Mathematical modeling of seed dissemination with a colter drill across the planting acreage

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Abstract. The article is devoted to the development of a mathematical model of seed dissemination process with a colter drill equipped with a discharge channel across the feeding area. This mathematical model makes it possible to determine the optimal technological and constructive parameters of the colter drill of the planter.

1. Introduction

Regularly spaced seed dissemination across the feeding area is one of the important conditions for high-quality grain sowing [1]. The evidence from practice shows that modern seeding machines do not fully meet the requirements for regularly spaced seed dissemination across the feeding area, which ultimately affects the yield of the crop [2]. A colter drill with a discharge channel, see figure 1, capable of eliminating the above-mentioned drawbacks has been developed to solve this problem [3].

Figure 1. The work scheme of a colter drill with a discharge channel: L – the length of the subdrill space; C-the width of the subdrill space; r – the radius of the drill seed tube; R – the radius of the bend of the drill seed tube; ϕ – the angle of the bend of the drill seed tube.
2. Model
To determine the rational constructive and technological parameters of the colter drill, it is necessary to develop a mathematical model that will reveal the correlation between the uniformity of seed material distribution and the constructive and technological parameters of the colter drill [4].

Since the seeds are randomly released, the density of dissemination can be calculated using the Poisson formula [5]:

\[ P(t) = ae^{-at}. \]  

where \( a \) is the frequency of seed release.

The mathematical expectation of one seed's release time is equal to:

\[ \int_0^{\infty} t P(t)dt = \int_0^{\infty} t ae^{-at} dt = \frac{1}{a} \]  

To ensure the desired average seeding rate (\( \lambda = 500 \) PCs/m²), select the parameter value from the following ratio:

\[ a = 2 \cdot B \cdot \lambda \cdot V, \]  

where 2\( B \) – the width of the furrow opener;
\( V \) – the speed of the colter planter;
\( \lambda \) – seeding rate.

In this case

\[ a = 0.07 \cdot 500 \cdot 2.5 \approx 87.5 \text{ seed/sec}. \]

To generate the point of initial location of the grain when it hits the drill seed tube and its initial speed, it was decided to use the built-in function of generating random values of the Visual Basic translator.

The following ratio was taken for the initial speed:

\[ (V_x, V_y, V_z) = (V_x^0, V_y^0, V_z^0) + (E_x, E_y, E_z), \]

where \( E = (E_x, E_y, E_z) \) – a random vector distributed according to the normal law with a probability density.

\( (V_x^0, V_y^0, V_z^0) \) – some vector determined by the design of the drill seed tube.

Since the mathematical expectation of a random vector \( E \) is equal to the zero vector, \( \bar{V} \) is the most likely seed release speed.

To generate a seed throw point inside the drill seed tube's rack, the following ratio was taken:

\[ \bar{Q} = (Q_x, Q_y, Q_z) + (E_x, E_y, E_z), \]

where \( \bar{Q} \) (0, 0, \( E_z \)) – the point where the seed is most likely to appear;

\( E = (E_x, E_y, E_z) \) – a random vector distributed according to the normal law, with the \( E_z \) coordinate determined by the velocity of the air flow.

\[ -\frac{d}{2} \leq E_x \leq \frac{d}{2}, \]

\[ -\frac{d^2}{4} - \frac{E_x^2}{4} \leq E_y \leq \frac{d^2}{4} - \frac{E_x^2}{4}, \]
0 ≤ E_z ≤ p ⋅ V_z \), \tag{8}

where \( p = \frac{1}{\alpha} \) – density of grain flow.

That is, the coordinates of the grain are formed within the section of the drill seed tube up to the colter drill rack.

The seed flow is formed taking into account the flow density according to the step scheme using the formula:

\[ E_z^i = i \cdot p \cdot V_z + E_z \] \tag{9}

The analyzed connections and dependences of the seed movement make it possible to identify the general flight pattern of the seeds presented in figure 2 in the "drill seed tube-reflector-soil" system after colliding with each other, with the walls of the drill seed tube, with the surface of the reflector, with the soil and to identify their location coordinates in the area of the soil.

According to the above method, it is possible to write a program in Visual Basic for a computer of the JBMPC type. Using this program, calculations were performed to determine the optimal parameters of the discharge channel and the reflector of the colter drill.

Simulating the process of seed dissemination across the feeding area, we obtain the coordinates of the landing places of grain seeds [1]. After analysis and statistical processing of these data, it is possible to assess the quality of seed dissemination across the feeding area [6].

For more convenient calculations the following values were accepted as constant for all variants: seeding rate \( N_e = 5 \text{mln. per 1 ha or (} \lambda = 500 \text{ PCs. / m2)} \), the speed of the colter drill \( V = 2.5 \text{ m/s)} \), the average speed of the seed material in the drill seed tube \( V_c = 20 \text{ m/s)} \), the width of the colter nozzle \( b = 70 \text{ mm)} \), the bending angle of the drill seed tube \( \varphi = 45^\circ \), the internal size of the drill seed tube – a radius of 14 mm, the bending radius of the drill seed tube \( R = 100 \text{ mm)} \).

3. Results and Discussion

The regularity of seed dissemination across the feeding area can be considered ideal if the value of the indicator of uneven dissemination is equal to one [7].

The following variable parameters were taken: the diameter of the discharge channel \( d \); the angle of inclination of the reflector to the horizon \( \alpha \); the angle between the faces of the reflector \( \beta \); the height of the reflector \( H \), the width of the reflector \( B \), the coordinates of points describing the surface of the reflector:

\[ \hat{O} = (O_x, O_y), \hat{M}_1 = (M_{1x}, M_{1y}, M_{1z}), \hat{M}_2 = (M_{2x}, M_{2y}, M_{2z}), \hat{P}_1 = (P_{1x}, P_{1y}, P_{1z}), \hat{P}_2 = (P_{2x}, P_{2y}, P_{2z}), \hat{F} = (F_x, F_z). \]

By changing the values of the diameter of the discharge channel and the constructive parameters of the reflector, it becomes possible to determine the distances between seeds, when they are fixed along the profile of the seed groove (along the X and Y axes).

Analyzing the results of the carried out calculations it can be noted that when the diameter of the discharge channel \( d = 28 \text{ mm)} \), the reflector height \( H = 20 \text{ mm)} \), width of reflector \( B = 20 \text{ mm)} \), the angle of inclination of the reflector to the horizon \( \alpha = 1050^\circ \); angle between the faces of the reflector \( \beta = 1350^\circ \); and for given numerical values of coordinates of points describing the surface of the reflector seeds

\[ \hat{O} = (39, -61), \hat{M}_1 = (10, -61), \hat{M}_2 = (-10, -61), \hat{P}_1 = (-15, -81), \hat{P}_2 = (14, -81), \hat{F} = (30, -79) \]

the maximum regularity of seed dissemination both along and across the seed groove is achieved.
Figure 2. The scheme of seed movement formation.
Figure 3 and figure 4 show the theoretical dependence of the regularity of the seed material distribution along the length and width of the seed groove on the diameter of the discharge channel \( d \) mm, angle \( \alpha \) degrees, with fixed values of the width of the reflector, the height of the reflector \( H \), angle \( \beta \).

The peak values of the response surface in the diagram show the areas that correspond to the values of rational parameters of the discharge channel and the seed reflector [9].

**Figure 3.** Dependence \( P = f(\alpha, d) \) along the seed groove, \( H = 20 \) mm; \( B = 20 \) m; \( \beta = 135^\circ \).

**Figure 4.** Dependence \( P = f(\alpha, d) \) across the seed groove, \( H = 20 \) mm; \( B = 20 \) mm; \( \beta = 135^\circ \).

**Figure 5.** The response surface that characterizes the regularity of seed dissemination along the length of the seed groove, depending on the speed of the machine \( V \) m/s and the discharge channel parameters where \( B = 20 \) mm, \( H = 20 \) mm, \( \alpha = 105^\circ \), \( \beta = 135^\circ \).

**Figure 6.** The response surface that characterizes the regularity seed dissemination across the width of the seed groove, depending on the speed of the machine \( V \) m/s and the discharge channel parameters where \( B = 20 \) mm, \( H = 20 \) mm, \( \alpha = 105^\circ \), \( \beta = 135^\circ \).
Figure 5 and figure 6 show the results of theoretical calculations of the regularity of seed dissemination along the length and width of the seed groove depending on the speed of the machine $V$ and the discharge channel parameters $d$ with fixed values of the inclination angle $\alpha$ of the reflector, the angle between the faces $\beta$ of the reflector, height of the reflector $B$ and width and reflector $H$.

4. Conclusion
The developed mathematical model makes it possible to reveal the correlation between the regularity of seed material distribution across the feeding area and the constructive and technological parameters of the colter drill. Thus, based on the optimal value of the seed dissemination across the feeding area, using this mathematical model, it is possible to determine the rational constructive and technological parameters of the colter drill.

Based on the research results, it can be noted that when the diameter of the discharge channel $d = 26–28$ mm, the reflector height $H = 20$ mm, width of the reflector $B = 20$ mm, the angle of inclination of the reflector to the horizon $\alpha = 102–107^0$; the angle between the faces of the reflector $\beta = 135^0$ and the speed of the machine's movement is in the range $V = 2...3$ m/s, maximum regularity of seed dissemination both along the length and width of the seed groove is achieved.

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