Analysis of the combined coulter point of the precision seed drill

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Abstract: The given analysis is committed towards the improvement of the design of the precision seeding drill coulter, especially regarding the main working element - the point. The quality of the furrow and seed bed formation directly depends on the coulter point. In the vertical plane, the coulter point has a combined wedge working surface with an acute and obtuse soil entry angle, and in the horizontal plane, it is arrow-headed at an angle less than the angle of friction of the soil on the steel. There are theoretically determined, values of the main design and technological characteristics of the improved point. As the result of laboratory research of a coulter improved design, it was defined that at the values of an angle of an entry into the soil of the upper part of the coulter within $\alpha = 60^{\circ} - 70°$, the lower part of the coulter within $\alpha' = 140^{\circ} - 160°$, the camber of the point in the horizontal plane $\gamma = 10^{\circ} - 15°$, a decrease in the draught of the coulter is achieved on average by 16%.

Keywords: seed drill, coulter, point, combined angle of entry into the soil, draught

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1 Introduction

Nowadays, in Ukraine, the cultivation of cultivated crops occupies one of the most important places in the agricultural production. Over the recent years, there has been an upsurge in the development of selection of new hybrids and varieties that can provide heavy yields. It should be pointed out that only the quality of the seed material cannot solve all the problems of cultivating cultivated crops. In order for the seeds to show their real potential, it is necessary to observe the conditions of agricultural technology of cultivation at a very high level. It is known that heavy yields are guaranteed by obtainment of early and even sprouts. This can be achieved not only due to seeding within the agricultural requirements period, but also due to an appropriate implementation of the technological process by working bodies involved in the sowing process (Melnyk, 2016).

In the modern period of development of agricultural engineering, maximum attention is being directed towards the improvement of the technological process efficiency by means of

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designing new constructions of working bodies of seed drills (Brunotte et al., 2000; Volokha, 2015; Vasylkovska et al., 2016; Nanka et al., 2019). In so far as, the distributor mechanisms of the precision seed drill have already reached their maximum perfection and secure the reasonably accurate seeding, then the provision of high-quality seed placement in the furrow depends entirely on the design of the coulter and its elements (Artemenko et al., 2010; Nielsen et al., 2017).

The coulter points work well at shallow depth of well-prepared soil, and that's why have been widely used in cultivated crops seeding. The main element of such a coulter is a point, the design of which determines the quality of the technological process implementation (Falola, 1996; Tatarov, 2016). The operation of the coulter point consists of two stages: spreading of the top soil layer and forming a furrow with a compacted bottom. Each stage of the technological process greatly affects the quality of the formation of conditions for rapid seed germination. Due to the movement and deformation of the soil by means of the point, a furrow is formed, and its profile directly affects the placement of seeds along the depth and length of the row (Artemenko and Onopa, 2019).

Nowadays in the world and Ukraine, the most famous manufacturers pay considerable attention to the improvement of the drills' working bodies. Thus, after analyzing the products of such brands as: Prospect of the Gaspardo Company (2017), Operating manual Amazone (2017), Prospect of the Kverneland Company (2017), Prospect of the Ribouleau Company (2018), Prospect of the Kuhn Company (2021), Elvorti – Vesta 8 Profi (2021), it can be affirmed that the most common coulter design is a pointed coulter with an obtuse angle of entry into the soil.

The main disadvantages of such coulters are as follows: low multipurposeness (the design of the coulter is targeted at the seeding of one or several types of crops); due to the under-preparation of the soil, the pointer due to obtuse angle of entry into the soil, tends to disrupt the desired sowing depth, so that requires additional load on the section of working bodies, and results into an increase in its draught; the furrow profile formed by such coulters does not ensure seed distribution uniformity along the depth. A significant advantage of the opener with an obtuse angle of entry into the soil is the formation of a compacted seed bed, this fact allows capillary moisture to be pulled to the seed, and ensures its rapid germination. The abovementioned property ensures that coulters with an obtuse angle of entry into the soil have found the greatest application on modern seeders.

Coulters with a sharp angle of entry into the soil (hoe boots) are more future-oriented. Due to the fact that they are moving the soil from a bottom to top, they work well with increasing soil moisture. The main disadvantages in their operation are as follows: formation of a "hill" ahead of the coulter which leads to a seeding process depreciation; the formation of a loose bottom of the furrow due to the placement of part of the soil to the surface of the row; as the result of the loose bottom of the furrow, the seeds are placed randomly in depth. Nevertheless, there is also a significant advantage of a design of a coulter with a sharp angle of entry into the soil. Due to the sharp angle, the coulter moves along the depth more evenly, better cuts the soil layer and has reduced draught.

2 Materials and methods

2.1 Recent research analysis oriented towards the improvement of a coulter design

The combination of acute and sharp angles of entry into the soil in the coulters design is an upcoming trend for the modernization of the existing structure. Due to this combination, it is possible to reduce the disadvantages of both types of coulters and combine all their advantages.

Chaudhuri (2001), Murray (2006), Altuntas et al. (2006), Zhang et al. (2016), Avankina et al. (2017), Aikins et al. (2020), Kuş and Yıldırım (2021) and others, studied the design features of coulters and their elements, as well as the influence of technological characteristics on the quality of the technological process implementation.

Thus, Chaudhuri (2001) in his work reviewed the various designs of coulters in laboratory and field conditions. It was defined that increasing the angle of attack of the coulter in the horizontal and vertical planes increases both the plane and the depth of the furrow. It was determined that the speed of its movement has a great influence on the load bearing characteristics of the coulter. It was also defined that the pulling of capillary moisture into the furrow zone after the coulter has passed is a critical aspect that affects the rate of seed germination compared to factors such as even seed placement along the depth and length of a row. It is observed that the coulter points do not work satisfactorily on compacted soils, and in this case it is necessary to use coulters with a sharp angle of entry into the soil.

Murray et al. (2006) has researched components of various coulters. The main disadvantages of coulters with an obtuse angle of entry into the soil were determined and they are as follows: when working on heavy soils, for high-quality operation of the coulter, it is necessary to load the coulter more, and this affects the density of the furrow, which can result into a deterioration of the conditions for seed germination; working on fields with a large amount of plant residues, the coulter presses them into the furrow, which can worsen the coulter running depth; with an increase in soil moisture or clay soils, a coulter with an obtuse angle of entry can disrupt the shape of the furrow due to the sticking of an excess soil layer on its surface. The research provides a grounding of disadvantages of coulters with a sharp angle of entry into the soil: lifting and washover on the surface of the furrow of the lower moist soil layer; openers with a sharp angle of entry into the soil are more suitable for sowing at greater depths; during the formation of a furrow, a coulter with a sharp angle can bring into the surface of the field not only the soil, but also plant residues, and as the result can worsen the formation of the seed bed. The research emphasizes that in order to project new designs of coulter points, it is necessary to combine all the advantages of both types of coulters or provide additional elements to eliminate shortcomings in their work.

Altuntas et al. (2006) while conducting experiments with coulters which have different angles of entry into the soil, have defined that the main characteristic of the coulter - draught, is significantly affected by the angle of tip in the horizontal plane and the angle of attack in the vertical plane. Also, the working width of the point, the depth of sowing and the moving speed of the aggregate have an impact. It was determined that the coulter with the angle of attack of the point 70 ° has the least draught. The research concludes that the coulter design directly affects the quality of sowing and the rate of seed germination.

Zhang et al. (2016) notes that the front part of the point has a significant influence on the character of furrow formation and the qualitative indicators of operation. Four variants of points have been investigated during the research. All of these points have different designs of the working surface and different angles of entry into the soil. It has been determined that the most suitable for use on coulters of direct seed drill is a point with a sharp angle of entry into the soil and a curved working surface. Such a coulter secures not only a reduced draught, but also a minimum removal of the lower soil layers on the surface of the furrow. During the operation of such a coulter, the top layer of plant residues is minimally moved to the sides, which most contributes to the formation of conditions for quick germination of seeds.

Avankina et al. (2017) in her research notes that coulters with a sharp angle of entry into the soil help to improve the stability of a movement along the depth, and with an obtuse one, vice versa, have the ability to be removed from the soil when they hit obstacles. The research concludes that it is necessary to combine the advantages of both types of coulters, on the basis of which the design of a combined rotary coulter for sowing small seeds is proposed.

Aikins et al. (2020), considering opener designs for direct seeding, concludes that coulter points, compared to disc ones, have a higher penetration ability and better prepare the seed bed, and this directly affects the crop yield. It is also noted that coulters with a sharp angle of entry into the soil work better on soils with increased density. According to the author's opinion, the main disadvantage of coulter points is poor work in the soil, which has a large amount of plant residues. It was defined that over-compactness of the seed bed can significantly reduce the rate of seed germination, that's why the design of the point must be able to secure the operation of the coulter in conditions of high soil moisture.

Kuş and Yıldırım (2021) upon researching precision seed drills, emphasizes – that the design of the working surface of the coulter has a significant impact on the quality of distribution seeds along the depth of the furrow In the research, it's being noted that for precision seed drills, the angle of entry of coulter point should correspond to the angle of entry into the soil of the disc coulter. The drop height of the seeds and the accuracy of seed placement along the depth of the furrow have a significant impact on precision seeding. And seed placement is the main factor that affects the speed of plant emergence on the field surface.

The carried out review of the baseline conditions of scientific research regarding the determination of rational design of the coulter of the row-crop seed drill, made it possible to reveal that there is needed new research and development of the coulter, the design of which would take into account the identified disadvantages in their operation. The proposed coulter must have a combined point and must fully meet the requirements of agricultural technology towards the sowing of cultivating crops.

2.2 Grounding of design features of a point of an advanced coulter

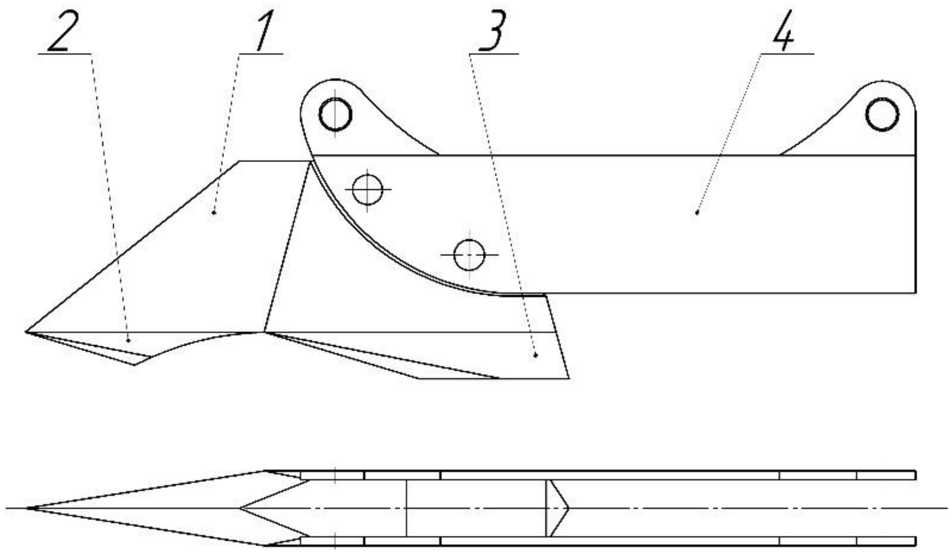
After analyzing modern coulter designs, it was determined that they do not allow sowing the entire variety of cultivated crops and are more focused on sowing one type of crop. Also, they do not provide the sufficient level of sowing quality and have significant draught.

In light of this, there is a need to continue the further research of the seed drill coulter, mainly the point, as a main element, which influences on the formation of the furrow and seed bed. In order to take into account, in the design of the point, all the advantages of coulters that were identified above, it is necessary to determine the functions that should be performed during the technological process. This way, during furrow formation, the coulter point of a row-crop seed drill goes through the following processes: the beginning of the formation of a furrow, the formation of a furrow, the formation of a seed bed.

In its turn, the beginning of furrow formation can be considered as a number of processes: improved access of the coulter into the soil, partial side displacement of the upper dry soil layer, top soil cutting off, uniformity of the coulter movement along the furrow depth. In a direct manner, the furrow formation itself is characterized by the following functions: the ability to eliminate obstacles in the path of the coulter, decreased coulter draught, the beginning of the furrow walls formation and compaction. The formation of the seed bed is characterized by the following functions: the formation of a seed bed in the form of a wedge hole target at fixing the seeds while contacting for the first time, the formation of a wedge-type seed bed targeted at improvement of the seed distribution uniformity along the depth.

In furtherance of the stated functions of the technological process performance, we have developed the improved coulter (Figure 1) which has a combined point, the upper and larger part of which has a working section with a sharp angle of entry into the soil, lower - smaller part, and compactor, located in the rear part of the furrow opener, which forms seedbed aimed at seed distribution uniformity along the depth, has a working surface with an obtuse angle of entry into the soil, and moreover, in the vertical plane, both working surfaces of the coulter are tilted at an angle less than a friction angle of the soil against steel. In order to eliminate the "hill" ahead of the coulter during the coulter operation, the furrow opener in the horizontal plane is sharpened at an angle less than the angle of friction of the soil against the steel. This makes it possible to point off on either sides from the furrow.

The offered coulter is working in the following way: while moving along a sowing depth, the upper part of the wedge furrow opener 1, which is sharpened at an angle less than the angle of friction of the soil against the steel, cuts the layer of the soil in the vertical plane. Through this process, the coulter movement is eased and the "hill" ahead of the coulter is eliminated by removing the topsoil on both sides of the furrow in the horizontal plane. When, both upper and lower parts of the coulter 2, meet obstacles and get into compacted areas of soil, they destroy these obstacles or throw compacted soil aside. The compactor, located in the rear part of the point 3, with an obtuse angle of entry into the soil, forms seedbed aimed at seed distribution uniformity along the depth. With the increase of soil moisture and weeds, the design of the coulter facilitates self-cleaning (Artemenko et al., 2019).



1 – upper part of a point; 2 – lower part of a point; 3 - compactor; 4 –sidewalls

Figure 1 The developed seed drill coulter with a combined point

With regards towards further grounding of the modernized coulter design, we have defined the main design and technological parameters that directly affect the quality of the furrow process formation and a coulter draught: in the vertical plane - the angles of entry of the lower and upper parts of the point into the soil; in the horizontal plane - the angle of tip of the point in the front part which affects the distance of throwing some part of upper soil layer aside; the stability of the coulter's movement in the longitudinal direction, the capability to surpass the compacted areas of a soil without changing the depth of movement; the taper angle of a coulter point compactor, which influences on the seed distribution uniformity along the furrow depth.

2.3 Substantiation of design parameters of the coulter point

To determine the conditions under which the draught of the coulter will be the least, it is necessary to obtain rational values of the angles of entry of the coulter into the soil in the vertical plane.

On the assumption that the soil for sowing cultivated crops is well prepared and is well-loosened, the interaction of the coulter with the soil can be represented as the interaction of an inclined plane with a fraction (Figure 2).

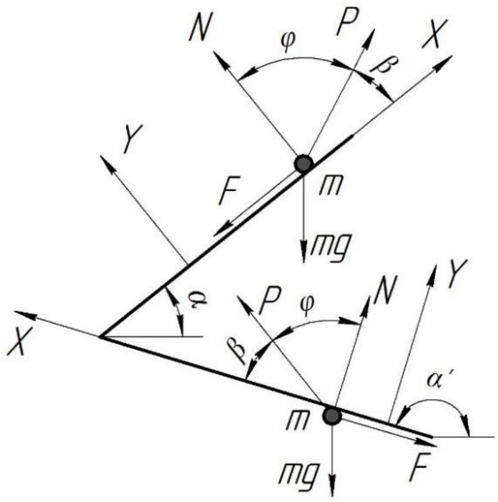


Figure 2 Pattern of forces acting on the point in a vertical plane

Let's consider the interaction of the point with the fraction of soil in the upper part. On some part of the soil *m*, which is located on the top of the point with angle of tip α is acting an active pushing force *P* at an angle *β*.

At an angle *β* (degrees) on the fraction of soil which is located on the top of the point, the point has an angle of attack α (degrees), is acting an active pushing force $P_{(N)}$. From the side of the point surface, is acting perpendicular to it normal reaction, force $N_{(N)}$. Parallel relatively to the point plane is directed against the friction force movement $F_{(N)}$. The friction force is related to the normal force as represented in the following equation:

$$F \leq N \times tg\varphi \quad (1)$$

where φ - friction angle (degrees).

The mass movements in projections on the axis X_iY are as follows:

$$-mg \times \sin\alpha - F + P \times \cos\beta = mW_X \quad (2)$$

$$-mg \times \cos\alpha + P \times \sin\beta + N = 0 \quad (3)$$

whereWX - acceleration along the axis *X* (m/s2); mg - gravitational force (kg m/s2).

Taking into account that $F = kN$, where $k = tg\varphi$ with respect to mW_x and *N*, we get:

$$N = mg \times \cos\alpha - P \times \sin\beta \quad (4)$$

$$mW_X = -mg \times sin\alpha - k \times (mg \times cos\alpha - P \times sin\beta) + P \times cos\beta \quad (5)$$

As follows from Equation 4 in order for the soil fraction to be located on the surface, it is necessary and sufficient that the force *N* would be positive, that is:

$$N = mg \times \cos\alpha - P \times \sin\beta \geq 0 \quad (6)$$

In other words, force P should not exceed:

$$P \leq mg \times \cos\alpha / \sin\beta \quad (7)$$

In order for the movement to start under such conditions, it is it is necessary and sufficient that the magnitude of the force mW_x would be positive, that is:

$$mW_X = -mg \times sin\alpha - k \times (mg \times cos\alpha - P \times sin\beta) + P \times cos\beta \geq 0 \quad (8)$$

In other words, force P should exceed:

$$P \geq \frac{mg \times \sin\alpha + kmg \times \cos\alpha}{k \times \sin\beta + \cos\beta} \quad (9)$$

This condition must be met when $k = tg\varphi$.

Substituting this equation into a dependence (9), we get:

$$P = \frac{mg \times \sin(\alpha + \varphi)}{\cos(\beta - \varphi)} \quad (10)$$

The obtained equation shows that the greater the angle of tip of the surface, the greater magnitude of the force P (N) is needed in order to ensure the movement of the soil fraction along the coulter point surface.

Calculation of the angle of attack of the lower part of the point α' (degrees), which begins the formation of a furrow, is performed similarly to the above and will look like:

$$P = \frac{mg \times \sin(\alpha' - \varphi)}{\cos(\beta - \varphi)} \quad (11)$$

The obtained equation shows that the greater the angle of tip of the plane the less value of the force P is needed in order to ensure the movement of the soil fraction along the point surface.

Analyzing the obtained Equations 10 and 11, taking into account that a friction coefficient of a black soil against a metal made it possible to set theoretical angle change range α and α' which will be: $\alpha \geq 40^\circ$, $\alpha' \leq 160^\circ$. It is known that the following factors influence the coulter draught: the material from which the point is made, physical and mechanical properties of the soil, working surface width. To allow further experimental researches, we will set the range of angle values in order to determine their rational values within the following limits: upper part of the point $\alpha = 40^\circ - 60^\circ$, lower $\alpha' = 120^\circ - 160^\circ$.

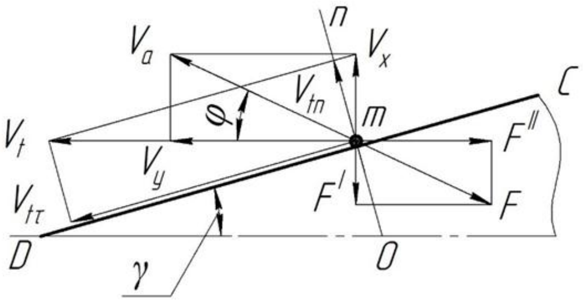


Figure 3 Interaction scheme of the soil grain with a lateral surface of a point in a horizontal plane

In order to assert an angle of tip of a point in a horizontal plane γ (degrees), let's consider the interaction of its lateral surface with the soil. Let's consider that the edge shape is of the form of a dihedral wedge, the soil is well loosened and is represented as granular soil. While a coulter is moving, the interaction of a soil fraction with a lateral surface of a point occurs in the form of a breakout (Figure 3). When the point is moving at a speed of V_t (m s^{-1}), soil grains, while reaching the working surface, will move in a direction deviated from a normal by the external friction angle with a speed V_a(m s^{-1}): $V_{tn}=V_t \times \sin\gamma$, $V_{tn}=V_a \times \cos\varphi$.

Absolute speed V_a of a grain m will have a meaning:

$$V_a = V_t \times \sin\gamma / \cos\varphi \qquad (12)$$

where V_t – coulter travel speed (m s^{-1}); φ – angle of friction (degrees).

The interdependence (12) shows that if angle γ decreases, the absolute speed of grains throwing is decreasing. The components of the grain absolute speed: along the coulter movement V_t and perpendicular to it V_x (m s^{-1}). The distance of a grain being thrown aside depends on the component:

$$V_x = V_a \times \cos(\gamma + \varphi) \qquad (13)$$

Substituting Equation 12 into Equation 13 and rearranging, we obtain:

$$V_x = \frac{V_t \times \sin\gamma \times \cos(\gamma + \varphi)}{\cos\varphi} \qquad (14)$$

Let's test Equation 14 for extremum (upon condition that dif V_y to γ equals zero) this will make it possible to determine maximum magnitude of a lateral component of an absolute speed. Upon conduction of appropriate rearrangements, we have obtained the following dependence:

$$2 \cdot \gamma + \varphi = \pi / 2 + \kappa\pi \qquad (15)$$

We will be considering the speed change in the interval [0; $\pi/2$], so an Equation 15 will be as follows:

$$\gamma = \pi / 4 - \varphi / 2 \qquad (16)$$

The Equation 16 makes it possible to determine that that the lateral component of the absolute speed will be maximum and the throwing of the soil aside will be greatest. The analysis of the dependency (16) shows that the lateral component V_x as the angle increases, first increases and then decreases. In the process of furrow formation, the upper part of the point throws the top dry layer of soil aside. That's why it is necessary to define the range of lateral throwing of the soil aside by means of the working surface of the upper part of the point.

Let's consider that with the maximum value of the lateral throwing aside speed, the soil grain moves away from the surface of the point and moves along the surface of the field with the initial speed V_{xo} (m s^{-1}).

The grain is affected by a friction force $F' = f_2 \times mg \times \cos(\gamma + \varphi)$ (N), (where f_2 - soil friction coefficient), which impedes its movement.

Then the differential equation of soil grain movement towards the direction V_x (m s^{-1}) will be:

$$m\frac{d^2 S(t)}{dt^2} = -f_2 \times mg \times \cos(\gamma + \varphi) \quad (17)$$

On integrating the Equation 17 with respect to t and calculating the time t (s) of movement of the grain from the condition that the final speed of the grain equals zero, we get

$$L = \frac{V_n^2 \times \sin^4 \gamma \times (ctg\gamma - tg\varphi)^2}{2 \times f_2 \times g \cos(\gamma + \varphi)} \quad (18)$$

Equation 18 shows that the distance L (m) of lateral throwing of soil grains aside depends on the camber angle of deflector device and the physical - mechanical properties of the soil and is a square-law to the travel speed of the machine. Upon the results of conducted analysis of the Equation 18, it is possible to define that taking the angle of the external friction of the soil $\varphi = 30^\circ$, we will get an angle of tip $\gamma = 30^\circ$, and also that the throwing soil speed range is increasing with the increase of the angle of tip up to 30°, and with further increase – decreases. While analyzing the conditions in which the coulter works and taking into account the agro-technical requirements for furrow formation, it is necessary that the lower moist layers would be placed on the soil surface in a minimum quantity, that's why for further researches, we consider $\gamma = 10^\circ - 20^\circ$.

In the research, which has been carried out by Artemenko et al. (2010), were considered the parameters of sharpening angle of a device targeted at seedbed formation by precision seed drill coulter and is obtained a dependency targeted at determination of an angle between furrow walls necessary for high-quality placement of seeds along the furrow depth. This dependence can also be applied to a compactor located in the rear part of the furrow opener. This compactor forms seedbed and has a working surface with an obtuse angle of entry into the soil. For further researches, we are going to consider the angle the compactor which forms seedbed within the range $\alpha_б = 25° - 35^\circ$.

On the ground of carried out analytical and research work, there was substantiated the design of an improved drill coulter with a combined surface of the pointer and sharp and acute angles of entry into the soil and defined its main technological parameters.

3 Results and discussion

3.1 Technique of laboratory researches of the improved coulter parameters

To verify the obtained results of theoretical researches, laboratory studies of the developed design of the coulter point of the row-crop drill were carried out. For this purpose, an experimental plant was developed on the basis of a soil channel 12 m long and 1 m wide (Figure 4).

Laboratory researches of the coulter point were carried out according to the following method. In order to determine the rational values of the angle of camber of the point in the horizontal plane, we used digital video recording. The camera was mounted on a bracket in the front part above the coulter with a focus directed towards the space in the point operation area perpendicular to the coulter axis. The shooting speed was 100 frames s^{-1}. The coulter speed varied from 1.0 to 2.5 m s^{-1}. The moisture content of the soil layer was prepared in accordance with the sowing conditions and varied from 16% to

20%. The soil used while conducting the research is clay-loam rich black soil, with an aggregate composition that meets the agro-requirements for sowing row crops. The coulter was set at a sowing depth of 4 cm. This depth is used for most crops when sowing within the limits of agricultural requirements. The surface of the soil channel was restored after each coulter pass. For each value of soil moisture, the experiments were repeated five times. After the researches were finished, the filmed material was processed on a PC using application programs.

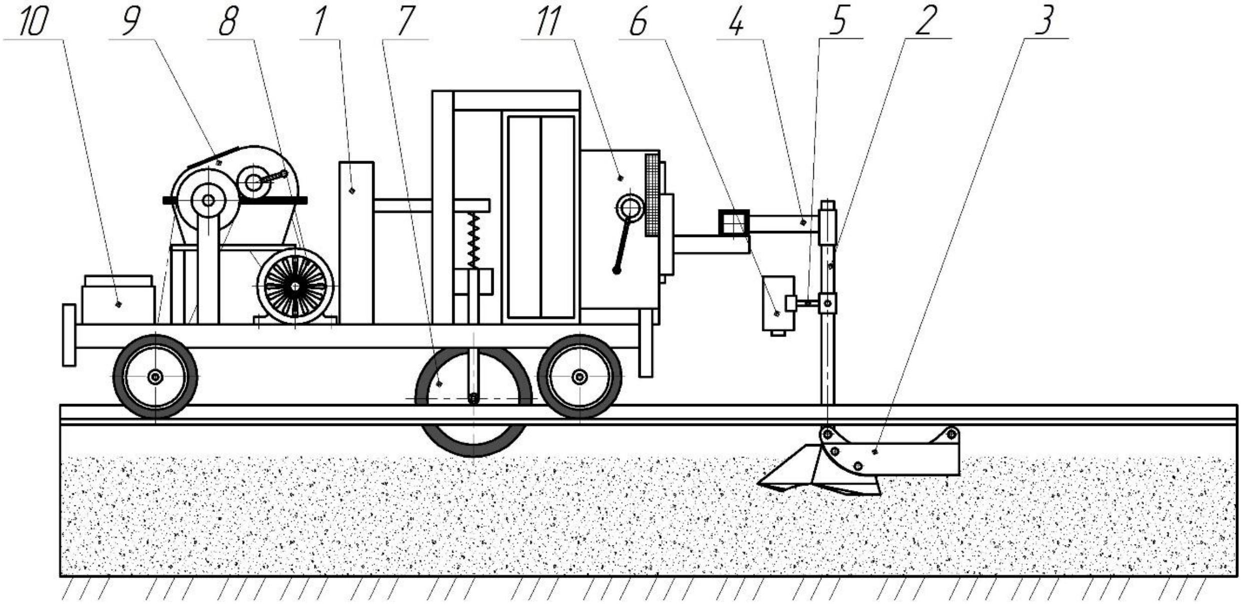


Figure 4 the scheme of experimental plant aimed at research of coulter point:
1 – self-propelled wagon; 2 – bracket; 3 – coulter; 4 – mounting bracket; 5 – digital video camera bracket; 6 – digital video camera; 7 – roller; 8 – electric motor; 9 – gear box; 10 – additional load; 11 – weighing batch adjuster

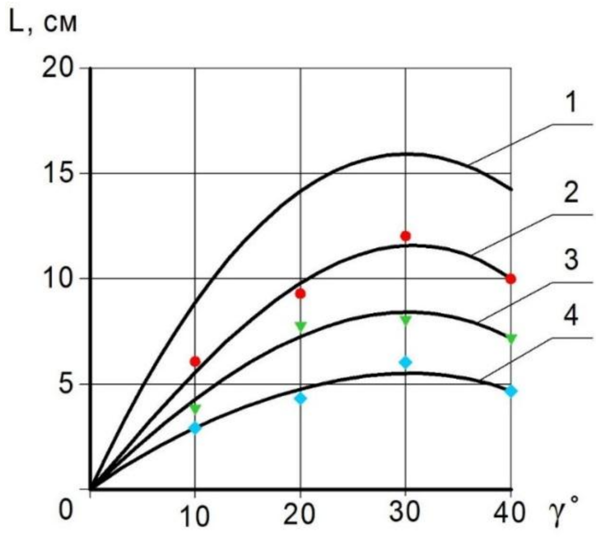
The further experimental researches were carried out on the same installation, but with an installed device for measuring the coulter draught. With the purpose of establishing the dependencies of the examined processes, all the obtained digital data were processed via methods of probability theory and mathematical statistics (Vasylkovskyi et al. 2015).

3.2 The results of laboratory researches of the improved coulter parameters

Identification tests aimed at grounding of point camber angle in the horizontal plane γ were carried out in order to verify the obtained theoretical preconditions, namely, the dependence of the distance of soil grain throwing aside of the upper horizon on the change of point camber angle. The point camber angle in horizontal plane γ is one of its main elements because it affects the quality of removal of the upper dry soil layers towards the furrow, ensuring that the seeds are wrapped in the lower wet soil layers.

In order to determine the rational value of the angle γ there were carried researches taking into account: the effect of soil moisture on the throwing distance; value of the angle of attack of the point front part $\alpha = 60^0$ (the rational meaning of which is theoretically defined above); the width of the point (were chosen on the basis of the improved coulter design condition and considering the interdependence of the section of the working bodies of the drill).

As a result of the conducted experiments, we obtained distance graphics of soil grains throwing depending on the angle of camber and soil moisture at a constant speed (Figure 5). As can be seen from the obtained dependences, the nature of the soil grains throwing is similar to the theoretical value (curve 1 is plotted according to the theoretical dependence of Equation 18), which points out that the reliability of obtained theoretical recommendations. On the basis of carried out work, it is clearly seen that the most effective parameter of the camber angle will be an angle close to γ=30° .



1 – theoretical dependence; 2,3,4 – with upper layer moisture W=16%, 18%, 20%

Figure 5 Throwing distance of soil grains via point in a horizontal plane depending on the angle value γ at V=2 m s^{-1}:

But along with the increase in the angle γ the coulter draught will increase, that's why, when determining its rational values, it is needed to take into account the design features of the coulter itself, its overall dimensions and dimensions for installing the coulter on the section of working bodies. Under field conditions, a more important factor in the coulter operation is the minimum draught, and the distance of throwing of the soil top layer should ensure the process of furrow formation. Forasmuch as, the upper layers must be thrown back to a distance so that they do not fall into the furrow during the coulter operation then analyzing Figure 5 it can be said that at the angle $\gamma = 15° - 25^0$ these conditions will be met, so this range can be used for further research.

3.3 The results of laboratory researches of the influence of the design parameters of the coulter point on the draught

In order to verify the obtained theoretical results of the influence of the design parameters of the coulter point on the draught, we have carried out an experimental research in the laboratory conditions using the method of mathematical modeling. As a result of carried out theoretical analysis, we have defined a separate design and kinematic parameters that affect the coulter draught. Also, preparatory exploratory theoretical and experimental researches make it possible to determine the influence of separate factors and determine their levels. Factors that have a significant impact on the operation of the coulter: the angle of the coulter upper part α (degrees), the angle of the coulter lower part α' (degrees), coulter speed V_t (m s^{-1}), coulter camber angle in horizontal plane γ (degrees). Parametric restrictions, which are equal variations of factors, are shown in Table 1. Optimization criteria Y (N) is chosen a coulter draught.

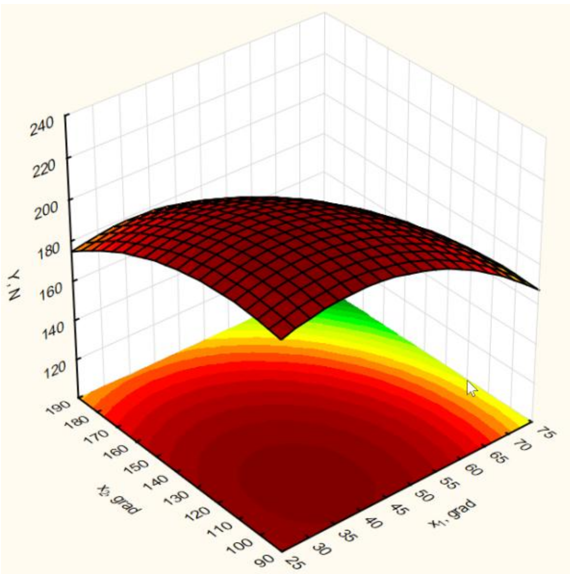
Table 1 Levels of variation of experimental research factors

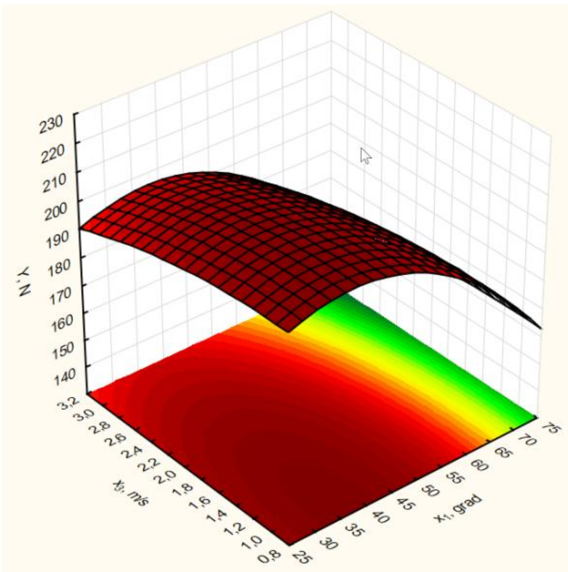
Factors		Level of variation		Variation interval
Item	Designation	Lower (-)	Upper (+)	
Angle of upper part of the point α, degrees.	x_1	40	60	10
Angle of lower part of the point α', degrees	x_2	120	160	20
Coulter speed V_t, m s^{-1}.	x_3	1,5	2,5	0,5
Coulter camber angle in horizontal plane γ, degrees.	x_4	15	25	5

In order to establish the relationship between the design and technological parameters of the coulter and define rational values, there were carried out a mathematical planning of the experiment via "STATISTICA 12" application software package. While conducting experimental researches, a matrix of the central compositional plan 2^4 + star points was implemented. The simulation results are shown in Table 2. All researches were carried out with a three-fold repeatability with entering the results into the table and calculating the average value of the obtained coulter draught.

Table 2 Results of the implementation of experimental studies

Factor	Effect Estimates; Var.:Y, N; R-sqr=,70491; Adj:,32934 (Output table, sta) 4 factors, 1 Blocks, 26 Runs; MS Residual=180,0015 DV: Y, N									
	Effect	Std.Err.	t(11)	p	-95,% Cnf.Limt	+95,% Cnf.Limt	Coeff.	Std.Err. Coeff.	-95% Cnf.Limt	+95,% Cnf.Limt
Mean/Interc	201,1620	9,484388	21,20981	0,000000	180,2870	222,0370	201,1620	9,484388	180,2870	222,0370
(1)x_1, grad(L)	-16,0000	5,477248	-2,92118	0,013908	-28,0553	-3,9447	-8,0000	2,738624	-14,0277	-1,9723
x_1, grad(Q)	-6,3726	6,449487	-0,98809	0,344347	-20,5679	7,8226	-3,1863	3,224744	-10,2839	3,9113
(2)x_2, grad(L)	-13,0000	5,477248	-2,37345	0,036926	-25,0553	-0,9447	-6,5000	2,738624	-12,5277	-0,4723
x_2, grad(Q)	-4,1226	6,449487	-0,63922	0,535764	-18,3179	10,0726	-2,0613	3,224744	-9,1589	5,0363
(3)x_3, m/s(L)	-5,1479	5,424326	-0,94903	0,362988	-17,0867	6,7910	-2,5739	2,712163	-8,5434	3,3955
x_3, m/s(Q)	-1,3729	6,119580	-0,22435	0,826600	-14,8420	12,0962	-0,6865	3,059790	-7,4210	6,0481
(4)x_4, grad(L)	17,3333	5,477248	3,16461	0,009005	5,2780	29,3887	8,6667	2,738624	2,6390	14,6943
x_4, grad(Q)	-2,8726	6,449487	-0,44541	0,664664	-17,0679	11,3226	-1,4363	3,224744	-8,5339	5,6613
1L by 2L	-0,7500	6,708231	-0,11180	0,912994	-15,5147	14,0147	-0,3750	3,354116	-7,7574	7,0074
1L by 3L	0,2500	6,708231	0,03727	0,970939	-14,5147	15,0147	0,1250	3,354116	-7,2574	7,5074
1L by 4L	1,0000	6,708231	0,14907	0,884196	-13,7647	15,7647	0,5000	3,354116	-6,8824	7,8824
2L by 3L	-0,5000	6,708231	-0,07454	0,941923	-15,2647	14,2647	-0,2500	3,354116	-7,6324	7,1324
2L by 4L	-0,7500	6,708231	-0,11180	0,912994	-15,5147	14,0147	-0,3750	3,354116	-7,7574	7,0074
3L by 4L	0,2500	6,708231	0,03727	0,970939	-14,5147	15,0147	0,1250	3,354116	-7,2574	7,5074





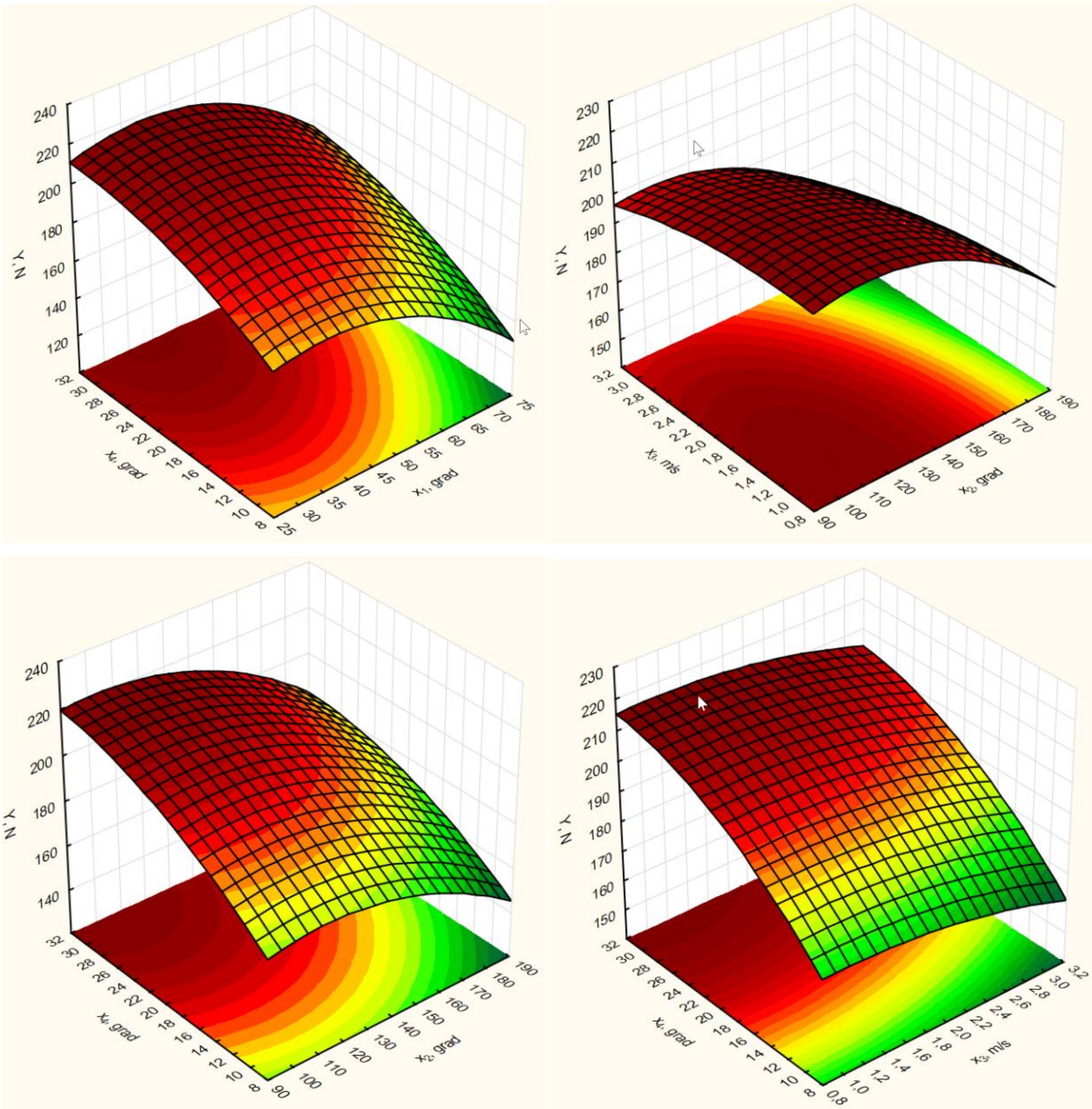


Figure 6 Response surfaces and lines of equal output of the pairwise influence of factors on the coulter draught

In Figure 6, the response surfaces and lines of equal output of the pairwise influence of factors on the optimization criterion are shown.

On the basis of the provided tabular results, a statistical mathematical model has been obtained. This model makes it possible to evaluate the influence of factors on the coulter draught and can be represented as follows:

$$Y = 201{,}162 - 8 \times x_1 - 6{,}5 \times x_2 - 2{,}5739 \times x_3 + 8{,}6667 \times x_4 - 3{,}1863 \times x_1^2 - 2{,}0613 \times x_2^2 - 0{,}6865 \times x_3^2 - 1{,}4363 \times x_4^2 - 0{,}375 \times x_1 \times x_2 + 0{,}125 \times x_1 \times x_3 + 0{,}5 \times x_1 \times x_4 - 0{,}25 \times x_2 \times x_3 - 0{,}375 \times x_2 \times x_4 + 0{,}125 \times x_3 \times x_4$$

For a more convenient visual assessment of the results of experimental researches, Figure 7 represents the profiles of factors desirability.

Analyzing the response surfaces and lines of equal response, the profiles of the factors desirability and the statistical mathematical model, it can be stated that the rational angle of entry into the soil of the upper part of the point is within $\alpha = 60° - 70°$ which is explained by the influence of the physical and mechanical composition of the soil and considering the friction force. The value of the angle of entry into the soil of the lower part of the point is within $\alpha' = 140° - 160°$, indeed in such conditions, occurs the minimum coulter draught. Also, coulter draught is significantly affected by the speed of its movement, and the rational values of this factor are in the range of values V_t=2-3 ms^{-1}. This coulter speed ensures the highest furrow formation quality. Point camber angle in the horizontal plane γ=10° - 15° allows you to get the necessary distance of throwing of the upper dry layer of soil aside from the furrow and ensure stability of its formation. It should be noted that draught is achieved with the indicated ranges of factor values Y=160(N)-185.5(N), which is lower than the serial coulter on average by 16%. For comparison, we used a coulter point with an obtuse angle of entry into the soil of the drill Vesta 12 manufactured by Elvorti, the draught of which is 200(N) – 212(N). Thereafter, the conducted laboratory researches have shown that the obtained theoretical calculations are in the range of rational values of the design and technological parameters of the improved coulter point of the precision seed drill. But to determine the optimal values of these parameters, there are needed further researches of the improved coulter in the field conditions using the whole variety of soils on which cultivated crops are sown.

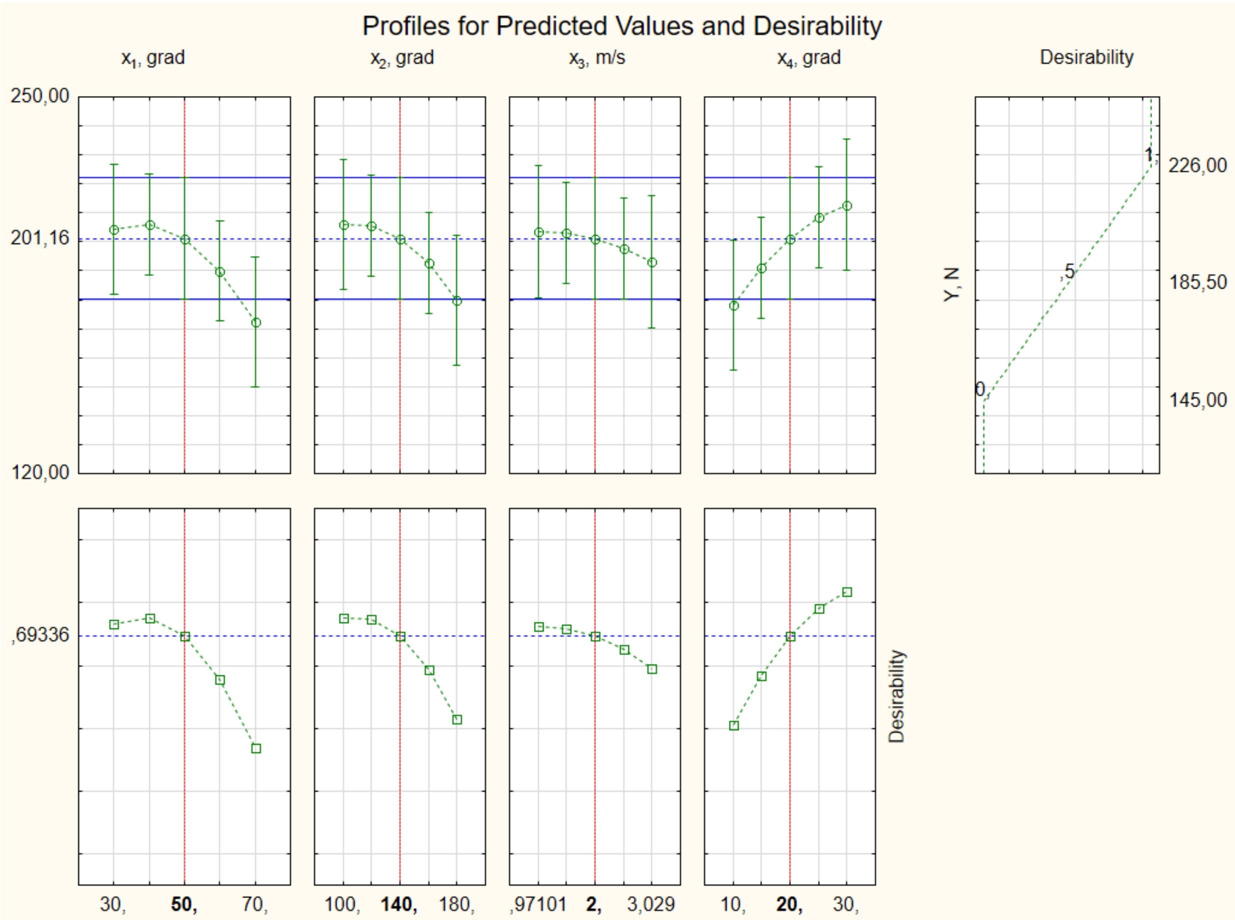


Figure 7 Profiles of factors desirability obtained while carrying out the central compositional plan 2^4 + star points

4 Conclusions

Based on the carried out analysis of the current state of development of the designs of precision seed drills coulters, it was determined that in order to combine all the advantages of existing designs, a promising direction for improving the coulters is the combination of sharp and obtuse angles of entry into the soil in the front part of the point.

As a result of the analysis of the operation of a serial coulter and carried out exploratory researches, there were proposed a combined wedge point which has a working surface with a sharp and obtuse angles of entry into the soil. Moreover, both working surfaces of the point in the vertical and sharpening of the point in the horizontal plane are less than the friction angle of the soil on steel, which gives the ability not only to form a furrow with a compacted seed bed, but also to throw away the soil to both sides of the furrow.

As a result of carried out theoretical and experimental researches in laboratory conditions, it was defined that the rational angle of entry into the soil of the upper part of the point is within $\alpha = 60° - 70°$, lower part of the point is within $\alpha' = 140° - 160°$, point camber angle in horizontal plane $\gamma = 10° - 15°$, with the given ranges of values of the design parameters of the point, a decrease in the coulter draught is achieved on average 16%.

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