Investigation of the uniformity of seed distribution during sowing of winter wheat

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Abstract. One of the main indicators of high-quality sowing of seeds of agricultural crops is their uniform distribution along the length, because the main influence is exerted by the sowing apparatus. In the proposed work, the sowing of seeds of grain crops using a coil seeding machine is considered as an object of research. As a subject of research, the dependences of the uniformity of the distribution of seeds along the length of the furrow on the unevenness of the specific working volume of the coil, the rotation frequency of the blower of the pneumatic seeder and the seeding rate are considered. The aim of the work is to improve the uniformity of the distribution of the area of nutrition that falls on each plant with an ordinary method of sowing winter wheat. The paper presents the results of theoretical prerequisites for determining the working volume of the seeding coil, the results of field experiments of the seeding apparatus using coils with different geometric characteristics. The analysis of the uniformity of seed distribution using regression analysis and Bayesian networks is carried out. The resulting determination coefficient of 0.82 allows us to conclude that the resulting mathematical model can be used for practical purposes. It is noted that the proposed cellular-honeycomb seeding coil stands out qualitatively among the grooved and grooved-screw.

1 Introduction

For sowing seeds of grain crops, from the point of view of providing the area of nutrition and convenience of caring for plants, it is advantageous to use an ordinary method of sowing [1-2]. At the same time, one of the qualitative indicators of sowing is the distribution of seeds along the length of the row [3-6], contributing to ensuring equal conditions for the area of nutrition of each plant. Its influence is especially pronounced taking into account the need to sow a wide range of crops at different seeding rates [7-8]. This indicator is influenced by the design parameters and operating modes of the seeding device. The most common among all other seeding machines are coil ones, the main advantages of which are simplicity of design and reliability. However, the parameters and

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operating modes of such devices, which ensure a uniform distribution of seeds along the length of the furrow, have not been sufficiently studied. As a rule, in such devices, grooved seeding coils are used, having both a straight and a helical shape, the working volume of which is regulated by a flap, and not by adapting the shape of the coil to the seeding conditions, which does not improve the uniformity of seeding to the proper extent. In addition, conditions are currently being created for the increasing availability of the use of composite materials and 3D printers as means capable of producing a wide range of geometric shapes of the product using materials that ensure operation in various conditions and for sowing a wide variety of crops.

It is also worth noting that the gearboxes of seeders for the drive of coil devices are in most cases quite metal-intensive and their use contributes to an increase in labor intensity, with frequent changes in the seeding rate or crops being sown, especially in conditions of breeding plots [9-10]. Among the devices on the market, it is worth highlighting seeding devices with a stepper motor [11], the principle of operation of which is based on pulsed alternating voltage supply to the motor windings, which creates a reactive rotational force. And unlike collector motors, stepper motors are capable, without losing torque at low speeds, of turning at a given angle depending on the number of pulses applied to the windings. The pitch of such motors is measured in degrees by which the rotor rotates. This advantage significantly complicates the design and is not always economically justified. In addition, the phenomenon of resonance is inherent in a stepper motor [11]. The use of collector electric motors in seeders with an electronic control system has found application in APV sowing machines [12], which, on the one hand, allowed to get rid of the chain drive and gearbox used in classic grain seeders, on the other hand, the use of this type of electric motor does not entail a significant complication and increase in the cost of the design with comparable reliability. The digital control module, which helps to regulate the operating modes of the APV seeding machine, reduces the labor intensity when changing the sown crops and seeding rates with the required accuracy, which is provided by the stepless rotation mode of the seeding shaft.

Thus, the study of the geometric parameters of the actuators for seeding coils and the modes of operation of the seeding apparatus using electric seeders and an electronic control system, where the dependences of the uniformity of seed distribution along the furrow length on the design parameters of the elements of the seeding apparatus of the seeder and the sowing modes of winter wheat seeds are considered as the subject of research, is relevant. The aim of the work is to improve the uniformity of the distribution of the area of nutrition that falls on each plant with an ordinary method of sowing winter wheat.

2 Materials and methods

The authors have developed a cellular-honeycomb (the type of cells resembles the shape of a honeycomb) sowing coil (Figure 1, y), which differs from a grooved (the standard most common shape of the working surface) and a grooved-screw (the profile of the working surface has a grooved shape directed along a helical trajectory along the cylindrical surface of the coil) (Figure 1, v) the fact that the coil consists of three segments offset by an angle dividing the angle \( \alpha \) into three equal parts, the thickness of the teeth, the number of cells or grooves (12 in the groove and groove-screw, 14 in the cellular-honeycomb). The working (useful) volume of the coil was determined by the following formula:

\[
V_r = N \cdot v,
\]

where \( N \) is the number of seeds that got into the soil for 1 revolution of the coil without taking into account the properties of seeds and their interaction with the medium, pcs.; \( v \) is the average volume of the grain, \( \text{mm}^3 \).
\[N_{co} = \frac{N_c}{k_z \cdot n_m}\]

\[N_c = \frac{Q \cdot A}{m_c \cdot n_r}\]

\[n_m = \frac{n_o}{V_{dv}}\]

\[\nu_r = \frac{V_{dv} \cdot v \cdot N_p}{n_o \cdot k_z \cdot m_c}\]

where:

- \(N_{co}\) is the specified number of seeds per linear meter of one coulter, pcs;
- \(N_c\) is the number of seeds in the coil, pcs;
- \(k_z\) is the filling coefficient of the coil, taking into account the filling capacity of the seed volume, fluidity, the influence of the brushes of the sowing apparatus that prevent the free flow of seeds;
- \(n_m\) is the number of revolutions of the coil per linear meter, 1/m;
- \(Q\) is the seeding rate, kg/ha;
- \(A\) – the width of the seeding machine, m;
- \(m_c\) – weight of one seed, kg;
- \(n_o\) is the optimal rotation speed of the seed shaft, rpm;
- \(V_{dv}\) – the speed of the drill, km/h;

Hence the working volume of the coil is determined by the formula:

\[v_r = \nu_r \cdot k_z \cdot m_c \cdot n_o \cdot l_d\]

The resulting formula can be used at the initial stage of designing the coils of sowing machines that do not create an active layer of seeds in the rotation zone [13]. It is necessary to set the basic parameters, such as the range of seeding rates, the optimal range of rotation speed of the seed shaft at the recommended speed of the drill, the above-mentioned properties of seeds.

The experiment was planned according to the standard statistical Box-Benken plan 3\(^3\), which involves 15 experiments, 3 independent factors with three ranges of variation and an optimization parameter – the unevenness of sowing, \(Y\), expressed in terms of the coefficient of variation in the distribution of seed seedlings. The unevenness of the specific working volume of the coil was found as the working (useful) volume of the coil falling on a window formed by two straight lines drawn at an angle \(\alpha\), tangent to the circle, with a diameter \(d\) equal to the average diameter of a grain of the “Krasa Dona” variety. CAD Compass 3D was used, measuring the specific working volume of the coil with a step equal to the angle \(\Delta\) by subtracting from the volume of a hollow cylinder the volume of a cylinder made in the form of a boss with a specified window (a hole in the form of a split pie) placed virtually in the body of the simulated coil. In this way, the influence of the geometric features of the coils during simulated rotation was investigated. Statistical indicators were obtained, one of which (coefficient of variation) was used as an independent factor \(X_1\), % (Table 1). The second and third independent factors were the frequency of rotation of the blower, expressed as a percentage of the maximum speed of rotation of the blower of the APV-120 pneumatic seeding machine, contributing to the movement of seeds through the seed duct \(X_2\), %, and the seeding rate \(X_3\), k/ha.
Analyzing the resulting scan of the three coils being compared (Figure 2), it can be concluded that the studied specific working volume of the coil, depicted as an area $V$, has obvious differences in the grooved coil $k$, smaller differences in the screw $v$ and practically no differences in the cellular-cellular coil $y$.

Preliminary studies have shown that with the width of the coils of the three studied forms equal to 26 mm at a shaft rotation speed in the range of 20-80% of the maximum, the seeding rate range was 75-225 kg/ha.

Table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Code designation, $X_i$</th>
<th>Variation intervals</th>
<th>Natural factor levels corresponding to the encodings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unevenness of the specific working volume of the coil, %</td>
<td>$X_{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of rotation of the coil</td>
<td>$X_{+1}$</td>
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On the basis of the experimental field of the FSBSI “Donskoy Agrarian Research Center” (Zernogradsky district of the Rostov region), field studies of the uniformity of seed distribution along the length of the row were conducted. The sowing was carried out by a Donskaya seeder, developed jointly with the Don State Technical University (Rostov-on-Don). The seeder is equipped with an APV PS-120 seeding machine, in which it is possible to replace the seeding shaft in the field with a shaft containing the necessary seeding coils (Figure 3). Before sowing, the required parameters (seeding rate, kg/ha, capture width, m, average speed, km/h, shaft rotation speed, %) were entered into the control unit of the seeder located in the tractor cab, after which a test seeding was carried out, blocking the seed ducts with an appropriate flap. The time of the test was indicated, after which the resulting mass of seeds was weighed, checking it with the required indicator. In case of a discrepancy with the desired value, the test was repeated, and the control unit at the same time contributed to the correction of the rotation speed of the sowing shaft in a smaller or larger direction. After that, winter wheat seeds were poured into a 120-liter hopper and sown. Depending on the speed of movement, the control unit adjusts the rotation speed of the seed shaft. The speed is determined by the speed sensor interacting with the support wheel of the seeder. When the seeder stops, the rotation of the seed shaft stops. As the grain ends in the hopper, or the seeder is lifted into the transport position, the grain supply stops due to the appropriate sensors installed on the seeder.

Fig. 3. Mounted seeder “Donskaya”
As a hypothesis, it was assumed that the coefficient of variation characterizing the uniformity of the distribution of seeds along the length of the row would depend on the type of coil used, the rotation frequency of the blower of the pneumatic seeding device and the seeding rate. The winter wheat variety “Krasa Dona” was used as a seed material. The plan of the Box-Banken experiment, consisting of 15 variations of three factors, was taken based on the least labor intensity of the process, the use of the optimal acreage of plots.

Among the common methods of data analysis such as regression, variance, in modern machine learning conditions, more and more often resort to the use of Bayesian networks — an acyclic oriented graph, relevant with frequent additions of certain factors and their numerical values, the possibility of calculating the optimal values of the factors of interest when fixing the target range of the output factor [15]. The significance of the factors and their relationship in the mentioned method of analysis is formulated in the form of probability, and the Bayesian network is based on Bayes' theorem [16]:

\[ P(A|B) = \frac{P(B|A)P(A)}{P(B)} \]

where \( | \) is the designation of conditional probabilities; \( P \) is the probability; \( A \) and \( B \) are events; \( P(A) \) and \( P(B) \) are probabilities of events \( A \) and \( B \) that are independent and do not affect each other; \( P(A|B) \) is the conditional probability of the truth of event \( A \) under the condition of the truth of event \( B \); \( P(B|A) \) is the conditional probability of the truth of event \( B \) under the condition of the truth of event \( A \).

The presented theoretical research methods served as the basis for creating the shape of the developed coil, and the described methodological steps became the basis for optimizing the parameters affecting the uniformity of seed distribution.

3 Results and Discussion

After the initial processing, it turned out that the values of the coefficient of variation, which characterizes the unevenness of sowing and is an optimization parameter, obey the law of normal distribution [17]. Accordingly, according to the data obtained, it is permissible to conduct a regression analysis. We built two models, one of which is linear, the other is nonlinear. The adequacy of the model was tested according to the Fisher criterion for a 5% significance level. We carried out the rejection of insignificant factors according to the Student's criterion and obtained a response surface characterizing the dependence of the smallest unevenness of sowing \( Y \), % on the unevenness of the specific...
The regression equations are obtained in the form:

\[ Y = 84.6 + 4X_1 - 0.2X_3; \]
\[ Y = 143 + 0.7X_1^2 - 1.05X_3 + 0.003X_3^2. \]

Fig. 5. The dependence of the smallest unevenness of sowing (Y), % of the unevenness of the specific working volume of the coil (X_1), % and the seeding rate (X_3), kg/ha.

The coefficient of determination was \( R^2 = 0.61 \) and 0.82. According to the obtained determination coefficients, it can be concluded that both models can be used in practice. The result will be 61 and 82% accuracy of calculations. An extremum with a pronounced center of dependence of the most significant factors is clearly represented on the response surface. According to the obtained surface, the most pronounced range of seeding rates, contributing to the best uniformity of seed distribution along the row, is the range of 160-225 kg/ha. However, for a more practical use of the data obtained, due to the fact that they can be supplemented with updated values or new data, such as yield, a Bayesian network was built, where only the most significant factors were displayed, using the same experimental plan with the results as in regression analysis (Figure 6).

Fig. 6. Bayesian network that characterizes the unevenness of sowing.
4 Conclusion

The improvement of the uniformity of the distribution of seeds along the length is facilitated by the adaptation of the parameters of the sowing apparatus to the required working conditions. If sowing of a wide range of crops and seeding rates is required, then the right choice of coils comes out in the first place, the significance of the geometric features of which have been confirmed by the conducted studies. In particular, we have obtained results indicating that the use of cellular-coil is most preferable when sowing winter wheat. The most significant factors were the unevenness of the specific working volume of the coil and the seeding rate. The obtained coefficient of determination of the regression equation 0.82 indicates the applicability of the obtained model in practice.

The use of Bayesian networks made it possible to analyze the probability of using one or another coil at a given seeding rate. So, with a seeding rate of 75–150 kg/ha, the most preferred coil with a probability of 80% turned out to be a cellular-coil.

References


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