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New seeding units for sowing winter wheat

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Abstract. One of the main parameters of high-quality sowing of agricultural seeds is their uniform distribution along the length, which is mainly influenced by the sowing unit. In the present work, the sowing of seeds of grain crops using a coil seeding unit is considered as an object of research. As a subject of research, the dependences of the uniformity of seed distribution along the length of the furrow on the non-uniformity 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 unit 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 concluding that the resulting mathematical model can be used for practical purposes. It is noted that the proposed cellular seeding coil stands out qualitatively among the grooved and grooved-screw coils. Its use with a probability of 80%, according to the constructed Bayesian network, at low seeding rates of 75-150 kg / ha contributes to ensuring the best indexes for the uniformity of sowing of winter wheat.

1 Introduction

For sowing seeds of grain crops, from the point of view of providing an area of nutrition and convenience of caring for plants, it is advantageous to use an ordinary method of sowing [14]. At the same time, one of the qualitative parameters of sowing is the distribution of seeds along the length of the row [19, 1, 15, 16], 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 [20]. This parameter is influenced by the design parameters and operating modes of the seeding device. The most common among all other seeding units are coil ones, the main

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advantages of which are simplicity of design and reliability. However, the parameters and 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 screw 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, at present, conditions are 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 [11,18]. Among the devices on the market, it is worth highlighting seeding devices with a stepper motor [9], 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 [9]. The use of collector electric motors in seeders with an electronic control system has found application in APV sowing units [10], which on the one hand made it possible 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 unit, 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 unit using electric seeders and an electronic control system, where the dependences of the uniformity of the distribution of seeds along the furrow length on the design parameters of the elements of the seeding unit of the seeder and the sowing modes of winter wheat seeds are considered as the subject of research. 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

We have developed a cellular (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 α into three equal parts, the thickness of the cogs, the number of cells or grooves (12 in the groove and groove-screw, 14 in cellular).The working (useful) volume of the coil was determined by the following formula:

$$V_r = N_{\text{co}} \cdot v, \quad (1)$$

where N_{co} – 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 environment, pcs;
v – the average grain volume, m^3.

$$N_{co} = \frac{N_c}{k_z \cdot n_m}, \quad (2)$$

where N_c – the specified number of seeds per running meter of one coulter, pcs;
k_z – the filling factor of the coil, taking into account the filling capacity of the seed volume, fluidity, the influence of the brushes of the sowing unit, preventing the free flow of seeds;
n_m – the number of revolutions of the coil per running meter, 1 / m.

$$N_c = \frac{Q \cdot A}{m_c \cdot n_r}, \quad (3)$$

where Q – the seeding rate, kg/ha;
A – the width of the seeding unit, m;
m_c – the weight of one seed, kg;
n_r – number of rows of the seeder, pcs.

$$n_m = \frac{n_o}{V_{dv}}, \quad (4)$$

where n_o – the optimal rotation speed of the seed shaft, rpm;
V_{dv} – the speed of the seeder, km/h.
Hence the working volume of the coil is determined by the formula:

$$v_r = \frac{V_{dv} \cdot v \cdot N_p}{n_o \cdot k_z \cdot m_c}. \quad (5)$$

The resulting formula can be used at the initial stage of designing the coils of seeding units that do not create an active layer [7, 3] of seeds in the rotation zone. 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 seeder, the above-mentioned properties of seeds.

The experiment was planned according to the standard statistical Box-Banken plan 33, which involves 15 experiments, 3 independent factors with three ranges of variation and an optimization parameter – the non-uniformity of sowing Y, expressed in terms of the coefficient of variation in the distribution of seedlings. The uniformity 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 α, 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 Δ by subtracting the volume from the hollow volume of the 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 parameters 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 unit, contributing to the movement of seeds through the seed duct X_2%, and the seeding rate X_3, k/ha.

To construct the scan (Figure), we used the circumference of the groove (cell), circumference length equal to the difference between the beginning of the coil turn and the end (in the case of a grooved-helical coil), the radius of the groove Rg and the angle between the beginning of the coil turn and the end (in the case of a helical coil β).

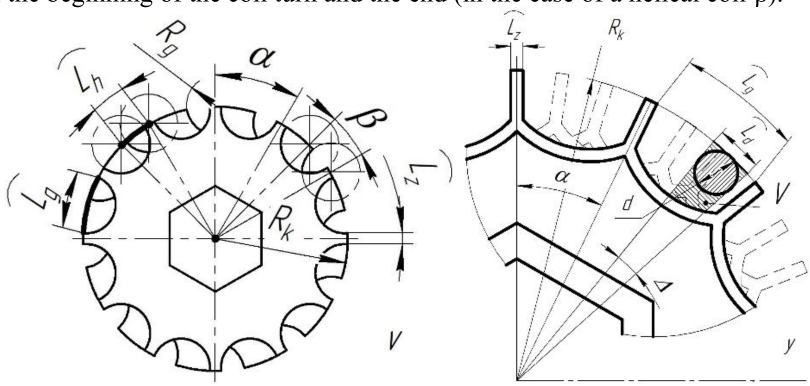

Fig. 1. Seeding coils. v – grooved-helical; y – cellular

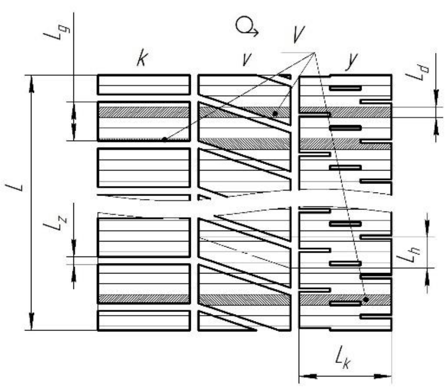

Fig. 2. Unfolding coils. k – grooved (classical); v – grooved-helical; y – cellular

Analyzing the resulting scan of the three coils being compared, 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 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. Factors and variation intervals

Factors	Code designation, X_i	Variation intervals	Natural factor levels corresponding to encodings		
			-1	0	+1
Irregularity of the specific working volume of the coil, %	X_1	–	0,9	4,5	5,7
Blower rotation speed, %	X_2	30	30	60	90
Height norm kg/ha	X_3	75	75	150	225

On the basis of the experimental field of the Donskoy Agrarian Research Center (Zernogradsky district, Rostov region), field studies of the uniformity of seed distribution along the length of the row were conducted. The sowing was carried out by the Donskaya seeder, developed jointly with Don State Technological University (Rostov-on-Don). The seeder is equipped with an APV PS-120 seeding unit, 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 the appropriate flap. The time of the test was indicated, after which the resulting mass of seeds was weighed, checking it with the required parameter. 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 well. 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"

After the emergence of seedlings, a study of the uniformity of sowing was carried out. Mesh strips divided into equal cells with sides of 50 mm each were used as measuring instruments [13, 4]. Preliminary studies have shown that large gaps in seedlings are observed on average after an interval of 1 m, and therefore measurements were carried out at an interval of 1.5 m to get the gap into the specified range (Figure 4). The amount of grain in each cell was calculated, the standard deviation, the average value and the coefficient of variation were found.

Fig. 4. Distribution of seedlings inside the measuring mesh strip

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-Benken 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 unit learning conditions, increasingly 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 [6, 8, 12]. 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 the Bayes' theorem [17]:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}; \quad (6)$$

where: | - the designation of conditional probabilities;
P – probability;
A and B – events; P(A) and P(B) – probabilities of events A and B, independent and not influencing each other;
P(A|B) – the conditional probability of the truth of event A under the condition of the truth of event B;
P(B|A) – 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

After the initial processing, it turned out that the values of the coefficient of variation, which characterizes the irregularity of sowing and is an optimization parameter, obey the law of normal distribution [5, 2]. 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 non-uniformity of sowing Y, % on the non-uniformity of the specific working volume of the coil X_1, % and the seeding rate X_3, kg/ha (Figure 5). The regression equations are obtained in the form:

$$Y = 84{,}6 + 4X_1 - 0{,}2X_3; \quad (7)$$

$$Y = 143 + 0,7X_1^2 - 1,05X_3 + 0,003X_3^2. \quad (8)$$

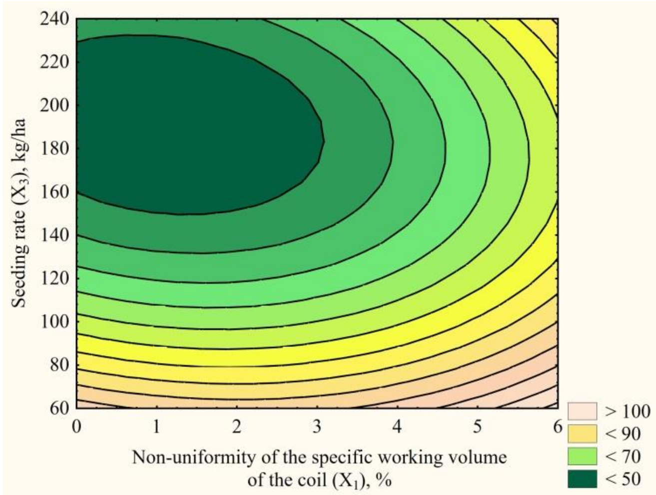

Fig. 5. The dependence of the smallest non-uniformity of sowing (Y), % of the non-uniformity of the specific working volume of the coil (X_1), % and the seeding rate (X_3), kg/ha

The coefficient of determination was R2 = 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, the 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).

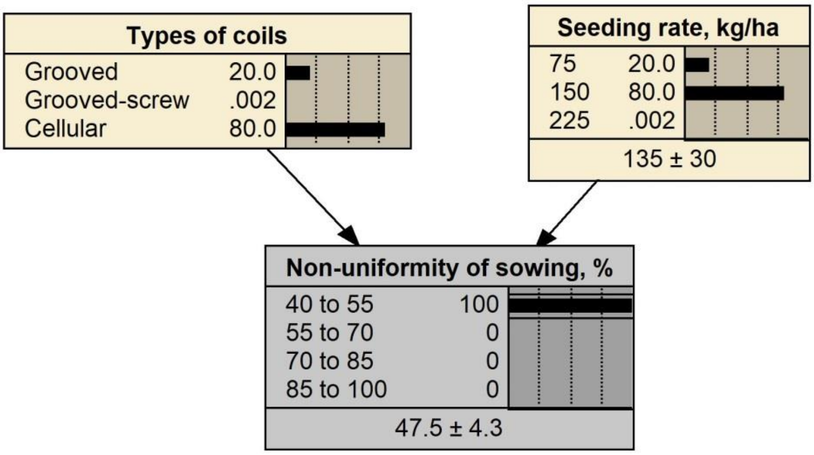

Fig. 6. Bayesian network that characterizes the non-uniformity of sowing.

As we can see in the figure above, when fixing the target range of the optimization parameter in the range of 40-55% (the minimum value of the coefficient of variation was

39%), the probabilistic values of the factors are displayed, when choosing which the desired result will be provided. At the same time, the values of factor X1 used in our study are displayed in nominal form. Thus, not only a mathematical model was obtained, which resulted in quantitative values of independent factors, but also a probabilistic model predicting the probability of intervals of independent factors for a given range of optimization parameters.

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 unit to the required working conditions. If sowing of a wide range of crops is required, the seeding rate, then the right choice of coils comes out in the first place, the significance of the geometric features of which has been confirmed by the conducted studies. In particular, we have obtained results indicating that the use of cellular coils is most preferable when sowing winter wheat. The most significant factors were the irregularity 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.

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