To the justification of the parameters of the disk case for undisturbed notches

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Abstract. The influence of technological parameters of the design of the housing of the discator for basic tillage on unrecorded cuttings on its traction resistance is studied. Resource-saving reforestation technologies, which allow to avoid stump clearing, cause the least harm to deforestation ecology and save material resources. Disk tools in the conditions of uncorrupted cuttings significantly surpass plow plows in terms of providing the required maneuverability. The advantage of the discs is the individual attachment of the hulls to the frame, which eliminates clogging of the hull with plant residues and soil. The design of the casing of the discator is investigated, which ensures the required quality of soil turnover and its preservation in the form of a continuous tape laid near the furrow on uncorrupted cuttings. The disk case increases the technical level of modern forest tillage tools, which will improve their competitive advantages among other forest machines used for plowing. As a result of experimental studies of the obtained regression model traction case disc header, allowing to determine its optimal parameters, ensuring the quality of technological process of tillage with minimum energy consumption. The mathematical model is used in the design of forest tools.

1. Introduction

Rational technology of reforestation involves the partial treatment of the soil in the form of cutting plow furrows or strips, this makes it possible to exclude the execution of operations for stump removal, which in turn significantly reduces energy and material losses. At the same time, the negative environmental impact on the soil, which occurs when stumps are stubbing, is reduced, as in this case, the upper humified soil layer is not removed and the underlying structureless horizons are not exposed [1-3]. In this case, the cleared strip in the cross section acquires a hollow profile, which contributes to the stagnation of water and local waterlogging. Forest cultures planted in such bands are underdeveloped and often die [4-6].

The plow plows provide a complete turnaround and preservation of the soil layer, which contributes to the incorporation of plant residues into the upper soil layer and the accumulation of humus, but is low effective on uncarved cuttings. Plow plows are not able to overcome the obstacles encountered (stumps, roots, etc.), they experience significant shock loads when meeting with it. In turn, disk plows are deprived of this disadvantage, but at the same time, spherical discs cannot ensure full rotation and
preservation of the soil layer under any of their structural and technological parameters [7-9]. The design feature of the discs is the individual attachment of the bodies to the frame of the instrument, which eliminates the clogging of the instrument with soil and plant residues [10-12].

The research is carried out in order to determine the optimal parameters of the discator housing that ensure a high-quality technological process of soil cultivation with the lowest energy consumption.

2. Materials and methods

The developed design of the disk case [13, 14] combines the advantages of a freely installed (rotating) disk case to overcome the obstacles encountered and a plowed body that provides high-quality tillage (in terms of a complete rotation of the soil layer and its preservation in the form of a solid tape).

Figure 1 shows the design of the proposed case of a diskator, containing a rack 1 with an axis, a rotating cutting edge 2 in the form of a spherical ring mounted freely on bearings on the axis by means of spokes 5. A fixed spherical disk 3 is rigidly fixed in the hole of the spherical cutting edge. A blade 4 is rigidly attached to the spherical disk, with the possibility of adjusting its position in the angle of rotation. The case of the discator works as follows: the rotating cutting edge 2 cuts the soil layer, the fixed spherical disk 3 and the blade 4 contribute to the turnover and laying of the layer near the furrow.

![Figure 1. The design of the diskator case: 1 – rack; 2 – spherical cutting edge; 3 – spherical disk; 4 – dump; 5 – knitting needles.](image)

The thrust force of the disk case was determined using the strain gauge shown in figure 2. The strain gauge consists of two frames, installed one below the other and articulated by oscillating leads. Offset frames relative to each other is possible only in the longitudinal direction. Strain gauge limits this degree of freedom. The square tube of the upper frame provides the mount with the diskator housing. The lugs of the lower frame and cylindrical axles are fastened to the tractor rods. The pre-tension of the strain gauge is produced by adjusting the nut. When the instrument moves in the soil, the lower frame moves relative to the upper one and stretches the strain gauge link. The tensile force of the strain gauge is converted into an electrical signal, which passes through a signal amplifier and is recorded by a recorder.

The studies shown in figure 3 were carried out in the Left-Bank Forestry of the Experimental Forestry Enterprise of the Voronezh State Technical University with sandy loam soil hardness of 17-22 kg/cm² and humidity of 6-8%, processing depth - 150 mm. Geometrical parameters of the discator case: the outer diameter of the spherical cutting edge is 770 mm, the hole diameter of the spherical cutting edge is 540 mm, the radius of curvature of the spherical disk is 1200 mm.
Studies suggested building a model of traction resistance, to solve the problem, a full factorial experiment was implemented [15, 16].

3. Results and discussion
For variable factors were taken: the angle of rotation of the blade (\(\Theta\)), angle of attack (\(\alpha\)) and angle of inclination (\(\beta\)) of the discator's body, the designation of factors and their levels are presented in table 1. The response function is the number of completely wrapped layers (\(y\)).

| Name                  | Factor      | Designation | Levels of factors, deg | Variation interval |
|-----------------------|-------------|-------------|------------------------|--------------------|
|                       |             |             | natural | normalized | upper | main | lower |            |
| Attack angle          | \(\alpha\)  | \(x_1\)     | 45      | 40         | 35    |      | 5      |            |
| Tilt angle            | \(\beta\)   | \(x_2\)     | 20      | 15         | 10    |      | 5      |            |
| Blade turning angle   | \(\Theta\)  | \(x_3\)     | 20      | 10         | 0     |      | 10     |            |

To test the normal distribution of the output quantity, a series of 30 experiments was carried out with \(\alpha=35^0\), \(\beta=10^0\), \(\Theta=0^0\). The normal distribution was checked by \(x^2\)– Pearson criterion. The results of this series are presented in the table 2. Statistical processing of the results of this series was carried out using the STATGRAPHICS application package, the \(x^2\)– Pearson criterion was 1.95, comparing this value with the tabular \(x^2 = 3.84\) (1.95 < 3.84), we conclude that the hypothesis of the normal distribution is accepted random variable.
The regression model of the traction in the form of a polynomial inequality

\[ g \]  

greatest dispersion of the fifth experience

\[ \text{Where} \]

We estimate the significance of the regression coefficients by calculating the inequality

\[ \text{For each regression coefficient, the standard deviation is:} \]

\[ S^2 \{ b_i \} = 0.086 \]

We estimate the significance of the regression coefficients by calculating the inequality:

Table 2. The results of a series of experiments.

| No. exp | \( y_0, \text{daN} \) | No. exp | \( y_0, \text{daN} \) | No. exp | \( y_0, \text{daN} \) |
|---------|----------------------|---------|----------------------|---------|----------------------|
| 1       | 265                  | 11      | 273                  | 21      | 266                  |
| 2       | 267                  | 12      | 270                  | 22      | 271                  |
| 3       | 275                  | 13      | 267                  | 23      | 274                  |
| 4       | 277                  | 14      | 275                  | 24      | 272                  |
| 5       | 271                  | 15      | 274                  | 25      | 267                  |
| 6       | 273                  | 16      | 271                  | 26      | 269                  |
| 7       | 271                  | 17      | 267                  | 27      | 271                  |
| 8       | 270                  | 18      | 271                  | 28      | 269                  |
| 9       | 272                  | 19      | 270                  | 29      | 274                  |
| 10      | 271                  | 20      | 270                  | 30      | 270                  |

The planning matrix of the main experiment to determine the quality of the reservoir turnover and the results of the experiments are presented in the table 3.

Table 3. Experiment planning matrix.

| No. | \( x_1 \) | \( x_2 \) | \( x_3 \) | \( x_1x_2 \) | \( x_1x_3 \) | \( x_2x_3 \) | \( y_1, \% \) | \( y_2, \% \) | \( y_3, \% \) | \( y_4, \% \) | \( y_5, \% \) | \( y_j, \% \) | \( S_j^2 \) |
|------|-----------|-----------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|
| 1    | –         | –         | –         | +           | +           | +           | –           | 129         | 131         | 134         | 132         | 132         | 131.6       | 3.3        |
| 2    | +         | –         | –         | –           | +           | +           | +           | 272         | 270         | 268         | 273         | 273         | 271.2       | 4.7        |
| 3    | –         | +         | –         | –           | +           | +           | –           | 113         | 116         | 118         | 118         | 116         | 116.2       | 4.2        |
| 4    | –         | –         | –         | +           | +           | –           | –           | –           | 237         | 237         | 238         | 234         | 236         | 236.4       | 2.3        |
| 5    | –         | –         | +         | +           | –           | –           | +           | 132         | 133         | 138         | 135         | 135         | 134.6       | 5.3        |
| 6    | +         | –         | +         | –           | –           | +           | –           | 278         | 276         | 276         | 279         | 280         | 277.8       | 3.2        |
| 7    | –         | +         | –         | +           | –           | –           | +           | –           | 117         | 119         | 118         | 120         | 119         | 118.6       | 1.3        |
| 8    | +         | +         | +         | +           | +           | +           | +           | 241         | 244         | 245         | 243         | 241         | 242.8       | 3.2        |

where \( y_j, S_j^2 \) – respectively, the average response and variance.

According to Cochren's criterion, we check the homogeneity of the dispersions of experiments. The greatest dispersion of the fifth experience \( S_j^2 = 5.3 \). From here:

\[ G_{\text{test}} = 0.193. \]

According to the table of distribution of the Cochren test for our case, we find \( G_{\text{tab}} = 0.46 \). The inequality \( G_{\text{calc}} < G_{\text{tab}} \) allows us to conclude that the dispersions of experiments are homogeneous. We will look for the regression model of the traction in the form of a polynomial:

\[ y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1x_2 + b_5x_1x_3 + b_6x_2x_3 + b_7x_1x_2x_3 \]

The estimated coefficients of the regression model are presented in the table 4.

Table 4. The regression coefficients of the mathematical model

|   | \( b_0 \) | \( b_1 \) | \( b_2 \) | \( b_3 \) | \( b_4 \) | \( b_5 \) | \( b_6 \) |
|---|----------|----------|----------|----------|----------|----------|----------|
|   | 191.2    | 65.9     | –12.65   | 2.3      | –4.8     | 0.95     | –0.1     | 0.05     |

Pre-determine the variance of the regression coefficients:

\[ S^2 \{ b \} = 0.086 \]

For each regression coefficient, the standard deviation is:

\[ S^2 \{ b \} = 0.293 \]
From the tables of t-distribution of student choose the value $t_{\text{tab}}$ at the level of significance $q = 0.01$ and number of degrees of freedom $f_0 = 32$.

Then:

$$t_{\text{tab}} = 2.73$$

Consequently:

$$t_{\text{tab}}/b_j = 0.8.$$ 

The above ratio does not hold for coefficients $b_{23}$ ($0.1 < 0.8$) and $b_{123}$ ($0.05 < 0.8$), therefore, we assume that these coefficients are not significant, but exclude the terms $b_{23}x_2x_3$ and $b_{123}x_1x_2x_3$ from the expression.

Rejecting insignificant members, we get a regression model in the form:

$$Y = 191.2 + 65.9x_1 - 12.65x_2 + 2.3x_3 - 4.8x_1x_2 + 0.95x_1x_3$$  \hspace{1cm} (1)

The adequacy of the obtained model will be checked by Fisher's F-criterion ($F_{\text{tab}}$), if $F_{\text{calc}} < F_{\text{tab}}$, then the model is considered adequate. In our case, the calculated value $F_{\text{calc}} = 0.72$, and $F_{\text{tab}} = 5.34$, the condition $F_{\text{calc}} < F_{\text{tab}} (0.72 < 5.34)$ is fulfilled, therefore the model is adequate and can be used to describe the object of study.

Using the expression:

$$x_i = \frac{\bar{x}_i - \bar{x}_{io}}{I_i}$$

where $\bar{x}_i$, $x_i$ – respectively natural and normalized value of the factor; $I_i$ – variation interval; $\bar{x}_{io}$ – natural value of the main level. Define

$$x_1 = (\alpha - 40)/5$$  \hspace{1cm} (2)

$$x_2 = (\beta - 15)/5$$  \hspace{1cm} (3)

$$x_3 = (\Theta - 10)/10$$  \hspace{1cm} (4)

Substituting (2), (3) and (4) into (1), and performing the transformations, we obtain the regression equation in the natural form:

$$Y = -407.95 + 15.87\alpha + 5.15\beta - 0.53\Theta - 0.192\alpha\beta + 0.019\alpha\Theta$$  \hspace{1cm} (5)

Having carried out a graphical analysis (figure 4-6) of the obtained model (5), it can be noted that the change in the angle of attack has the most significant effect on the pull, the change in the angle of inclination relative to the vertical, the least change in the angle of rotation of the blade has the least effect. With an increase in the angle of attack and the angle of rotation of the blade, the pulling force increases, and with an increase in the angle of inclination relative to the vertical, it decreases, change of angle of inclination and angle of inclination significant deviation from the tractive effort.

![Graph of tractive effort versus angle of attack and angle of inclination with $\Theta = 0^\circ$.](image)
4. Conclusion

The conducted research allowed us to build a regression model of the discator case, which will allow determining its optimal technological parameters, ensuring the required quality of tillage with the lowest energy consumption with sufficient permeability of the tool in conditions of uncorrupted cuttings. The proposed disk enclosure will enhance the competitive advantages of diskators among other forest tillage tools. Research can be used in the design of forest tillage machines.

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