Optimization of parameters of ecological-meliorative product for preseed treatment of soil

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Abstract. It has been established that the imbalance of soil processes caused by insufficient intake of organic matter into the soil causes its degradation, decreased fertility, and humus content. There is a problem of ensuring environmental safety. It was also established that the development of new or the improvement of existing structural and technological solutions for tillage is of particular practical interest. Pre-sowing cultivation of the soil is a thorough closure and preservation of moisture through the creation of the upper mulched surface, the destruction of weeds and the creation of favorable conditions for seed germination at a biologically optimal depth of planting. For the steppe zone of the North Caucasus (Krasnodar Territory, Rostov Region and Stavropol Territory), which is the main grain-sowing zone in Russia, research is needed to develop innovative means for pre-sowing treatment that provides the accumulation and preservation of moisture and nutrients, reduces fuel consumption and stable movement of working bodies in soils having different densities. To solve this problem, the hypothesis was put forward at Kuban Agrarian University that in order to ensure moisture conservation and reduce energy consumption, stability of movement of the working bodies of the device in soils with different densities is required, while the stand must deviate under the influence of external resistance in three planes. The research was developed and protected by the patent “Device for presowing tillage”. Studies have been carried out to optimize the energy costs of an innovative tool for presowing tillage using experimental design methods that confirm effectiveness.

1. Introduction
It is known from a review of sources [1–4] that as a result of intensive machining, in most cases, the dynamic equilibrium in the soil-plant-atmosphere ecological system is violated, and the biogeochemical circulation of substances also changes. The imbalance of soil processes due to insufficient intake of organic matter in the soil causes soil degradation, decreased fertility and humus content. It was also established that this is caused by the imperfection of technologies and technical means of primary tillage, working bodies of the equipment in the production of agricultural products. In this connection, there is a problem of ensuring environmental safety (reducing erosion, compaction, loss of soil moisture, etc.). Therefore, research is needed in the field of search and development of technologies and technical means of tillage of a new generation.

It is also known that the soil cultivation process is one of the most labor-consuming and energy-intensive agricultural operations. Production consumes from 30 to 40% of all energy costs in agriculture [5]. At the same time, the yield of agricultural products depends on the quality of processing of almost 25% cultures. Modern agricultural machines for soil cultivation, produced in a
wide range in the CIS countries and abroad, do not fully solve the problem of maintaining fertility and reducing energy costs, have a high cost, low functionality and operational reliability. Therefore, at the moment, studies of mechanized farming processes and the development of new or improved structural and technological solutions for tillage are of particular practical interest.

Pre-sowing cultivation of the soil is a thorough closure and preservation of moisture through the creation of the upper mulched surface, the destruction of weeds and the creation of favorable conditions for seed germination from a biologically optimal depth of planting. Pre-sowing tillage is carried out at the depth of seed placement. An important processing condition is the creation of a small-aggregate composition on the soil surface and the production of a compacted flat bed to ensure friendly seedlings. The disadvantages of pre-sowing soil preparation with existing cultivators are that the bottom (bed for seeds) with a serrated profile is obtained. Racks and dividers are involved in soil compression, in tearing and dividing the soil into two strips. The low quality of loosening of the soil structures of the upper horizon does not provide the conditions for the effective accumulation and use of soil moisture, does not contribute to the guaranteed yield of grain crops in the conditions of risky dry farming. Research to solve this problem is also necessary especially for the steppe zone of the North Caucasus (Krasnodar Territory, Rostov Region and Stavropol Territory), which is the main grain-growing zone of Russia.

The following agronomic requirements are presented for pre-sowing tillage [6]. The depth of loosening of the soil should correspond to the depth of seeding with a deviation of ± 1 cm, and with dry soil of 1...1.5 cm. After cultivation, the topsoil should be finely lumpy and completely pruned weeds. The bottom of the furrow after cultivation should be flat. It should be noted here that an even and dense bed for seeds eliminates the undermining of the root system of plants during their vegetation. The height of the crests of the loosened layer should not exceed 3-4 cm, therefore, harrowing is often carried out simultaneously with cultivation.

A study of the experience of cultivating winter wheat in the Northern zone of the Krasnodar Territory [7–10] made it possible to establish that after tilled predecessors (corn for silage, grain, sunflower, etc.). The main tillage is carried out with disk implements (BDT-3M, BD-10, BD-10B, BDT-7A, etc.). At the same time, tillage units make multiple passes along the field (along and across the field and along the diagonal of the field). As a result, the soil is unevenly compacted in depth and in the width and length of the field, which reduces its water permeability. In case of uneven soil compaction. Subsequent continuous cultivation with basic implements (KPS-4A, KShU-4, KShU-12) does not provide the required quality of pre-sowing treatment in depth, evenness of the bottom, combing, clumpiness and the degree of cutting of weed vegetation. Moreover, in soils with different densities, according to the depth of processing and the width of the grip of the tillage implement, the rigid fastening of the racks of the working bodies to the rails of the frame leads to unstable movement in the soil of the working bodies and increased fuel consumption.

Therefore, the problem arose from the need for the development of ecological and reclamation technical equipment providing the accumulation and preservation of moisture and nutrients, reducing fuel consumption and the steady movement of working bodies in soils with different densities.

To solve this problem, we formulated the following hypothesis: «To ensure the conservation of moisture and reduce energy consumption, the stability of the movement of the working bodies of the device in soils having different densities is required, while the stand must deviate under the influence of external resistance in three planes». For its implementation, it is necessary to conduct exploratory research; to develop an ecological reclamation remedy for presowing tillage; to develop a methodology and conduct research to optimize its parameters.

2. Methodology
Based on a review of scientific papers, the shortcomings of similar tools used in practice are identified. In this connection, a remedy protected by the RF patent was proposed [11], the novelty of which is that a stand fixed through springs in three places on a rectangular bracket can deviate under the
influence of external resistance in three planes, which ensures the stability of workers device organs in soils having different densities. The essence of the proposed tool is shown schematically in Figure 1.

**Figure 1.** Diagram of an innovative tool for presowing tillage: a – the general view of the device (side view); b – the general view of the device (top view); c – the working body and spring suspension of the plane-cutting strut (side view); d – the working body (type top); e – frontal section A-A of the working body. 1 – two-beam frame; 2 – support wheels; 3 – hinge system; 4 – brackets; 5 – glasses; 6, 9 – holes; 7 – racks; 8 – shanks; 10 – coil springs; 11 – lancet paws; 12 – gaps.
The operation of the device is as follows. When treating the soil with a working body, a load P acts on it, arising from the latter overcoming the soil into which paw 11 is buried. To simplify the problem, we believe that such a load is constant, i.e. P = const, and does not cause elastic deformation of the springs 10, and hence the struts 7, while the paw 11 is on a given recess in the soil and moves together with the frame 1 of the cultivator quite stable. Imagine now that this load increased due to the fact that the cultivator began to cultivate the soil with a density much higher than that in the first case and so much that it caused angular elastic deformation of the springs 10 together with the struts 7. Moreover, the elastic cylindrical springs 10 allow the paw 11 of the device to deviate in the direction opposite to the soil seals. The deviation of the paws occurs due to the movement of the shank 8 relative to the brackets 4 in all planes by the size of the gap 12, as a result, the springs 10 experience elastic deformation by attaching them to the shank 8 and glasses 5, which ensures free movement of the rack 7 in all directions.

For research, the KPS-4A base cultivator with a BZSS-1.0 harrow (4 pcs.) was upgraded by replacing the strut mount with springs. The tests were carried out on a field of 40 ha after harvesting corn for grain. The soil was heavily compacted by multiple passages of maize harvesting equipment and vehicles. Its main processing was carried out by the BDT-7 disc harrow in four passes: along and across the field, as well as along the diagonals of the field.

The experimental research program includes optimization of the parameters of the working bodies of an innovative tool for pre-sowing tillage using experimental design methods [12–14]. To set up a two-factor experiment, we chose a symmetric compositional plan of the BK type. Moreover, when analyzing the factors, it was determined that the essential (variable) factors affecting the amount of fuel consumption of the product are the speed of movement and the stiffness of the springs. The levels of factors (table 1) are selected in a "standard way" i.e. so that their optimal values fall in the center of variation. During operation of the unit, fuel consumption was measured using measuring tanks mounted on the tractor. As instrumentation (measuring) support for the equipment for experiments, we used measuring tapes, rulers, probes, stopwatch, movie camera, photo equipment, etc. with data processing on a PC. Field humidity, full moisture capacity, volumetric mass of the soil, specific gravity of the soil, porosity, soil density, value of average hardness did not have significant deviations. They were checked using one-factor experiments, according to the methods in accordance with GOST 20915-75.

Table 1. Factors, intervals and levels of variation

| Variable factors | Coded designations, $X_i$ | Interval variation, $\Delta_i$ | Levels factors $\pm 1$ | $0$ | $-1$ |
|------------------|---------------------------|-------------------------------|------------------------|-----|-----|
| Speed, $X_1 (V_i)$, km/h | $x_1$ | 2 | 12 | 10 | 8 |
| Rigidity, $X_2 (K_i)$, kN/m | $x_2$ | 1 | 3 | 2 | 1 |

where $x_1$ – the coded designation of the speed of the cultivator, which has a range of variation from $V_{\text{min}} = 8$ km/h to $V_{\text{max}} = 12$ km/h, and the speed $V_0 = 10$ km/h – taken as the middle of the interval; $x_2$ – coded designations of spring stiffness with an interval of variation from $K_{\text{min}} = 1000$ N/m to $K_{\text{max}} = 3000$ N/m, and stiffness $K_0 = 2000$ N/m – taken as the middle of the interval.

3. Results
Translation of real values into coded values is carried out according to:

$$x_i = \frac{X_i + X_{i0}}{\Delta_i}.$$ 

The experiments were carried out in triplicate, and the average values were entered in table 2, which presents the planning matrix of a two-factor experiment using the program MNK of the BK-type.
The experiment was conducted randomly according to the number of experience, i.e. in a random sequence to eliminate the influence of systematic errors caused by external factors (for example, inaccurate control, etc.).

**Table 2.** Planning matrix for a two-factor experiment to determine the cultivator fuel consumption depending on the speed of movement $V_i$ and spring stiffness $K_i$.

| №  | Natural factors | Factor levels | Response, kg/ha |
|----|-----------------|---------------|-----------------|
|    | $X_i (V_i)$, km/h | $X_2 (K_i)$, kN/m | $x_1$ | $x_2$ |
| 1  | 12              | 3             | +1     | +1     | 3.72 |
| 2  | 8               | 3             | -1     | +1     | 3.61 |
| 3  | 12              | 1             | +1     | -1     | 3.65 |
| 4  | 8               | 1             | -1     | -1     | 3.21 |
| 5  | 12              | 2             | +1     | 0      | 3.25 |
| 6  | 8               | 2             | -1     | 0      | 3.3  |
| 7  | 10              | 3             | 0      | +1     | 3.41 |
| 8  | 10              | 1             | 0      | -1     | 3.18 |
| 9  | 10              | 2             | 0      | 0      | 3.12 |

After the experiment (according to table 2) and as a result of mathematical processing of the experimental data, the regression equation in the canonical form is obtained taking into account the determination of its coefficients:

$$Y = 8.062 - 0.976x_1 - 0.431x_2 - 0.41x_1x_2 + 0.55x_1^2 + 0.24x_2^2$$

(2)

where $Y$ – fuel consumption, kg/ha. The obtained coefficients are checked for reliability by the Student criterion, and the equation itself - by the Fisher criterion.

Differentiating the equation with respect to each variable and equating the derivatives to zero, we obtain a system of linear equations. Having solved the resulting system, we find the coordinates of the response center: in coded values, we obtain $x_1 = -0.24491$ and $x_2 = -0.28976$, which corresponds to the actual values $X_1 = 9.51$ km/h, $X_2 = 1.71$ kN/m when translating them according to the formula (1).

We found values $x_1$ and $x_2$ substituted in the original equation (2) and found the value of the parameter in the center of the response surface. The value of the optimal fuel consumption is $Y_S = 3.05247$ kg/ha. To analyze the factors $x_1$ and $x_2$ near the center of the response, we carry out the canonical transformation of equation (2). We get the equation:

$$Y - Y_S = 0.1878x_1^2 + 0.2722x_2^2$$

(3)

where $Y_S$ – optimal fuel consumption, kg/ha.

Figure 2, 3 show the graphical views obtained according to the analysis of equation (3).
Figure 2. Surfaces of the fuel consumption response of the cultivator from spring stiffness (two-dimensional cross-section, graphs): a – surface of the fuel consumption response of our ecological reclamation remedy versus processing speed ($V_i$) and spring stiffness ($K_i$); b – response surface in contours, c – graph of the technological parameter $\gamma$. 
Figure 3. Surfaces of the fuel consumption response of the cultivator from spring stiffness (two-dimensional cross-section, graphs): 
a – graph of the technological parameter; 
b, c – types of $X_1$ or structural parameter $X_2$ at fixed values.
4. Conclusion

Thus, the tasks are completed. A new design tool has been developed. The technical and economic advantage of the proposed technical solution in comparison with the known ones is obvious, because it allows you to expand the operational characteristics of the cultivator working on various soils with different densities.

With the values of the speed of cultivation $X_1 = 9.51$ km/h, the stiffness of the springs $X_2 = 1.71$ kN/m, the value of the optimal value of fuel consumption $Y_S = 3.05247$ kg/ha.

Verification of the effectiveness of the proposed tool showed that it provides a reduction in energy costs for pre-sowing tillage due to the steady movement of working bodies on soils with different densities and more rational use of soil moisture reserves.

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