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Optimization of the design parameters of the sprayer rotary device for the chemical treatment of the near-stem zone of fruit trees

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Abstract. Spraying with herbicides allows you to successfully control weeds. When processing perennial plantations of fruit and berry crops, a certain problem is bypassing the tree trunk. To ensure the quality of soil cultivation in the near-stem areas, a sprayer design with a rotary device was developed. The novelty of this design is confirmed by the patent of the Russian Federation. In the theoretical aspect, a study was made of the uniformity of surface treatment of near-stem zones. As a result, the dependence of the treatment area of the near-stem zones on the diameter of the boles, the distance between them and the angle of rotation of the sprayer's working body was obtained. The uniformity criterion was the maximum area of processing and the minimum area of double processing of the zone near the bole. The optimal initial installation angle of the working body was 58º…60º.

1 Introduction

Wild plants (weeds) inhibit the growth and development of cultivated plants. Potential yield loss of fruit and berry crops due to weeds can average about 7% [1-2]. The problem of plant protection is relevant not only in Russia, but also abroad [3-4].

Timely weed control is considered one of the main factors in increasing yields and improving the quality of grown fruit and berry products. Today, both mechanical methods [5-7] and chemical methods are widely used for weed control [8-9].

At this stage of development, chemical methods of plant protection are the most promising and have no alternative in their field. Chemical protection of plants from pests, diseases and weeds is an integral part of the technological cycle of crop cultivation and requires strict adherence to the regulations. Proper use of herbicides can reduce weed infestation by up to 90-98% [10-11].

The effectiveness of chemical treatment is determined:

– rational combination of chemicals;

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– norms of consumption of working fluids;
– optimal droplet sizes;
– density and uniformity of the coating of the treated surface.

Currently, for chemical treatment of weeds, self-propelled sprayers with pneumatic type sprayers have received the greatest prospects [12-14]. They allow you to ensure the optimal droplet size. Large droplets do not hold well on plant leaves, and the small droplet size contributes to their dispersion by the wind [15-16].

When processing perennial plantations of fruit and berry crops, a certain problem is bypassing the tree trunk. For high-quality uniform processing of protective near-stem zones, a dynamic change in the position of the sprayer is necessary [17-20].

The aim of the research is to develop a design scheme of the sprayer, which ensures uniform surface treatment of the near-stem zones of perennial plantations in order to destroy weeds.

To ensure the quality of soil cultivation in the near-stem areas, a sprayer design with a rotary device was developed. **The novelty of** this design is confirmed by patents of the Russian Federation RU 2368139 and RU 2275022.

2 Materials and methods

2.1 The design of the sprayer for the treatment of the near-stem zone

To achieve this goal, the design of a low-volume sprayer was proposed (Figure 1). This sprayer has a rotary device 9 with an apron 10 in the form of a loop, on which sprayers 7 are installed. When treating near-stem zones of trees, the rotary device of the sprayer goes beyond the centerline of the row by 10...15 cm. The atomized working fluid thus settles in the area limited by the apron. The novelty of this design is confirmed by a patent for the invention [21-22].

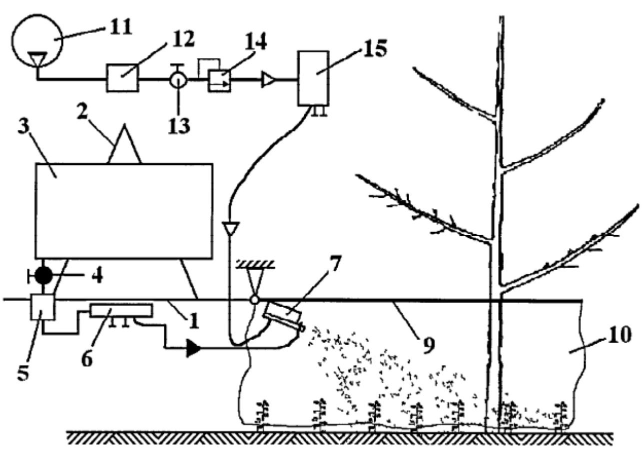


Fig. 1. Scheme of a sprayer for the treatment of near-stem zones of fruit trees.

The weed killer (Figure 1) is a frame 1 with a hinge 3. A tank 2, a flow valve 4 and a surge tank 5 are fixed on the hinge 3 with a distribution liquid manifold 6 connected by flexible hoses to a pneumatic slotted sprayer 7. The atomizer 7 is fixed on the telescopic bar of the rotary device 9, from which the apron 10 hangs down, covering the area treated by the atomizer. The atomizer is supplied with air from the compressor 11 through the receiver 12, the air valve 13, the pressure regulator 14 and the air manifold 15.

The rotary device (Figure 2) is connected to the frame 1 by means of a hinge 16 and a return spring 17. The spring 17 ensures the return of the rotary device to its original position until it stops 18.

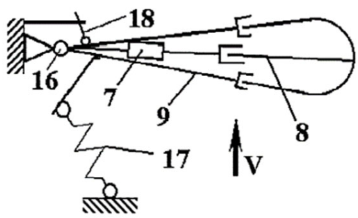


Fig. 2. Scheme of the rotary device of the sprayer.

2.2 The operation of the sprayer for the treatment of the near-stem zone

When the tractor moves with a mounted sprayer between the rows, the rotary device 9 with the sprayer 7 is located between the trees in the near-trunk zone. When the rotary device 9 comes into contact with the trunk of the tree, it rotates around the axis of the trunk. The spring 17 is stretched and the rotary device with the sprayer 7 leaves the zone of the row. After it leaves the trunk, it returns under the action of the spring 17 to its original position up to the adjustable stop 18, located between the trees.

On the telescopic bar 8 of the rotary device, one or more sprayers can be fixed, depending on the required working width. The apron 10, installed on the rotary device, prevents the working fluid from being carried away and getting onto the tree trunk, increasing the environmental friendliness of the process. The apron 10 is made of durable rubberized fabric and, if necessary, is cut into strips from below to spread the working fluid over protruding weeds in order to increase the fluid contact zone.

The liquid to the atomizers 7 flows by gravity from the tank 3 through the surge tank 5 and the liquid collector 6 into the feed tubes of the atomizers. The herbicide turns into small droplets under the action of an air stream coming from the slot nozzle of the sprayer 7. Air is supplied to the pneumatic slot sprayers 7 from the tractor compressor 11 through its receiver 12, valve 13 and air manifold 15.

2.3 Advantages of the sprayer design for the treatment of the near-stem zone

The proposed scheme of work is quite simple. The device is characterized by low metal consumption due to the absence of a pump, a pressure reducing device and other communications. The absence of a pump saves energy for supplying fluid to the sprayers. The flow rate of the working fluid is regulated by: the air pressure from the tractor compressor, the position of the surge tank in height and the size of the outlet openings of the spray tubes. Mounting sprayers with clamps makes it easy to change their number when changing the flow rate of the working fluid and the density of the treatment coverage [22-23].

2.4 Optimization of the sprayer parameters for the treatment of the near-stem zone

Three main parameters of the rotary device of the sprayer were identified that affect the quality of chemical treatment [24]:

- rotator installation angle;
- S distance between tree trunks;
- D tree trunk diameter.

Other design parameters of the sprayer were not considered, since they do not affect the quality of the chemical treatment.

The choice of the optimal values of these parameters was carried out on the basis of a symmetrical compositional plan [25-26]. The maximum value of the installation angle of the rotary device relative to the tree trunk is $\alpha_{max} = 70^o$. The minimum installation angle of the rotary device relative to the tree trunk is $\alpha_{min} = 50^o$. The distance between boles of fruit trees varied in the range $S = 2000 \dots 4000$ mm. The values of the diameter of the stem of the fruit tree were taken: the minimum $D_{min} = 40$ mm and the maximum $D_{max} = 300$ mm. The entire range of diameter sizes of a fruit tree trunk was divided into two parts: $D = 40 \dots 100$ mm and $D = 100 \dots 300$ mm (Table 1).

Table 1. Factors, intervals and levels of variation.

Factors	Coded designation	Variation interval	Factor levels		
			-1	0	+1
Angle of installation of the rotary device, α degree	x_1	10	50	60	70
Distance between stems, S mm	x_2	1000	2000	3000	4000
a) tree trunk diameter, D mm	x_3	20	40	60	100
b) tree trunk diameter, D mm	x_3	100	100	200	300

The response was taken [27, 28]:
- Y_o area treated twice, mm2;
- Y_n uncultivated area near the trunk, mm2.

3 Results

As a result of processing the mathematical model of the rotary device, the regression equations were obtained [26]:

– for double-treated area near the bole

$$Y_{o,D=40\dots100} = 6.22 + 0.005x_1 + 0.09x_2 - 0.43x_3 + 0.025x_1x_3 + +8.23x_1x_2 + 0.039x_1^2 - 0.027x_2^2 + 0.02x_3^2, \quad (1)$$

$$Y_{o,D=100\dots300} = 4.85 + 0.03x_1 + 0.08x_2 - 0.82x_3 - 0.023x_2x_3 - -0.009x_1x_2 - 0.005x_1x_3 + 0.083x_1^2 - 0.017x_2^2 + 0.11x_3^2, \quad (2)$$

– for the uncultivated area near the trunk

$$Y_{n,D=40\dots100} = 0.015 - 0.0046x_1 - 0.005x_2 + 0.018x_3 - 0.007x_1x_3 - 0.007x_2x_3, \quad (3)$$

$$Y_{n,D=100\dots300} = 0.13 - 0.05x_1 - 0.04x_2 + 0.13x_3 - 0.029x_2x_3 + +0.024x_1x_2 - 0.036x_1x_3 + 0.0096x_1^2 + 0.013x_2^2 + 0.032x_3^2, \quad (4)$$

After the transformations (for $x_2 = 0$) we got the following expressions:

– for double-treated area near the bole

$$0.0452x_1^2 + 0.0144x_3^2 = Y_{0,D=40\dots100} - 3.398\,, \quad (5)$$

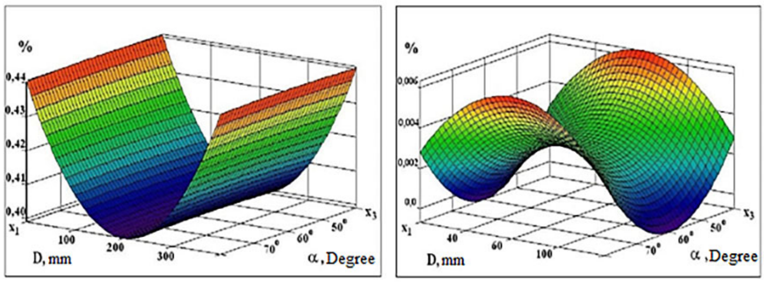
$$0.0827x_1^2 + 0.11x_3^2 = Y_{o,D=100\dots300} - 3.34\,, \quad (6)$$

– for the uncultivated area near the trunk

$$0.0035(x_1^2 - x_3^2) = Y_{n,D=40\dots100} - 0.0028\,, \quad (7)$$

$$0.0416x_3^2 - 0.0004x_1^2 = Y_{n,D=100...300} - 0.399\,, \qquad (8)$$

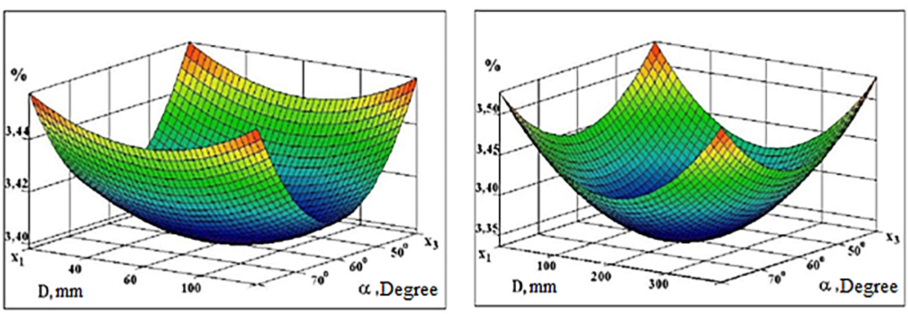
For a more detailed study, according to equations (5-8), three-dimensional response surfaces were constructed (Figure 3 and Figure 4).



a) $D = 40 \dots 100$ mm; b) $D = 100 \dots 300$ mm

Fig. 3. Dependence of the uncultivated area Y_n near the stem on the α installation angle of the rotary device and D of the stem diameter.

Analysis of the surfaces showed that at small stem diameters $D < 100$ mm the area of the untreated area of the zone does not depend on the α angle of the sprayer rotary device (Figure 3a). Increasing the trunk diameter $D > 100$ mm leads to a significant influence of the installation angle α of the sprayer working body on the area of the untreated surface. The range of changes in the uncultivated area is within ±0.003%. The optimal value corresponds to the angle of rotation of the working body 60° (Figure 3b).



a) $D = 40 \dots 100$ mm; b) $D = 100 \dots 300$ mm

Fig. 4. Dependence of the double-treated area Y_n near the stem on the α installation angle of the rotary device and D of the stem diameter.

An analysis of the surfaces of double treatment showed that the change α of the installation angle of the working body depends on the diameter D of the bole. With large trunk diameters D > 100 mm this dependence is more pronounced (Figure 4b). The optimal value in both cases of operation in the wellbore zone is observed at $\alpha = 58 \dots 60^{\circ}$.

4 Conclusion

The proposed scheme of the sprayer for the chemical treatment of near-stem zones of fruit trees. The absence of a pump and reducing and safety devices saves metal consumption in the manufacture and energy supply of liquid to the atomizers. The novelty of the presented device is protected by patents of the Russian Federation [21-22].

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The use of a three-factor experiment made it possible to determine the optimal parameters of the working body of the rotary device of the sprayer and its operating modes, provided that agrotechnical requirements for the quality of processing are met. According to the obtained regression equation according to the criterion of the maximum area of processing near the stem and the minimum area of double processing, the initial installation angle of the working body was $\alpha = 58 \ldots 60^o$.

References

1. N. Sharma, M. Rayamajhi, Advances in Agriculture 7960175 (2022)
2. C. A. Landau, A. G. Hager, M. M. Williams, Science of the Total Environment **830**, 154764 (2022)
3. A. Alsharekh, M. A. El-Sheikh, A. A. Alatar, E. M. Abdel-Salam, Agronomy **12(3)**, 703 (2022)
4. V. Lesieur, M. Jourdan, T. Thomann, B. Gooden, Biocontrol Science and Technology **32(5)**, 586-606 (2022)
5. V. V. Blednykh, P. G. Svechnikov, I. P. Troyanovskaya, Procedia Engineering **206**, 1577-1582 (2017)
6. Y. Syromyatnikov, I. Troyanovskaya, S. Voinash, A. Orekhovskaya, V. Sokolova, K. Maksimovich, R. Galimov, S. Lopareva, Journal of Terramechanics **98**, 1-6 (2021)
7. B. Tarasenko, V. Drobot, I. Troyanovskaya, A. Orekhovskaya, S. Voinash, V. Sokolova, K. Maksimovich, R. Galimov, S. Lopareva, Journal of Terramechanics **99**, 29-33 (2022)
8. I. V. Fetyukhin, A. S. Popov, V. V. Tolpinskii, IOP Conference Series: Earth and Environmental Science **1010**, 012047 (2022)
9. A. Monteiro, S. Santos, Agronomy **12(1)**, 118 (2022)
10. I. B. Borisenko, M. V. Meznikova, E. I. Ulybina, IOP Conference Series: Earth and Environmental Science **843**, 012021 (2021)
11. S. Wang, T. Xu, X. Li, Horticulturae **8(2)**, 166 (2022)
12. G. Samseemoung, P. Suwan, P. Soni, Agriculture **7(10)**, 89 (2017)
13. A. I. Belousova, A. V. Moiseev, D. A. Fillipov, E3S Web of Conferences **126**, 00013 (2019)
14. E. I. Trubilin, S. I. Borisova, V. I. Konovalov, M. I. Chebotarev, A. D. Gumbarov, International Journal of Emerging Trends in Engineering Research **8(1)**, 170-176 (2020)
15. S. Pascuzzi, F. Santoro, A. S. Anifantis, V. Bulgakov, I. Holovach, S. Ivanovs, Sustainability **12(11)**, 4644 (2020)
16. M. R. Bueno, J. P. A. R. da Cunha, D. Santana, Biosystems Engineering 154 (2016)
17. S. Ahmed, B. Qiu, F. Ahmad, H. Xin, C. W. Kong, Agronomy **11(6)**, 1069 (2021)
18. S. Ahmed, B. Qiu, H. Xin, F. Ahmad, J. Lin, C.W. Kong, Agronomy **12(4)**, 873 (2022)
19. I. L. Rogovskii, L. L. Titova, K. Y. Maksimovich, M. M. Ohiienko, V. A. Smelik, A. P. Scherbakov, IOP Conference Series: Earth and Environmental Science **723**, 022035 (2021)
20. M. Xalilov, R. Yusupov, E3S Web of Conferences **264**, 04041 (2021)
21. S. M. Borisova, V. V. Tsybulevskij, Patent RU 2368139 C1 (2009)
22. V. V. Tsybulevsky, G. V. Serga, S. A. Tverdokhlebov, V. S. Zubenko, V. N. Grivizirsky, A. A. Samsonov, Patent RU 87876 U1 (2009)

23. G. G. Maslov, S. M. Borisova, V. V. Tsybulevskij, A. V. Palapin, Patent RU 2284693 C2 (2006)
24. E. I. Trubilin, S. M. Borisova, V. V Tsybulevskij, Patent RU 2275022 C1 (2006)
25. L. Afanasiy, B. Utepov, S. Allaniyazov, E3S Web of Conferences **264**, 04004 (2021)
26. V. V. Tsybulevsky, B. F. Tarasenko, S. V. Oskin, IOP Conference Series: Earth and Environmental Science **666**, 032090 (2021)
27. R. Yu. Dobretsov, S. B. Dobretsova, I. P. Troyanovskaya, E. A. Tikhonov, D. I. Nuretdinov, Journal of Physics: Conference Series **2094**, 042028 (2021)
28. S. K. Papusha, D. A. Kotov, V. V. Zhadko, E3S Web of Conferences **193**, 01026 (2020)