Automated device for the differential application of herbicides in the near-trunk zone of fruit

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Abstract. The information on the justification of the design parameters of the spraying unit of the herbicidal sprayer is provided. A technical description of the operation of the sprayer with an automated system for deflecting the spray unit from the axis of the row is given. The results of field studies of the herbicidal treatment of fruit crops by an automated device for applying herbicides to the near-stem zone of the orchard using an additional air flow are obtained.

1. Introduction

Weed plants negatively affect the growth of cultivated plants and their productivity, actively deplete the fertile soil layer, so from one hectare they can carry up to 150-200 kg of mineral substances. Currently, the main method of controlling weeds in gardens is herbicide treatment, it allows to reduce the clogging of garden plantings by 90-96% [1]. Currently used domestic sprayers for herbicide treatment of rows of perennial plantings do not fully comply with modern requirements for machines of this type. As a result of the process, there are significant deviations in the uniform distribution of the working fluid along the width of the row, the density of the coating of the treated surface due to imperfections in the design of the sprayers used. The main disadvantage of such devices is that when treating with herbicides in windy weather, the possibility of transferring drops of the herbicide solution by wind flows over considerable distances is not excluded. In this case, part of the droplets of the herbicide solution may have a negative impact on the environment. Therefore, the improvement of technical means for the application of herbicides in garden plantings should be aimed at improving the quality and effectiveness of chemical treatment in the near-stem zones of garden plants in accordance with the requirements of modern agricultural technologies, reducing the consumption of a chemical preparation and negative impact on the environment, creating the most favorable conditions for obtaining high yields [2]. The purpose of the work is to analyze the qualitative indicators of making the working fluid, to justify the design parameters and to develop an automated device for making herbicides in the near-stem zone of the orchard with the possibility of efficient operation at a wind speed of more than 3 m/s.

2. Materials and methods

Theoretical studies were carried out using the provisions of mathematical analysis, analytical geometry, taking into account the agrotechnical, technological, constructive and qualitative requirements for the process of chemical treatment of orchard rows. A special program and methodology for laboratory experimental research and preliminary tests was developed on the basis of
GOST 53053-2008, GOST ISO 5682-1-2004 and other state and industry standards for testing agricultural machinery [3,4]. To conduct laboratory research, experimental stands and facilities created at the Federal State Budget Scientific Institution FSAC FIM were used. Statistical processing of the research results was carried out using Mathacad Prime 3 and Excel. The quality of spraying the working fluid of the herbicides was evaluated by the following indicators: the actual flow rate of the working fluid; uneven flow rate of the working fluid between the individual nozzles; plant cover density; dispersion of the working fluid. The sprayer was set to a predetermined flow rate of the working fluid (N, l/ha) by selecting the flow rate (Q, l/min) through all nozzles at a speed (Vp) of 5 km/h and a working width (V, m) calculated by the formula 1:

\[ Q = \frac{H \cdot B \cdot V_p}{600} \]  

(1)

For herbicide treatment of the trunk space of the fruit on the spraying nodes of the sprayer, 4 slotted nozzles from Lechler AD90 were installed at an operating pressure of 0.35 MPa. The operating speed of the sprayer is 5 km/h. The predetermined flow rate of the working fluid (120 l/ha) and the working pressure (0.35 MPa) were set and controlled by the Bravo 180 on-board computer. The actual flow rate of the working fluid (Qf, l/ha) was determined during test spraying by developing the full capacity of the sprayer. The actual liquid consumption per 1 hectare was determined by the volume of liquid consumed and the area of the treated area. The deviation of the actual flow from the set (Qv, %) was calculated by the formula 2:

\[ Q_v = \frac{Q_f - Q_z}{Q_z} \times 100 \]  

(2)

Qf - where is the actual flow rate of the working fluid, l/ha, Qz - given flow rate of the working fluid, l/ha. The flow rate of liquid through each atomizer was determined at a pressure of 0.35 MPa by collecting liquid in the measuring cylinders (GOST 1770-74) for 30 seconds. in triplicate (stopwatch SOSPR-26 No. 9914, 1976 GOST 5072-79). The density of the coating and the dispersion of the spray of the working fluid was determined at a pressure of 0.35 MPa and a sprayer speed of 8 km/h. The thickness of the coating and dispersion were determined using water-sensitive cards of the company "Syngenta" with dimensions of 50 * 70 mm each, which were placed on the ground in 3 rows with 3 cards on each side. The density of the droplet coating was determined by counting the droplets on each card by microscopy followed by processing of the results according to GOST R 53053-2008. The coating density (P0) of drops/cm² was calculated by the formula 3:

\[ \Pi_0 = \frac{n_k}{s_n} \]  

(3)

where \( n_k \) - is the total number of recorded drops, \( s_n \) - is the scanned area, cm².

3. Results and discussions

It is known that the uniformity of the distribution of the drug across the width of the rod, mainly affects the location of the nozzles on the rod and the height of their placement relative to the surface, as well as the overlap of the spray nozzles at adjacent passages of the unit [5,6,7]. For high-quality processing of row-spacings of garden plantings using slotted sprayers, it is necessary to determine the height of their installation above the soil level, taking into account the orientation of spray nozzles relative to the treated surfaces (by the angle of inclination of sprayers and the front of the spray jet (Fig. 1).
Where \( K, \text{ mm} \) is the width of the spray band, \( l, \text{ mm} \) is the amount of overlap of the spray plumes, \( L, \text{ mm} \) is the distance to the ground, \( \alpha \) is the angle of the spray plume. Width of the processed strip \( K, \text{ mm} \) is determined by the formula (4).

\[
K = 2 \cdot L \cdot \tan\left(\frac{\alpha}{2}\right)
\]  

(4)

Using the formula (4), we determined the width of the treated strip by sprayers with different angles of the spray pattern and the distance of their installation above the strip. The simulation results are presented in graphical form on (Fig. 2).

![Figure 2. The dependence of the width of the processed strip on the installation distance of the sprayer with different spray angles](image)

In our case, nozzles with 90º turned out to be the most suitable for herbicidal treatment. Theoretically, the width of the treated strip with slotted nozzles with spray angles from 60º to 120º, installed vertically above the processing surface at a distance of 40 mm to 500 mm, varies from 50 mm to 1700 mm. Based on the required processing width of the trunks of garden stands, we choose the distance between the sprayers equal to 312 mm. To confirm the calculations, a field experiment was conducted in laboratory conditions. The laboratory setup was a sprayer-herbicide under the sprayers of which a corrugated surface was placed, located at an angle of 300º to the surface and 40 measuring cups. The total number of corrugations was 40 pieces in increments of 35 mm. In the steady-state operation of the sprayer, at the same time all the measuring cups were substituted under the corrugated surface, then the liquids falling into the corresponding measuring cup were counted. According to the experimental data, we constructed the dependence (Fig. 3) of the percentage distribution of the liquid outflow of two nozzles located at a distance of 312 mm from each other with a placement height of 430 mm.

![Figure 3. The percentage distribution of fluid along the width of the spray jet of 2 slotted nozzles at a height of 360 mm.](image)
This graph showed that the use of two Lechler AD90 slotted nozzles with a spray angle of 90° and a distance of 400 mm between them based on the required amount of treatment of the near-barrel zone equal to 700-800 mm in the spraying unit for the herbicidal treatment is justified and sufficient for its effective application. As a result of research conducted at VIM, a device was developed to control weed vegetation in fruit stands. The prototype of the sprayer has passed preliminary tests according to a special test program. Specialists of the FGBNU FSAC VIM proposed an original design of a device for introducing herbicides into the near-trunk zone of a fruit garden with an air curtain for protection against side wind flows [8,9], the main characteristics of which are given in Table 1.

**Table 1. Technical specifications.**

| Index                                                                 | Value               |
|----------------------------------------------------------------------|--------------------|
| **A type**                                                           | Mounted            |
| **Type of work**                                                     | Herbicide Weed     |
| Aggregated (traction class and tractor brands)                       | Treatment          |
| **Main drive**                                                       | Belarus MTZ 82, 1.4 class t.s. |
| **Working speed, km / h**                                            | 3,7                |
| **Transport speed, km / h**                                          | 14,5               |
| **Construction width, mm**                                           | 3100 - 5100        |
| **Working width, mm**                                                | 3300 - 5300        |
| **The number of personnel serving the unit, including:**             | 1                  |
| a) tractor driver                                                    | 1                  |
| **Overall dimensions of the unit, mm:**                              |                    |
| - length                                                             | 1050               |
| - width, mm:                                                        |                    |
| - in working position                                                | 3100 - 5100        |
| - in transport position                                              | 2440               |
| - height                                                             | 1590               |
| **Ground clearance of working bodies, mm**                           | 430                |
| **Minimum turning radius at the outermost point, m**                 | 5,3                |
| **The required width of the headland, m**                            | 10,8               |
| **Machine weight, kg**                                               | 360                |
| **Tank capacity, l**                                                 | 600                |
| **Dimensions protective housing of the working rod, see:**           |                    |
| - length                                                             | 65                 |
| - width at the lower cut                                             | 19                 |
| - height                                                             | 13                 |
| **Distance between sprayers, cm**                                    | 40                 |
| **Number of spray guns**                                             | 4                  |
| - a type                                                             | Slotted Lechler AD90 |
| **Pump productivity, l/min.**                                        | 105                |
| **Deviation of the rods from the axis of a row of trees**            | automatic          |
The device for introducing herbicides into the near-trunk zone is a hinged-type structure, fixed on a three-point linkage of the tractor. It is aggregated with tractors of traction classes 0.9 - 1.4. The herbicide application device consists of a welded frame on which are mounted: capacity (tank) for the working fluid; telescopic extendable rods; elements of the hydraulic system for the working fluid, consisting of a pump and a distributor-regulator with safety valves and a mixer; spray unit with automatic deflection system. The frame is a welded construction of square pipes and is used for mounting the main equipment of the device. A plastic tank with a sealed lid and a built-in tank for washing hands is used as a container for the working fluid. The main bar is fixedly mounted on the frame, from which the side rods come out from two sides. The extension of the side rods to the right and left of the center of the sprayer makes it possible to change the working width of the grip depending on the width of the row spacing and occurs through electric motors. The movable rods have spray nodes at the ends with automated devices for their removal from the tree trunk. At the ends of the spray nodes are laser sensors for detecting obstacles. The spraying units by means of rods are pivotally connected to electric motors mounted on a movable rod. During operation, the spraying unit has the ability to deviate from the axis of a number of trees in a horizontal plane, which allows you to treat the soil around the tree trunk. After the tree has passed, the spraying unit takes its initial position through the action of electric motors. To obtain a better coating of plants with a herbicidal solution during spraying, it is necessary to spray the drug into drops of a minimum size. Studies have shown that small droplets have three times the contact surface. To increase the efficiency of the processing process, the device is additionally equipped with a compressor unit that delivers compressed air through the air duct to a special technological hole in the upper casing, while the protective covers of the spraying unit consist of two parts (upper and lower) when connecting between which the walls of the casing there is a narrow gap necessary to create an “air curtain” around the perimeter of the protective cover (Fig. 4).

![Figure 4. Spray assembly of the herbicide applicator](image)

Where 1 is the upper casing, 2 is the lower casing, 3 is the hole for supplying compressed air, 4 are the spray nozzles. In order to improve the quality of the technological process and the efficiency of the deviation of the spraying unit from the soybean of a number of trees, increasing the effective area of the coating of the working fluid and protecting the bark of the fruit stands, an automatic system for deviating the spraying unit, containing laser sensors, electric motors with rods, was developed. The use of a spray unit with an automated deflection system, in comparison with the usual mechanical deflection mechanism, improves the quality of processing the trunk zone and increases the processing area of the trunk zone by 12.5% (Fig. 5).

![Figure 5. Comparison of the processing areas of the automated spray unit (S1) and conventional (S2); 1,2 - fruit tree stem](image)
The technological process of the machine is as follows. Before starting work, the mixer is filled with a chemical, the pump is turned on, and using mixer armature, the working fluid is prepared and supplied to the tank. The unit is placed at the beginning of the rut, the tractor driver by pressing the appropriate buttons in the cab transfers the movable rods from the transport position to the working one. To do this, due to the electric cylinders, the rods are moved to a horizontal position, and due to the electric motors, the movable rods of the sprayer are advanced to the desired working width, based on the row spacing. Height adjustment over the grass stand (treatment height) is carried out by raising or lowering the sprayer of the hydraulic linkage of the tractor taking into account the height of the weeds. Then, the tractor driver turns on the PTO shaft, turns on the compressor, the chemical solution comes from the main tank through the filter to the pump. The pump directs the flow of fluid under pressure to the pressure regulator, excess fluid flows back into the tank. A flow with a predetermined pressure enters from the pressure regulator via pressure hoses to the spraying units and is then sprayed by nozzles. At the same time, compressed air from the compressor through the air ducts is fed into the space between the upper casing and the lower casing, thereby creating an air curtain around the casing, which protects the spray torches from drift by a side stream of wind. Further, when the spraying unit approaches the tree trunk, information from the laser sensor enters the control controller, where it is converted into a control signal which is supplied to the electric motors, they turn on and move the thrusts to the side, thereby spraying the unit around the tree stem, processing the herbicidal solution (Fig. 6). After that, the process is repeated.

![Figure 6. Scheme of operation of an automated system for deflecting a spray unit: 1- thrust deflection electric motor, 2- wood stem, 3- laser sensor, 4- spray rod movement thrust, 5 - spray node with a casing, 6 – rod](image1)

To assess the performance of the sprayer-herbicide in the field, relevant studies were carried out, which included the determination of indicators of purpose, agrotechnical assessment, safety and ergonomic assessment. An agrotechnical evaluation of the sprayer was carried out by measuring the actual flow rate of the working fluid, the unevenness of the flow rate, the median-mass diameter of the droplets, and the density of the coating on the sheet surface (Fig. 7).
The studies were carried out on industrial plantings of fruit crops in the Moscow region (Fig. 8).

**Figure 8.** Device for applying herbicides in the orchard

The conditions for the studies are shown in table 2.

**Table 2.** Research conditions

| Indicator                                           | The value of indicators |
|-----------------------------------------------------|-------------------------|
| Assessment Date                                    | 07/10/2019              |
| Test place                                          | p. Mikhnevo, Moscow region |
| Type of plantings:                                 |                         |
| - culture, grade                                    | Apple tree, Melba        |
| - tree height, m                                    | 2 - 2.5                 |
| Relief                                              | Smooth                  |
| Microrelief                                         | Smooth                  |
| Air temperature, at a height of 0.5 m, °C           | 19                      |
| Relative humidity, %                                | 64,0                    |
| Wind speed, m/s                                     | 0,2 - 0,9               |
| Wind direction in relation to the movement of the machine, deg. | North, 20°  |
| Age of plantations, years                           | 5 - 7                   |
| Row spacing, m                                      | 5,0                     |
| The distance between the trees in a row, m          | 3,0                     |
| The number of weeds, pcs/m²                         | 25 - 35                 |
| Height of weeds, cm                                 | 16 - 37                 |

Test conditions were typical of the middle zone. The research results are presented in table 3.
### Table 3. Technical characteristics of the manipulator.

| Indicator                                                      | The value of indicators According to tests |
|---------------------------------------------------------------|--------------------------------------------|
| Working speed, km / h                                        | 3,7                                        |
| Working width, m                                              | 5,3                                        |
| Working pressure in the system, MPa                          | 0,3                                        |
| Actual flow rate, l / ha                                      | 120,3                                      |
| Uneven flow rate across the width of the capture, %           | 2,71                                       |
| Median-mass diameter of the droplets, microns:                |                                            |
| - large                                                       | 286,7                                      |
| - medium                                                      | 365,8                                      |
| - small                                                       | 255,4                                      |
| The average density of the coating of the sheet surface, pcs / cm² | 64,74                                      |
| including by categories, %:                                   |                                            |
| - more than 65 pcs/cm²                                       | 43,5                                       |
| - 65 pcs/cm²                                                  | 4,3                                        |
| - less than 65 pcs/cm²                                        | 52,2                                       |
| The experimentally weighted median-mass diameter of the droplets, microns | 187,5                                      |

#### 4. Conclusions

With an average unit speed of 3.7 km/h, at a pressure of 0.3 MPa and with uneven flow rate between the individual nozzles, about 2.71%. The actual total flow rate of the working fluid was 120.3 l/ha. The density of the coating of the sheet surface, on average, was 64.74 pcs/cm². The average weighted experimentally, the median-mass diameter of the droplet was 187.5 microns and is in fractions, respectively: coarse - 286.7, medium - 365.8 and fine - 255.4 microns. The operation of the additional air flow not only eliminates the undesirable demolition of the working solution at a wind speed of more than 4 km/h, but also increases the fine dispersion of the spray by 1.7 times, and also improves the coverage density of control cards by 38%. The automated deviation system of the spray unit showed its operability and the necessary speed at speeds from 1.8 to 7.8 km/h, although when spraying the unit did not reach speeds of more than 5.7 km/h. The treatment area of the near-trunk zone increased by 12.5% compared with the sprayer without using this system.

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