

## **THEORETICAL AND EXPERIMENTAL SUBSTANTIATION OF THE DESIGN OF AN OPENER FOR INTRASOIL BROADCAST SOWING OF GRAIN CROPS**

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### **Abstract**

NUKESHEV, S., K. ESKHOZHIN, D. KARAIVANOV, T. SANKIBAEV and N. KAKABAYEV, 2016. Theoretical and experimental substantiation of the design of an opener for intrasoil broadcast sowing of grain crops. *Bulg. J. Agric. Sci.*, 22: 862–868

Existing seeder openers for intrasoil broadcast sowing of grain crops do not fully provide quality seeds scattering. Low nonuniformity of seeds scattering can be assured by vibro-distributors but they have a complicated design. An original opener design for quality intrasoil broadcast sowing is proposed. The V-shaped sweep of the opener consists of cutting blades which create a closed subsoil space.

A pendulum scatterer in the form of a hemisphere is pivotally suspended inside. Theoretical studies are based on classical mechanics. As a result of theoretical investigation, an expression is obtained for determination of the length of a grain fallen in the under-sweep space. The optimal parameters of the scatterer are determined experimentally: its base diameter, its height and its location according to the bottom of the furrow.

*Key words:* opener, seed, grain scatterer, V-shaped sweep, intrasoil broadcast sowing, seed tube

### **Introduction**

Increased productivity of crops is the main objective in the creation and improvement of technological processes and working devices of agricultural machines. The main stage in the cultivation technology of grain crops is sowing the seeds, providing the most favorable conditions for germination and further development of plants. Optimal conditions are created in the application of science-based timing of sowing, seeding rate, methods of seeding and providing a rational area of plant nutrition (Heege, 1981; Bepamiantova and Lavruhin, 1991; Heege and Felbhaus, 2002; Artamonov, 2007; Karayel and Omerzi, 2007). Analysis of the research shows that intrasoil broadcast sowing method creates the most favorable conditions for the growth and development of crops (Heege, 1981; Bepamiantov and Lavrukhin 1991; Heege and Felbhaus, 2002; Artamonov, 2007). Also, the seeds are distributed more evenly across the field than

with drill seeding. In comparison with the closed and ordinary drill sowing, the intrasoil broadcast method increases the yields of crops by an average of 10... 30% (Shevchenko and Domrachev, 2005; Manchev, 2011; Ponamarev, 2014). In order to provide for the distribution of seeds and fertilizers in under-sweep space, the openers of intrasoil broadcast seeders are supplied with various seed scatterers. The most common passive scatterers are simple in design and in various shapes. However, their uneven distribution of seeds and fertilizer granules at the working width is high. Vibrating scatterers achieve low unevenness of grain distribution, but they have a complicated structure. In this regard, a research aimed at improving the uniformity of seed distribution on the sowing area by applying an opener with a scatterer on stubble seeders in under-sweep space for intrasoil broadcast sowing is relevant and is of practical importance.

The purpose of this paper is to reduce the uneven distribution of seeds on the sowing area by substantiation of

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constructive schemes and rational parameters of a seed tube and a scatterer for intrasoil broadcast sowing of grain crops.

The object of investigation is the technological process of intrasoil broadcast sowing of grain crops.

## Materials and Methods

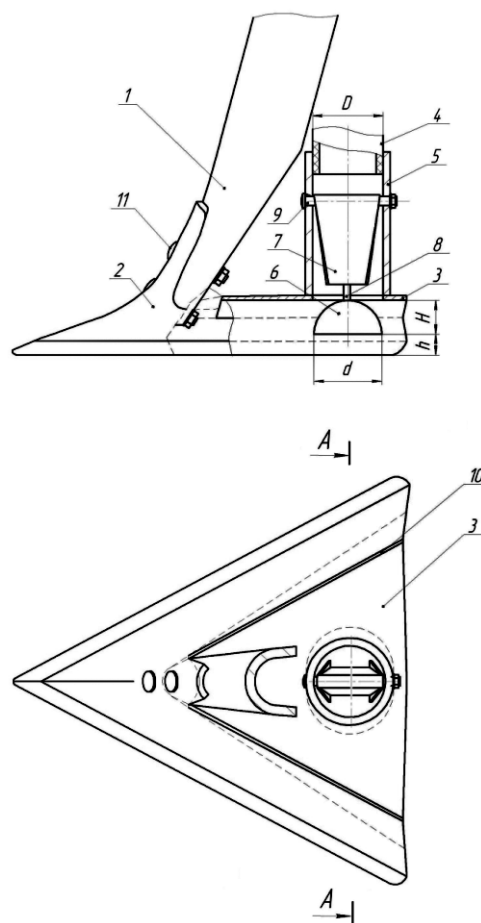
Analysis of the working bodies of the existing anti-erosion seeders, sowing complexes and research on their improvement shows that their openers sow seeds by continuous manner with a row-width of 12 .. 14 cm and unoccupied strips remain between the rows, which cover a quarter of the area of fertile land. With this method of seeding, a mutual inhibition occurs in plant shoots, uneven and inadequate tillering of stems, as well as increased infestation of weeds leading to ineffective use of water, heat and light by the plants which results in a significant effect on yield and seed quality.

The technical problem is to reduce the non-uniformity of distribution and to increase the width of the sown strip of seeds and/or fertilizers. To solve this problem at the Department of Technical Mechanics of the S.Seifullin Kazakh Agro Technical University an opener is developed where the V-shaped sweep contains a peak located above its blades. Thus, a subsoil closed space is formed between the inner surfaces of the sweep wings and the peak (Patent 29217 RK). Inside this under-sweep space a pendulum scatterer in the form of a hemisphere is pivotally suspended by a clamp. The hemisphere axis of rotation is parallel to the horizontal hinge axis of the clamp and coincides with the machine movement direction.

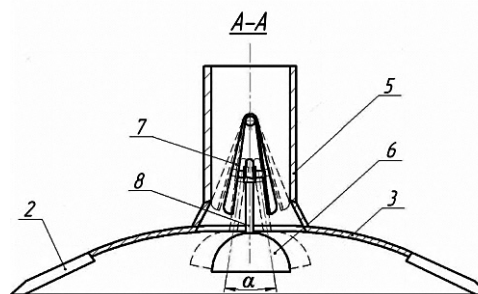
Figure 1 presents the assembly drawing of the opener and Figure 2 – the section view A-A. Figure 3 presents the distribution of the seeds and fertilizer granules in soil.

The opener consists of a shank 1 with a V-shaped sweep 2 assembled by bolts 11 and a peak 3 which is joined to the sweep by cogs 10. The peak is over the blades of the sweep and in this space there is a pendulum scatterer 6 hanged by pin 9, bracket 7 and rod 8. The flexible seed tube 4 ends with a steel nozzle 5.

The seeder works as follows: When the tractor moves, seeds and fertilizer granules fall from the seed tube 4 to the scatterer 6, ricochet and broadcast uniformly on the whole surface of the closed under-sweep space. During seeder movement the sweep blade cuts weeds and loosens the soil, which moves back along the surface of the peak and then falls down covering the sown seeds and fertilizers. Subsequently, the whole furrow is compacted by a roller. As a result, mutual depression of the grains is eliminated and germination zone is increased, which appears to provide the best conditions for plant growth and development. As a result of



**Fig. 1. Assembly drawing of an opener for intrasoil broadcast sowing**



**Fig. 2. The section view A-A of the opener from Fig. 1**

the free-tillering stems, plants cover the gaps between adjacent rows of sown seeds that can effectively use the entire area of the sowing field. This increases field germination, plant adaptability to harvesting and reduces weed infestation of crops, thereby increasing grain yield by 18... 25 percent per hectare (Lavrukhin, 2003).

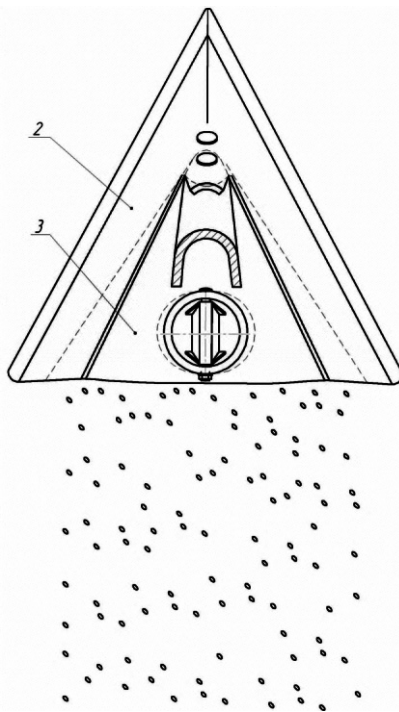


Fig. 3. Distribution of seeds and fertilizer granules in soil by the opener from Fig. 1

Theoretical studies on yields are an expression that connects all the major structural and technological parameters. The theoretical results have clarified and confirmed by experimental studies, based on the methods of statistical design of experiments in the laboratory and laboratory and field conditions.

Scatterers with various parameters have been made with the purpose of experimenting (Figure 4). For optimization criteria, the width of the sowing row and the uneven distribution of seeds in the row are taken. Those characterize the quality of the sowing process.

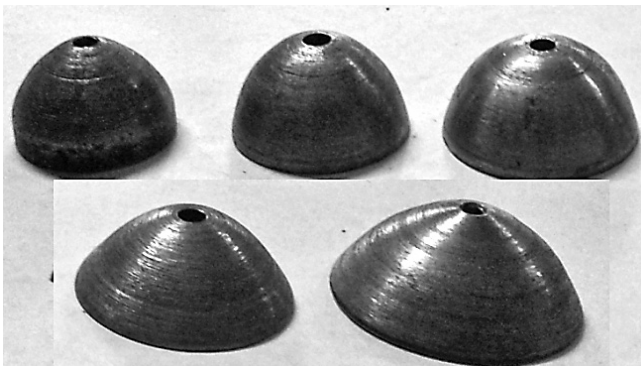


Fig. 4. Experimental pendulum scatterers

It is a priori known that the quality of work of the opener depends on its design and technological parameters, which have been chosen as the main controllable factors:

- Diameter of the pendulum scatterer base, mm;
- Scatterer positioning above the furrow bottom, mm;
- Height of the scatterer, mm;

The diameter of the rod 8 is defined on the conditions to maximize the nozzle throughput capacity.

### Results

Row-width depends on seeds falling distance. And the seeds falling distance depends on the output speed of seeds (grains) from the nozzle. To substantiate the optimal opener parameters it is necessary to determine the seeds (grains) speed at the nozzle output.

During its movement to the soil a seed (grain) passes three sections (Figure 5): AB, BC, CD.

In section AB the particle (seed, grain) slides on slope with angle  $\alpha$  (Figure 5):

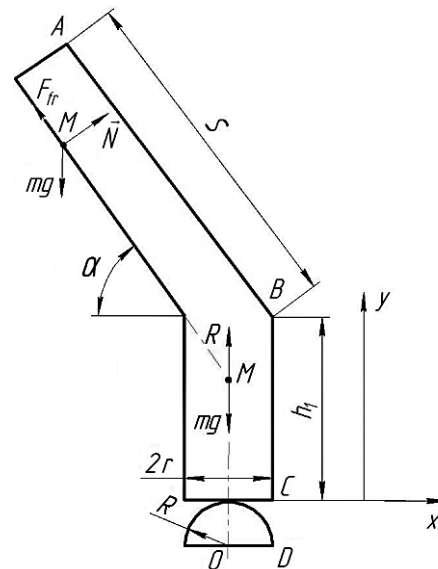


Fig. 5. A drawing of the seed tube sections with forces acting on the particle in sections AB and BC

The speed in point A is:  $v_A = v_0$ , in point B –  $v_1$ .  
The forces acting on the particle are: gravity force  $\vec{mg}$ , friction force  $F_{fr} = f \cdot m \cdot g \cdot \cos \alpha$  and slope reaction  $N$ .

From the theorem of kinetics follows energy change in grain speed  $v_1$ :

$$\frac{mv_1^2}{2} - \frac{mv_0^2}{2} = mgS \sin \alpha - fmgS \cos \alpha \tag{1}$$

Thus, we obtain the speed in the end of section as:

$$v_1 = \sqrt{2gS(\sin\alpha - f\cos\alpha) + v_0^2} \quad (2)$$

In section BC the particle falls on the scatterer (Fig. 5). The equation of its movement according to Newton's second law is:

$$m \frac{dv}{dt} = -mg - kmv,$$

or

$$\frac{dv}{dt} = -g - kv, \quad (3)$$

where:  $\vec{mg}$  – gravity force,  
 $\vec{R} = km\vec{v}$  – material resistance force,  
 $\vec{v}_2$  – speed in point C.

After integration one obtains:

$$-\frac{1}{k} \ln(kv + g) + t + C_1. \quad (4)$$

Substituting into (4) the initial conditions  $t = 0$ ;  $v = v_1$ , one determines:

$$C_1 = -\frac{1}{k} \ln(g + kv_1).$$

Substituting this value of the arbitrary constant in equation (4) one obtains:

$$\frac{1}{k} \ln \frac{g - kv}{g + kv_1} = -t,$$

or:

$$v = \frac{1}{k}(g + kv_1)e^{-kt} - \frac{g}{k}. \quad (5)$$

After substituting  $v$  as  $\frac{dv}{dt}$  in (5) and integrating, one obtains

$$y = \frac{g}{k}t - \frac{1}{k^2}(g + kv_1)e^{-kt} + C_2. \quad (6)$$

Because when  $t = 0$ ;  $y = h_1$ , then

$$C_2 = h_1 + \frac{g + kv_1}{k^2}$$

and:

$$y = h_1 - \frac{g}{k}t + \frac{1}{k^2}(g + kv_1)(1 - e^{-kt}) \quad (7)$$

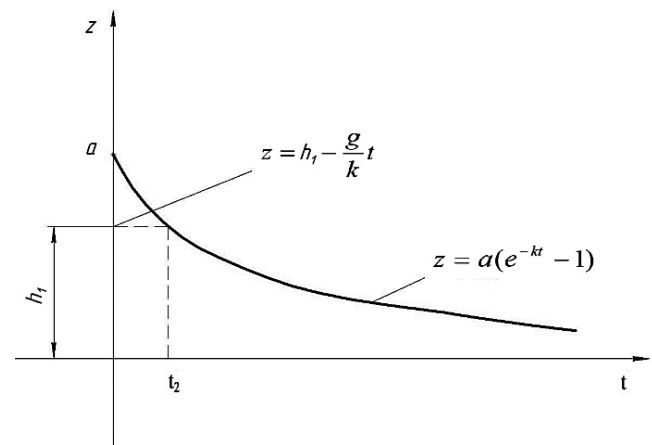
Considering that at point C –  $y = 0$ ,  $v = v_2$ ,  $t = t_2$ , the pre-determined  $t_2$  from (7) is:

$$h_1 - \frac{g}{k}t_2 = a(e^{-kt} - 1);$$

$$t_2 = \frac{k}{g} \left[ h_1 - a(e^{-kt} - 1) \right], \text{ where:}$$

$$a = \frac{1}{k^2}(g + kv_1).$$

In the previous equations the coefficient  $k/g$  is very important because when  $g = \text{const}$ ,  $k$ -factor effect is directly proportional to the time of particle falling  $t_2$ , thus the larger  $k$ , the more  $t_2$ . From the physical nature of the process it is evident that  $k$  is no different from the particle windage factor. Figure 6 shows the falling time with respect to (w.r.t.) the height of the vertical section BC.



**Fig. 6. Falling time of the particle w.r.t. the height of the vertical section BC (Fig. 5)**

The particle speed in the end of this section  $v_2$  may be obtained from (5):

$$v_2 = \frac{1}{k}(g + kv_1)e^{-kt_2} - \frac{g}{k}. \quad (8)$$

To determine the particle falling distance we study its movement in section CD (Figure 7). The particle strikes the scatterer surface (hemisphere with radius  $R$ ) with absolute speed  $v_2$ . The angle of impact  $\beta$  is:

$$\sin \beta = \frac{r}{R}, \quad (9)$$

where  $r$  is the distance from the nozzle axe to the particle. Experiment shows for main quantity of particles fall near the nozzle surface and in calculation  $r$  is equal to the radius of the nozzle.

If we assume the collision (of bodies) in point C to be perfectly elastic, the impact and reflection angle are equal. In this case, the reaction force  $R$  decomposes into a normal  $N$  and a tangential  $T$  components. The particle speed  $v_c$  after the impact will be in the direction of the reactive force  $F_r$ .

We decompose the particle speed after impact on the scatterer into horizontal and vertical components:

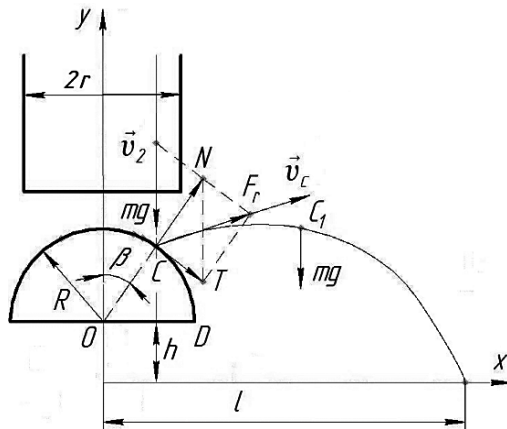


Fig. 7. The trajectory of particle falling in under-sweep space (after impact on the scatterer)

$$v_x = v_2 \sin 2\beta,$$

$$v_y = v_2 \cos 2\beta.$$

The differential equation of the particle movement is:

$$\left. \begin{aligned} m\ddot{y} &= -mg \\ m\ddot{x} &= 0 \end{aligned} \right\} \quad (10)$$

After integration of (10) one obtains:

$$\left. \begin{aligned} y &= -g\frac{t^2}{2} + C_3 t + C_4 \\ x &= -C_3 t + C_4 \end{aligned} \right\} \quad (11)$$

Under initial conditions when  $t = 0$ :  $x_0 = r$ ;  $y_0 = h_c = h + \sqrt{R^2 - r^2}$ , equation (11) will be as follows:

$$\left. \begin{aligned} y &= -g\frac{t^2}{2} + (v_2 \cos 2\beta)t + h_c \\ x &= (v_2 \sin 2\beta)t + r \end{aligned} \right\} \quad (12)$$

The time for the particle to fall on the soil (on the furrow bottom)  $t_3$  may be determined from condition

$$y = -g\frac{t_3^2}{2} + (v_2 \cos 2\beta)t_3 + h_c = 0,$$

where:

$$t_3 = \left( \frac{v_2}{g} \cos \beta \right) + \sqrt{\frac{v_2^2}{g^2} + \frac{2h_1}{g}} \quad (13)$$

From equations (12) and (13) one can determine the grain falling distance  $x_{\max}$  (from the nozzle axe) in the under-sweep space:

$$x_{\max} = (v_2 \sin \beta)t_3 + r. \quad (14)$$

## Discussions

Analysis of equation (14) shows parabolic dependence of the particle falling distance w.r.t. the impact angle  $\beta$  (Figure

8). When  $\beta = 40 \dots 60^\circ$ , the falling distance is maximum. This is because for these values of the angle  $\beta$  direction of the velocity vector after the impact is closest to the horizontal direction of flight.

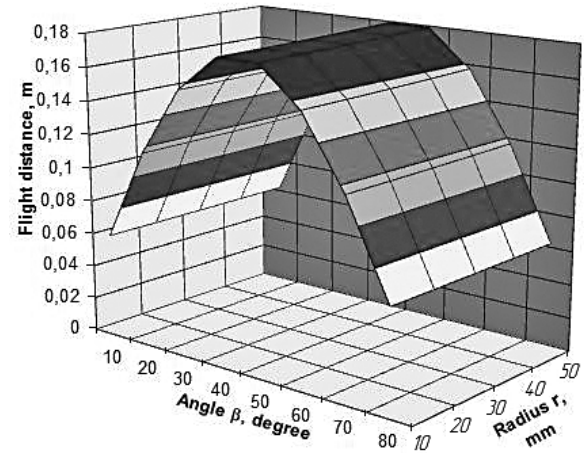


Fig. 8. The particle falling distance  $x_{\max}$  w.r.t. the impact angle  $\beta$  and nozzle radius  $r$

Some particles fall on the scatterer with different radius ( $x_0 = 0 \div r$ ) and therefore will have a different falling distance. This increases the particle scattering in the under-sweep space. By varying the shape of scatterer surface one can obtain a different relation between the radius  $r$  and the impact angle  $\beta$ , and in this way get a different pattern of particle scattering.

To test the efficiency of the proposed technical solutions and determine their optimal parameters experimental studies were performed. The experiment was made on the program of the central composite rotatable second order planning. Conditions and experimental data are presented in Table 1.

Thus, the regression equation of the unevenness of particle distribution across the row width is:

$$Y_3 = 30.86 - 0.307x_1 + 0.183x_2 - 0.549x_3 + 0.387x_1x_2 + 1.112x_1x_3 - 1.237x_2x_3 + 1.689x_1^2 + 0.706x_2^2 + 1.885x_3^2; \quad (15)$$

Since equations of the second degree in the form of (15) are complex for analyzing, in order to get an idea about the geometric form of the response function of the corresponding dependence, we transform it to the canonical form:

$$Y_3 - 20.8 = 1.826x_1^2 + 0.913x_2^2 + 1.541x_3^2; \quad (16)$$

In (16) it should be noted that the response surface is a rotational ellipsoid, and its minimum is at the center of the ellipsoid, because all the coefficients are with positive signs. Extremum lies within the study area, which confirms the correctness of the choice of variation limits of variables. Coordinates of the center of the figure are:

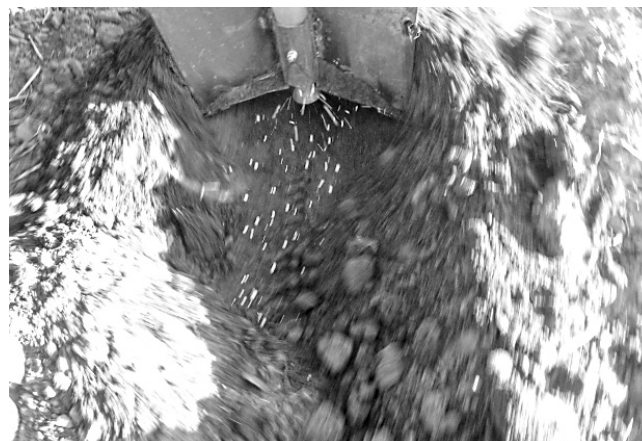
**Table 1**  
**Planning matrix and experimental results**

Opener		Input factors			Parameter of optimization
Natural		Diameter of the scatterer base. mm	Distance between the scatterer base and the furrow bottom. mm	Height of the scatterer. mm	Unevenness of seed distribution across the row width. H
Coded		$X_1$	$X_2$	$X_3$	$Y$
Varying of the factors	+1.682	48.41	23.05	26.73	-
	+1	45	21	24	-
	0	40	18	20	-
	-1	35	15	16	-
	-1.682	31.59	12.95	13.27	-
Varying interval		5	3	4	-
Number and conditions of experiments	1	+	+	+	11.5
	2	-	+	+	6.4
	3	+	-	+	9.6
	4	-	-	+	6.8
	5	+	+	-	5.6
	6	-	+	-	11.2
	7	+	-	-	8.5
	8	-	-	-	5.9
	9	+1.682	0	0	3.3
	10	-1.682	0	0	10.5
	11	0	+1.682	0	7.8
	12	0	-1.682	0	11.6
	13	0	0	+1.682	4.4
	14	0	0	-1.682	8.3
	15	0	0	0	12.5
	16	0	0	0	11.7
	17	0	0	0	13
	18	0	0	0	10.6
	19	0	0	0	12
	20	0	0	0	11.5

$$x_{1S} = 0.0559; x_{2S} = -0.045; x_{3S} = 0.113.$$

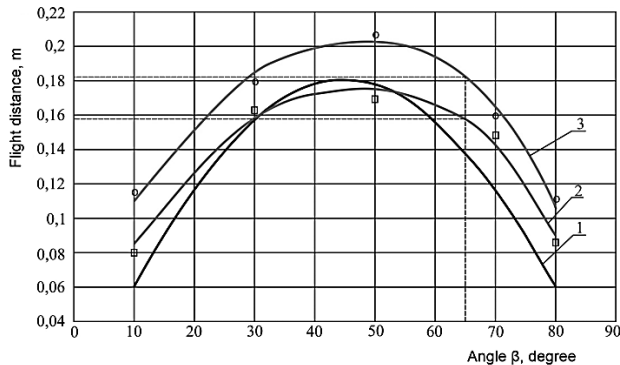
After decoding the coordinates of a singular point, the following natural values of the factors are obtained: Diameter of the scatterer base  $d = 40$  mm; Distance between the scatterer base and the furrow bottom  $h = 18$  mm; Height of the scatterer  $H = 20$  mm, where unevenness of seed distribution across the row width is 10.8 %.

Experiments are made to determine the quality indicators of work with optimal parameters via a moving conveyor belt with fixed adhesive tapes. The results of these experiments show that at machine speed of 6–8 km/h and an average rate of 120 kg/ha, the width of sowing row of experimental set is 18–20 cm. Field tests show operability of the opener and the sown row width of about 20–21 cm (Figure 9).



**Fig. 9. Field test of the opener**

It is clear from Figure 10 that the results of theoretical studies (curve 1) are close to the experimental data (curves 2 and 3). The greater falling distance in experimental studies is due to the travelling speed of the machine (in field test) or to the belt (in experimental set) as well as to the distance between the scatterer base and the furrow bottom. Hence, by increasing the height of the under-sweep space one can obtain width of the seeding/fertilizing strip up to 23 cm.



**Fig. 10. Falling distance of the particle  $l$  according to impact angle  $\beta$**   
**1 – theoretical results; 2 – field tests results;**  
**3 – experimental set results**

## Conclusion

To solve the problem of ensuring the quality of seed distribution during subsoil-broadcast sowing of cereals an original design of an opener with pendulum scatterer is proposed. A hemispherical scatterer is pivotally hung in the under-sweep space. Such a design decreases influence of field relief on the scattering quality and excludes nozzle clogging. Methodology for determination of falling distance of particles (seeds or fertilizer granules) in under-sweep space is proposed. The optimal values of scatterer parameters are experimentally determined: diameter of the scatterer base  $d = 38\text{--}40$  mm; distance between the scatterer base and the fur-

row bottom  $h = 16\text{--}18$  mm; height of the scatterer  $H = 19\text{--}21$  mm. When applied, unevenness of seed distribution across the row width is 10–11%.

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