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THE OPTIMUM GEOMETRICAL FORM MODELING OF THE "STRIEGEL" TYPE HARROW

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ABSTRACT

The work is devoted to the development of the technique for choosing the optimal shape of the curved working part of the tooth of the harrow of the "Striegel" type. As a criterion of technical and economic efficiency of the application of the curved tooth of the harrow, the area of the projection of the tooth shape is considered taking into account the angle of possible deviation. The task was to find out from the experimental studies obtained how a significant amount of weed plants are destroyed when the force reaches a certain value and at what values of the force the tearing off of the stems and pulling out of the winter wheat occurs. According to the model of the process of removing weeds of weeds, the spring tooth must overcome resistance without longitudinal bending. On the basis of the data obtained, the authors developed a mathematical model characterizing the dependence of the projection area of the tooth shape on the radius of its curvature and the angle of rotation in the soil, a model characterizing the force exerted on the soil from the radius of curvature of the bend of the harrow tooth and the possible tooth deflection in the soil and the model characterizing limiting efforts on the roots of winter wheat, depending on the degree of development of the root system and soil moisture. On the basis of the models obtained, an algorithm is proposed for selecting the optimal geometric shape of the curved part of the tooth of the barrel harrow, depending on the development of the crops and soil moisture.

Keywords: striegel harrow, winter wheat, modeling, correlation-regression analysis, solution search.

INTRODUCTION

In accordance with the goal of modernizing agricultural production, set in the State Program for the Development of Agriculture until 2020 [7], issues related to the improvement of the means of mechanization of the agro-technical complex and the technology for their application are of particular relevance today.

One of the most important agro-technical methods aimed at increasing the yield of winter wheat is harrowing of crops, traditionally carried out in the spring-autumn period [2]. Harrowing, carried out in early spring, completes 3-4 days after the onset of physical ripeness of the soil. The quality of harrowing can reduce the loss of moisture to a minimum, destroy weeds [8], and also increase the nitrogen content in the soil, creating favorable conditions for plant growth [4].

In turn, the quality of harrowing depends on the mass of the harrows, the shape of the teeth, the angle of their penetration into the soil, the soil moisture, the length of the rods and the speed of the harrows. Differences between harrows on the quality of closure and preservation of moisture for sowing ultimately affect the productivity of crops [10]. Thus, at present, the issue related to the choice of technology and technology for the implementation of the harrowing of winter crops with the aim of increasing crop yields is topical.

The purpose of this paper is to select the optimal geometric shape of a harrow with spring teeth of the "Striegel" type, maximizing the area of soil cultivation, taking into account the criterion of the pressure exerted on the soil.

MATERIALS AND METHODS

There is a whole range of scientific works on the selection of tools and harrowing technologies. The use of modern harrow hoes, medium and heavy harrows with spring teeth (such as "Striegel") and tooth chain harrows is presented in [1]. The construction of the crenellated teeth with a sliding-cutting principle is presented in [9].

According to the data of both domestic [3] and foreign studies [11], harrows with spring teeth are the most optimal for the treatment of seedlings, as well as stubble conservation. So when using the Striegel harrow, plants receive additional nutrition, and moisture is retained by mulching at a depth of 1-6 cm. The operating costs per hectare are reduced, productivity is increased. In addition to the significant effect of costly chemicals for chemical treatment, the mechanical control of weeds and the use of the original harrow, the Striegel looks economically most profitable.

The shortcomings of the harrowing of winter crops include the possibility of harm to the unsettled crops, which in some cases not only does not contribute to higher yields but can also reduce it.

In this regard, a number of developments aimed at improving the shape of the spring harrow are known. In particular, in the study [6], the authors, changing the shape and angle of inclination of the core part, sought to ensure its maximum penetration. In the course of this development, improvements have been made in the form of a working part of the tooth curved along the radius, made with a cutting edge lying in the longitudinal-vertical plane passing through the axial line of the tooth, which is confirmed by the corresponding patent for the invention [5].

The authors' investigations carried out within the framework of this work are aimed at realizing the possibility to provide adjustment of the spring harrow with the limitation of the zone of oscillation of the lower part of the tooth in the transverse plane for specific operating conditions using the process of cutting for soil deformation. The technical result of this decision is the improvement of the operating and energy performance of the machine-tractor aggregates.

The solution of the problems associated with the disadvantages of using the bar-helical harrow is the change in the shape of the tooth. To conduct the research, prototypes of the teeth were made (Figure-1) and a laboratory installation (Figure-2) consisting of support posts, pipes with an adjusting mechanism. On the pipe there is a fixation for fixing the tooth to be examined. The adjustment mechanism consists of: two metal disks with holes for fixing the tooth sample at a certain angle to the vertical. At the bottom of the installation, a box with soil is inserted.

(a) (b) (c)

Figure-1. Test teeth:a) a straight tooth; b) a tooth, with a working part curved by a radius of 30 mm; c) a tooth with a working part of a curved radius of 50 mm.

Figure-2. Installation for conducting laboratory experiments.

In the laboratory, experiments were conducted to determine the rigidity of the tooth in various planes. In addition, the movement of the tooth in the soil was simulated.

RESULTS AND DISCUSSIONS

Based on the experimental data obtained on the stand and characterizing the dependence of the harrowing area as the main technical and operational parameter of the harrow from its geometric dimensions, which included the shape of the bend (tooth radius) and the possible rotation of the tooth in the plane by the authors, the following dependence was obtained:

$$Y_1 = 1182.1 + 5.23 \cdot X_1 + 2.33 \cdot X_2, \quad (1)$$

Where

Y_1 - tooth harrowing area, mm^2; X_1 - the geometry of the harrow tooth (in particular, the radius), mm; X_2 - angle of rotation of the harrow tooth in the plane, degrees

The correlation coefficient of the obtained dependence was 0.93, which indicates a high degree of convergence of the obtained dependence and the possibility of its application in practical calculations. A two-dimensional graph of the obtained dependence is shown in Figure-3.

When carrying out the harrowing process, an effort is exerted on the ground, with an excessive amount of which harrowing may not only be ineffective, but also reduce the yield of winter wheat, damaging the root system of undeveloped crops.

To construct a model that allows estimating the amount of effort exerted on the ground when harrowing with "Striegel" type teeth, a statistical material was collected in the experimental setup, characterizing the

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dependence of the force on the geometrical characteristics of the harrow tooth and its possible deviation in the harrowing plane.

Based on the regression analysis of the obtained data, the following dependence is constructed:

$$Y_2 = 1.68 + 0.00081 \cdot X_1 + 2.27 \cdot X_3, \qquad (2)$$

Where

Y_2 is the force transferred to the ground by the tooth when harrowing, kgf; X_1 - geometry of the harrow tooth (in particular the radius), mm; X_3 - the magnitude of the possible deflection of the harrow tooth in the harrowing plane

The correlation coefficient of the obtained dependence was 0.99, which indicates an extremely high degree of convergence of the obtained dependence and the possibility of its application in practical calculations. A two-dimensional graph of this dependence is shown in Figure-4.

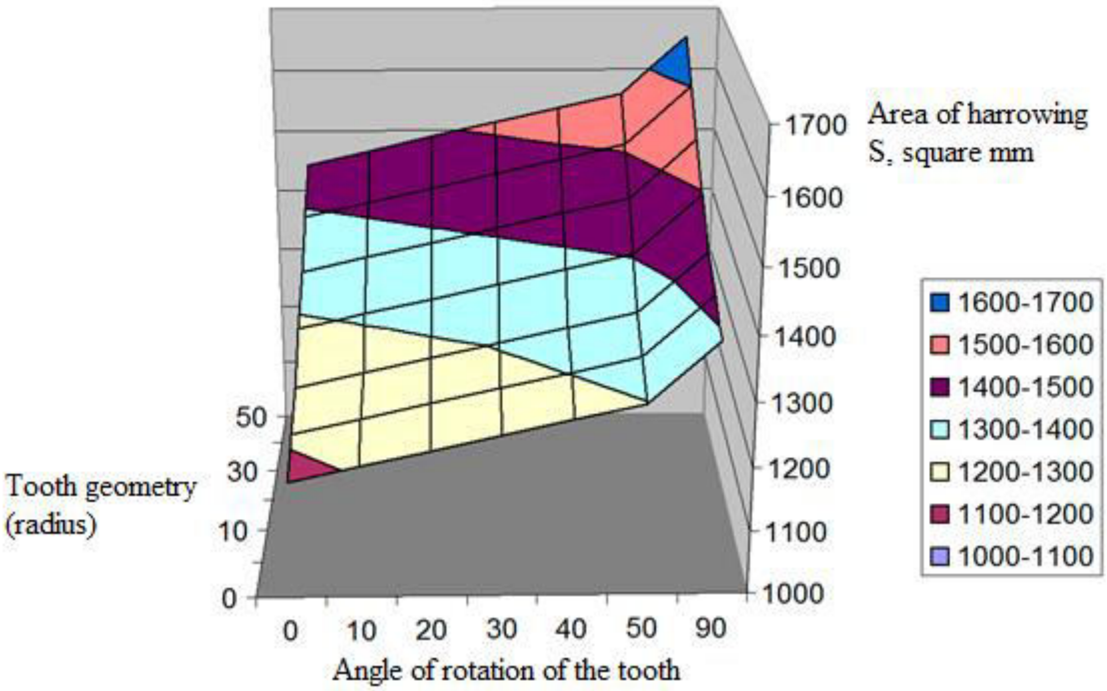

Figure-3. Graphical interpretation of the area of the projection of harrowing with a tooth of the "Striegel" type from the radius of curvature of the tooth and the angle of rotation of the tooth in the plane.

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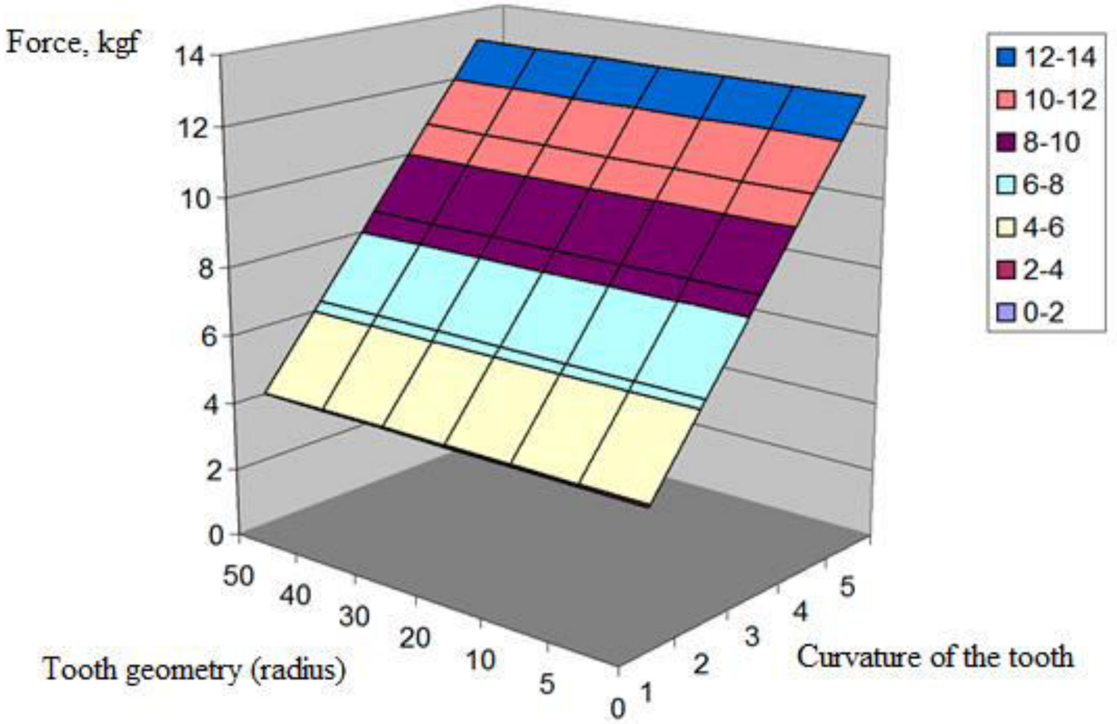

Figure-4. Graphical interpretation of the dependence of the force exerted when harrowing with a tooth of the "Striegel" type from the radius of curvature of the tooth and the amount of tooth deflection in the harrowing plane.

The harrowing force affects the root system of winter wheat, taking into account the size of the plants (the root system strength) and the condition and type of soil. The authors collected statistical information on the maximum effort from the condition of the intactness of the root system of plants transferred to the harrowing plane, depending on the size of the plants and soil moisture. As a result of statistical data processing, the following dependence was obtained:

$$Y_3 = 1.267 - 0.0261 \cdot X_4 + 0.721 \cdot X_5, \qquad (3)$$

Where

Y_3 is the ultimate force, to transfer to the ground by a tooth in the harrowing proceeding from the conservation conditions of the root system of winter wheat, kgf; X_4 - relative humidity of soil, %; X_5 - the strength of the root system of plants, determined by the height of winter wheat, cm

The correlation coefficient of the obtained dependence was 0.99, which indicates an extremely high degree of convergence of the obtained dependence and the possibility of its application in practical calculations. A two-dimensional graph of this dependence is shown in Figure-5 and in Table-1.

Table-1. Dependence of the limiting force transmitted to the ground by a tooth when harrowing from the soil state and the development of the root system of winter wheat.

Name of an indicator		**Relative humidity of soil, %**					
		5	**8**	**10**	**15**	**18**	**20**
Height of plants, cm	2	2.5785	2.5002	2.448	2.3175	2.2392	2.187
	5	4.7415	4.6632	4.611	4.4805	4.4022	4.35
	10	8.3465	8.2682	8.216	8.0855	8.0072	7.955
	15	11.9515	11.8732	11.821	11.6905	11.6122	11.56
	18	14.1145	14.0362	13.984	13.8535	13.7752	13.723

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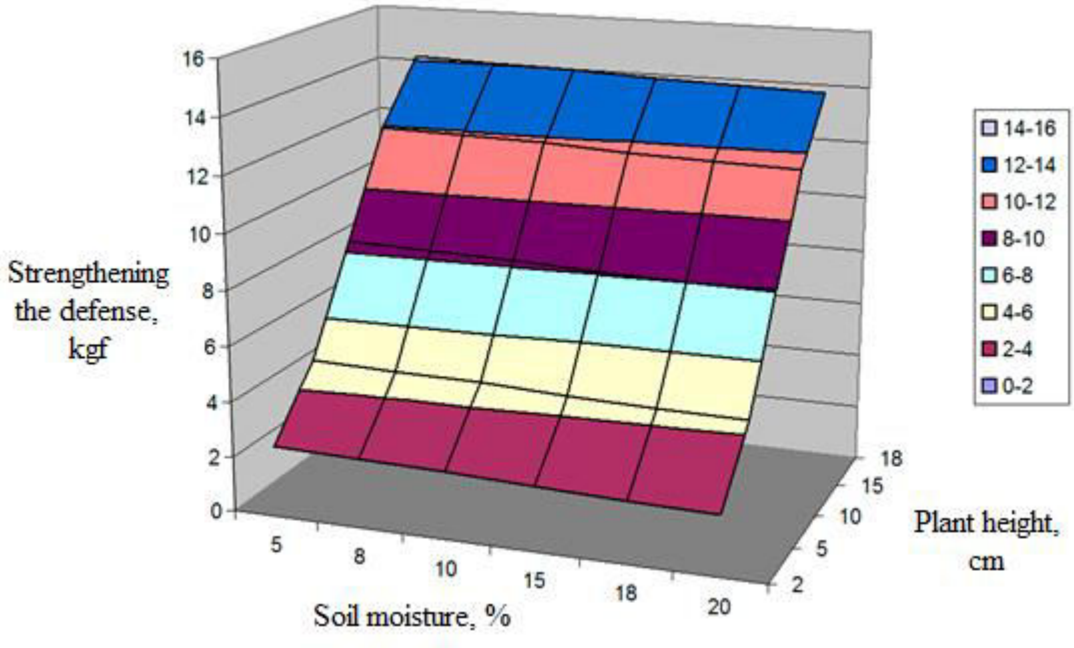

Figure-5. Graphical interpretation of the dependence of the limiting force transmitted to the ground by the tooth during harrowing, based on the conditions of preservation of the root system of winter wheat on the soil condition and development of the root system of winter wheat.

Further on the basis of the tool "Search for solutions" MS Excel, the authors selected the radius of curvature of the tooth of the Harrow type "Striegel", focusing on the one hand on the need to maximize the ground treatment area, on the other - based on the maximum allowable effort under the conditions of preservation of the root system of winter crops in harrowing.

As an example, we will illustrate the selection of the curvature of the harrows of the "Striegel" type used for two conditions of winter and soil (identified in gray in Table-1). The results are presented in Table-2 and Table-3.

Table-2. Selection of the curvature of the teeth when harrowing winter crops with a height of up to 10 cm with a relative soil moisture of 8%.

Name of an indicator	Meaning				
Curvature of the tooth	1	2	3	4	5
Radius	70	70	0	0	0
Area at an angle of 90	1757.9	1757.9	1391.8	1391.8	1391.8
Aneffort	4.006	6.2767	8.49	10.76	13.03
Ultimate effort	8.2	8.2	8.2	8.2	8.2

Obviously, in order to increase the treatment area, the radius of curvature of the tooth with a possible deviation of 1-2 cm is recommended to take the maximum - up to 70 mm. When the tooth is deflected by 3 cm using a harrow, it is recommended to use a harrow with straight teeth. It should also be noted that when the deflection of the teeth is 4-5 cm, harrowing is not recommended in principle, due to the excess of the effort above the maximum permissible and the risk of yield reduction.

Table-3. Selection of the curvature of the teeth when harrowing winter crops with a height of up to 15 cm with a relative soil moisture of 18%.

Name of an indicator	Meaning				
Curvature of the tooth	1	2	3	4	5
Radius	70	70	70	70	0
Area at an angle of 90	1757.9	1757.9	1757.9	1757.9	1391.8
Aneffort	4.0067	6.2767	8.5467	10.8167	13.03
Ultimate effort	11.6	11.6	11.6	11.6	11.6

CONCLUSIONS

Based on the conducted field experiments, as well as the processing of results and mathematical modeling, it can be concluded that the authors proposed a method for justifying the choice of the effective geometric shape of a harrow of the "Striegel" type, in particular the radius of curvature of the tooth, maximizing the area of cultivation of the soil, depending on soil condition and degree of rooting of winter crops including:

a) Model of the dependence of the area of the harrowing projection with the tooth of the "Striegel" type from the radius of curvature of the tooth and the angle of tooth rotation in the plane, which makes it possible to determine the harrowing efficiency based on the selection of the geometric shape of the shaving tooth.

b) Model of the dependence of the force exerted by harrowing with the tooth of the "Striegel" type on the radius of curvature of the tooth and the amount of tooth deflection in the harrowing plane, which makes it possible to evaluate the influence of the variable geometry of the harrow tooth on the root system of winter sprouts.

c) The model of the limiting force transmitted to the ground by a tooth when harrowing from the size of winter wheat germs and soil conditions, on the basis of which it is possible to assess the conditions for the application of bar-shaped teeth of different geometries based on the ultimate requirements for damage to the root system of winter wheat

d) The algorithm for selecting the radius of curvature of a tooth of a harrow of the type "Striegel", based on the criterion of maximizing the soil treatment area on the one hand, and the criterion of the maximum allowable effort for the conservation of the root system of winter crops in harrowing, on the other.

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