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IMPROVING THE EFFICIENCY OF A SOWING TECHNOLOGY BASED ON THE IMPROVED STRUCTURAL PARAMETERS FOR COLTERS

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Дослідження присвячені підвищенню ефективності технологічного процесу сівби сільськогосподарських культур на підставі проведення теоретичних і експериментальних досліджень функціональних залежностей операцій технологічного процесу від параметрів сошників. Були обґрунтовані їх варіанти, наступний синтез яких в різних поєднаннях, в залежності від вимог, дозволив створити сімейство універсальних, комбінованих і спеціальних сошників.

На основі співставлення аналізу і експериментальних досліджень широко використовуваних конструкцій сошників і параметрів їх роботи були виявлені недоліки в експлуатації, а також встановлено їх вплив на зниження врожайності зернових культур. При цьому теоретично обґрунтували вплив типу та конструкції сошників на взаємодію з насінням і ґрунтом при проведенні посівних робіт в різних умовах. Це дозволило встановити зв'язок між параметрами сошників і операціями технологічного процесу.

На підставі отриманих даних розробляли нові конструктивні елементи і типи сошників (їх сімейство), які забезпечують вимоги агрономічної науки і споживачів. Вони вдосконалюють технологічні процеси взаємодії їх конструктивних параметрів (лобової поверхні, наральника, бічних щік) з ґрунтом. Це покращує формування борозни для насіння, розміщення його рівномірно по площі і глибин, і загортання вологим ґрунтом. Цим поліпшуються умови проростання насіння, розвитку культурних рослин і підвищується врожайність до 10 %.

Ці робочі органи здатні виконувати рядовий, вузькорядний, розкидний, протиерозійний посів і підсівати зріджені сходи, підвищують врожайність і захищають ґрунт від ерозії.

Так, в результаті виконання даної роботи вдосконалено і створено таке сімейство сошників для зернових сівалок:

– універсальні наральникові: наральниковий сошник, анкерний сошник, наральниковий сошник з комбінованим наральником, сошник з комбінованим наральником з вирізами в щоках і ущільнювачем-сепаратором ґрунту, наральниковий сошник з спрямовувачем і регульованим відбивачем насіння;

– вузькорядні: наральниковий сошник;

– комбіновані: комбінований наральниковий сошник з прямим кутом входження в ґрунт з спрямовувачем і відбивачем насіння;

– протиерозійні: наральниковий сошник, анкерно-дисковий сошник з механізмом навішування, лаповий сошник, дисковий сошник

Ключові слова: диференціація насіннєвого шару, сошник наральниковий, лобова поверхня, комбінований наральник, вирізні бокові щоки сошника

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1. Introduction

Crop production accounts for one of the leading places in the overall structure of agriculture. One of the basic field operations that defines the future yield of agricultural crops is seeding. It is the quality of sowing that affects the dynamics of shoots and, consequently, the harvest. Colters are the principal working bodies of seeders, thereby defining the quality of sowing. That is why the issue on constructing colters of different designs is given so much attention.

Ensuring the effective functioning of grain seeders necessitates the introduction of appropriate changes to the design of colters. Created nearly a century ago, colters have not changed significantly. There is currently no any set of colters for specific needs in production. There are no recommendations for their effective use. Given this, a task was set to construct a family of colters with improved indicators that would enable the qualitative planting of the entire spectrum of cultures. It is important to devise recommendations for the effective application of improved standard colters, as well as experimental ones.

It is known that grain seeders are mainly equipped with tipped (anchor and keeled) and disc colters, which have certain flaws and do not meet current agricultural requirements. They do not form a multilevel planting soil layer; the disc colters do not compact it in the zone of seed distribution; they do not separate the surface layer of soil; they do not eliminate the under-colter inclined surface. Colters of all types neither form nor adequately orient a grain flow.

There is an ongoing research aimed at improving colters, but there have been no significant changes to the design of industrially fabricated colters that could change the technological process of a grain seeder. There is no a set of colters that would enable the high-quality sowing in all grain-producing areas by various techniques, with reduced energy consumption, which could improve yield and resist the deflation of soil. There are no, up to now, such working bodies that could form a multi-level planting soil layer with appropriate parameters. All existing designs do not separate soil to improve the resistance to its deflation. Still an integral part of the technological process is the existence of the under-colter inclined surface, upon which seeds are placed, being planted non-evenly for depth and area. There are no scientifically based recommendations on the effectiveness of application of colter types that take into consideration the soil-climatic conditions. It is necessary to substantiate scientifically the structural parameters for colters, which could improve the technological process of their interaction with soil. To form a furrow for seeds of the desired shape and size, to plant the seeds evenly for area and depth, and to cover them with moist soil. Based on the above, the chosen field of the current research is important and relevant.

2. Literature review and problem statement

Recent decades have witnessed active research into tipped colters aimed at improving the quality of sowing, that is improving the seed distribution uniformity for area and depth on order to form more favorable conditions for seed germination.

Germany, Ukraine, and Sweden commonly use tipped universal colters. Their versatility implies that a colter has two tips.

The original design of an anchor colter was proposed in Sweden [1]; it has a removable furrow-forming wheel.

A similar colter was designed in Germany [2], which also has a tip with two caps.

Paper [3] reports results of research underlying the construction of a colter with a variable curvature of the tip.

The above data show that all technical solutions were executed without enough scientific justification.

Another direction for colters improvement is the construction of such working bodies that would compact the layer of soil in the area of seed deposition.

Thus, authors of [4, 5] constructed a colter equipped with a paw and a compacting roller.

In Germany, seeders AT300/AT600 (Köckerling, Germany) are used for stubble sowing, equipped with paw colters, set in two rows.

Authors of [6, 7] constructed a combined colter for planting seeds and fertilizers with a soil layer between them.

The seeders made by the firm Simulta (Finland) use, for seeding cereal crops, a combined colter, which is a combination of a disk knife and a keeled tip.

The reported technical solutions in the form of combinations of arrow paws and compaction rollers, as well as the combined working bodies, have not been scientifically substantiated. Left unjustified are not only the design parameters, but the installation settings for the paw and compaction rollers as well.

According to the author of work [8], most working bodies of tilling machinery are a development of the two-edge or three-edge wedge. Colter also represents a two-edge wedge.

Studies into improvement of tipped colters cover many areas. Important is to drill seeds into a moist soil, to compact it in the area of seed deposition, to reduce the removal of moist soil layers to the surface.

Paper [9] noted, when studying the interaction between anchor colters and soil, that the process of discarding soil particles depends on the design parameters of a colter and the mode of its operation. The farther from the longitudinal centerline of the colter movement the soil is discarded, the thinner is the layer that covers the seeds, that is, their covering depth decreases. The authors considered the interaction of colters with different angles of soil penetration. The paper identified the need to construct a colter with an intermediate angle of soil penetration – between sharp and obtuse angle.

Researchers [10, 11] reported results describing the interaction between a colter and soil. The authors suggested that improving the quality of operation of colters necessitates undertaking a research into key design parameters for colters. Some researchers found that the rough bottom of a furrow prevents seeds from rolling and improves the uniformity of their distribution [12]. The proposed colter could be used for sowing the cultivated crops only because grain crops vary considerably in their properties and they need different conditions and different working bodies, that is, it is necessary to conduct additional studies considering the properties of seeds for grain crops.

Recently, many researchers have aimed to construct colters that could make it possible to obtain crops resistant against wind erosion. Hence the need to combine the uniform seeds distribution and their covering with a compacted layer of soil. This to some extent stabilizes the water-air regime of soil, contributes to the accelerated output of plants onto surface and their better rooting in soil, which ultimately protects the soil from erosion.

Colters of various designs were investigated in [13, 14]. These studies explored working bodies for broad sowing. The unresolved issue in these studies is the lack of scientific basis for the guiding elements of seeds in these colters.

Paper [15] reports results from comparative tests of an anchor colter with the right angle of penetration, showing its advantages and disadvantages. This paper failed to solve the following: justification of the parameters for a frontal surface, a tip, the side cheeks of tipped colters.

Article [16] described a comparative study of five grain seeders made by firms Amazone (Germany), Howard (Denmark), Lemken (Germany), Potinger (Austria), and Sulka (France).

The main unresolved issue in disc colters is the absence of a device for soil compaction to optimal values in the area of seed deposition, as well as the uneven arrangement of seeds in soil. Existing types of colters do not fully meet modern agricultural requirements. This is the result of the absence of sufficient scientific substantiation of the basic parameters for colters.

Given the above, one can argue on that the colters applied at present have a series of disadvantages, which is why it is necessary to emphasize the complex issue related to the justification of the basic parameters for colters. By synthesizing their best variants that depend on specific requirements, it is advisable to construct a family of colters for grain seeders.

3. The aim and objectives of the study

The aim of this study is to construct a family of colters for seeders in order to enhance efficiency of sowing seeds for different agricultural crops based on the improved parameters for the covering working bodies.

To accomplish the aim, the following tasks have been set:

– to analyze the impact of parameters for existing types and design of colters on the technological process;

– to substantiate theoretically the colters parameters during their interaction with soil and seeds;

– to estimate experimentally quality indicators in the operation of experimental colters of various purpose versus control (standard types);

– to substantiate recommendations on application of colters of various types.

4. Materials and methods to study the modelling of processes of interaction between colters and soil

4. 1. Substantiating the shape and parameters for the frontal surface of colters and their influence on the operational process

A frontal surface of the colter is characterized by the shape and cross-sectional size. In the horizontal-transverse cross-section, a frontal surface can take the shape of a wedge, the arc of a circle, parabolic, wedge-round with parallel and converging side cheeks.

The frontal surface of the colter affects its soil penetration, the way it is discarded, as well as energy indicators.

Important are its steady movement for depth, the minimum discarding of soil and the resistance to a colter movement.

The impact of the wedge on soil particles was first considered in [19]. Detailed studies into the regularities of furrow-formation in the operation of colters were reported in [20, 21].

Increased discarding of soil by a colter has a negative impact not only on its structure, but also on the quality of seed covering.

In the current work we consider the colters, which in the cross-section represent different surfaces (Fig. 1–4), a parabola, a wedge-rounded shape, which is a combination of v-shaped and rounded surfaces. And, at the top, this surface has the shape of a wedge whose edges smoothly pass into a rounded surface. The third shape is wedge-round with the cheeks' ends bent inside the colter. The fourth shape is different from a previous one by the vertically installed flat knife in the beginning along the middle.

To analyze the process of discarding soil by a colter, we consider the flight of particles. Equation of particles motion takes the form:

$$x = V_0 t \cos\alpha, \qquad (1)$$

$$y = V_0 t \sin\alpha - \frac{gt^2}{2}, \qquad (2)$$

where V_0 is the initial velocity of a particle movement, α is the inclination angle of the initial velocity vector to the horizon, t is the time of a particle movement, g is the acceleration of gravity.

By solving equations (1), (2), we determine the range of a particle flight horizontally (3):

$$x_2 = l = \frac{V_0^2 \sin 2\alpha}{g}. \qquad (3)$$

For the colter, the speed of discarding soil particles at a section with a two-edged flat surface is determined from expression:

$$V_0 = V_c \sin(\beta + \varphi), \qquad (4)$$

where V_c is the progressive speed of a colter, β is the half of opening angle of frontal edges, φ is the angle of external friction of soil against a colter.

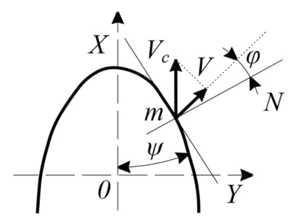

Fig. 1. Diagram of the frontal surface of a colter of a parabolic shape

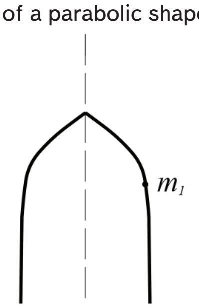

Fig. 2. Diagram of the frontal surface of a colter of a wedge-round shape

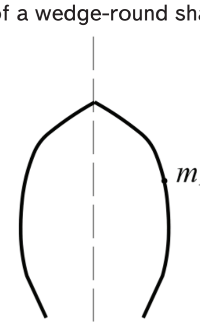

Fig. 3. Diagram of the frontal surface of a colter of a wedge-round shape with the cheeks' sides bent inside the colter

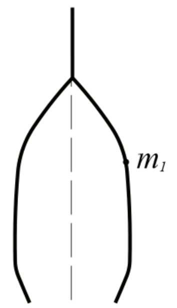

Fig. 4. Diagram of the frontal surface of a colter of a wedge-round shape with the cheeks' sides bent inside the colter and a vertically installed knife

When modeling the process of interaction between colters and soil, one can estimate the projection of velocity vector V with a parabolic frontal surface from expression:

$$V = V_c \sin(\psi + \varphi), \tag{5}$$

where ψ is the angle between the tangent to the frontal surface and the colter's longitudinal axis.

For the colter (Fig. 2), the speed of discarding the soil is determined: at a section of flat edges – from expression (4), at the curvilinear section – from formula (5).

Substituting (4) and (5) in equation (3), we obtain a functional dependence of the range of soil particles flight on the structural and operational parameters for a colter.

For colters, at a section with a wedge surface:

$$l = \frac{V_c^2 \sin^2(\beta + \varphi)\sin 2\alpha}{g}. \tag{6}$$

For colters, at a section with a curvilinear frontal surface:

$$l = \frac{V_c^2 \sin^2(\psi + \varphi)\sin 2\alpha}{g}. \tag{7}$$

It can be concluded that in terms of quality and energy assessment of colters operation the frontal surface of tipped colters must be wedge-round.

4. 2. Substantiating the parameters for a tip and their influence on quality indicators for performance

When a tip interacts with soil, the colter must penetrate the soil to the depth seeds deposition, move steadily in a longitudinal-vertical plane, must not carry the moist soil layers onto the surface. No less important is the minimum discarding of soil and the resistance to colter movement.

A tip is characterized by the angle of soil penetration (the front angle), by the shape in the cross-section and by width.

We studied the tip, which has elements of sharp and obtuse angles of soil penetration (Fig. 5).

The reaction of soil to the lower part of the tip is directed upwards, while the reaction of the upper layer of soil on the top part of the tip with an acute angle of soil penetration – downward. Therefore, the vertical components of these reactions, owing to being oppositely directed, will mutually counteract against each other. In this case, the colter will steadily move in a longitudinal vertical plane.

This is confirmed by the equations of equilibrium of this colter in two variants. First, when R_{sl} and R_n are equal in signs:

$$G_c \cdot l_c = R_n \cdot l_n + R_{sl} \cdot l_{sl} \tag{8}$$

and second, when these forces have different signs:

$$G_c \cdot l_c + R_{sl} \cdot l_{sl} = R_n \cdot l_n. \tag{9}$$

Another advantage of the combined tip is the fact that its upper part discards away the top dry layer of soil, while the bottom moist layer of soil is compacted by the bottom part of the tip.

This is the fundamental difference and advantage of this tip from existing ones.

In the process of selecting the most effective shape, we investigated three models of colters with combined tips.

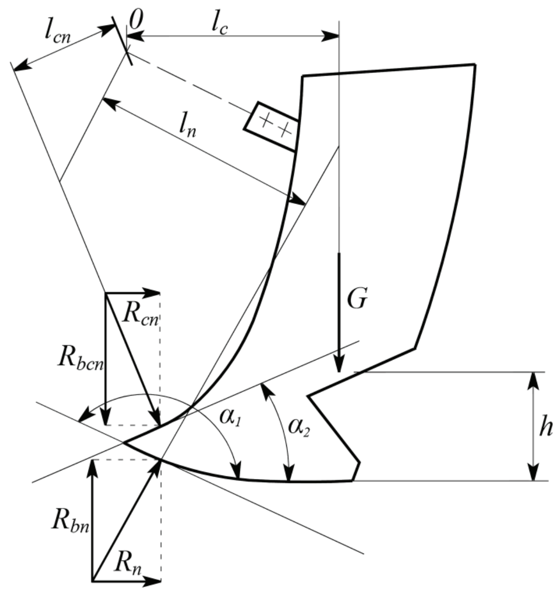

Fig. 5. Schematic of interaction between the forces of a colter and the combined tip and soil

To describe the curvilinear surfaces of these tips by analytical expressions, we considered several functions. Numerical values for the coefficients were found using the method of least squares. To describe the shape of a tip's profile in the colter of the first model, the most appropriate is a parabolic dependence:

$$y = ax^2 + bx. \tag{10}$$

The coefficients a and b and their standard errors Δa and Δb were determined from formulae:

$$a = \frac{\sum x_i^2 y_i^2 \cdot \sum x_i^2 - \sum x_i y_i \cdot \sum x_i^3}{\sum x_i^4 \cdot \sum x_i^2 - \sum x_i^3 \cdot \sum x_i^3}, \tag{11}$$

$$b = \frac{\sum x_i y_i \cdot \sum x_i^4 - \sum x_i^2 y_i \cdot \sum x_i^3}{\sum x_i^4 \cdot \sum x_i^2 - \sum x_i^3 \cdot \sum x_i^3}, \tag{12}$$

$$\Delta a = \sqrt{\frac{E_i^2}{n-2} \cdot \frac{\sum x_i^4}{\sum x_i^4 \cdot \sum x_i^2 - \sum x_i^3 \cdot \sum x_i^3}}, \tag{13}$$

$$\Delta b = \sqrt{\frac{E_i^2}{n-2} \cdot \frac{\sum x_i^4}{\sum x_i^4 \cdot \sum x_i^2 - \sum x_i^3 \cdot \sum x_i^3}}, \tag{14}$$

where x_i and y_i are the coordinates of experimental points at the profile of a colter; E_i are the absolute deviations of experimental values for y_i from those calculated using formula (10) with coefficients *a* and *b* found from formulae (11), (12). Summing is based on the number *n* of experimental points.

The best values were demonstrated by the following coefficients: $a=(0.06\pm0.01)$ cm^{-1}, $b=(0.21\pm0.01)$ cm^{-1}.

The profile of colter of the second model is described by function:

$$y=\frac{x}{cx+d}, \tag{15}$$

which was preliminary converted into a linear function:

$$y'=c+dx'. \tag{16}$$

In this case, the coefficients *c* and *d* and their standard errors Δc and Δd were computed from formulae:

$$c=\frac{\sum x_i'^2\cdot\sum y_i'^2-\sum x_i'y_i'\cdot\sum x_i'}{n\cdot\sum x_i'^2-\sum x_i'\cdot\sum x_i'}, \tag{17}$$

$$d=\frac{n\cdot\sum x_i'y_i'-\sum x_i'y_i'}{n\cdot\sum x_i'^2-\sum x_i'\cdot\sum x_i'}, \tag{18}$$

$$\Delta c=\sqrt{\frac{E_i^2\cdot\sum x_i'^2}{\left(n\cdot\sum x_i'^2-\sum x_i'\cdot\sum x_i'\right)\cdot(n-2)}}, \tag{19}$$

$$\Delta d=\sqrt{\frac{E_i^2\cdot n}{\left(n\cdot\sum x_i'^2-\sum x_i'\cdot\sum x_i'\right)(n-2)}}. \tag{20}$$

We obtained the following values for the coefficients: $c=(0.201\pm0.05)$ cm^{-1}, $d=(0.110\pm0.03)$ cm^{-1}.

As regards a colter of the third model, it is impossible to represent the equation of its profile in the form (15) or (16) over the entire range of values for *x*, but this is achieved by using function (10) at the values for coefficients *a* and *b* in two intervals:

$a=(0.0722\pm0.01)$ cm^{-1}, $b=(0.221\pm0.02)$ cm^{-1},

$c=(0.0264\pm0.01)$ cm^{-1}

– upper curve,

$a=(-0.0287\pm0.002)$ cm^{-1}, $b=(-0.540\pm0.05)$ cm^{-1},

$c=0.010$ cm^{-1}

– lower curve.

In the preparation of experimental data, we chose for each case 10...12 points. The sum of squares of deviations between the calculated values for the respective functions and experimental ones ranged from 0.1 to 0.3 cm^2.

By substituting the values for coefficients *a*, *b*, *c*, *d* in formulae (10) and (15), we obtained the resulting expressions for dependences that describe the curvilinear shape of tips in the investigated colters. Colter of the first model:

$$y=0.0612x^2+0.213x. \tag{21}$$

Colter of the second model:

$$y=\frac{x}{0.201x+0.110}. \tag{22}$$

Colter of the third model:

$$y_1=0.0722x^2+0.221x+0.0264,$$

$$y_1=0.0287x^2+0.540x+0.010. \tag{23}$$

Given the results from our research, it can be argued that the rational tip of a colter is a combined tip, which in the lower part has an obtuse angle of soil penetration and in the upper part – a sharp front angle. Such a colter will steadily move in a longitudinal-vertical plane while its upper part discards the top dry layer of soil and the bottom moist layer of soil is compacted by the bottom part of the tip.

4. 3. Substantiating the parameters for a colter's cheeks

The length of a colter's cheeks must prevent the sapping of soil until the seeds reach a furrow's bottom. Only after the seeds reach the bottom of the furrow the soil must collapse and cover them.

The main disadvantage of the conventional process of soil shedding is the formation of a sloping surface under the colter, which is why the seeds are covered at a different depth. By studying this process, the following assumptions were adopted. The process of shedding involves the volume of soil that exerts a passive pressure. Soil shedding occurs as a result of its volume slipping along the plane located at angle δ equal to $\pi/4+\varphi'/2$ (Fig. 6).

By analyzing the process of soil shedding and the forces that accompany it, we build a soil movement differential equation:

$$m\frac{d^2l}{dt^2}=mg\sin\delta-f'mg\cos\delta, \tag{24}$$

where *m* is the mass of the volume of shed soil per unit time, *l* is the motion path of the volume of soil at shedding, *f′* is the coefficient of internal friction of soil.

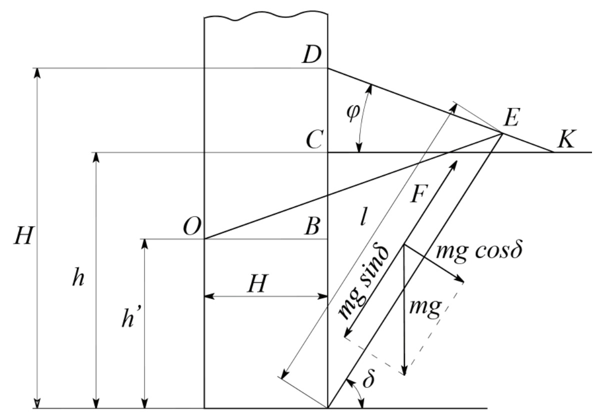

Fig. 6. Scheme for determining the parameters of soil shedding into a furrow

By integrating equation (24) twice at initial conditions: $\vartheta_n=0$, $l=0$ and $t=0$, via transforms, we obtain:

$$l=\frac{gt^2}{2}\cdot\frac{\sin(\delta-\varphi')}{\cos\varphi'}. \tag{25}$$

The shedding time of the volume of soil is determined from the last equality:

$$t=\sqrt{\frac{2l\cos\varphi'}{g\sin(\delta-\varphi')}}, \tag{26}$$

where

$$l=\frac{h}{\sin\delta}. \tag{27}$$

Formula (18) then takes the form:

$$t=\sqrt{\frac{2h\cos\varphi'}{g\sin\delta\sin(\delta-\varphi')}}. \tag{28}$$

To improve the process of soil shedding and the uniform covering of seeds, we investigated colters with cutouts at the side cheeks of various shapes and parameters (Fig. 7–10).

The process of soil shedding in this colter occurs as follows.

Since the cutout line *AB* descends along the motion of a colter while point *B* is the lowest point along this line, the soil particles, which are at this point, will reach the bottom of the furrow faster than the rest. When a particle moves away from point *B* along line *AB*, the distance from it to the bottom of the furrow increases, which means it would reach the bottom of the furrow at a later moment. Thus, a continuous layer of soil, which flows through line *AB*, will descend backwards along the course of the colter. Such layers of soil flow through the lower lines in cutouts *AB* from both sides of the colter. And given that the tipped colters have a small transverse size (up to 25 mm), these soil layers intersect in space between the cheeks, thereby forming a solid layer of soil. It completely covers the distance between the side cheeks of the colters. The seeds that get to the bottom of the furrow, even if some of them retain the energy for rolling across its bottom, but such a possibility is prevented. The soil layer that comes through the cutouts at the sides covers seeds at the bottom of the furrow, preventing their redistribution after collision with the soil. As a result, the distribution of seeds improves, both in terms of area and depth.

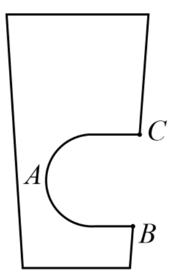

Fig. 7. Diagram of the colter's cheeks cutouts with horizontal lines connected by arc

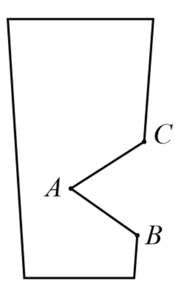

Fig. 8. Diagram of the colter's cheeks cutouts of angular shape

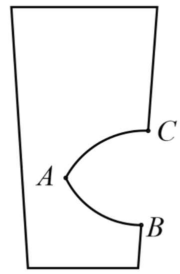

Fig. 9. Diagram of the colter's cheeks cutouts of curvilinear shape

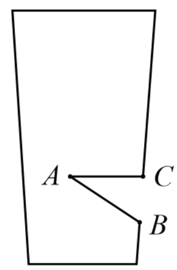

Fig. 10. Diagram of the colter's cheeks cutouts with a horizontal upper line

It should be noted that cutouts in the cheeks must be performed such that point *C* is on the surface of the field if the planting horizon is wet enough. Cutouts are made below the surface, at 2...3 cm, if the upper soil layer is not wet enough.

Our study has shown that among the four experimental models the best indicators, in terms of furrow-formation and seed covering, were demonstrated by models shown in Fig. 8–10. The model in Fig. 10 is better than all working bodies in preventing the dry soil shedding into a furrow and contributes to a more uniform covering of seeds. The result of solving differential equation (24) is the determined motion path of the volume of soil at shedding (26) and the time of soil shedding (28). These equations illustrate the dependences of these parameters in the process of soil shedding, which confirms the conclusion about a better variant of the model.

5. Experimental study of colters

5. 1. Modification of the procedure for experimental research

5. 1. 1. Procedure for laboratory study

The methods for laboratory studies into the process of covering seeds have several advantages over field tests. They make it possible to obtain the predefined state of a soil medium (its composition, density, humidity) and to maintain it over 10...15 days at significant changes in weather conditions and uneven pre-sowing preparation. It is difficult under field conditions to define the regularities in covering seeds.

A strain-gauge method with oscillographic recording makes it possible to simultaneously measure various magnitudes (force, fluctuations in the depth of run, soil density) with high accuracy (0.5...1.0 %) in places that are difficult to access for other methods of research, while avoiding disruptions in the colter operations. Moreover, the choice of a strain-gauge research method was based on the fact that the absolute and relative magnitudes for the seeding process indicators are often very low and it is difficult to measure them with instruments built on a mechanical principle.

When studying soil shedding following a colter's run we used a photography method, which made it possible to capture the process at the time of movement of a working body and to perform the necessary measurements and subsequent analyses.

To measure the horizontal and vertical components of a resistance force to the colters' motion we applied a custom-made instrument. It consisted of two dynamometers, one of which measured the horizontal component, and the other – vertical component, of the force of resistance; two vertical and two horizontal links. The electric circuit of this device was composed of the oscilloscope N-115 (VISHOM, USSR), an oscilloscope power supply of the type P-133 (VISHOM, USSR), the amplifier 8ANCh-7M (VISHOM, USSR), a power supply unit for the amplifier.

To determine the uniformity of motion for depth, the standard and experimental colters were installed using special leashes that hosted the potentiometers. A rod of the potentiometer, by using a lever and a connecting rod, was connected to the upper transverse beam of the trolley. Ends of the electric winding in the potentiometer were connected, by flexible wires, to the connector fixed atop the trolley. The ends of the winding were connected, by a cable, to the galvanometer of the oscilloscope.

The calibration of instrumentation and the colter, installed at a special leash, implied the following.

The colter was lowered to the operating position and placed at the predefined depth. This position of the colter in soil, corresponding to the starting line on oscillographic paper, was accepted as the origin (a zero line). The colter was raised up and lowered down relative to the zero line. Potentiometer readings were recorded on the tape of the oscilloscope at each centimeter of depth for the colter penetration. Stability of the colters' motion was filmed to be examined. A grain seeder hosted a screen marked up with horizontal lines per each 10 mm. At the level of the disks' axes and in the middle part of the colters we attached rods that passed through the screen guides and, by upper ends, displayed the positions of changing elements vertically. To exclude the influence of the inclination of the frame on a change in the position of the screen for height, the latter was installed in the plane passing through the axes of the seeder's wheels.

A cameraman with a movie camera sat in a specially mounted seat behind the seeder and filmed the movements of rods across the screen. Depending on the motion speed of the assembly, the filming was performed lengthwise the plot from 30 to 50 m. The process of colters motion in soil was filmed in parallel.

To measure the traction resistance of colters in a soil channel, as well as for determining the efforts arising in springs of the disc and the keeled colter, we used strain-gauge instruments, which included strain gauges glued to the special links, the oscilloscope N-115, a power supply unit for the oscilloscope (type P-133), the amplifier 8ANCh-7M, a power supply unit for the amplifier.

We studied furrow-formation and the uniformity of seeds distribution in the following way. Parameters for a soil shedding zone following the run of the colter were determined in a soil channel by a photography method. This method made it possible to capture the process at the time of movement of a working body and to perform the necessary measurements and subsequent analysis of the phenomena that accompany it.

When studying the colters and their elements in a soil channel, the evaluation was based on the following indicators: the depth and width of the residual groove, the height and width of the hill along the furrow, the uniformity of colters motion for depth, the vertical and horizontal components of resistance against the movement of colters.

All these indicators were registered at different speeds of colters motion. In the soil channel, we ensured the trolley's speed equal over the first interval: 1.24; 1.51; 1.7; 2.0; 2.96 m/s, and over the second interval: 2.42 m/s; 2.74 m/s; 3.2 m/s; 4.73 m/s. The seeds were sown in the field at speeds matching the speeds of a tractor's gearbox; 6.8; 8.0; 9.5; 11.7; 13.8 km/h. The length of control section in a soil channel was equal to 10...12 m at channel's length 25 m. Under field conditions, the length of control section was equal to 50 m.

Soil's moisture content was determined by taking a batch at three levels: 0...50, 50...100, 100...150 mm. It was dried in a drying cabinet.

Soil hardness was determined by the Revyakin densitometer (VISHOM, USSR). In the soil channel, measurements were performed at the beginning of the experiment at three locations along the length of the channel. In this case, the plunger was pressed into the soil at 20...30 mm below the depth of colters motion. Under field conditions, measurement of hardness was performed along a diagonal of the plot.

5. 1. 2. Field research procedure

Field experiments were conducted at two stages.

At the first stage, we performed a qualitative assessment of operation of the experimental colters compared to standard working bodies at different speeds and at different depth of their motion, under different soil and climatic conditions, that is under actual industrial conditions at the time of our research.

The first phase of the study was conducted at a testing farm named after May Day at Kharkiv National Technical University of Agriculture named after P. Vasylenko (Ukraine) at the experimental field of the Department of Industrial Training.

The second stage of the study was conducted at a testing farm named after May Day at KhNTUA named after P. Vasylenko and at farms in Kharkiv oblast (Ukraine).

This stage of the research implied a qualitative assessment of operation of the experimental colters at different speeds, under different soil-climatic conditions.

The tasks at this stage included studying soil parameters in the course of research; estimating the field surface relief before and after runs of the colters; determining the operability of the new types of colters under industrial conditions; assessing the uniformity of seed distribution in terms of area and depth; studying the influence of colters on field germination and yield.

5. 1. 3. Procedure for processing experimental data

The specificity of agricultural indicators that are distinguished by wide natural variability requires the mandatory application of statistical methods to process them.

Statitical treatment of data in determining agri-technical indicators for seeders implies the following. By defining the sample approximate size (the number of samples, repeatability), we obtain preliminary source data based on which we calculate the mean value, standard deviation, and their derivatives – coefficient of variation and relative error (accuracy of experiment). Based on these data, we establish the resulting required sample size and, upon obtaining initial quantities, we determine the average value and its error (for soil indicators) or an error percentage (for the germination of seeds).

We compute a sample size based on the magnitude of variation for an indicator depending on the required accuracy of determination.

We processed the oscillograms using the device POBD-12 (VISHOM, USSR). Before enabling the instrument, we draw parallel lines in the oscillogram based on the maximum and minimum deviation of the curve; we measured the distance from the minimal straight line to zero line h_1 and from the maximal straight line to the line of zero H.

Ordinate of the curve h_2 was determined from expression:

$$h_2 = \mathrm{H} - h_1. \tag{29}$$

We established then the interval:

$$\lambda = \frac{h_2}{\mathrm{H}} \tag{30}$$

and boundaries for classes. In determining the boundaries of classes, we took into consideration the distance from a zero line to the minimal straight line – h_1.

The average value for a class was determined from formula:

$$K_{cp} = \frac{\alpha_\eta + \alpha_{\eta n}}{2}, \tag{31}$$

where n is the number of classes; α_n is the lower boundary of classes; α_{n+1} is the upper boundary of classes.

The mean ordinate of the curve from a zero line was derived from the following expression:

$$X_{CP} = \frac{K_1 + K_2 + \ldots + K_n}{P_1 + P_2 + \ldots + P_n} = \frac{\sum K_1}{\sum P_1}. \tag{32}$$

The data obtained in this fashion, as well as other from other experiments, were represented in the form of statistical series.

The number of experiments was determined, in order to ensure a 5 % accuracy of results, from formula:

$$n = \frac{t^2 + \sigma^2}{m^2}, \tag{33}$$

where n is the required number of measurements; t is the criterion of reliability, which at confidence level of 0.95 was adopted to equal two; δ is the root mean square deviation; m is the mean error of an experiment.

The film was processed by viewing the frames using the device for reading film-based texts «Mikrofoto»-5PO-1 (Ekran, USSR), as well as when viewing the shot films using the film projector Kashtan (KINAP, USSR).

The frequency of shooting was determined using a generally accepted procedure using the dependence:

$$W_c = \frac{V_{ob} \cdot K}{\delta \cdot m}, \text{ fps} \tag{34}$$

where V_{ob} is the velocity of an object movement (colters); k is the coefficient of obturation, which takes into account what part of the cycle within a frame change is the exposure; $1/m$ is the image scale, which characterizes the ratios of linear dimensions of an image on the film to the directed size of the object; δ is the amount of offset of an object's image over the exposure time of a frame. This magnitude should not exceed 0.03 mm and is determined from formula:

$$\delta = V_{ob} \frac{1}{m} t = V_{pi} t, \tag{35}$$

where t is the frame exposure time; V_{pi} is the speed of an image movement. The frequency of shooting equaled 64 fps.

The depth of colters run was determined using the film per every three frames.

5. 2. Parameters for the frontal surface of tipped colters

In order to establish the influence of parameters for the colter's frontal surface on agrotechnical (the width and depth of a groove, the range of soil flight, the width and height of the lateral soil hill) and energy indicators (resistance forces to colter motion), the experiments were conducted.

All the specified indicators were registered at different speeds of colters motion. In the soil channel, the trolley's speed was maintained that equaled in the first interval: 1.24; 1.51; 1.7; 2.0; 2.96 m/s, and in the second interval – 2.42 m/s; 2.74 m/s; 3.2 m/s; 4.73 m/s. The seeds were sown in the field at speeds matching the speeds of a tractor's gearbox; 6.8; 8.0; 9.5; 11.7; 13.8 km/h. The length of control section in a soil channel was equal to 10...12 m at channel's length 25 m. Under field conditions, the length of control section was equal to 50 m.

Soil's moisture content was determined by taking a batch at three levels: 0...50, 50...100, 100...150 mm. It was dried in a drying cabinet.

Soil hardness was determined by the Revyakin densitometer. In the soil channel, measurements were performed at the beginning of the experiment along the length of the channel. In this case, the plunger was pressed into the soil at 20...30 mm below the depth of colters motion. Under field conditions, measurement of hardness was performed along a diagonal of the plot.

We studied the following surfaces: parabolic, wedge-round with parallel and converging side cheeks, and wedge-round with converging cheeks and a knife positioned vertically (Fig. 1–4).

The influence of parameters for the colter's frontal surface on the process of furrow-formation is shown graphically in Fig. 11, *a*, *b*, Fig. 12, *a*, *b*. The reference indicators were the width and height of a lateral soil roller, as well as the width and depth of the residual furrow.

Diagrams of dependence of indicators for furrow-formation on the parameters and shape of the frontal surface show that increasing the forward speed of colters from 1.24 to 2.96 m/a increases the width of a lateral soil hill (Fig. 11, *a*) for all models of colters. More intensively for control models, that is the wedge surface and in the shape of the arc of a circle. The nature of dependence for all experimental models is almost the same. The absolute values for the reference indicator are the lowest for models (Fig. 3). This indicator is 10...15 mm larger for the model in Fig. 4. For the parabolic and wedge-round – the width of a soil roller grew from 45...50 mm to 100...105 mm, that is the best results for this indicator are demonstrated by the wedge-round model with parallel and converging cheeks, as well as the wedge-round model with a knife-divider. The worst results were demonstrated by control models. The parabolic one has intermediate indicators among control models and the three named the best.

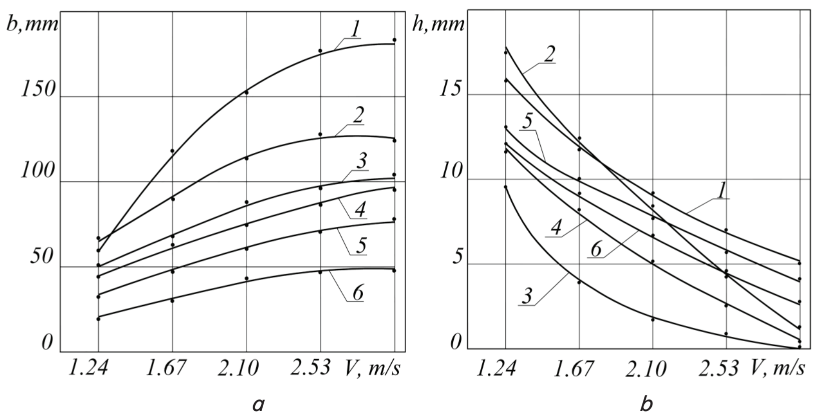

Fig. 11. Dependence of *a* — width *b* and *b* — height *h* of the cross-section of a soil hill on speed *V* and shape of the colter's frontal surface: 1, 2 — control models of colter; 3, 4, 5, 6 — models of colters, respectively (Fig. 1—4)

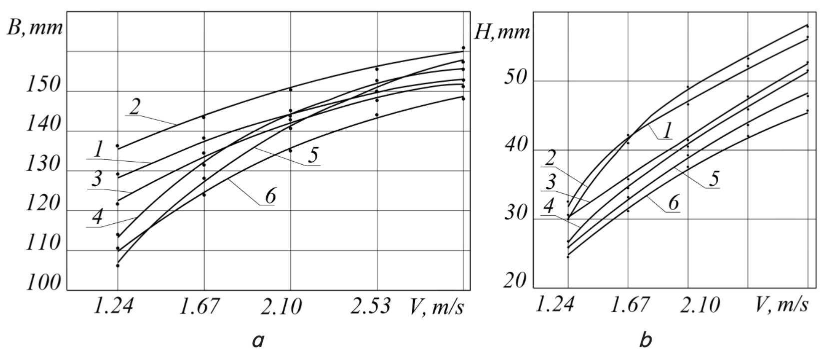

Fig. 12. Dependence of *a* — width *B* and *b* — height *H* of the residual groove on speed *V* and shape of the colter's frontal surface: 1, 2 — control models of colter; 3, 4, 5, 6 — models of colters, respectively (Fig. 1—4)

The height of a lateral soil roller decreases with an increase in speed in the specified limits for all examined models in line with dependences close to the curvilinear ones (Fig. 11, *b*).

This indicator decreases more intensively for control models, which demonstrate the greatest absolute values for this reference indicator. In all experimental models the nature of dependences is almost the same.

The lowest absolute values for this indicator are demonstrated by the parabolic model. the largest – by the wedge-round one.

Models in Fig. 3, 4 changed the reference indicator under these conditions from 13...16 mm to 2...3 mm.

Summarizing the dependences in this diagram we can conclude that the more preferred positions are demonstrated by models in Fig. 1, 3, 4. The wedge-round model occupies an intermediate position between the two specified groups of models.

The width and depth of the residual furrow characterize the quality of covering the seeds for depth. The smaller these indicators, the better the working body meets agricultural requirements for covering the seeds for depth. Fig. 12, *a*, *b* shows the dependences of these indicators for the studied models on translational velocity within the limits specified.

The diagram in Fig. 12, *a* shows that increasing the speed of models from 1.24 to 2.96 m/s increases the width of a residual furrow in line with dependences close to the curvilinear ones. The nature of dependences for all models is almost the same. The absolute growth of this indicator for control models ranges from 126...135 mm to 152...162 mm. Experimental models under these conditions demonstrate the increase in the width of the residual furrow ranging from 108...122 mm to 150...158 mm. The more favorable indicators are demonstrated by models in Fig. 1, 3, 4. The model in Fig. 2 is characterized by the growth of the reference indicator from 128 to 153 mm.

The depth of the residual furrow most realistically reflects the depth of covering the seeds. Diagrams (Fig. 12, *b*) of dependence of this indicator under the above conditions for all models are close to linear. The largest increase in the furrow depth is demonstrated by control models (from 30...32 mm to 56...58 mm). Among experimental models, the worst indicators were demonstrated by the parabolic model, for which this indicator increases from 30 to 53 mm. In other models, the depth of the residual furrow increases with 25...28 mm to 46...51 mm.

Analysis of dependence diagrams of the indicators for furrow-formation for the studied models on an increase in their movement speed from 1.24 to 2.96 m/s allows us to argue on that the experimental results are in good agreement with theoretical research.

In addition, the results from experiments allow us to conclude that in terms of quality of furrow-formation when using colters, it is necessary, when designing new and improving existing working bodies, that the frontal surface of tipped colters should have the profile that is of a wedge-round shape in cross-section.

5. 3. Studying the shape and parameters for a tip

A tip is one of the main structural elements of the colter, which primarily affects indicators for the process of interaction between soil and the colter.

We tested under field conditions colters with various tips.

A control colter is the standard keeled colter. The first type of a colter is the experimental keeled colter whose surface is described by equation (21).

The second type of a colter is the experimental colter whose tip's surface is described by equation (22).

The third type of a colter is the experimental working body, the shape of the tip is described by equation (23).

These colters were investigated under laboratory and field conditions. Under field conditions, the colters were evaluated according to the uniformity of seed distribution along a row and for depth. The research results are given in Tables 1, 2.

Data on the uniformity of seed distribution for depth (Table 2) may indicate that the more favorable indicators of the experimental colters are explained primarily by the shape and parameters for a tip.

The advantage of the combined tip is that the reaction of soil on the lower part of the tip is directed upwards, while the reaction of the surface layer of soil on the upper part of the tip with an acute angle of soil penetration – downwards. In this case, the vertical components of the reactions of soil on the upper and lower parts of the tip are directed in opposite directions, they would mutually counteract against each other, which reduces their impact on the colter; ideally, these components can be equal by modulo and their effect on the colter could be reduced to zero. In this case, the colter moves steadily in the longitudinal-vertical plane that promotes the uniform distribution of seeds not only for depth, but also for area.

Table 1

Influence of parameters for tipped colters and the speed of their movement on the distribution of seeds along a row

Colters	Speed, m/s	Indicators				
		x, mm	σ, mm	V, %	m, mm	P, %
Control colter	0.79	11	10.01	91	0.5	4.55
	1.85	16	16.16	101	0.67	4.2
	2.66	21	23.1	110	0.96	4.5
Colter type I	0.79	17	15.64	92	0.78	4.6
	1.85	20.5	20.29	99	1.01	4.9
	2.66	22	23.76	108	0.99	4.5
Colter type II	0.79	14	12.18	87	0.5	3.6
	1.85	18	17.1	95	0.85	4.75
	2.66	21.5	22.14	103	0.92	4.2
Colter type III	0.79	18.5	16.28	88	0.81	4.4
	1.85	21	19.74	94	0.98	4.7
	2.66	23.5	23.03	98	1.25	4.9

Table 2

Influence of parameters for tipped colters and their movement speed on the distribution of seeds for depth

Colters	Speed, m/s	Indicators				
		x, mm	σ, mm	V, %	m, mm	P, %
Control colter	0.79	36.5	10.58	29	1.5	4.1
	1.85	30	10.8	36	1.3	4.3
	2.66	23	10.12	44	1.1	4.78
Colter type I	0.79	35.5	11.0	31	1.1	3.09
	1.85	30	11.4	38	1.09	3.6
	2.66	24	10.08	42	1.0	4.16
Colter type II	0.79	43	11.18	26	1.1	2.55
	1.85	39	10.92	28	1.09	2.79
	2.66	35	11.55	33	1.13	3.22
Colter type III	0.79	42	10.08	24	1.0	2.38
	1.85	40	10.0	25	1.0	2.5
	2.66	37	9.9	27	0.99	2.67

Another advantage of the combined tip over all others is that during operation of the colter the upper part of the tip with an acute angle of soil penetration discards the upper dry layer of soil, unfavorable for seed germination, while the bottom wet layer of soil is compacted by the bottom part of the tip with an obtuse angle of penetration, creating more favorable conditions for the germination of seeds in terms of soil density and its moisture content.

Data from this experiment allow us to state that in terms of the basic quality indicators of operation the preferred ones are the experimental colters (Fig. 2–4), and, among them, specifically the colter in Fig. 4, which includes a guider and a seed reflector of curvilinear shape and has the combined tip. Owing to these parameters, these colters demonstrate the best results.

5. 4. Studying the shape and parameters for the side cheeks of tipped colters

To study the length of the colter's cheeks and the shape of their cutting, we performed experiments involving four anchor colters with a length of cheeks from 20 to 80 mm at an interval of 20 mm.

Our experiments have shown that for anchor colters the recommended length of their cheeks is within 40...60 mm (Fig. 13).

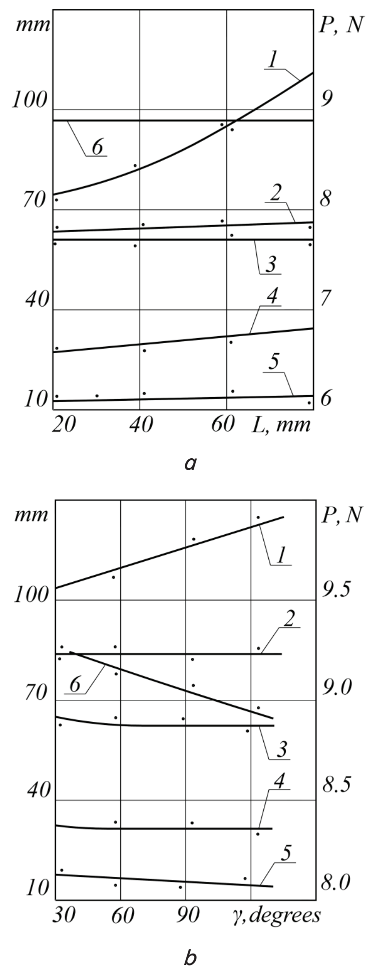

Fig. 13. Influence of the length of cheeks *a* and their cut *b* on reference indicators: 1, 4 – width and depth of the groove; 2 – range of soil flight; 3, 5 – width and height of the lateral soil hill; 6 – colter's resistance

We studied the models of colters with a change in the angle of cheeks' cut from 30 to 120° at a step of 30°. Experiments were conducted at a depth of the working bodies' motion of 70 mm at a speed of 2.0 m/s. The research results make it possible to conclude that the difference in the resistance to movement of the studied models is within 1 N.

Taking into consideration the adhesion and rate of shedding the wet and dry soil particles, the rational angle of the cheeks' cut is roughly 45...65°.

In the course of our study, a solution has been found on a radical change in the process of soil shedding, the resulting being the elimination of a serious drawback.

It has been proposed that one should make the cutouts in the cheeks of colters of a certain shape, for example angular. The cutouts are made by two lines so that they converge at one point in the beginning and then diverge from behind. In this case, the upper line in the motion backwards may ascend or be horizontal, and the lower – descend.

At such a process of soil shedding all the seeds fall on the horizontal surface of the bed for seeds.

We have constructed an experimental colter and performed field tests (Table 3).

Table 3

Influence of the rear configuration of colter's cheeks on the uniformity of seed deposition for depth

Colters	Seeder speed, m/s	Indicators for uniformity				
		x, mm	σ, mm	V, %	m, mm	P, %
Experimental	0.78	62.0	3.0	4.9	0.5	0.9
	1.9	48.4	3.9	8.0	0.6	1.3
	2.65	45.0	3.9	8.6	0.7	1.1
Standard keeled	0.78	46.0	7.0	20.3	1.2	2.6
	1.9	48.0	8.8	18.4	1.4	3.0
	2.65	26.0	7.2	27.8	1.0	3.7
Standard anchor	0.78	93.0	11.5	12.5	1.9	2.0
	1.9	73.5	10.5	14.3	1.5	2.0
	2.65	54.0	9.2	17.1	1.0	1.9

The lowest coefficient of variation is demonstrated by the experimental colter.

Note that the coefficient of variation for experimental colters is 2...3 times lower than that for the standard ones.

These technical solutions ensure the steady movement of colters in a longitudinal-vertical plane, improve the process of soil shedding and laying the seeds on a bed of the furrow that ensures their uniform distribution for depth.

6. Discussion of results of constructing a family of colters for seeders

It was established that the technological process involving tipped colters is affected by such basic structural parameters as the shape and size of the frontal surface, of the tip, of the side cheeks.

When solving the task on the theoretical substantiation of colters parameters during their interaction with soil and seeds the results obtained were based on the application of a mathematical apparatus (1) to (28) and physical modelling (Fig. 1–10), as well as the described experimental study (a soil channel, equipment for strain measurements, photo and video recording, other means). Advantages of the proposed solutions are explained by the following: the procedure employed the causal links between the parameters for colters and operations within the technological process. We investigated the influence of basic parameters of colters on the operations in the technological process. The result of our study is the obtained best variants for parameters of the frontal surface, the tip, the side cheeks in a tipped colter (equations (1) to (28), Fig. 1–10, diagrams in Fig. 11–13, Tables 1–3).

The scientific literature reports no such studies into the shapes of a frontal surface (Fig. 1–4). The colter with a combined tip (Fig. 5) has no analogs. The shape of side cheeks, explored in the current work, has not been found in the literature (Fig. 6–9). This technical solution dramatically improves the process of soil shedding and covering the seeds and eliminates the technological disadvantage – the inclined under-colter soil surface.

The proposed solutions make it possible to deal with a problematic issue in the following way:

– the frontal surface of tipped colters, in order to reduce the range of discarding the soil, must be of a wedge-round shape in the cross-section (Fig. 2, 3);

– the best shape of a tip is combined (Fig. 5) – the upper part with a sharp angle and the lower part – with a blunt angle (equation (23));

– the side cheeks of a colter must have cutouts of angular shape (Fig. 10), which eliminate the inclined surface under the colter and contribute to laying the seeds at the predefined depth.

The current study has the following limitations:

– in the substantiation of the frontal surface, the lower limit of width of the colter for grain crops should equal 20 mm. Reducing this size inhibits grain passage along the channel of a colter. Increasing this size increases the resistance to the movement of s colter and a groove, making it difficult for the soil to shed and to cover the seeds at the predefined depth;

– the surface of the combined tip in a longitudinal-vertical plane must be described by equations (13) to (15).

Better results were demonstrated by the colter whose surface is described by equation (15), (Tables 1, 2).

An increase in the curvature of surface of the upper part of tip poses a danger of heaping the soil ahead of the colter. An increase in the curvature of the bottom part of a tip could result in pushing the colter upwards and its unsteady movement in a longitudinal-vertical plane, that is the uneven seed deposition for depth.

Certain disadvantages in the research, as well as difficulties in their implementation, are associated with the fact that the material base becomes obsolete while possibilities to renew it are limited. Further research should tackle increasing the operating speeds, lowering energy costs. However, one could encounter such difficulties as: increasing operating speeds above 12 km/h dramatically increases the discarding range of soil and the resistance to the colters motion. It is necessary to find ways to neutralize these phenomena or significantly reduce them.

The results obtained within the framework of solving the task on estimating quality indicators for the operation of experimental colters are based on the procedure for conducting experiments, which employed the causal relations between the parameters of colters and operations in the technological process.

We also applied an operational method for assessing quality of colters operation. The essence of this method implies making it possible to evaluate each operation within the process, rather than at the end of the process. This provides an opportunity to adjust each operation, which acts as the source parameters for a subsequent operation. As a result, we substantiated the best variants for parameters of the frontal surface (Fig. 11, 12), the tip (Tables 1, 2) and the side cheeks (diagrams in Fig. 13, Table 3). It should be noted that the scientific literature contains no studies into such shapes of the frontal surface (Fig. 1–4). The colter with a combined tip (Fig. 5) has no analogs. The shape of side cheeks, explored in the current work, has not been reported in the literature (Fig. 6–9). This technical solution dramatically improves the process of soil shedding and covering the seeds and eliminates the technological disadvantage – the inclined under-colter soil surface. The proposed solutions make it possible to deal with a problematic issue in the following way: in terms of methodology, one has to apply the causal relation between parameters for the working bodies and operations within the technological process, as well as the operational method for assessing each operation in the process. This provides an opportunity to modify the required parameter after each operation without waiting for the end of the technological process. In particular, it is recommended to use:

– the shapes of the frontal surface (Fig. 1–4), or close to them, depending on the type of soil and its parameters;

– the colters should employ a combined tip (Fig. 5), with the curvature of surfaces described by equations (13) to (15), or close to them, taking into consideration the soil parameters;

– the cutouts in cheeks of the tipped colters (Fig. 7–10) with an obligatory consideration of soil parameters.

However, the current study has the following constraints:

– soil moisture content should not exceed 20 %, because an increase in humidity could clog the colters, and the process would be disrupted;

– under field conditions, soil should be prepared in accordance with the agricultural requirements;

– existing colters are effective in the process at speeds up to 12 km/h, while at an increase in speed the colters clog neighboring working bodies, which changes the process of covering the seeds for depth.

The results obtained make it possible to propose the following recommendations for the use of standard and experimental colters.

Double-disc, single-disc, and anchor colters with an acute angle of soil penetration should be used on dense soils with high resistivity, (4...5 N/cm^2), and for seeding with deep covering (up to 10 cm). The disc colters are less demanding in terms of soil preparation, they satisfactorily operate on contaminated and over-wet soils (exceeding 20 %).

The keeled colters with an obtuse angle of soil penetration should be applied on well loosened soils with a low specific resistance (2...3 N/cm^2), and for the seeds covering which according to agricultural requirements is allowed at small depth, typically up to 5 cm.

The colters with right angle of soil penetration and with a combined tip must be used on soils with a medium resistivity (3...4 N/cm^2) and for the seeds whose covering depth is from 4 to 8 cm. These colters show the improved uniformity of seed distribution in soil, therefore, they should be used for sowing those crops that should meet higher agricultural requirements.

The anchor-disc colters are more versatile, capable of operating on any soils with a different resistivity for sowing any grain crops whose seeds are more demanding in terms of the agricultural soil parameters at seeding depth of 4...8 cm.

On erosion-prone soils, it is recommend using the disc and tipped colters with the soil's upper layer compactors-separators, with improved uniformity of seed distribution for area and depth.

The advantages of these solutions are due to the fact that their use could improve efficiency of colters operation, would expand their functionality and retain or improve soil fertility. The proposed solution could address the problematic issue owing to these recommendations while their implementation would enhance the effectiveness of sowing agricultural crops and preserve soil fertility.

Certain constraints in these solutions are related to the fact that the recommendations were made without specifying other parameters of soil, so it is advisable to advance the current research by considering the basic parameters for soils that significantly affect the technological process.

7. Conclusions

1. Based on the analysis of development of the design of colters, it was found that their main parameters have not been theoretically and experimentally justified. This refers to the shape and size of the frontal surface, the tip, and the side cheeks, which significantly affect the technological process.

2. We have theoretically substantiated the new concept of the process of furrow-formation and soil shedding by constructing the colter with a combined tip. We have improved the shape of the colter cheeks' cut in the form of cutouts of angular shape. We have calculated and justified the basic structural and kinematic parameters for tipped colters, namely the frontal surface, the tip, and the cheeks, which made it possible to reliably estimate the indicators of their interaction with soil. That provided an opportunity to qualitatively perform the process of furrow-formation, distribution of seeds, as well as extend the functionality of these working bodies.

3. The experimental results confirm theoretical findings on that the new types of colters reduce the mean coefficient of variation in longitudinal unevenness by 20...45 %, and transverse – by 4...17 %. We have substantiated the rational parameters for colters of main types, synthesizing which, depending on requirements, has allowed the construction of a family (about 10 varieties) of colters for grain seeders. These colters form a multi-level planting horizon, enhance the uniformity of seed distribution, improve the conditions for their germination and development of cultivated plants. The recommended types of colters are capable of row, narrow-row, scattered, anti-erosion planting, protecting the soil from erosion and increasing yields.

4. Recommendations on the use of standard and experimental working bodies have been proposed.

Double-disc, single-disc, and anchor colters with an acute angle of soil penetration should be used on dense soils with high resistivity, (4...5 N/cm^2), and for seeding with deep covering (up to 10 cm). The disc colters are used on contaminated and over-wet soils (exceeding 20 %).

The keeled colters with an obtuse angle of soil penetration should be applied on well loosened soils with a low specific resistance, (2...3 N/cm^2), and for the seeds covering which according to agricultural requirements is allowed at small depth, up to 5 cm.

The colters with right angle of soil penetration and with a combined tip must be used on soils with a medium resistivity, (3...4 N/cm^2), and for the seeds whose covering depth is from 4 to 8 cm.

The anchor-disc colters are more versatile, capable of operating on any soils with a different resistivity, for sowing any grain crops whose seeds are more demanding in terms of the agrotechnical soil parameters at seeding depth of 4...8 cm.

On erosion-prone soils, it is recommend using the disc and tipped colters with the soil's upper layer compactors-separators, with improved uniformity of seed distribution for area and depth.

References

1. Pat. No. 374480 Shvetsiya. Ankerniy soshnik (1973). MPK A01S 7/20. No. 7306200-2; declareted: 03.05.1973; published: 04.11.1974, Bul. No. 51.
2. Pat. No. EP 0898860 A1 Germaniya. Soshnik. MPK A01C 5/06. No. 98114444.7; declareted: 01.08.1998; published: 03.03.1999.
3. Demidov, G. K. (1976). A. s. 451421 SSSR, MKI A01/S 7/20. Soshnik kilevidniy. Referativnyy zhurnal, 6.
4. Homenko, M. S., Zyryanov, V. A., Nasonov, V. A. (1989). Mehanizatsiya poseva zernovyh kul'tur i trav. Kyiv: Urozhay, 168.
5. Savinych, P. A., Kurbanov, R., Kuboń, M., Kamionka, J. (2015). Stability of semi-mounted sod seeder motion. Agricultural Engineering, 3, 101–108. doi: http://doi.org/10.14654/ir.2015.155.140
6. Odegnyalov, M. I. et. al. (1976). A. s. 498926 SSSR, MKI A01/S 7/20. Kombinirovanniy soshnik. Referativniy zhurnal, 11.
7. Adamchuk, V., Bulgakov, V., Gorobey, V. (2016). Theory of two-disc anchor opener of grain drill. Scientific proceedings of international scientific conference «Conserving soils and water», 21, 71–73.
8. Goryachkin, V. P. (1940). Obshchie printsipy ispytaniya sel'skohozyaystvennyh mashin i orudiy. Sobranie sochineniy. Vol. 4. Moscow: Sel'hozgiz, 250.
9. Morozov, I. V., Vlasenko, V. G., Olumuyiva, I. F. (1998). Rezul'taty issledovaniy naral'nikovyh soshnikov. Kyiv, 7.
10. Zur Wirkpaarung Schar. Boden die Einzeikorn Samashine Kretschmar Sibylle (1988). Agrartechnik, 38 (1), 17–20.
11. Kornienko, S., Pashenko, V., Melnik, V., Kharchenko, S., Khramov, N. (2016). Developing the method of constructing mathematical models of soil condition under the action of a wedge. Eastern-European Journal of Enterprise Technologies, 5 (7 (83)), 34–43. doi: https://doi.org/10.15587/1729-4061.2016.79912
12. Budagov, A. A., Petunin, A. F. (1965). Soshnik dlya tochnogo razmeshcheniya semyan propashnyh kul'tur. Mehanizatsiya i elektrifikatsiya sotsialisticheskogo sel'skogo hozyaystva, 6, 17–21.
13. Palevski, P. (1977). Izuchenie soshnikov dlya razbrosnogo poseva zernovyh kul'tur. Nauchn. trudy Vyssh. sel's'kotop. In-zh-g. Kolarov-Plovdiv, 2, 15–19.
14. Conceição, L. A., Barreiro, P., Dias, S., Garrido, M., Valero, C., da Silva, J. R. M. (2015). A partial study of vertical distribution of conventional no-till seeders and spatial variability of seed depth placement of maize in the Alentejo region, Portugal. Precision Agriculture, 17 (1), 36–52. doi: https://doi.org/10.1007/s11119-015-9405-x
15. Semenov, A. N., Morozov, I. V. (1974). Issledovanie ankernogo soshnika s pryamim uglom vhozhdeniya v pochvu. Cb. nauch. tr., 11 (142), 43–47.
16. Shiryaev, A. M. (1966). Vliyanie mikrorel'efa polya na ustoychivost' hoda diskovogo soshnika v pochve. Zapiski LSHI, 109, 106–114.
17. Bahtin, P. U. (1971). Fiziko-mehanicheskie i tehnologicheskie svoystva pochvy. Moscow, 126.
18. Goryachkin, V. P. (1965). Sobranie sochineniy. Vol. 1-3. Moscow: «Kolos», 620, 456, 384.
19. Zheligovskiy, V. A. (1941). Eksperimental'naya teoriya rezaniya lezviem. Trudy MIMESH. Moscow: Sel'hozgiz, 105–116.
20. Semenov, A. N. (1959). Zernovye seyalki. Moscow: Mashgiz, 381.
21. Schoen, H. et. al. (1998). Die Landwirtschaft: Lehrbuch fuer Landwirtschaftsschuhlen. Bd. 3. Landtechnik, Bauwesen. Muenchen: BLV-Verl.-Ges., 576.
22. Morozov, I. V., Vlasenko, V. G., Bun, I. (1997). Operatsionnyy metod otsenki kachestva raboty mashin na primere soshnikov seyalok. Tehnologiya proizvodstva i konstruirovaniya sel'skohozyaystvennyh mashin, 93–97.
23. Piryatin, V. D. (1962). Obrabotka rezul'tatov eksperimental'nyh izmereniy po sposobu naimen'shih kvadratov. Kharkiv: Izd. HU, 216.