Analysis of the process of pneumatic conveying of seeds through the seed drill tube

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Abstract. This paper presents the methodology and results of experimental studies of the dependence of the flight distance of seeds in the sub-coulter space on the speed of airflow, provides a comparative analysis of theoretical and experimental studies. The experiment results in determination of mathematical expectation of seed flight distance, mean square deviation, coefficient of variation, absolute and relative errors. The resulting function is linear in nature and shows a directly proportional relationship of factors. For the quantitative evaluation of compliance of theoretical and experimental studies, the authors chose the following criteria: correlation coefficient \( r \), Fisher criterion \( F \) and Student coefficient \( t \). Calculations results in the following values: \( r = 0.535 \); \( t_p = 1.031 \); \( F_p = 3.493 \). Comparative analysis of theoretical and experimental studies shows that dependencies have an average force relationship (\( r = 0.535 \)), the difference between them is not significant (\( t_P > t_p \) ), and the proposed model is adequate (\( F_P > F_p \)).

1. Introduction

It is known that highly productive seeding has an optimal stem density, high leveling, good development of all plants, morphological structure of the tillering node, which depends to a greater extent on the level of agricultural machinery at the initial stages of seeding, in particular, the placement of seeds in the depth and area of nutrition. These requirements determine the leading role of the seeding operation in forming high-yield grain crops. Generally, it is the shortcomings of the seeding operation affecting the most responsible initial stages of plant development, become an obstacle to the growth of grain yields even in the conditions of intensifying production. Consequently, it is possible to increase grain yield by improving crop production technologies, in particular, seeding operation [1].

The analysis of previous studies shows that the reserve to increase the productivity of cultivated grain crops is the use of subsurface broadcast (rowless) seeding. This method satisfies to the greatest extent agrotechnical requirements to placement of seeds in the soil. The advantage of this method over others is that the uniform distribution of plants in the field area provides equal lighting, nutrition and moisture. This seeding method almost completely eliminates competitive intraspecific struggle, which provides a more complete realization of the biological potential of cultivated plants. Also, if the same conditions are met at subsurface broadcast seeding, seedlings of grain crops appear more amicably and for one - two days earlier than the seedlings of ordinary crops, plant tillering is more powerful, the
number of weeds and the weight of their green mass is much less. In addition, the uniform distribution of plants on the area is one of the most important agrotechnical methods to control wind and water erosion in their action zone [2].

The most common working body for subsurface broadcast seeding is the lancet leg. To ensure the distribution of seeds in the sub-coulter space over the entire working width of the seed distributor, it is necessary that the seeds have sufficient speed when they come off the distributor. In this case, the change in the flight distance of the seed is achieved by changing the seed speed when leaving the distributor.

Currently, it is widely used seeding machines that use the kinetic energy of the airflow to transport the seeds to the coulters. In this case, the seeds acquire high speeds, which increases the range of seed rejection in the sub-coulter space.

The task is to obtain an even placement of seeds in the sub-coulter space using the kinetic energy of the flow. To solve the problem it is necessary to determine the main dependencies of kinetic energy transfer from the airflow to the seeds in the seed drill tube of the seeding machine and to determine the necessary directions of seeds movement under the conditions of energy transfer.

2. Methods and results of experimental research

One way to regulate the speed of the seed is to use the energy of airflow when pneumatically conveying the seed from the dispenser to the bottom of the furrow. Therefore, to obtain a guaranteed distribution of crop seeds across the entire working width of the tine, it is necessary to establish the dependence of the flight distance of the seeds in the sub-coulter on the speed of airflow.

During pneumatic conveying, seeds pass through a number of sections of the seed drill tube and distributor, where each section changes the value of their speed and movement direction.

Previous studies [3] have shown a theoretical dependence of the flight distance of seeds in the sub-coulter space on the airflow speed.

\[ l_m = 0.209 + 9 \cdot 10^{-4} u, \]  

where \( l_m \) is the flight distance of seeds determined theoretically, m;

\( u \) is airflow speed, m/s.

This dependence shows that increasing the speed of airflow increases the range of the seed.

In theoretical studies, we determined the flight distance of the seed ignoring the complexity of the shape of the seed and its position in space at the moment of leaving the distributor. Therefore, it was necessary to clarify the influence of airflow speed in the seed drill tube on the speed and flight distance of the seeds. For this purpose, we conducted a one-factor experiment [4].

In most agricultural production conditions, the value of confidence probability ranges from \( \alpha = 0.8 \) up to \( \alpha = 0.95 \), in most cases, and the value of relative error ranges from 10 to 25% [5].

The number of experimental repetitions shall follow the adopted distribution law. So, under the law of normal distribution

\[ \frac{\varepsilon_a}{\nu} = t_a \sqrt{\frac{N}{N}} \]  

where \( \nu \) is the coefficient of variation;

\( \varepsilon_a \) is relative error;

\( t_a \) is table coefficient;

\( N \) is repetition of experiments.

Based on these recommendations we accept \( \varepsilon_a = 10\% \) at \( \alpha = 0.95 \). We accept the coefficient of variation for the law of normal distribution equal to 0.3. Then, using formula (2) and table data [5], we find that the number of experience repetitions should be more than 42. We accept the number of repetitions of the experiment equal to 100.
We conducted experimental studies on a universal stand with a "soil channel" [3]. The pneumatic conveying system of the stationary laboratory unit received winter wheat seeds one by one and transported them by airflow to the distributor. After leaving the distributor, the seeds flew away from it for some distance. Changing the speed of airflow produced a change in the flight distance of seeds. Sheets of dense paper coated with solidol allowed to avoid rolling the seeds after landing. We measured the distance from the distributor to the seed with a ruler. Removing a lancet paw from the laboratory unit helped to eliminate the impact on the trajectory and range of the seeds. Airflow speed in the pneumatic conveying system varied from 2.5 to 6.5 m/s at 1 m/s intervals.

After measuring the distance for all seeds, we used well-known methods [5] to determine the average flight distance at a given airflow speed, standard deviation, coefficient of variation, as well as absolute and relative errors of the mean values. In this case, we checked the information on the reliability of the rule $3\sigma$, on the drop-down points on the criterion of Irwin, and then carried out verification of compliance with the law distribution of experimental value on the criterion of Kolmogorov.

Average value of measured value (mathematical expectation)

\[ M = \frac{1}{N} \sum_{i=1}^{N} x_i, \text{ PCs.} \]  

(3)

Mean square deviation of the measured value

\[ \sigma = \sqrt{\frac{\sum (x_i - M)^2}{N}}. \]  

(4)

Coefficient of variation

\[ V = \frac{\sigma}{M} \cdot 100, \%. \]  

(5)

Absolute error of the average value

\[ m_0 = \frac{\sigma}{\sqrt{N}}. \]  

(6)

The relative error of the experience

\[ \alpha_0 = \frac{m_0}{M} \cdot 100, \%. \]  

(7)

Table 1 shows the results of determining the values of these parameters.

**Table 1.** Some variability indicators of speed impact analysis airflow to the distance of seed rejection;

| Airflow speed $u$, m/s | Mathematical expectation of the flight distance $M$, m | Mean square deviation $\sigma$, m | Coefficient of variation $v$, % | Absolute error $m_0$, m | Relative error $\alpha_0$, % |
|------------------------|---------------------------------------------------|---------------------------------|-------------------------------|-------------------------|--------------------------|
| 2.5                    | 0.2027                                            | 0.055                           | 32.6                          | 0.0055                  | 3.26                     |
| 3.5                    | 0.2042                                            | 0.059                           | 34.3                          | 0.0059                  | 3.43                     |
| 4.5                    | 0.2044                                            | 0.062                           | 35.6                          | 0.0062                  | 3.56                     |
| 5.5                    | 0.2057                                            | 0.065                           | 37.1                          | 0.0065                  | 3.71                     |
| 6.5                    | 0.2097                                            | 0.07                            | 39.5                          | 0.007                   | 3.95                     |
Based on the results of the experiment, we have constructed a graphic dependence of the flight distance of the seed on the airflow speed, which is shown in Figure 1.

![Figure 1](image1.png)

1 – approximated dependence; 2 – experimental dependence

Figure 1. Dependence of the seed's flight distance on the airflow speed

By approximating the dependence presented in Figure 1, we obtain the equation

$$l_s = 0.167 + 25 \cdot 10^{-4} u$$

(8)

where $l_s$ is the flight distance of seeds obtained experimentally, m;

$u$ is airflow speed, m/s.

The obtained experimental dependence shows that the flight distance of the seed in the sub-coulter space increases in proportion to increasing airflow speed. Next, it is necessary to check this dependence for the adequacy of the theoretical one.

3. Comparative analysis of theoretical and experimental studies

We determined the correctness of the mathematical model by comparing the results of the influence of airflow speed in the seed drill tube on the flight distance of seeds received experimentally with the results of theoretical studies.

![Figure 2](image2.png)

1 – theoretical dependence; 2 – experimental dependence

Figure 2. Graph of the dependence of the flight speed of the seed on the airflow speed.

Figure 2 shows graphs of the dependence of the seed's flight distance on the airflow speed obtained theoretically and experimentally. Comparison of these graphs shows that the nature of the processes is almost the same. This indicates the correctness of the adopted mathematical model.
To quantitatively assess the compliance of theoretical and experimental research as indicators used for determining the appropriateness of the assumed admissions in the development of a mathematical model, we chose the following criteria: correlation coefficient $r$, Fisher criterion $F$ and Student coefficient $t$, determined by the following formulas:

The correlation coefficient $r$ [4]

$$r_{yt} = \frac{\delta_{yt}}{\delta_{yt}} , \text{ at } \delta_{yt} \leq \delta_{yt}, \quad (9)$$

where $\delta_{yt}$ is the mean square deviation of the variable calculated theoretically on a mathematical model;

$\delta_{yt}$ is the mean square deviation of a variable value obtained experimentally.

$$\delta_{yt} = \sqrt{\frac{\sum y_{T}^2}{n}} - \bar{y}_T^2 ; \delta_{yt} = \sqrt{\frac{\sum y_{E}^2}{n}} - \bar{y}_E^2 , \quad (10)$$

where $y_T$, $y_E$ are respectively theoretical and experimental values of the variable;

$\bar{y}_T$, $\bar{y}_E$ are the theoretical and experimental values of the mathematical expectations of the variable, respectively.

The correlation coefficient estimates the closeness of the relationship between theoretical and experimental values of a variable. The strength of relationship is estimated according to Table 2 [6, 7].

| Value of the correlation coefficient $r$ | Strength of the relationship |
|----------------------------------------|-------------------------------|
| it is close to zero                    | it is absent                  |
| it is up to 0.5                        | it is poorly expressed        |
| It is from 0.5 to 0.8                   | it is of medium strength      |
| it is more 0.8                         | it is strength                |
| it is close to $\pm 1$                 | it is close to functional     |

Student coefficient $t$ [4]

$$t = \frac{\bar{y}_T}{\bar{y}_E} , \text{ at } \bar{y}_T \geq \bar{y}_E . \quad (11)$$

Comparing the coefficient $t$ obtained by calculation with the tabular value $t_T$, we determine the significance or not of the difference between theoretical and experimental data (at $t_p < t_T$ the difference is not significant and the model is accepted).

Fisher Criterion $F$

$$F = \frac{D_{yt}}{D_{yt}} , \text{ at } D_{yt} \geq D_{yt} . \quad (12)$$

The Fisher criterion shows the adequacy of the model to experimental data. If the calculated value of $F_p$ is less than the table value of $F_T$ ($F_p < F_T$), the model is considered adequate to the experimental data and is accepted as correctly describing the process [4].

We defined the Fisher Criterion for the number of degrees of freedom - 5 (number of points or measurements) for theoretical and experimental data at 5% significance level.

Table 3 shows the results of the comparative analysis.
Table 3. Analysis indicators of the adequacy of dependency

|      | $M$   | $\sigma$ | $D$       | $r$      | $t_p$ ($t_p=2.78$) | $F_p$ ($F_p=6.4$) |
|------|-------|----------|-----------|----------|--------------------|-------------------|
| $l_m$| 0.2117| 0.0014   | $2.025 \times 10^{-6}$ | 0.535    | 1.031              | 3.493             |
| $l_p$| 0.2053| 0.0027   | $7.073 \times 10^{-6}$ |         |                    |                   |

The analysis of the values of the considered parameters shows that theoretical and experimental dependencies have an average force ($r=0.535$) relation, the difference between them is not significant ($t_p > t_p$), and the proposed model is adequate ($F_p > F_p$).

4. Conclusion

The use of subsurface broadcast (rowless) seeding allows increasing the productivity of cultivated grain crops due to a more uniform placement of seeds in the field area. The seeding machines that use the kinetic energy of the airflow to transport the seeds by the seed tubes from the dispenser to the bottom of the furrow, allows obtaining the necessary speed of the seed movement when leaving the distributor and the required flight distance in the sub-coulter space, which leads to the placement of seeds across the full width of the work tool.

The experiment on revealing the dependence of the seed's flight distance in sub-coulter space on the airflow speed has resulted in determining the mathematical expectation of flight distance, the mean square deviation, coefficient of variation, absolute and relative errors. The resulting dependence, represented by equation (8), is linear in nature and shows a directly proportional relationship of factors. To quantitatively assess the compliance of theoretical and experimental studies, we chose the following criteria: correlation coefficient $r$, Fisher criterion $F$ and Student coefficient $t$. Calculations resulted in the following values: $r=0.535$; $t_p=1.031$; $F_p=3.493$. Comparative analysis of theoretical and experimental studies showed that dependencies have an average force relationship ($r=0.535$), the difference between them is not significant ($t_p > t_p$), and the proposed model is adequate ($F_p > F_p$).

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