RESEARCH ON A GRAIN CULTISEEDER FOR SUBSOIL-BROADCAST SOWING
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ДОСЛІДЖЕННЯ ЗЕРНОВОЇ СІВАЛКИ-КУЛЬТИВАТОРА ДЛЯ ПІДҐРУНТОВО-РОЗКИДНОЇ СІВБИ

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ABSTRACT
The paper presents the results of theoretical and experimental studies on determining process efficiency of subsoil-broadcast sowing by means of improving the diagram and determining the technological parameters of a cultiseeder tined coulter / opener. The design of a tined coulter, where seeds are fed to its right and left sub-coulter spaces through various seed pipes, has been suggested. A simulation model of the process of seed movement and deflection in the sub-coulter space has been suggested. As a result of the conducted experimental studies, the statistics of the air drag coefficient and the recovery coefficient, the deviation angle of a seed flight operating trajectory after its divergence from the theoretical one, have been found. Rational parameters of a separator-distributor have been determined. Field experiments have been conducted in order to compare agro-technical performance indices of the experimental coulter and a commercial one.

РЕЗЮМЕ
В статті наведены результати теоретичних та експериментальних досліджень зі встановлення ефективності технологічного процесу підґрунтово-розкидної сівби шляхом вдосконалення схеми та визначення раціональних параметрів лапового сошника сівалки-культиватора. В результаті узагальнення запропоновано конструкцію лапового сошника, до якого у правий та лівий підлапові простори насіння подається різними насіннєпроводами. Запропоновано імітаційну модель процесу відбивання та руху насіння у підлаповому просторі. За результатами експериментальних досліджень встановлено статистичні характеристики коефіцієнта опору повітря та коефіцієнта відновлення, кута відхилення реальних траєкторій польоту насіння після відбивання від теоретичної. Визначено раціональні параметри відбивача-розподільника. У виробничих умовах проведено експериментальні дослідження з порівняння агротехнічних показників роботи для експериментального і серійного сошників.

INTRODUCTION
One of the main indicators of sowing quality is the uniform distribution of plants by feeding area (*Zhai C., et al., 2019*). Until now, the most common method of sowing cereals is ordinary, in which plants occupy only about 30% of the field area. Agrotechnical science has established that the necessary factors for the growth and development of cereals – light, water and nutrients can be rationally used only with a uniform distribution of seeds over the field area (*Vlăduţ D.I. et al., 2018*). The plants closest to the optimal feeding area are obtained by applying the soil-spreading method of sowing (*Jha A. & Kewat M., 2013*), which is performed by a seeder-cultivator. In addition to increasing yield capacity, this method allows you to combine pre-sowing tillage with sowing, which reduces the time of sowing, operating costs and causes less loss of soil moisture (*Rogovskii I. et al., 2020*).

In order to provide high accuracy of seed distribution on a field surface, a great number of coulter designs has been suggested. Coulters with passive seed distributors, which are simply engineered and more reliable compared to active distributors (mechanical and pneumatic ones), are considered to be more advanced.

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In order to change the direction of seed movement in passive distributors and maintain the necessary speed of seed distribution across the width of gripping, kinetic energy obtained from falling from a certain height is used. The change of movement directions in the existing distributors can be made in the process of oblique impacting or in the process of sliding on a curvilinear surface.

The advantages of seeder-cultivators can be especially effective when it is used in farms, in most of which energy resources are represented by one or two tractors of traction class no more than 14 kN. Pre-sowing tillage and sowing are performed by one tractor (*Voicea I. et al., 2020*). This causes a significant gap between the implementation of pre-sowing cultivation and sowing, which negatively affects the yield.

Analysing the results of research on mechanization of subsoil-spreading sowing method, it should be noted: all studies confirm the high efficiency of this method (*Farooq M. et al., 2011*), which is performed by seeder-cultivators (*Turan J. et al., 2015*); reasonable advantage of passive distributors in comparison with mechanical and pneumatic active distributors (*Jin H. et al., 2014*); change of the direction of movement of seeds by passive distributors can be carried out in two ways – sliding on a curved surface or reflection (*Verma A. & Guru P., 2015*). The method of sliding is more studied, but it has a number of disadvantages. It requires vertical feeding of seeds, which is not always possible; distributors operating on the principle of reflection are studied superficially (*Saitov V.E., 2014*); most studies have not taken into account the randomness of the physical and mechanical properties of seeds (*Abbaspour-Gilandeh Y. et al., 2018*).

Given the above, we can assume that a promising tendency is the development of openers for subsoil-spreading sowing with distributors operating on the principle of reflection (oblique impact). To implement this direction, it is necessary to study the process in detail, taking into account the statistical characteristics of seed properties (*Rogovskii I.L. et al., 2020*).

Thus, it is to the point to develop a cultiseeder. Here, the operating elements of cultiseeders should be maximally reliable.

The purpose of the study is to increase the efficiency of the process of subsoil spreading by improving the scheme and determining the rational parameters of the opener of the seeder-cultivator.

MATERIALS AND METHODS

Constructive Elements

The method of determining the statistical characteristics of the coefficient of air resistance K was, as follows: using the installation (Fig.1), the time of fall of series of seeds t_i from a given height H was determined; according to the graphical dependences $K=f(t)$ for different values H, provided $x=H$, for each t_i, the corresponding values K_i were determined, which were processed statistically.

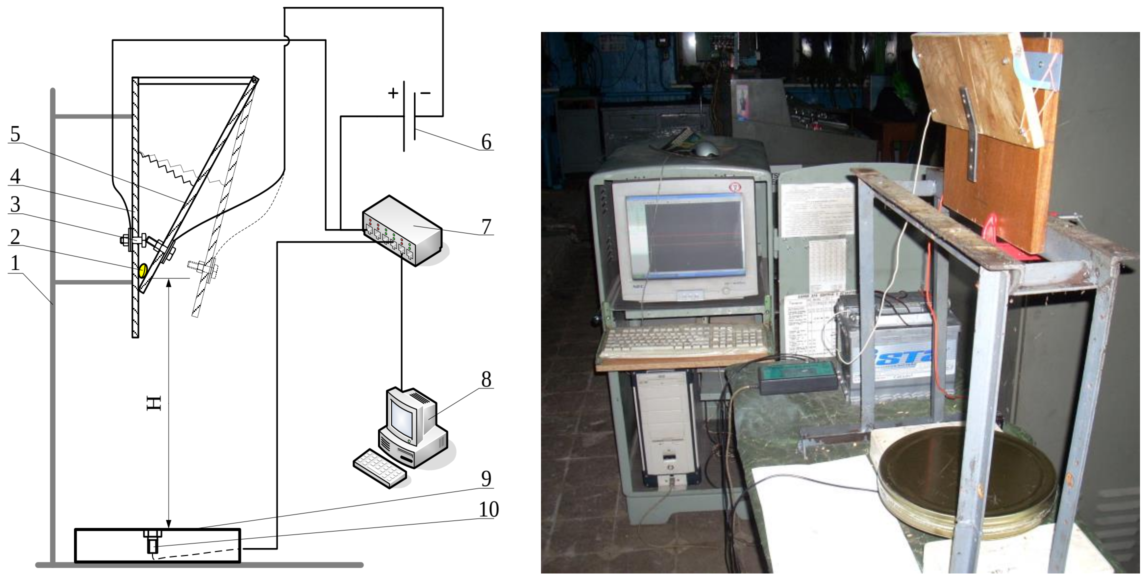

Fig. 1 – The scheme of the installation for defining seed falling time

1 – support; 2 – seeds; 3 – contact; 4, 5 – fixed and movable valve surface; 6 – current source; 7 – USB oscilloscope; 8 – PC; 9 – site; 10 – vibration sensor.

Statistical characteristics of the recovery factor K_b were determined by the flight range of the seed L_i after falling from a fixed height on an inclined reflector. According to graphic dependencies $K_b=f(L)$, a corresponding value L_i was determined for each value K_{bi}. The obtained values K_{bi} were processed statistically. The speed of seeds after climbing from the curved part of the seed line was determined by the flight range of the seed L_k after passing through the seed line of a certain radius. The method of multivariate testing is used to substantiate the optimal values of angles $\alpha_1(x_1)$ and $\gamma(x_2)$ and the height of the sub-blade area $h(x_3)$. The results of the implementation of the planning matrix of the experiment are presented in table 1.

According to the indicators of lateral scattering of seeds, due to the oblique impact, the angles τ between the central plane and the plane of the seed trajectory, flight range l and lateral deviation from the central plane c were taken (Fig.2). After the seeds fall from a fixed height H without initial velocity and reflection by the reflector *2*, the values l and c are measured. According to the obtained data, the statistical characteristics of the studied parameters are determined. Studies to determine the uniformity of seed distribution across the width of the seeding strip were performed on the installation, the scheme of which is shown in Fig.2.

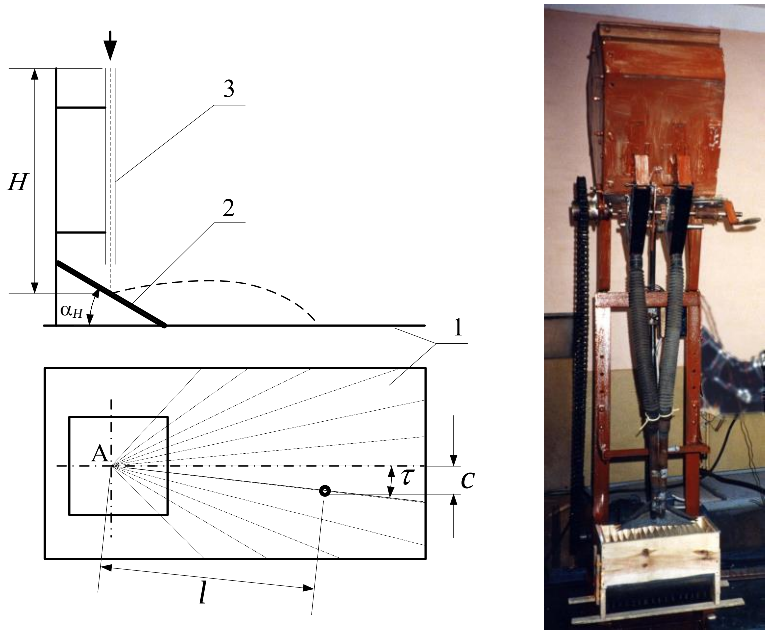

Fig. 2 – Scheme and general view of the of installation for defining seed distribution uniformity on seeding strip width

1 – platform; 2 – reflector-distributor; 3 – guide.

The grain of each cell was weighed. The average mass of seeds in the cells was taken as a number of random variables. After statistical processing, the coefficient of variation was obtained, which was taken as an estimate of uniformity (*Rogovskii I.L.. et al., 2019*).

Optimization criterion of the broadcasting process is the uniformity of seed distribution across the operating element width, which is characterized by the variation coefficient V.

Table 1

Levels of factor variation when determining optimal parameters of distributors

№	Factors		Levels of variation:		Interval of variation
	Title	Symbols	upper +	lower -	
1	Angle between deflecting and horizontal surfaces α_1, (deg.)	x_1	88	68	10
2	Angle between the intersection line of deflective and horizontal surfaces and the direction of movement γ, (deg.)	x_2	65	45	10
3	Height of sub-coulter space h, (m)	x_3	0.04	0.02	0.01

The Box-Behnken plan matrix for three factors was used in the planning of the experiments (Table 2).

The main parts of the cultivator blade opener are (Fig. 3a): two seed ducts *1*, which have rectilinear inclined cylindrical sections *2* and *4*, and torus-like upper *3* and lower *5* sections; the reflector-distributor *6* and the cultivator blade *7* with the shield *8*. The reflector-distributor is a prism, the two working borders of which (right and left) are installed at certain angles to the horizon and the direction of movement. During the movement of the drill-cultivator by the sowing machine *9*, the seed drill is fed into the seed lines, from which it enters the reflector-distributor 6 at a certain angle (Fig. 3b). After reflection, the seed flies in the sub-blade area for some distance.

Table 2

The results of the implementation of the planning matrix of the experiment (Box-Behnken plan)

Codes			Codes and natural values			y (ν, %)
x_1	x_2	x_3	x_1 (α_1, deg.)	x_2 (γ, deg.)	x_3 (h, m)	
+1	+1	0	88	65	0.030	60
+1	-1	0	88	45	0.030	54
-1	+1	0	68	65	0.030	40
-1	-1	0	68	45	0.030	48
+1	0	+1	88	55	0.040	38
+1	0	-1	88	55	0.020	62
-1	0	+1	68	55	0.040	36
-1	0	-1	68	55	0.020	60
0	+1	+1	78	65	0.040	26
0	+1	-1	78	65	0.020	53
0	-1	+1	78	45	0.040	41
0	-1	-1	78	45	0.020	60
0	0	0	78	55	0.030	29

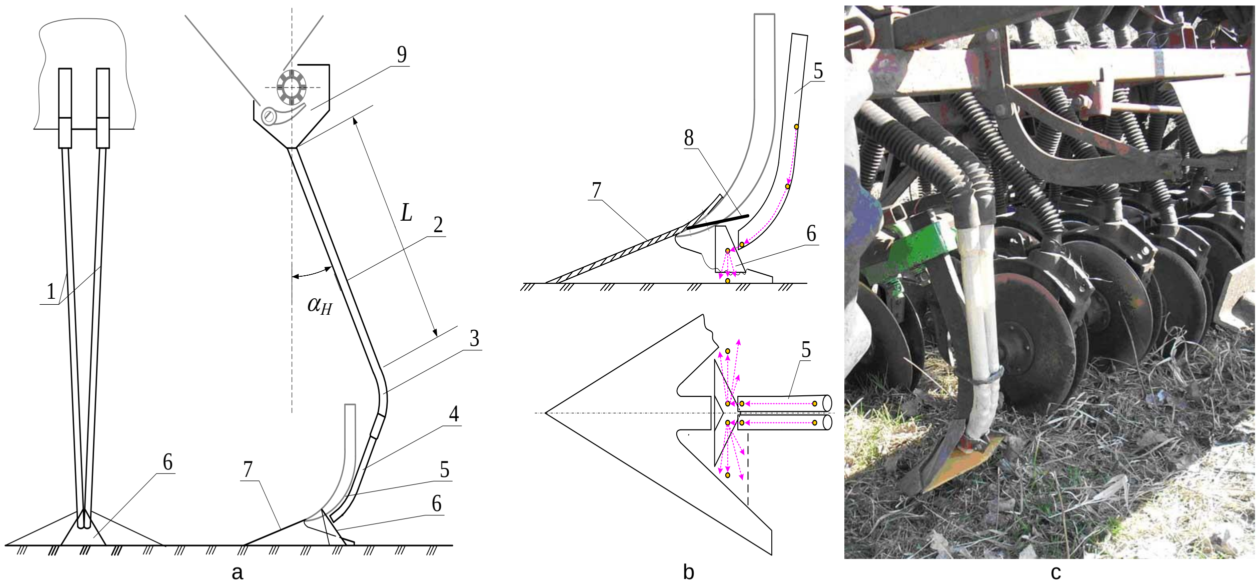

Fig. 3 – Cultivator blade of drill coulter

a – scheme; b – reflector-distributor in the sub-blade area; c – general appearance

Due to the different physical and mechanical properties of some seeds (coefficients of recovery and air resistance), the flight distances are different, which determines the distribution of grain along the bottom of the furrow. An important feature of the proposed opener is that in the right and left sub-blade area the seeds are fed by different seed ducts, which eliminates the divider of the seed flow.

Field research was conducted at the NULES of Ukraine "Agronomic Research Station" on winter wheat. A serial cultivator blade 33 cm wide with a special riser and a reflector-distributor with reasonable parameters was installed instead of the disk opener of the John Deere N542C seeder.

Theoretical Elements

The coefficient of speed change K_{zV2} is defined as the ratio $K_{zV2}=(K_b \times \cos\alpha_2/\cos\beta)$, where K_b – the coefficient of recovery, α_2 and β – the angles between the direction of speed before and after the impact and the normal, respectively. The process of seed movement along the lower section of the torus-shaped seed line is considered as the movement of a material particle along a cylindrical surface with a horizontal axis. In this case, the following forces act on the seed: the component of gravity $F_1=m \times g \times \cos\alpha_4$; friction force due to gravity $F_2=f \times m \times g \times \sin\alpha_4$; friction force due to centrifugal force $F_3=f \times m \times V^2/R$; air resistance force $F_4=K \times m \times V$, (where R – the radius of curvature). The process of motion along the arc of a cylinder with radius R is considered. The change in velocity is determined by the loss of kinetic energy E. In this case, the speed V_2 after passing the seed arc Δl will be determined by the equation:

$$V_2 = \sqrt{V_1^2 + 0.0348 \cdot \Delta\alpha \left(g \cdot \cos\alpha_4 \cdot R - f \cdot g \cdot \sin\alpha_4 \cdot R - f \cdot V_1^2 - K \cdot V_1 \cdot R\right)}. \quad (1)$$

From the lower torus-like section of the seed line, the seed enters the prismatic reflector-distributor. The process of reflection is reduced to oblique impact (Fig.4). For this case, the coefficient of speed change K_{zV} and speed after impact V_2 will be defined as:

$$K_{zV} = V_2/V_1 = \cos\alpha\sqrt{K_b^2 + \mathrm{tg}^2\alpha}\ , \ V_2 = V_1 \cdot \cos\alpha \cdot \sqrt{K_b^2 + \mathrm{tg}^2\alpha} \quad (2)$$

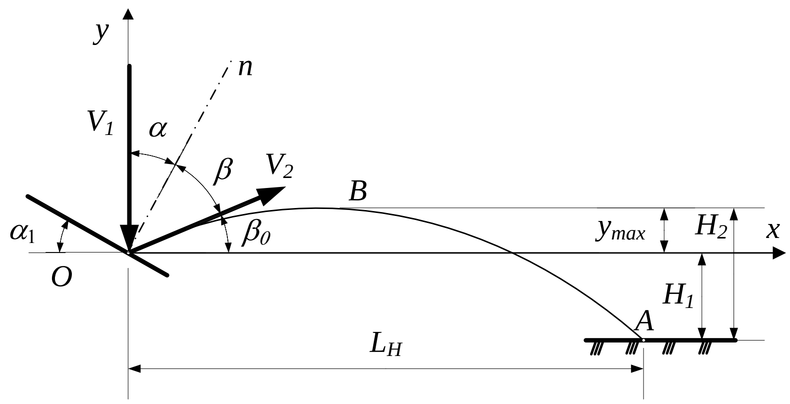

Fig. 4 – The scheme of seed movement after reflection without taking into account air resistance

Using dependences (2) it is seen that the change of angle α is within 20 - 70° and causes a change in K_{zV} from 0.48 to 0.95 (at K_b=0.35). The effect K_b on K_{zV} decreases with increasing α. The speed after reflection V_2 and the angle β_0 determine the parameters of the flight trajectory of the seeds in the sub-blade area, which are the flight range L_H and the height of the trajectory above the bottom of the furrow H_2. These parameters are determined by the equations:

$$L_H = g^{-1} \cdot V_2^2 \cdot \sin\beta_0 \cdot \cos\beta_0 + V_2 \cdot \cos\beta_0 \cdot \sqrt{V_2^2 \cdot \sin^2\beta_0 + 2 \cdot g \cdot H_1} \cdot g^{-1},\ H_2 = V_2^2 \cdot \sin^2\beta_0 \cdot (2 \cdot g)^{-1} + H_1 \quad (3)$$

where H_1 – the height of the reflection point above the bottom of the furrow.

Listed in Fig.4. The scheme provides for the vertical supply of seeds to the reflector-distributor, which makes it impossible to place the seed line outside the cultivator blade. And such placement significantly increases the reliability of the cultivator blade opener.

To simplify, we consider the process by which it is conventionally assumed that the cultivator blade is stationary and the soil moves with speed V_r. Then the basic L_2 and z_3 are determined by equations (3), respectively, with $V_2=V_r$, $\beta_0=\varphi$, $H_2=z_3$, $H_1=z_1$. So:

$$L_2 = g^{-1} \cdot V_r^2 \cdot \sin\varphi \cdot \cos\varphi + V_r \cdot \cos\varphi \cdot \sqrt{V_r^2 \cdot \sin^2\varphi + 2 \cdot g \cdot z_1} \cdot g^{-1},\ z_3 = V_2^2 \cdot \sin^2\varphi \cdot (2 \cdot g)^{-1} + z_1 \quad (4)$$

where $z_1=l_c \times \sin\beta$.

The movement of the soil under the action of the cultivator blade opener was studied in order to determine the length L_2 and height z_3 of the sub-blade area (Fig.5). Considering the wing of the cultivator blade as a wedge and taking into account the scientific positions on the laws of interaction of the triangular wedge with the soil, the dependences between the speed of the operating device (wedge) V_b and the relative speed of soil seam V_r are used.

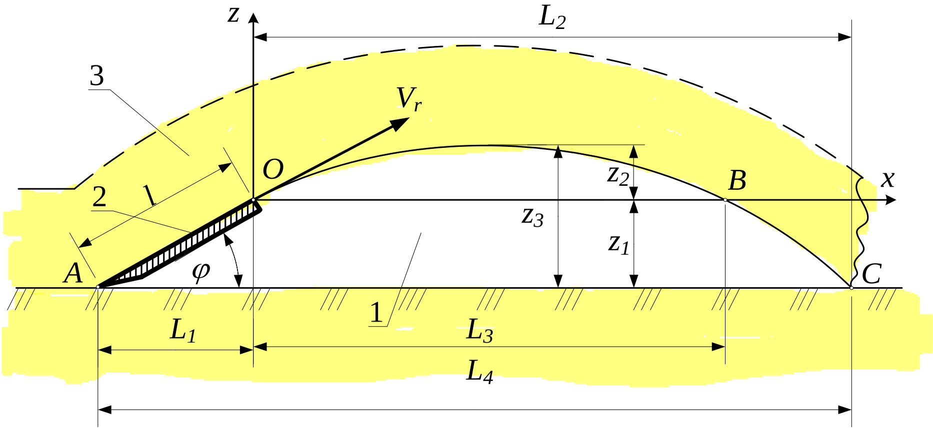

Fig. 5 – The main parameters of the sub-blade area
1 – sub-blade area; 2 – wing of blade; 3 – soil seam

Estimated increase in yield – 21.6%, when calculating the specific energy consumption, the equation for determining the power on the tractor hook N_w will look like this:

$$N_w = N_{eH} \cdot \eta_N \cdot \eta_{mT} \cdot \left[1 - A_\delta + \left(B_\delta - f \cdot g \cdot \{3.6 \cdot \eta_N \cdot \eta_{mT} \cdot W_e\}\right) \cdot V_P\right], \tag{5}$$

where N_{eH} – rated effective engine power of the tractor, kW; η_N – coefficient of use of the engine nominal effective power; η_{mT} – efficiency of tractor transmission; A_δ, B_δ – factors that determine the dependence of the skid coefficient δ on the operating speed V_p (subject to constant engine load) dependence $\delta = A_\delta - B_\delta \times V_p$ (based on the results of the analysis of traction characteristics for tractors John Deere 3071 A_δ=20.6 and 18.5; B_δ=0.99 and 0.90 respectively); f – coefficient of resistance to tractor rolling; W_e – energy saturation of the tractor, kW/t.

To determine the specific resistance of the working machine K_V (kN/m) used the dependence $K_V = K_0 + K_0 \times K_s \times (V_p - V_0)$, where K_0 – specific resistance at $V_p = V_0$=5 km/h, kN/m; K_s – the rate of increase of traction resistance with increasing speed by 1 km/h (in fractions of a unit); V_p – working speed of the unit, km/h. Before determining the energy-saving working speed of the sowing unit, combined graphs of dependences of the width of capture B_p, specific resistance K_V and productivity on the working speed V_p were constructed under the condition of using 90% of the effective power of the tractor engine, when plotting the factors of formula (16) are taken as follows: N_{eH}=58 kW; η_N=0.9; η_{mT}=0.9; f=0.18; W_e=18 kW/t; A_δ=0.206; B_δ=0.99; K_s=0.045.

RESULTS

The main evaluation characteristic of seed movement through the seed duct and in the process of reflection is the coefficient of speed change K_{zv}, which is defined as the ratio of speed after passing the operating device V_2 (or its section) to the input or potential (maximum possible) speed V_1. The process of movement of seeds by the seed duct, which has the form of an inclined cylinder, is considered as the movement of a material point on an inclined plane. The seed is affected by gravity $G=m \times g$, friction $F=f \times m \times g \times \sin\alpha_H$ and air resistance $R=K \times m \times V$, where m – seed mass, kg; g – acceleration of free fall, m/s^2; f – friction coefficient; α_H – angle of inclination of the seed line; K – coefficient of air resistance. After solving the differential equation, the velocity V_2, without taking into account the air resistance ($K=0$), will be determined by the dependence $V_2=(2 \times g \times L_H \times n)^{1/2}$, where L_H – length of seed duct; $n=\cos\alpha - f \times \sin\alpha_H$. It is advisable to take the potential speed V_1, speed of falling from a height $L_H \times \cos\alpha_H$, which is determined by the dependence $V_1=(2 \times g \times L_H \times \cos\alpha_H)^{1/2}$.

With the following initial parameters, the coefficient of speed change will be determined:

$$K_{zV_1} = V_2 \cdot V_1^{-1} = \sqrt{(\cos\alpha_H - f \cdot \sin\alpha_H) \cdot (\cos\alpha_H)^{-1}} = \sqrt{1 - f \cdot \mathrm{tg}\alpha_H} \, . \tag{6}$$

Taking into account the air resistance ($K \neq 0$), the solution of the differential equation will look like:

$$V_2(t) = n \cdot g \cdot K^{-1} \cdot \left(1 - e^{-K \cdot t}\right), \; x(t) = n \cdot g \cdot K^{-1} \cdot t - n \cdot g \cdot K^{-2} \cdot \left(1 - e^{-K \cdot t}\right) \tag{7}$$

In this case, the coefficient of speed change is determined by the equation:

$$K_{zV_1} = V_2 \cdot V_1^{-1} = n \cdot g \cdot K^{-1} \cdot \left(1 - e^{-K \cdot t}\right) \cdot (2 \cdot g \cdot L_H \cdot \cos\alpha_H)^{-1/2} \, . \tag{8}$$

The dependences of the coefficient of speed change K_{zV1} during the movement of seeds in an inclined cylindrical seed line, taking into account the air resistance from the path L_H and K (at $\alpha_H=20°$; $f=0.25$) are shown in Fig.6. From the figure we see that at $L_H=1.0$ m, $K=1.0$ sec^{-1} (close to real conditions) $K_{zV1}=0.81$, i.e. the speed decreases by 19%. Under such conditions $K=0$, $K_{zV1}=0.93$. That is, air resistance causes a decrease in speed by 14%. The process of movement of seeds on the upper torus-like section of the seed line is reduced to a single oblique impact.

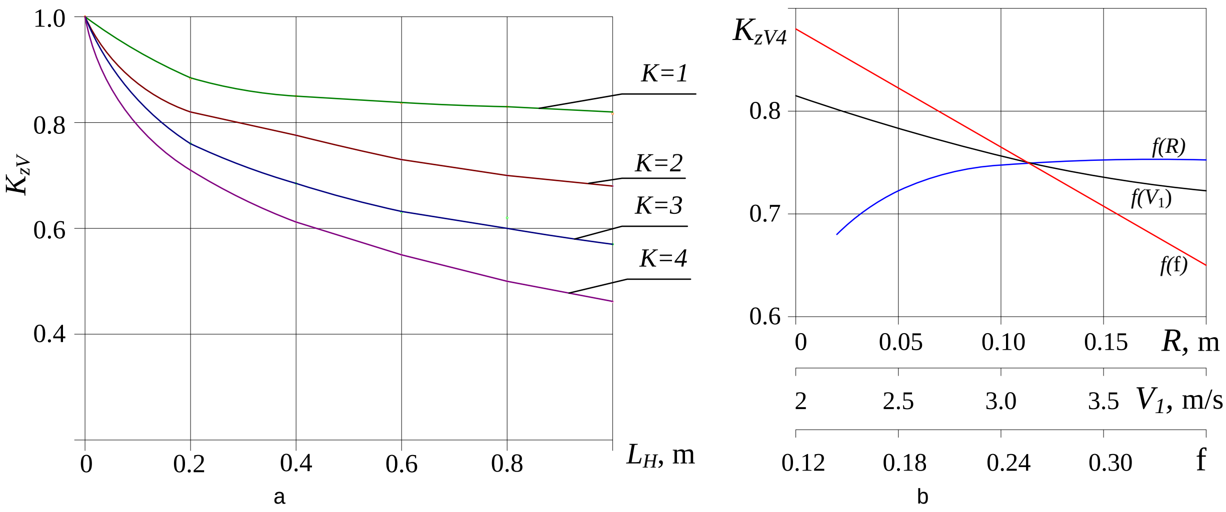

Fig. 6 – Dependence of the coefficient of speed change K_{zv}
a – on length of the seed line L_H and the coefficient of air resistance K; b – on the initial speed V_1, the radius of the arc R and the coefficient of friction f

According to the calculations, the output speed V_2 of the previous arc Δl is taken as the input V_1 for the next. The influence of the main factors of the process on the coefficient of speed change K_{zV4} can be seen from Fig.6. It is worth noting that at a speed $V_1>1.5$ m/s, the radius of curvature R has little effect on the rate of speed change K_{zV4}. This is explained by the fact that the main loss of kinetic energy (up to 90%) through the friction, is due to centrifugal force, the magnitude of which (energy) does not depend on the radius. The analysis of the process established that within the velocities of 2.0 m/s and 23.2 m/s the speed losses caused by the acting forces are distributed as follows: by the force of gravity of the seed (7 - 13%); centrifugal (71 - 82%); air resistance force (12 - 17%).

The working surface of the reflector x, y, z is inclined to the horizontal plane at an angle α_1, and the line of its intersection with the horizontal plane is an angle γ with an axis $0y$ that is parallel to direction of movement. The seeds are fed in a longitudinal vertical plane at an angle to the horizontal. The option when $\varepsilon=90°-\alpha_1$ was researched. This condition guarantees the normal position of the reflection plane relative to the reflection plane. Flight range L_H and trajectory altitude H_2 are determined under the conditions: $\beta_0=\varepsilon$, $\alpha=90°-\gamma$. The width of the capture L_b is related to the range L_H by the ratio $L_b=L_H\times\cos\psi$, where ψ – the angle between the speed V_2 and the transverse direction). In this case, the angle β will be defined as $\beta=arctg(tg\gamma/K)$. Graphic dependence of the main characteristics of the process of reflection and movement of seeds in the sub-blade area on the angle γ (provided V_1=1.5 m/s; $\varepsilon=12°$; H_1=0.02 m) is shown in Fig.7.

As the angle γ increases, all characteristics decrease; when increasing γ from 40 to 70° the average value of the recovery factor (K_b=0.33), the speed V_2 decreases from 1.04 to 0.761 m/s; angle ψ – from 35° to 0; seed flight distance in the transverse direction L_b – from 0.091 to 0.052 m; height of the flight trajectory of seeds H_2 – from 23.3 to 20.1 mm. According to the analysis of the results of previous experimental studies, the most uniform distribution of seeds occurs under the condition $L_b=0.5\times b$, where b – the working width of the blade wing. We take the working width of the blade wing $b=0.15$ m, so the desired flight range is 0.07 - 0.08 m. From the Fig.7 we see that values L_b correspond to the angle γ in the range of 55 - 60°. At values γ from Fig.7 we have: $\psi=14°$ - 0; H_2 – from 0.0233 to 0.0216 m. Therefore, according to the results of theoretical analysis at V_1=1.5 m/s; $\varepsilon=12°$; H_1=0.02 m the optimal value of the angle γ is in the range of 55 - 60°.

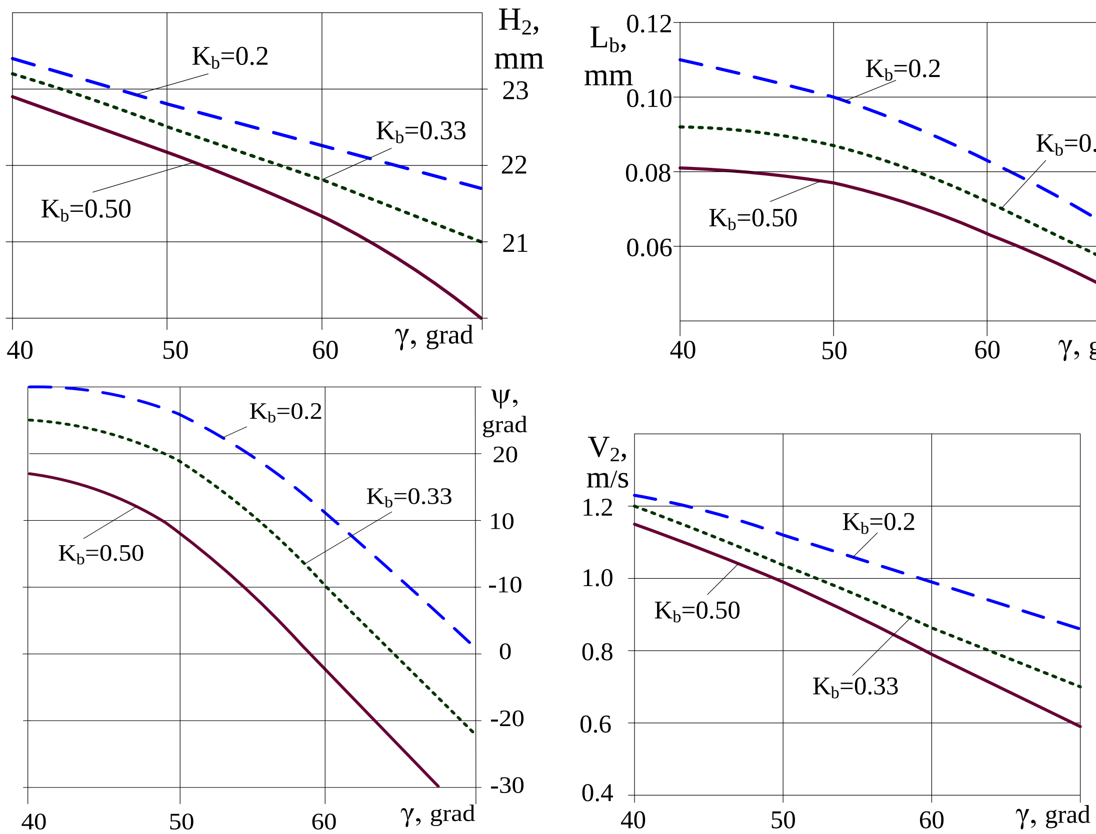

Fig. 7 – Graphic dependence of the main characteristics of the process of reflection and movement of seeds in the sub-blade area on the angle γ

According to the results of calculations for the cultivator blade with a width of 0.33 m (β=28°; γ=32.5°; l_1=0.054 m; l_2=0.031 m; l_c=0.042 m; φ=16°) for V_e within 2 - 2.5 m/s (7.2 - 9 km/h) L_2 from 0.17 to 0.26 m, and z_3 from 0.031 to 0.036 m. The value z_3 is slightly larger than the theoretical height of the trajectory H_2, which is 0.022 - 0.023 m (H_2 Fig.7). Statistical characteristics of the coefficient of air resistance K are given in table 3. Clear patterns of the influence of height of falling on K are not revealed. As the value K for each crop varies considerably, the speed of the seed before hitting the distributor also changes, which contributes to the quality of seed distribution along the bottom of the furrow. Statistical characteristics of the recovery factor K_b were determined for wheat seeds, barley and peas. The experiments were performed at height of fall of 0.5 m and angles of inclination of the reflective plane to the horizon of 20° and 30°. The obtained values of statistical characteristics are given in table 4.

Table 3

Statistical characteristics of air resistance coefficient *K*

Culture	Value of characteristics			
	K_{min}	K_{max}	m_K	ν, %
Wheat	0.307	3.59	1.09	45.3
Barley	0.460	2.30	1.24	27.5
Peas	0.425	2.64	1.03	55.6

Table 4

Statistical characteristics of the recovery rate K_b

Characteristic	Value of characteristics at an angle of inclination α_b					
	20°			30°		
	wheat	barley	peas	wheat	barley	peas
The minimum value	0.02	0.02	0.02	0.10	0.10	0.10
The maximum value	0.55	0.55	0.51	0.64	0.66	0.64
The arithmetic mean	0.33	0.31	0.26	0.41	0.38	0.34
Coefficient of variation, %	36.4	42.1	34.9	32.0	38.0	34.8

Analysing the data in table 4 it should be noted: the recovery factor is a random variable and varies for different cereals within significant limits (0.1 - 0.66). The average value K_b varies from 0.26 to 0.41, and the coefficient of variation from 32 to 42%. Fluctuations in the value cause variation in the flight range of the seeds, which contributes to better distribution of seeds in the transverse direction. The coefficients of speed change during the movement of seeds along the curved lower part of the seed line are determined in order to establish the reliability degree of the regularities of the process main factors influence of the, obtained by theoretical calculations.

The research results are given in table 5: V_K – input speed taking into account air resistance (K=1.0), m/s; V_{2T} – theoretical input speed, m/s; V_{2E} – experimental input speed, m/s.

From the table 5 we see that the difference between the theoretical and experimental values of the coefficient of speed change does not exceed 10%. Therefore, we can assume that the reliability of theoretical calculations is quite high. Experiments to determine the parameters of lateral scattering of seeds were carried out at heights of the fall H (0.5 and 1.0 m), and angles α (20 and 30°) (Fig.2). According to the results of processing the corresponding measurements (Fig.8), the following characteristics were obtained for winter wheat: the average value of the angle $\tau(m_\tau)$ 18.1 - 22.1°; coefficient of variation (60 - 64%); the average value of the flight range $l(m_l)$ (0.13 - 0.16 m); coefficient of variation (34 - 37%). As the angle of installation of the plane to the horizon α and the height of the fall H increases, there is a tendency to decrease the value of m_τ and m_l. Characteristic values for some crops vary from 7 to 11%. The deviation of the plane of the flight trajectory of the seed from the central contributes to a more uniform distribution of seeds at the bottom of the furrow.

Table 5

Comparison of theoretical K_{zVT} and experimental K_{zVE} values of speed coefficients

H, m	V_K, m/s	V_{2T}, m/s	V_{2E}, m/s	K_{zVT}	K_{zVE}	ΔK_{zV}, %
0.5	2.82	2.22	2.19	0.787	0.777	-1.2
0.75	3.37	2.57	2.68	0.764	0.795	3.9
1.0	3.72	2.80	3.11	0.753	0.836	9.9

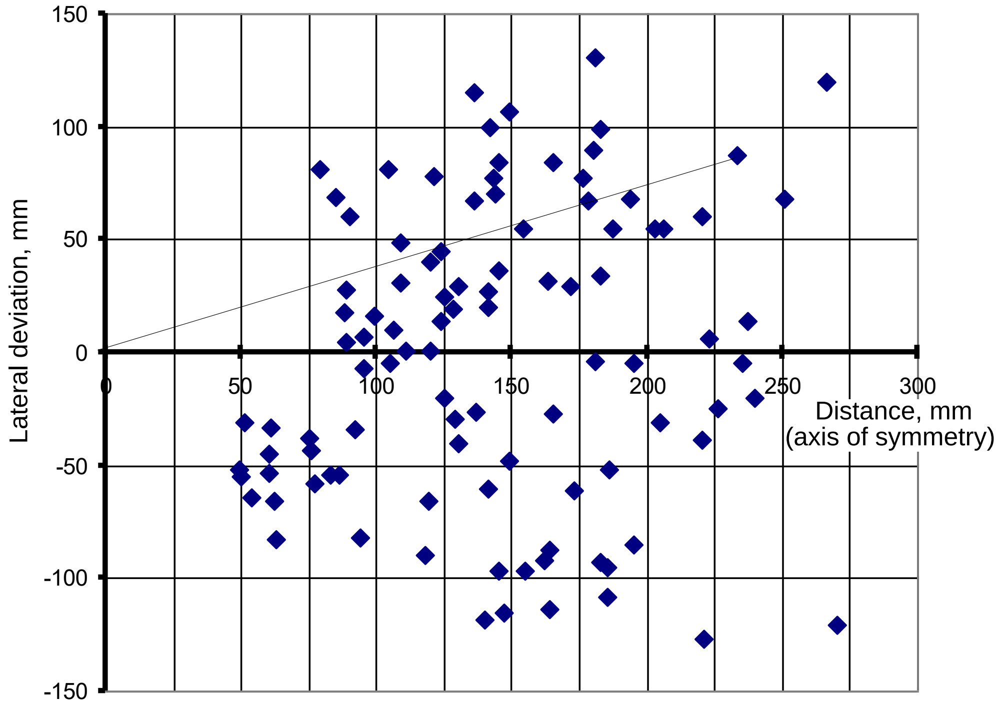

Fig. 8 – The nature of the placement of seeds after reflection

The main parameters of the reflector-distributor with a flat reflection surface are: the height of the reflection point above the bottom of the groove – H_1; the angle between the direction of the speed V_1 at which the seed is fed to the reflector and the horizontal plane – ε; the angle between the reflective and horizontal planes – α_1; the angle between the line of intersection of the reflective and horizontal planes and the direction of movement – γ, height of sub-blade area – h. According to the results of previous research, we accept H_1=0.02 m. According to our reasonable scheme of the reflection process $\varepsilon=90°-\alpha_1$. To substantiate the optimal values α_1, γ and h the method of planning a multifactorial experiment is applied. After processing the experimental data, we obtained the regression equation of the coefficient of variation of the distribution of seeds along the width of the cultivator blade wing, which will look like this:

$$\nu = 29 + 3.875\cdot\alpha_1 - 2.875\cdot\gamma - 11.75\cdot h + 12.65\cdot\alpha_1^2 + 8.65\cdot\gamma^2 + 7.40\cdot h^2 + 3.25\cdot\alpha_1\cdot\gamma - 2\cdot\gamma\cdot h\,. \quad (9)$$

At fixed values h, the regression equations will look like this:

- at $h = 0.02$ m: $\nu = 1193 - 21.134\cdot\alpha_1 - 12.14\cdot\gamma + 0.0325\cdot\alpha_1\cdot\gamma + 0.127\cdot\alpha_1^2 + 0.0865\cdot\gamma^2$, (10)

- at $h = 0.03$ m: $\nu = 1185 - 21.134\cdot\alpha_1 - 12.34\cdot\gamma + 0.0325\cdot\alpha_1\cdot\gamma + 0.127\cdot\alpha_1^2 + 0.0865\cdot\gamma^2$, (11)

- at $h = 0.04$ m: $\nu = 1191 - 21.134\cdot\alpha_1 - 12.54\cdot\gamma + 0.0325\cdot\alpha_1\cdot\gamma + 0.127\cdot\alpha_1^2 + 0.0865\cdot\gamma^2$. (12)

The corresponding response surfaces are shown in Fig.9. From the figure we see that depending on the angles α_1 and γ there are minimum values of the coefficient of variation ν of seed distribution, which correspond to the optimal values of α_1 and γ. As the value h increases, ν decreases (the indicator improves) to a certain value h, and then it does not change. For example, at α_1=78° and γ=55° for h=0.02 m, ν=48.2% and for h=0.04 m, ν=24.7%. Given the fact that when increasing h by more than 0.03 m value ν decreases slightly, it is advisable to consider the condition h=0.03 m. The optimal value of the angle γ at h=0.03 m is determined by equation (11) under the condition $d\nu/d\gamma=0$. Then at α_1=78° value γ_{opt}=56.6°. As well as according to theoretical researches (Fig.1) at α_1=78°, optimum values of an angle γ are within 55 - 60° which coincides with experimental data. Thus, the following parameters of the prismatic reflector-distributor are substantiated by experimental research: $\varepsilon=90°-\alpha_1=12°$; α_1=78°; γ=56.6°; h=0.03 m; H_1=0.02 m.

The following agrotechnical indicators of work for experimental and serial openers, respectively, were obtained: average depth of wrapping – 3.8 and 4.1 cm; coefficient of variation – 15.3 and 19.7%; number of spikelets per 1 m^2 – 612 and 496; grain weight of one spikelet – 1.54 and 1.48 g. The quality index of seed distribution in the transverse direction (coefficient of variation) for the experimental opener – 28.6%.

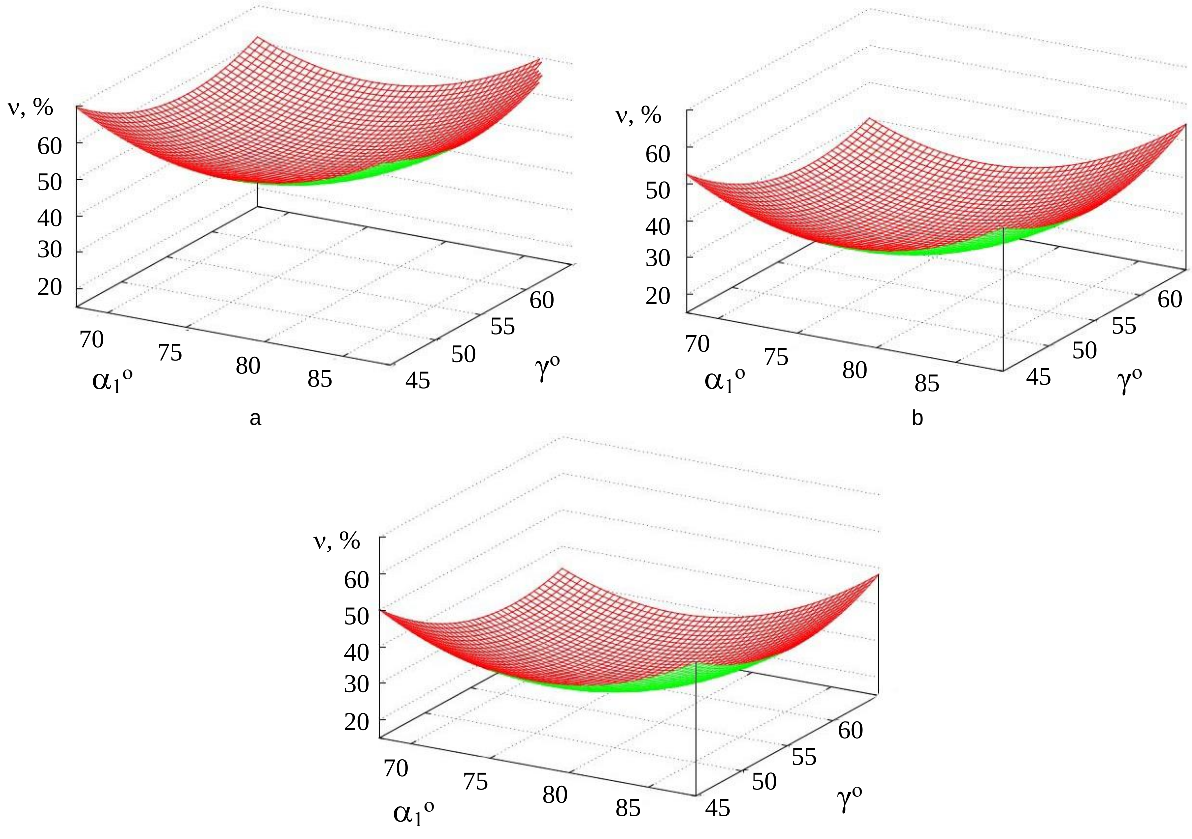

Fig. 9 – Graphs of the dependence of the coefficient of variation ν on the angles γ and α_1
a – h=0.02 m; b – h=0.03 m; c – h=0.04 m

It was found that for John Deere 3071 more energy-saving operating speed was of 8.4 km/h with a width of B_p=5.4 m.

CONCLUSIONS

It is established that neglect of air resistance in the seed line leads to an error of more than 15%. In the process of movement of seeds on the lower curvilinear section at the input speed of 1.5 - 3 m/s speed losses are distributed as follows: due to the force of friction from the gravity of the seeds (7 - 13 %); friction force from the centrifugal force (71 - 82%); air resistance (12 - 16%).

The dependences of the length L_2 and height z_3 of the sub-blade area on the cultivator blade parameters and the seeder-cultivator speed V_e were performed analytically according to the calculations made for a typical cultivator blade (b=0.33 m) at V_e from 2.0 to 2.5 m/s (7.2 - 9.0 km/h), L_2 from 0.17 to 0.26 m; z_3 from 0.031 to 0.036 m.

Field tests of the experimental cultivator blade opener show that the coefficient of variation of the depth of seed earning decreases compared to the serial disc opener, by 4% (from 15.3 to 19.3%); the uniformity of seed distribution in the transverse direction is 28.6%; the number of spikelets per 1 m^2 increases by 23% (from 496 to 612 pcs.) with a grain weight of one spikelet of 1.48 - 1.54 g, which allows us to predict an increase in yield by 22%.

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