Regression analysis of ploughshare parameters for different depth sowing of seeds and fertilizers

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Abstract. The study reveals the disadvantages of technical units intended for sowing grain crops. Vectors of modernization of existing and the design of new working bodies of sowing equipment were identified. The arrangement and principle of ploughshare operation for different depth sowing of seeds and fertilizers is described. The results of the planned experiment are presented, the regression equations are obtained describing the process of changing the uniformity of seeds distribution along the length and width of the planted furrow. Based on regression equations, response surfaces, uniformity of seed distribution along the length and width of the planted furrow are built depending on the design parameters of a ploughshare. The experimental studies revealed that the uniformity of seed distribution (85.5% in length and 76.3% in width of the planted furrow) is achieved with the following ploughshare parameters: drift angle $\alpha=15$ degrees; roll angle $\beta=15$ degrees; cutout length of a lower edge of a leg $L=50$ mm. With these design parameters, the proposed ploughshare provides a uniform depth of seeding-down and meets the corresponding agricultural requirements. At the same time, mineral fertilizers are embedded below the horizon of the main crop at 30...40 mm.

1. Introduction

The technology of cultivating crops includes a set of operations with crops and soil, in agrotechnical terms, with a complex of machines.

Since in the territory of the Russian Federation a sufficient amount of land is subject to erosion, it is necessary to be competent when choosing the tillage technology and applied tools [1, 2] in order to create certain conditions for the growth of plants and to obtain the maximum possible yield. At the same time, it was found that the value of crop production depends on the initial conditions in a particular field area, the initial state of the sowing material and the development of the cultivated crop during growing. Yield depends on stem density by 50%, on the number of grains in a spike – by 25% and on the thousand-kernel weight – by 25% [3].

Thus, the greatest yield is obtained with the optimal stem density for a particular crop under specific soil-ecological conditions. In other words, plants are placed in a particular area so that each of them has sufficient moisture, sunlight and nutrients in abundance, and at the same time there is no unused area.

Many scientists considered the issues of achieving the optimal area of plant nutrition and the optimal planting width during sowing of grain crops [4–8]. It was established that the uniformity of distribution of seeds over the feeding area largely depends on the sowing method and structural features of ploughshares [9–11].
Thus, the studies aimed at developing technological processes and creating technical means that ensure high-quality sowing is an urgent task.

2. Object and Methods of Study
The purpose of the study is to improve the sowing quality due to the use of ploughshares for different depth sowing of seeds and fertilizers.

The object of the study is the process of ensuring uniform sowing of grain seeds with ploughshares for different depth sowing of seeds and fertilizers.

The subject of the study is the regularities of the process of uniform distribution of seeds with ploughshares for different depth sowing of seeds and fertilizers.

Under the conditions of the soil protection system of agriculture it is possible to increase the yield of cultivated crops by providing the following indicators:

- plant life conditions, i.e. seeding into the wet layer of soil, to the same depth;
- optimal density of productive stem, i.e. uniform distribution of seeds over the feeding area [12].
- rational regime of plant nutrition, i.e. application of mineral fertilizers below the seeding level of the main crop (Fig. 1) [13].

Thus, the basis of soil protection agriculture is an agricultural system involving technological operations that ensure the improvement of soil agrophysical properties. A system of machines is formed to perform the operations provided for by a particular technology. It is assessed as a factor providing the required technology aimed at obtaining the maximum possible yield with minimum labor and material costs [14].

At the same time, on the one hand, there is a clear connection between the yield and the applied crop cultivation technology and on the other – the system of machines with their agrotechnical indicators.
Let us present this connection in the form of the “Soil – technology – machines – yield” system (Fig. 3).

The components of this system are as follows:

1. Basis for harvesting – soil with its physical and mechanical properties.
2. Technology of cultivating crops taking into account agrotechnical and economic requirements.
3. System of machines for this technology with certain agricultural indicators.
4. Yield and its production costs.

In the presented system (Fig. 2), the input parameters include physical and mechanical properties of soil and the agricultural background in general. The output parameters include the maximum possible yield with the minimum possible labor costs. The control function of the system, which ensures optimal output parameters, is a technology that meets agricultural and technical-economic requirements, which is interconnected with the used machine system.

Figure 2. Soil – Technology – Machines – Yield

If agrotechnical and technical-economic requirements are not provided by the machines, their modernization is necessary, and in some cases the development of fundamentally new machinery is required. Improvement and creation of new machines is considered in conjunction with the required technology [15]. The requirements for machines may be divided into three categories: technological, technical-operational and economic. Let us consider sowing machines as an integral part of any crop cultivation technology.

Most equipment today provides ordinary sowing, which in some cases is characterized by the formation of thick rows, with a plant feeding area in the form of a rectangle with an aspect ratio of 1:10, which does not provide sufficient nutrients for the plant. At the same time, mineral fertilizers are introduced during sowing in the same horizon with seeds [16, 17].

Sowing machines are required to provide technological parameters: uniform depth of seeding, optimal placement of seeds along the area, introduction of mineral fertilizers below the level of seeding of the cultivated crop. Besides, it is necessary to meet maintenance and economic requirements common to all types of equipment (Fig. 3).

Based on the above, it can be concluded that the modernization of existing and the creation of new working tools of sowing machines that ensure the rational placement of sowing material is an urgent task.
3. Experimental research

A ploughshare for different depth sowing of seeds and fertilizers (Fig. 4) [18] was developed to provide the system indicators. The prototype was made in the common use center “Additive Technologies and Materials Processing” of Omsk State Agrarian University.

When the ploughshare is landed, points 1 (Fig. 4) cut the soil from both sides forming grooves into which mineral fertilizers are poured through fertilizer headers 3 and hollow headers. Since the headers are structurally installed at a drift angle α, the soil is shifted to the center of a ploughshare, and due to the fact that the headers are installed at the roll angle β, it is squeezed up. Loosened soil moves along lateral inner planes of the headers, then passes to racks and partially showers through the cutout with angle τ. The drop off soil incorporates mineral fertilizers, while the racks compress this soil with their lower edges forming a seed bed, onto which seeds of the cultivated crop are poured through seed headers 4 and hollow racks. The soil, when leaving the interstitial zone of a ploughshare, drops off and buries the sown grooves. The proposed ploughshare provides the uniform depth of seeding-down and meets agrotechnical requirements. At the same time, mineral fertilizers are embedded 30...40 mm below the horizon of the main crop.

As noted earlier, one of the main technological requirements is the optimal placement of seeds in the area. It is this indicator that depends on the design parameters of the ploughshare.

In order to identify the rational parameters of the ploughshare, let us determine the indicators of seed distribution uniformity.

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**Figure 3. Requirements for agricultural machinery**
The dependencies of seeds distribution along length and width of the planted groove on the structural parameters of a ploughshare are determined by the regression analysis. The previous studies revealed that three parameters in the ploughshares of this type affect the uniformity of seed distribution: drift angle $\alpha$, roll angle $\beta$ and cutout length of the lower edge of a rack $L$. Thus, a symmetric orthogonal composite design of the second order [19, 20] with three factors was chosen as a model: drift angle $\alpha$, roll angle $\beta$ and cutout length of the lower edge of a rack $L$.

The distribution of factors by their variation levels is given in Table 1.

| Table 1. Variation levels of factors |
|-------------------------------------|
| Factor                             | Drift angle $a$, deg. | Roll angle $\beta$, deg. | Cutout length $L$, mm |
|-------------------------------------|
| Coded identification               | $X_1$                | $X_2$                | $X_3$                |
| Base level $(X_{s0})$              | 15                   | 15                   | 50                   |
| Variability interval $(\Delta X_i)$| 10                   | 10                   | 25                   |
| Upper level $(x_i = +1)$           | 25                   | 25                   | 75                   |
| Lower level $(x_i = -1)$           | 5                    | 5                    | 25                   |
| Star point $+\alpha(x_i=2)$        | 2.85                 | 2.85                 | 80.375               |
| Star point $-\alpha(x_i=-2)$       | 27.15                | 27.15                | 19.625               |

During the implementation of the planned experiment the regression equations were obtained describing the process of changing the uniformity of seed distribution along the length and width of the planted furrow, which in coded and natural values have the following form:

- along the length of the planted furrow:
  \[
  Y = 0.843549 + 0.005419 \cdot X_1 + 0.009061 \cdot X_2 - 0.01405 \cdot X_3 + 0.004449 \cdot X_{12} - 0.00545 \cdot X_{13} - 0.00545 \cdot X_{23} + 0.00616 \cdot X_{11} - 0.06813 \cdot X_{22} - 0.06345 \cdot X_{33}
  \]
  (1)

- across the width of the planted furrow:
  \[
  Y = 0.403802 + 0.003072 \cdot \alpha + 0.023172 \cdot \beta + 0.011288 \cdot L - 0.000045 \cdot \alpha \cdot \beta - 0.000022 \cdot \alpha \cdot L - 0.000022 \cdot \beta \cdot L - 0.000064 \cdot \beta^2 - 0.000102 \cdot L^2
  \]
  (2)

- along the width of the planted furrow:
  \[
  Y = 0.749468 - 0.01619 \cdot X_1 - 0.00978 \cdot X_2 - 0.00715 \cdot X_3 - 0.0033 \cdot X_{12} - 0.02364 \cdot X_{13} - 0.02364 \cdot X_{23} - 0.0026 \cdot X_{11} - 0.06776 \cdot X_{22} - 0.03627 \cdot X_{33}
  \]
  (3)

- across the length of the planted furrow:
  \[
  Y = 0.329738 + 0.005096 \cdot \alpha + 0.023706 \cdot \beta + 0.008397 \cdot L - 0.000033 \cdot \alpha \cdot \beta - 0.000095 \cdot \alpha \cdot L - 0.000095 \cdot \beta \cdot L - 0.000027 \cdot \alpha \cdot L - 0.0000681 \cdot \beta \cdot L - 0.0000581 \cdot L^2
  \]
  (4)

Based on the regression equations, the response surfaces of the uniformity of seed distribution over the length and width of the planted furrow are constructed depending on the varying parameters.
Figure 5. Dependencies of seeds distribution uniformity on cutout length and roll angle, at drift angle: 
\[ a - \alpha = 5 \text{ deg}; \ b - \alpha = 15 \text{ deg}; \ c - \alpha = 25 \text{ deg}. \]

Figure 6. Dependencies of seeds distribution uniformity on cutout length and drift angle, at roll angle: 
\[ a - \beta = 5 \text{ deg}; \ b - \beta = 15 \text{ deg}; \ c - \beta = 25 \text{ deg}. \]
4. Conclusion
The analysis of presented dependencies makes it possible to conclude the following: the rational parameters of a ploughshare, which ensure the best distribution of seeds along the length of the planted furrow, are the drift angle $\alpha=25$ degrees, the roll angle $\beta=15$ degrees and the cutout length of the lower edge of a rack $L=50$ mm. Besides, the rational parameters at which the best distribution of seeds over the width of the planted furrow is achieved are the drift angle $\alpha=5$ degrees, the roll angle $\beta=15$ degrees and the cutout length of the lower edge of a rack $L=50$ mm. Moreover, it was found that the increase of the drift angle leads to a more even distribution of seeds along the length of the planted furrow, which reduces the uniformity across the width.

Thus, the following parameters are considered rational: drift angle $\alpha=15$ degrees; roll angle $\beta=15$ degrees; cutout length of the lower edge of a rack $L=50$ mm. With these values, the seed distribution uniformity was 85.5% along the length and 76.3% across the width of the planted furrow.

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