Innovative method of strip-till 3-D spraying in chemical treatment of crops to implement resource-saving approaches in strip-till technology

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Abstract. A new approach to the technology of chemical treatment of crops based on the technological process of volumetric 3-D spraying, which differs favorably from the classical technology of continuous spraying, is developed. The development makes it possible to competently and efficiently apply working chemical solutions depending on the phase of growth and development of the cultivated plant on the object of treatment. When designing the technological process of volumetric 3-D spraying, the architectural features of the cultural plant were taken into account. The applied approach to the application of the working solution to the plant allows combining the methods of solid and strip spraying. For this purpose, a technical solution is offered to retrofit a serial boom sprayer with special bodies for separation of liquid flows and directing the liquid to the object of treatment. In this case a new, more stable flow in width and height is formed. The paper considers the results of studies of the technological process of chemical treatment with the use of strip technology in terms of quality indicators. The technical solution makes it possible to perform fast equipment adjustment in the field without using special tools. At the same time, it is possible to switch from solid spraying to strip spraying and vice versa. When switching to strip spraying, the spray solution is sprayed strictly along the strips of the crop and covers the entire surface of the stem and leaves. This allows you to reduce the cost of applying liquid chemicals and accurately redistribute the spray solution. As a result of the technology the goals of reducing costs, improving the quality of chemical treatment and increasing the environmental friendliness of the chemicalization process are achieved.

1. Introduction

When planning the costs of crop production, it is necessary to find new ways to save costs. One of the promising solutions to these issues is the transition to strip-till technology, which shows the best results in the cultivation of row crops. The essence of the technology is to make production energy work in strips, in which favorable conditions for growth and development of cultivated plants are created, and weeds in the interstrip space are suppressed by cultivated plants, being in the worst conditions. However,
the weak side of technology is an increase in the cost of chemical treatment of soil and crops, which reaches 20-30% in the cost structure. This is largely due to the use of unreasonable amounts of expensive chemicals and the use of equipment not adapted to work within the desired band. By using equipment that is not capable of applying chemicals in strips, producers are forced to deviate from the basic principle of strip technology. This leads to an increase in the cost of production, the application of unreasonable amounts of chemicals and an increase in the risk of emergencies in the agricultural production industry [1-3]. In order not to accumulate difficult environmental problems, at the stage of introducing new technologies [4,5] and technical solutions for their implementation [6-8], the solution of environmental problems should be put before the developers of such approaches and make them not less important than profit making [9-11]. This proves the need to change the approach to the implementation of existing crop technologies [12-14].

According to the Russian Agricultural Center data, 65.1 thousand tons of plant protection products will be used throughout Russia in 2020 (figure 1). The share of chemical means of plant protection is 97.6% (63.5 thousand tons). Application of technological process of banding in the field of chemical plant protection is a good method for reduction of applied chemicals. The treatments recommended for banding include fungicides, insecticides, desiccation, defoliation and application of plant growth regulators. Taking into account the structure of sown areas in Russia for 2020, strip farming is possible to apply on 18.5 million hectares.

![Figure 1. Market of pesticides consumed in the field in Russia in 2020.](image)

If part of chemical protection and crop nutrition operations on these territories are carried out in strips, it is possible to significantly improve the ecological situation of the territory in terms of reduction of pesticide inputs. Moreover, this reduction depends directly on the crop grown. Namely, it depends on the ratio of the width of the treated strip to the width of the untreated strip. In case of implementation of the strip-till technology on the territories applicable to strip-till farming, the total reduction of pesticides applied in Russia will be 5.1% (1.13 thou. tons) and 13.2% (2.984 thou. tons) for 0.7 m and 0.9 m inter-row spacing, respectively.

A team of scientists from Volgograd State Agrarian University has been developing and successfully implementing the technology of strip-tillage of row crops for more than 5 years [15-17]. The technology is based on solving the problems of producing high-quality products for reasonable money while taking care of the environment [18,19]. Implementation of this technology gives the most significant effect when applied to row crops and industrial crops [20,21] and has good prospects in vegetable, melon crops, in growing medicinal herbs and in cotton growing [22,23]. The main idea is to give the usual sprayer the function of volumetric 3-D spraying, allowing to achieve the effect of "enveloping" the object of exposure with guaranteed application of the composition on the inner surface of the leaf and stem of the plant. This reduces the consumption of the solution for the area between the
rows, redistributing it to the object of the main effect [2]. To solve this technical problem were used side nozzles installed in a special flow divider with spray cones oriented towards each other (figure 2). During spraying of working solution between the upper edges of the spray cones formed a zone of intersection with a spray angle of less than 180˚, and the lower edges are in the zone of the sketch of the projection of the row of plants on the soil.

![Figure 2. Experimental double side nozzle holder.](image)

2. Materials and methods
Distribution of the drug with a given accuracy is one of the most important indicators of the quality of spraying [24]. During operation of the sprayer, boom oscillation affects the degree of spray coverage. Thus, in the traditional method of continuous application of chemicals, even on a leveled surface with a boom length of 12 m, the amplitude of oscillations reaches 0.2 m [25].

During the sprayer movement there are dynamic boom oscillations, affecting the uniformity of spraying solution distribution over the width of the capture. Changing the height of the boom significantly affects the flow rate of the spray liquid. For example, a boom height change of 0.1 m results in a 40% increase in spray liquid consumption in the overlapping area. Toxicity zones are formed. At the same time, zones with reduced application rates are formed on adjacent plots. In the end, this leads to lower yields and environmental pollution. Also, when considering the effect of boom sway on the environmental performance of the chemical application process, consider that increasing the height of the boom installation results in loss of product due to drift. The chemical application process becomes more sensitive to weather conditions. As the distance from the nozzle to the treated surface increases, the flight time of the spray liquid droplet increases. This leads to intensification of water evaporation in the droplet of the working solution and reduction of the droplet diameter. And this, in turn, leads to a violation of the coverage requirement of the applied preparation on the object of treatment. This is why the height of the boom above the treated surface is a factor that affects the manufacturability and environmental friendliness of the spraying process.

To eliminate the disadvantages of the technological process of applying chemicals for row crops in the system of ecological strip-till farming, an innovative technological process of 3-D volumetric spraying is offered within the framework of resource-saving technology realization (patent of the Russian Federation №2709762). This technological process is designed for strip application of working solution strictly to the object of treatment with high quality coverage over all surfaces of the crop plant (3-D volumetric effect). In addition, due to the deflection of the spray axis from the vertical, a new, more stable flow in width and height is formed [24,25]. The implementation of this approach solves the problems of environmentally friendly technology and reduction of the hectare application rate due to competent redistribution of working solutions from the inter-row to the object of treatment. The geometric parameters of the flow formed by merging allow reducing the distance from the boom to the treated surface by 2 times. At the same time the possibility of continuous spraying is retained. Innovative distributor bodies with slotted nozzles are mounted on the sprayer boom for this. During the spraying operation, the spray liquid flows through the divider bodies and a new liquid flow is created by merging the two flows from the adjacent nozzles (figure 3). This results in a more stable flow in width and height.
The qualitative performance of strip spraying is markedly improved [24]. By transferring a part of the working solution from the soil surface to the object of treatment within a desired band, we achieve a reduction of the chemical load on the soil. This proves the environmental friendliness of the technological process of strip chemical treatment.

![Figure 3. The fusion of the fluxes of the working solution in the strip chemical treatment.](image)

3. Results

The results of the study of working solution droplet distribution on the surface of leaves by tiers, on the stem and on the reverse side of sunflower leaves confirmed the advantages of the new technology of strip chemical treatment compared to the traditional continuous spraying. This difference is especially noticeable when analyzing the qualitative indicators in terms of coverage density by the working solution drops depending on the tiers of leaves, leaf and stem sides of the cultivated plant [24,25]. With a continuous method of applying the drug to the object of treatment (for example, sunflower in the phase of 3-4 pairs of leaves). Distribution of the applied preparation was as follows (Figure 4): 49% of deposited drops were found on the upper tier, 39% on the middle tier, and 12% on the lower tier.

At the same time, no drops of the drug were found on the reverse side of the leaves and on the stem. As we can see, the localization of treatment is in the upper part of the plant. And the leaves located on the lower tier are treated in insignificant amounts. When treating against diseases and pests, it is extremely important to apply the drug to the localization sites of the disease or pest. That is, the lack of treatment of the reverse side of the leaf and stem, as well as the extremely non-uniform distribution of the drug across the crop suggest that with the vertical method of continuous application, the quality of treatment needs to be improved. When analyzing data on the distribution of droplets on the object treated with the innovative method of strip chemical treatment with the effect of 3-D spraying, the quality performance is improved. The distribution of the applied solution occurs more evenly over the tiers of the cultivated plant. On the upper tier 30% of all deposited droplets were found, on the middle tier 23%, on the lower tier 19%. On the reverse side of leaves, 13% of the drug was detected, and on the stem 15%. If we talk about the total volume of the drops formed on the object of treatment with the new method of application of the preparation, in comparison with the continuous spraying, the streaky spraying has higher quality indicators in terms of coverage density. If we take the useful effect of operations on chemical protection against diseases and pests - application of the drug to the crop, and the effect of pollution to be the hit of chemical drops on the soil outside the object of treatment, the effect of soil pollution can be significantly reduced by redistribution of applied solutions from the interrow to the crop by the innovative method of strip-till chemical treatment (Figure 2). By redistributing the working solution from the inter-row to the cultivated plant, the hectare application rate can be reduced. At the same time the value of the reduction of the hectare application rate varies depending on the ratio of the treated strip to the untreated one. For row crops with 0.7 m row spacing the reduction will be 20-24%. Taking into account improvement of the quality of the drug application on the object
the amount of the active substance applied can also be reduced.

![Figure 4. Distribution of the preparation in terms of coating density depending on the method of treatment.](image)

But to determine the value of reduction it is necessary to conduct additional research. This approach allows us to assert that the application of the method of strip chemical protection of plants leads to a reduction of environmental pollution by chemicals, thereby the pollution effect of the traditional method of treatment by redistribution and reduction of the distance between the sprayer boom and the top of the plant becomes a useful effect (figure 5).

![Figure 5. Distribution of the working fluid flows in solid and striped spraying.](image)

Thus, the assessment of spraying quality when applying the method of strip chemical treatment of plants on the example of sunflower showed the advantage of this method in comparison with the continuous spraying, and the installation of innovative divider bodies with oriented towards each other spraying torches contributes to creating a more stable flow and improving the quality of crop treatment.

Redistribution of working solution flows from the inter-row to the object of treatment allows us to conclude about the advantages of the new method of applying the preparation to the crop. At the same time the ecological effect increases depending on the width of the inter-row. At the inter-row width of 0.7 m the environmental friendliness of the technology increases by 20 - 24%.
4. Conclusion
The applied technological processes of chemical treatment of sunflower crops do not fully take into account the architectural features of the plant, due to which the quality of spraying in the phase of development of 2 - 8 pairs of leaves is reduced. A new method of applying the solution to the plants taking into account the redistribution of the solution from the inter-row to the treated strip will be considered as the most effective. For this purpose, a technical solution has been developed that allows mixing streams of working solutions directed towards each other to form a new stream. Application of the lateral spraying method allows conversion of spray flows from each nozzle into a new, more stable flow, which has constant geometric parameters with a larger area of coverage at the tip of the plants and unchanged when the sprayer boom oscillates.

Based on theoretical calculations, taking into account previously obtained laboratory and field test data, the reduction of working fluid consumption during sunflower treatment with 0.7 m row spacing is 20 - 22%. In the future, this technology can be successfully applied in the production of vegetable and cucurbitaceous crops, and when treating cotton with 0.9 m row-spacing, this technology is especially relevant, as it will allow to achieve a reduction of chemicals by 35 - 40%. Volgograd region is one of the leaders in the production of vegetable crops, which can also be grown using strip technology. Also this technology has good prospects for implementation on melon crops, medicinal herbs and in cotton growing.

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References
[1] Kambulov S I, Maksimov VP, Tsarev Yu A and Zubrilina E M 2019 Scientific life 2 19-26
[2] Nesmiyan AY, Chernovolov V A, Semenihin A M, Zabrodin V P and Nikitchenko S L 2018 Research on Crops 3(19) 560-7
[3] Lipkovich E L, Nesmiyan AY, Nikitchenko S L, Shchirov V V and Kormiltsev YG 2020 Scientia Iranica 2(27) 745-56
[4] Churzin V N and Dubovchenko A O 2020 Proc. of the Lower Volga Agro-University Comp 1 (57) 158-67
[5] Melnik V I 2015 Zemledelie 1 8-12
[6] Danilov M V and Abaev V V 2019 Bulletin of scientific conferences 3(43) 46-7
[7] Ebrahimi M A, Khoshtaghazal M H, Minaei1s and Jamshidi B 2018 Agricultural Engineering International: CIGR Journal 2(20) 144-54
[8] Bondarenko A M, Nesmiyan AY, Kachanova L S and Kormiltsev Y G 2019 Bulletin of the Don Agrarian Science 3(47) 33
[9] Zavrazhnov A I, Balashov A V, Dyachkov S V, Omarov A N and Strykin S P 2017 Achievements of science and technology in the AIC 1 52-5
[10] Shchukin S V, Gornich E A, Trufanov A M, Voronin A N 2019 Proc. of the Lower Volga Agro-University Comp 4 (56) 119-67
[11] Churzin V N and Dubovchenko A O 2020 Proc. of the Lower Volga Agro-University Comp 3 (59) 181-9
[12] Lukmenev V P 2015 Proceedings of the Orenburg State Agrarian University 51(1) 41-6
[13] Balashov A V 2018 Science in Central Russia 31(1) 14-20
[14] Belenkov A I, Tyumakov Yu A and Sabo M U 2015 Bulletin of the Altai State Agrarian University 126(4) 5-10
[15] Shaprov M N and Borisenko P I 2013 Proc. of the Lower Volga Agro-University Comp 4(32) 193-7
[16] MIGuoHua, WUDaLi, CHENYanLing, XIATingTing, FENGGuoZhong, LIQian,
SHIDongFeng1, SUXiaoPo and GAOQiang 2018 *Scientia AgriculturaSinica* **51**(14) 2758-70

[17] Jaskulska I, Gałęzewski L, Piekarczyk M and Jaskulski D 2018 *Italian Journal of Agronomy* **13**(3) 194-9

[18] Canales E, Bergtold J and Williams J. 2018 *Agricultural and Resource Economics Review* **47**(1) 90-117

[19] Borisenko I B and Meznikova M V 2020 *Bulletin of the Don Agrarian Science* **4**(52) 19-27

[20] Bozhko I V, Parkhomenko G G and Kambulov S I 2018 *Tractors and agricultural machinery* **5** 26-31

[21] Borisenko I B and Meznikova M V 2021 *Bulletin of the Don Agrarian Science* **1**(53) 19-27

[22] Borisenko I B, Meznikova M V and Ulybina E I 2021 *Proc. of the Lower Volga Agro-University Comp* **2**(62) 193-7

[23] Zubarev Yu N 2014 *Perm Agrarian Bulletin* **7**(3) 17-21

[24] Borisenko I B, Meznikova M V and Ulybina E I 2020 *Proc. of the Lower Volga Agro-University Comp* **4**(60) 193-7

[25] Borisenko I B, Ovchinnikov A S, Meznikova M V, Fomin S D, Bocharnikov V S, Rogachev A F and Ulybina E I 2019 *Conference on Innovations in Agricultural and Rural Development IOP Conf. Series: Earth and Environmental Science* **341** 012092 doi:10.1088/1755-1315/341/1/012092