analytical study and using “STATISTICA” software, the graphs in Figure 2 and Figure 3 were built out. The graphs can be used to determine the positioning parameters of a nozzle with a known spray angle on the spraying system for herbicide application. The distance of the nozzle from the rose bush is chosen within the range acceptable for the planting scheme.

The graphs of Figure 2 and Figure 3 are built on data obtained at specific values of the parameters characterizing oil-bearing rose plantations and nozzles. For use with other values of the input parameters, it is necessary to take into account the influence of the difference on a controlled parameter. For example, the length of the nozzle (L_p) other than 100 mm should be taken into account when determining the maximum distance (X_{max}) at which the nozzle can be located from the oil-bearing rose bush.

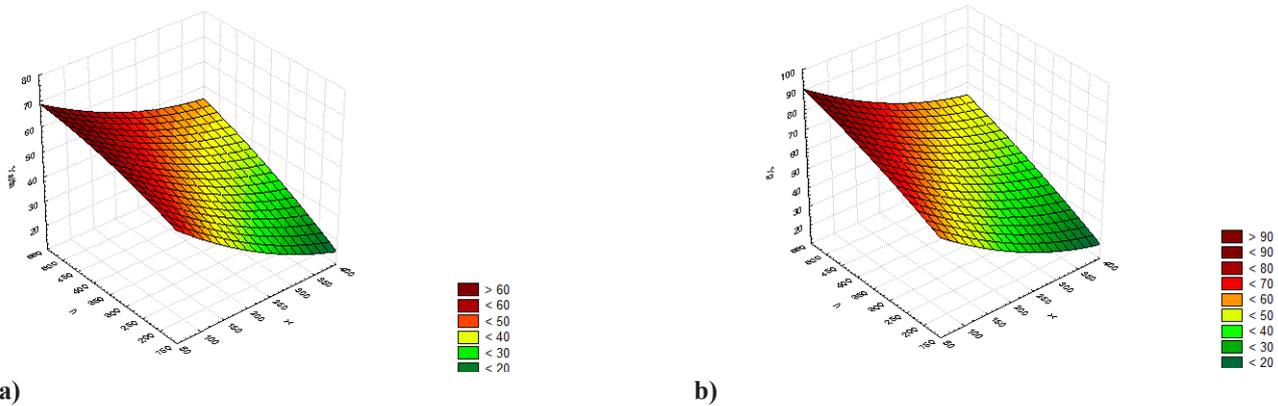


a)

b)

Fig. 2. Dependency of the spray angle in respect of the position occupied by the nozzle for herbicides at the spraying width of soil surface

a) the entire undercrown area; b) half of undercrown area



a)

b)

Fig.3. Dependency of the angle of the nozzle inclination to the horizontal in respect of its position at:

a) the entire undercrown area; b) half of undercrown area

Precise use of the results of the analytical study is made possible by derived on their basis the regression mathematical models presented in Table 2. The accuracy of their application is assessed with the indicator R-squared (R^2) (Mitkov, 2011), called in the statistical studies “coefficient of determination”. With their help can be calculated the spray angle to be provided and the angle of inclination at which the nozzle must be positioned for each of the three planting schemes and both sprayed width (entire and half of undercrown area).

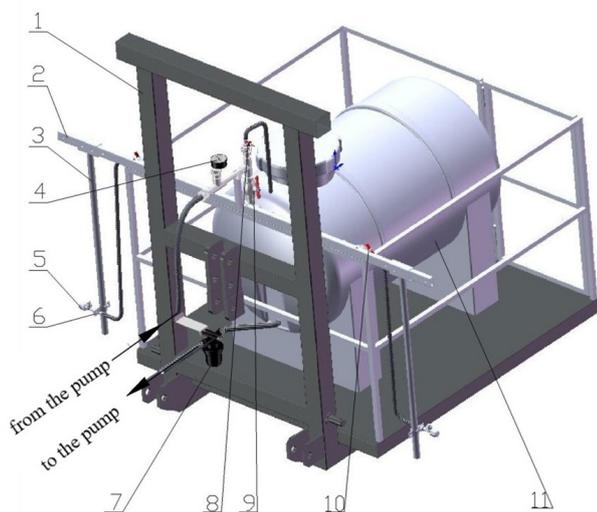
On the basis of the results obtained in the computer study, a carrier structure was developed on which the elements of

the spraying system would be placed. A scheme of the spraying system complete with it is presented in Figure 4.

The newly developed carrier structure consists of a horizontal bar 2, vertical booms 3 and the attachment units 6 for the nozzles 5. It is designed to allow the positioning of the nozzles vertically and horizontally, thereby guaranteeing to conduct the technological operation at each put into practice schemes of rose planting and various schemes of spraying. Options are provided for attaching it to existing sprayers (boom or fan type) or other suitable agricultural implement.

Table 2. Mathematical formulas for determining the spray angle and the angle of the nozzle inclination to the horizontal in respect of the occupied position

Sprayed area	Calculated parameter	Mathematical formulae	Coefficient of determination, R ²
The entire width of the soil surface under bush crown	Spray angle	$\alpha_1 = 107.7793 - 0.3779 \cdot X + 0.0343 \cdot h + 0.0003 \cdot X^2 + 0.0003 \cdot X \cdot h - 0.0001 \cdot h^2$	0.934
	Angle of nozzle inclination to the horizontal	$\gamma_1 = 54.2789 - 0.1929 \cdot X + 0.068 \cdot h + 0.0001 \cdot X^2 + 0.0001 \cdot X \cdot h - 5.4583E - 5 \cdot h^2$	0.974
Half of the width of the soil surface under bush crown	Spray angle	$\alpha_{1/2} = 107.9102 - 0.3785 \cdot X + 0.0018 \cdot h + 0.0003 \cdot X^2 + 0.0003 \cdot X \cdot h - 9.7083E - 5 \cdot h^2$	0.913
	Angle of nozzle inclination to the horizontal	$\gamma_{1/2} = 56.4957 - 0.2169 \cdot X + 0.1052 \cdot h + 0.0002 \cdot X^2 + 4.8741E - 5 \cdot X \cdot h - 4.9375E - 5 \cdot h^2$	0.987

**Fig.4. Scheme of a herbicide spraying system, mounted on the basic module of the oil-bearing rose implement MP-1**

1 – basic module; 2 – horizontal bar, 3 – vertical booms; 4 – pressure gauge; 5 – nozzle; 6 – connecting unit; 7 – filter element; 8 – adjusting tap; 9 – main shut-off tap; 10 – section shut-off tap; 11 – fluid tank.

In Figure 4, the carrier structure is mounted on the base module 1 of the MP-1 oil-bearing rose implement (Bozhkov et al., 2015). The figure also shows other elements of the spraying system necessary for the implementation of the plant protection operation, incl. filter element 7, adjusting 8 and shut-off taps 9 and 10, pressure gauge 4 for the working fluid, pipelines, etc. The volume of the fluid tank 11 for the herbicidal solution is selected according to the needs of the rose-growing farm and the load capacity of the available agricultural tractor linkage. Increasing the pressure of the

working fluid in the system is provided with a pump driven by the PTO (power take-of) or hydraulic system of the tractor (not shown in Figure 4).

The spraying system can be used to control weeds in plantations with similar formation schemes. It could be successfully used to perform vital for young perennials watering, when the plantations are in areas away from permanent sources of water supply, as well as for irrigation of fruit bush plants (cornel, blackberry, raspberries) in the periods before the construction of facilities for the implementation of proven water-efficient irrigation technologies (Petrova, 2016; Kireva & Petrova, 2018). Liquid fertilizers can be locally introduced into the soil, incl. organic mineral fertilizers (Enakiev, 2010), after their preliminary preparation in a form allowing it to be sprayed.

Conclusions

Based on the results of the experimental tests, a hypothesis has been raised about the possibility of realizing a technical solution which would allow treatment of the soil surface under the crown of the oil-bearing rose bush with an herbicide without falling it onto the plant foliage.

The conducted computer simulation allowed determining the parameters for positioning the nozzles on the sprayer booms (height from the soil surface, distance from the rose bush, slope to the horizontal) that can be directly used in completing the herbicide spraying system for weed control in oil-bearing rose plantations. Irrespective of the width of spray area (entire or half of undercrown area), the maximum height of the vertical nozzles must not exceed 500 mm. The minimum height is as close as possible to the soil surface, taking into account the particularities of its profile. The distance of the nozzles from the rose bush depends on the stage of vegetative development, the type and quality of pruning, the available spraying equipment, etc.

The angles at the tip of the torch of nozzles (spray angles), which guarantee the quantitative and qualitative treatment of the soil surface at the base of the oil-bearing rose bush, have been determined – when treating entire undercrown area in the range of 28.5° to 84.5°, when treating a half of undercrown area from 23.6° to 79.0°. Between 22.0° to 62.0° for entire undercrown area and 24.9° to 79.1° for half of undercrown area varies the angle of the nozzle's inclination to the horizontal depending on the position occupied by it. The selection of the spraying pattern and nozzles shall be made in order not to allow working fluid to fall on the foliage of the oil-bearing plant.

Mathematical formulas have been derived, which enable precise determination of the spray angle to be provided and the angle of inclination at which the herbicide nozzle must be located, in accordance with the specific operating conditions, incl. the technological scheme of planting, the scheme of spraying, etc.

The conceptual design of a sprayer carrier structure providing different positioning of nozzles for weed control at the base of bushes has been developed. On its basis, a boom spraying system was completed for weed control in oil-bearing rose plantations and plants with similar formation schemes, for localized introduction of liquid fertilizers into the soil, etc.

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