Justification of constructive technological scheme of multifunctional unit

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Abstract. It is developed a multifunctional soil processing unit with interchangeable working implements in the form of flat hoes to perform the subsoil tillage at 16…25 cm or cultivator hoes for carrying out pre-sowing tillage at 5…12 cm. Experimental studies of the unit have been carried out to study the effect on its traction resistance of the parameters of flat hoes, their location according to the scheme of “direct” and “reverse” wedge on the frame of unit, the optimal position of the middle plane-cutting paw relative to the side paws. The tillage unit was aggregated with the MTZ-82 tractor. The apex angle of flat hoes has been 95° and 110°, the width of their capture was 0.76 m. Processing of winter rye stubble was carried out with the use of tillage unit on heavy loamy sod-podzolic soil at its moisture content of 23.8% and hardness in the soil layer from 1.73 to 2.36 MPa. Processing of firm cultivated soil was carried out with the use of tillage unit on medium loamy sod-podzolic soil at its moisture content of 15.2% and hardness in the soil layer from 0.54 to 2.23 MPa. The traction resistance of flat hoes with a apex angle of 110°. Installation of flat hoes in the form of a “straight” wedge and the position of the middle flat hoes with the maximum displacement relative to the side flat hoes can reduce the pulling force of the tillage unit.

1. Introduction
According to the strategy of development of agriculture in Russia until 2020, the main direction of modernization of equipment for crop production is the universalization of combined tillage units [1]. One of the ways to solve this problem is to equip technical equipment with sets of interchangeable working implements, which will ensure their quick adaptation to various conditions, including the required type of tillage, ultimately will significantly reduce the range of tillage equipment.

The analysis of the design of technical means for the implementation of basic soil-free tillage and pre-sowing tillage revealed the absence of tillage machines on the market for agricultural equipment capable of performing both types of soil tillage efficiently and reliably using one machine [2-4]. In connection with the above, the development of a multifunctional soil-cultivating unit intended for the implementation of basic subsurface tillage to a depth of 16…25 cm with the creation of a mulch layer or pre-sowing tillage to a depth of 5…12 cm is relevant.
The aim of the work is to substantiate the constructive-technological scheme of a multifunctional unit designed for the implementation of the main tiller-free tillage with the creation of a mulch layer or pre-sowing tillage.

2. Materials and methods

The results of studies of the developed universal implement for the main tillage showed that the application of the basic subsurface tillage technology is characterized by high efficiency in agrolandscape conditions Northeast region of the European part of Russia [5, 6]. In it the disk working implements in the form of spherical disks loosen and partially reverse the top layer of the soil layer descending from the flat hoes. In this regard, a basic structural and technological scheme of a multifunctional tillage unit with interchangeable working implements in the form of flat hoes for performing basic tillage at 16…25 cm or cultivating hoes for pre-sowing treatment at 6…12 cm (Figure 1) is proposed. Disk sections are used in conjunction with both types of working implements. The design of the unit provides for equipping it with replaceable adapters for additional (finishing) tillage, which can be used as packer rollers, harrows, etc.

![Figure 1](image_url)

**Figure 1.** A scheme of placement of the working implements of the soil-cultivating unit (flat hoes are installed according to the “reverse” wedge): a, b – flat hoes and disk sections at the minimum and maximum angle of attack; c – cultivator hoes and disk sections with a minimum angle of attack: 1 – support wheel; 2 – mechanism for adjusting the position of the support wheels; 3 – frame; 4 – flat hoes; 5 – disk sections; 6 – mounting bracket disc section; 7 – removable timber; 8 – cultivator hoes.

The tillage unit consists of a frame, support wheels with a mechanism for regulating the depth of tillage, interchangeable working implements in the form of flat hoes or lancet cultivator hoes, disk sections. The disk sections have the adjustment of the tillage depth and the stepwise adjustment of the angle of attack by means of the fact that the mounting brackets have a hinged connection, allowing them to be installed from different sides of the beam and at different distances between each other. The rigid mounting of the sections of the disk working implements on the frame allows them to be partially used together with the wheels as a supporting element that maintains the stability of the depth of the course of the flat or cultivator hoes.

For the implementation of pre-sowing tillage at 5…12 cm instead of flat hoes, lancet cultivator hoes with a width of 300…330 mm, disk sections and, if necessary, replaceable adapters for additional tillage are installed on the frame of the unit. Cultivator hoes have a rigid mounting on the frame and are installed in two rows at a distance of 450…500 mm. The second row of cultivator hoes is mounted on a removable bar. When the unit is working on the pre-sowing tillage, the disk sections are lengthened due to interchangeable axles of a greater length and additional disks. At the same time, their angle of attack...
should be reduced to $0 \ldots 5^\circ$ so that when tilling at low angles of attack the disk sections provide additional leveling and compacting of the soil.

The frame bar for mounting disk sections is located at an angle $\beta$ (Figure 1a). It corresponds to the average installation position of the disk sections between the maximum and minimum angle of attack. That allows achieving the range of control of the angle of attack within $0 \ldots 20^\circ$ degrees required for disking soil without changes in the angle of installation of the beam mounting disk sections. But this happens only due to the permutation of the mounting bracket of the disk sections on different sides of the beam unit and a different number of disks on the axis of the section. This greatly simplifies the construction of the unit.

When choosing the layout of the working implements on the frame of the unit, it is important to choose the method of positioning the flat hoes according to the “direct” or “reverse” wedge. A review of the literature on this topic did not reveal an unambiguous opinion about the rational installation of flat hoes, although researchers note a significant influence of the layout of flat hoes on the traction resistance of tillage machines [7, 8].

To study the effect of the placement pattern and the parameters of the flat hoes (the angle of the paw solution) on the implement’s traction resistance, a laboratory-field installation (Figure 2) and a set of flat hoes with a solution angle of $70^\circ$, $95^\circ$ and $110^\circ$ have been developed. The installation design allows you to register the traction resistance of the working implements under investigation by means of the DPU-20-2 dynamometer installed in its spoke, as well as to change the position of the middle flat hoe relative to the side hoes. The initial plan of the experiment involved participation as one of the factors of the angle of the flat hoe solution. But during the test experiments it was found that the characteristics of the tractor MTZ-82 does not allow it to develop the tractive effort required to work with the laboratory setup, on which three hoes with an angle of solution are installed $70^\circ$ with a tillage depth of more than 18 cm.

![Image](image1.png)

**Figure 2.** Location of flat hoes with a approach angle of $2\gamma = 110^\circ$ on the installation frame with the displacement $S$ (m) of the middle hoe relative to the side hoes.

To determine the optimal angle of the hoe solution, one-factor experiments were carried out for two options for the location of flat hoes according to the “direct” and “reverse” wedge with the average hoe shifted relative to the side hoes by $S = \pm 0.4$ m during their work on the stubble and a clean pair.

Studies of the operation of a tool on a firm cultivated soil (the previous treatment is the cultivation of steam at $8 \ldots 10$ cm) were performed on medium loamy sod-podzolic soil with a moisture content of 15.2% and hardness in a layer up to $10$ cm $\pm 0.54$ MPa, $10 \ldots 20$ cm $\pm 1.58$ MPa, $20 \ldots 30$ cm $\pm 2.23$ MPa. The depth of tillage was $h = 23$ cm. The laboratory-field installation was aggregated with tractor MTZ-82. The angle of the solution of $2\gamma$ hoes is $95^\circ$ and $110^\circ$, the width of the claw is 0.76 m.

Studies of the work on the stubble were carried out on a medium loamy sod-podzolic soil with a moisture content of 16.8% and a hardness in a layer up to $10$ cm $\pm 2.27$ MPa, $10 \ldots 20$ cm $\pm 2.77$ MPa, $20 \ldots 30$ cm $\pm 2.80$ MPa. The depth of tillage was $h = 18$ cm.
For a more detailed study of the influence of the parameters of the location of the flat hoes according to the “direct” and “reverse” wedge scheme on the flat-cutter draught and to determine the optimal position of the middle flat hoe relative to the side hoes, a three-level Box-Benkin plan of experiment was made for three factors. During the experiment, the effect of the following factors was investigated: the location of the average hoe $S$ (m), the average flat hoe relative to the side hoes, the speed $V$ (km/h) of the aggregate and the depth of soil processing $h$ (m) on the pulling resistance $P_T$ (kN) of the flat hoes. The designation of factors, the levels and intervals of their variation are given in table 1.

| Factor code | Factor name, its designation and unit of measure | Factor level | Variation interval |
|-------------|-----------------------------------------------|--------------|--------------------|
| $x_1$       | Movement speed $V$, km/h                       | 3.20, 5.55, 7.90 | 2.35               |
| $x_2$       | Location of the average flat-cutting foot relative to the side hoes $S$, m | -0.4, 0, +0.4 | 0.4 |
| $x_3$       | Tillage depth $h$, m                           | 0.16, 0.20, 0.24 | 0.04               |

As an optimization criterion, the traction resistance $P_T$ (kN) of flat hoes, which determines the choice of the installation of the working flat-cutting implements of the unit according to the “direct” or “reverse” wedge, is taken.

Subsurface tillage processing in the course of the experiments was carried out on the stubble of winter rye on a plot of field with sod-podzolic soil of heavy loam composition with a moisture content of 23.8% and hardness in a layer up to 10 cm – 1.73 MPa, 10…20 cm – 2.28 MPa, 10…20 cm – 2.36 MPa. The laboratory-field installation was aggregated with tractor MTZ-82. The movement of the machine-tractor unit was carried out using 5 (with a gearbox), 3 (with a gearbox) and 2 (with a gearbox) gears. Slipping of tractor thrusters was not taken into account.

3. Results
The data obtained in the course of single-factor experiments to determine the optimal angle of the hoe solution in the form of graphs $P_T = f(V)$ are presented in Figure 3.
Analysis of the experimental results revealed that regardless of the magnitude of the speed of movement, the traction resistance of flat hoes with an apex angle of $2\gamma = 95^\circ$ significantly exceeds the tractive effort spent on moving flat hoes with an apex angle of $2\gamma = 110^\circ$. For example, during the main tiller-free processing of stubble, the difference in traction resistance of flat hoes arranged according to the “direct” wedge scheme is 5.7...12.1%, and when installing the hoes according to the “reverse” wedge – 4.7...7.4% When processing pure steam, this difference for the “direct” wedge is 14.7...20.2%, and for the “reverse” wedge – 13.4...19.1%.

The obtained data confirmed the results of previous studies on the determination of energy consumption for joint tillage of flat hoes and disk working implements [9, 10] and showed the advantage of using flat hoes with an apex angle of $2\gamma = 110^\circ$ in the agrolandscape conditions of the Northeast of European parts Russia. This is primarily due to the fact that the arable land of our region is characterized by the location of the main part of the root system of plants in the soil layer up to 12...15 cm. That practically minimizes the possibility of covering the blades of flat hoes with plant roots and makes irrelevant use of hoes with apex angles less than necessary to avoid the plowshare blade covering the weed roots. Smaller traction resistance of flat hoes with an apex angle of $2\gamma = 110^\circ$ is caused by the fact that as the angle of the paw solution increases, the area of plowshares and the shoe blade and, accordingly, the volume of the soil subjected to deformation decreases. The use of wide-flat hoes with an apex angle of more than $2\gamma = 110^\circ$ is irrational due to the need to increase the stiffness of the shoe of the hoe and, as a consequence, the growth of its size and weight.

The conducted single-factor experiments do not allow one to determine the optimal position of the middle flat hoes relative to the side hoes, therefore, a three-level second-order Box-Benkin plan of an experiment is implemented for three factors, one of which is the size of the offset $S$ (m) of the average flat hoes relative to the side hoes. The obtained data were processed using programs Microsoft Excel and Statgraphics Plus 5.1. After implementing the plan of the experiment and processing the data, a regression model was obtained, tested for adequacy by Fisher's F-test (probability $p = 0.95$):

$$Y_i = 10.946 + 0.198 \cdot x_1 + 1.569 \cdot x_3 - 0.476 \cdot x_2^2 - 0.771 \cdot x_3^2.$$  \hspace{1cm} (1)

For the analysis of the regression equation (1), three-dimensional graphs of traction resistance $P_T$ of flat hoes from the location of the middle flat hoes relative to the side hoes, the speed of the unit $V$ and the depth of processing $h$ of the soil are built (Figure 4).

4. Discussion

The analysis of the response surfaces obtained confirmed the well-known data that the main influence on the traction resistance of flat hoes has a tillage depth and speed of movement [11, 12]. Moreover, if the increase in speed is almost linearly reflected in the increase in tractive effort, then with an increase in the depth of tillage it grows along a clearly defined parabolic curve, which is explained by the movement of the working implements below the depth of the previous plowing.

The influence of the location of the flat hoes according to the “direct” or “reverse” wedge scheme on
the traction resistance of the flat-cutter is not so clearly expressed. Installation of working implements with a maximum displacement of the middle hoe relative to the side hoes at $S = \pm 0.4$ m for the hoe installation scheme in the form of a “direct” wedge reduces, depending on the speed of movement, the pulling force by 4.3…5.4%, for “reverse” wedge – by 4.2…4.7%. The values of traction resistance of flat hoes installed at a distance $S = \pm 0.4$ m for both hoe placement schemes are almost equal. For example, for the “reverse” wedge scheme at the minimum speed at a depth of processing $h = 0.2$ m, the pulling force of the flat-cutter is 0.14 kN less compared to the “direct” wedge scheme. At the maximum speed of movement, the opposite situation is observed with a difference of 0.06 kN, which makes it possible to use any of the layouts of flat hoes when developing the design of a multifunctional tillage unit. In our case, from a constructive point of view, the layout of flat hoes in the form of a “reverse” wedge is more acceptable. The optimal distance of the location of the average flat hoe relative to the side hoes is $S = 0.35…0.40$ m, a further increase in the distance between the rows of the hoes is impractical due to the increase in the overall dimensions of the designed unit.

![Figure 4](image.png)

**Figure 4.** Influence of the speed $V$ (km/h) of the movement of the unit ($x_1$), the position $S$ (m) of the average flat hoe relative to the side hoes ($x_2$), the depth of processing $h$ (m) of the soil ($x_3$) on the traction resistance of the $P_T$ (kN) flat-cutter: a $- h = 0.2$ m ($x_3 = 0$); b $- S = 0$ m ($x_2 = 0$); c $- V = 5.55$ km/h ($x_1 = 0$).

5. Conclusion

Thus, as a result of research, a basic structural and technological scheme of a multifunctional tillage unit with interchangeable working implements has been developed, the optimum parameters of flat hoes have been determined, and the layout of them on the frame of the unit has been substantiated.

The results of the experiment showed that flat hoes with a solution angle of $2\gamma = 110^\circ$ with lower traction resistance with the same quality of processing are most acceptable. Depending on the speed and installation of the hoes, the traction resistance of flat hoes with an angle of $2\gamma = 95^\circ$ when processing stubble is 4.7…12.1% higher than that of the hoes with an angle of $2\gamma = 110^\circ$, while processing steam by 13.4…20.2%.

Setting an average flat hoe with a maximum displacement relative to the side hoes by $S = \pm 0.4$ m with the hoe mounting scheme in the form of a “direct” wedge allows reducing the tool pull by 4.3…5.4%, depending on the speed of movement; for “reverse” wedge – by 4.2…4.7%. The values of traction resistance of flat hoes installed at distance $S = \pm 0.4$ m for both hoe placement schemes are almost equal, which in the development of a soil-cultivating unit makes it possible to use any of the
plots. From a constructive point of view, the layout of flat hoes in the form of a “reverse” wedge is more acceptable. The optimal distance of the average flat hoe relative to the side hoes is $S = 0.35…0.40$ m.

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