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RESEARCH ARTICLE

Grounding of Design and Technology Parameters of Combined Coulter Furrow Opener of Precision Seed Drill

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ABSTRACT

A formation of a seedbed is an important step during seed sowing process. A quality of seedbed formation influences on seeds distribution along both a row and a depth and is triggering the opportunity to obtain early and even sprouts. The design of the furrow opener is the main element that has a direct impact on the qualitative formation of seedbed and technological parameters of coulter operation. During the research, there has been analyzed the modern construction of precision seed drills coulters and specified advantages and disadvantages of their operation. It has been established that the most advanced are coulters having a working section with a combined angle (sharp and obtuse) of entry into the soil. The attained results afforded to develop an improved design of the coulter furrow opener of the precision seed drill. There was brought forward a combined wedge furrow opener, the upper part of which has a working section with a sharp angle of entry into the soil, lower - and compactor, located in the rear part of the furrow opener, which forms seedbed has a working surface with an obtuse angle of entry into the soil. There were obtained analytical dependences targeted to determine the main structural and technological parameters of the operating elements of a combined coulter furrow opener which is used to seed cultivated crops: the angles of entry into the soil of the upper and lower part of the furrow opener, compactor in the rolling plane and the angle of tip of the furrow opener in the horizontal plane.

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Introduction

In the modern development stage of agriculture in Ukraine, cultivation of cultivated crops holds a valuable place for the most part of agricultural production.

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Over the last years, there has been an upsurge in the development of breeding new cultivars and hybrids that are capable of providing high yields. Nevertheless, high-yield cultivars cannot solve all the problems of cultivating cultivated crops independently. For the purpose of the cultivars to show their real potential, it is necessary to observe the conditions of agricultural technology of cultivation thoroughly and at a high level. It is a fact of life that heavy yields are guaranteed by obtainment of early and even sprouts, not only due to seeding within the agricultural requirements period, but also due to the correct execution of the production process by working tools that affect the speed of seed germination (Melnyk O., 2016). For this reason, nowadays, the attention is being increasingly focused on securing of maximum accomplish efficiency of the technological process by improving the designs of working tools of seeding machines (Brunotte J. et al, 2005; Vasylkovska K. et al, 2016; Nanka A. et al, 2019). Through the prism of researches (Volokha M.P., 2015, Nielsen S. et al, 2017), it has been establised that the placement of seeds relatively to the depth and length of the row directly influences the speed of its germination and, as a consequence, the crop yield. Seeding aggregates used on modern precision seed drills ensure seeding of satisfactory accuracy (Volokha M.P., 2015; Mostypan M. et al, 2017). That said, when seeding, the seeds are distributed in a furrow non-uniformly. The vast majority of the time, the uniform distribution of the seeds along the furrow sole depends on the design of the coulter (Artemenko D. et al, 2010).

In so far as, the majority of cultivated crops are seeded at shallow depth and in well-prepared soil, according to agrotechnical requirements, the mount of coulter furrow opener on precision seed drills became the most widespread. The furrow opener is a major element of the precision seed drill coulter that ensures for furrow formation and its design has a direct impact on the quality of the technological process (Falola O., 1996, Tatarov G., 2016). The technological operation process of the coulter furrow opener consists of several stages: separation of the topsoil and forming of a furrow with a compacted sole (Voitiuk D. et al, 2005). Therefore, each stage greatly affects the quality of the conditions formation for rapid seed germination. Thuswise, the movement of the coulter furrow opener in the soil is associated with the displacement of the soil particles in the front part and deformation in the rear bottom part. As a consequence of the soil displacement and deformation by the coulter furrow opener, there is formed a furrow. Whereas, the furrow profile influences not only on the distribution of the seeds along the row, but also along the depth (Artemenko D. et al., 2010).

Specification of Advantages and Disadvantages of Precision Seed Drills Coulters

Reviewing modern aggregates, targeted for seeding of cultivated crops, presented by famous manufacturers (Gaspardo. SP Range, 2017, Kuhn. Planter 3, 2015, Monosem, 2018, Kverneland, 2017, Amazone, 2017, Elvorti - Chervona zirka, 2016), it may be affirmed that the design of the seed coulter furrow opener has achieved its final appearance in the shape of a runner or a furrow opener with a obtuse angle of entry into the soil (runner boot) (Figure 1).

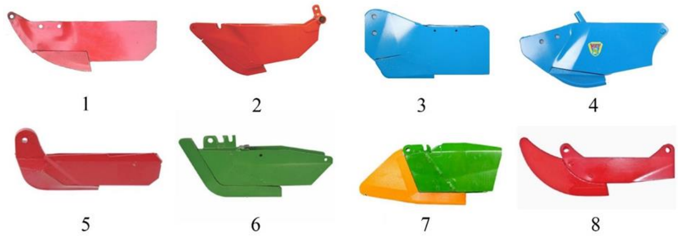

Figure 1. The design of modern precision seed drill coulters 1 – Gaspardo (SP Range); 2 – Kuhn (Planter 3); 3,4 – Ribouleau (Monosem); 5 - Kverneland (Monopill); 6,7 – Amazone (ED 6000); 8 - Elvorti (Vesta)

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 obtuse angle of entry into the soil, the coulter does not maintain the required depth of seeding in a sufficient way, so that requires additional load on the section of working tools, and this leads to an increase in its draught; the furrow profile formed by such coulters does not ensure seed distribution uniformity along the depth. Nevertheless, there is also a significant advantage of such a design. While forming a furrow, coulters with an obtuse angle of entry into the soil, press on the soil from a top to bottom, making the bottom of the furrow compacted (hard). This fact allows capillary moisture to be pulled to the seed, and ensures its rapid germination. That’s why, they found the most widespread use on modern seed drills. From the point of view of technological characteristics, coulters with a sharp angle of entry into the soil are more future-oriented. They form a furrow by moving the soil from a bottom to top; they show good operation while seeding in moist soil.

The main disadvantages in their operation are as follows: while moving, the coulter with a sharp angle of entry into the soil forms some kind of a “hill” ahead of the coulter, and this can lead to a seeding process depreciation. During the operation, some part of a soil from a furrow is placed on a daylight surface, which causes the furrow bottom to become loose; the loose bottom of the furrow does not foster seed distribution uniformity along the depth. But still, 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.

In an effort to improve the implementation quality of the seeding technological process and the efficiency of the coulter, there is needed an additional open-end research in order to eliminate defined disadvantages and increase the advantages in the operation of the precision seed drills coulter. The development of an improved combined design of the coulter furrow opener and the grounding of its basic design and technological parameters that affect the quality of the technological process implementation is of importance.

Materials and Methods

Recent Research Analysis Oriented Towards the Improvement of Coulter Design

The upcoming improvement trend of existing coulters design is the integration of sharp and obtuse angles of entry into the soil in front part of the coulter. This makes it possible to combine all the advantages of both types of coulters and minimize their disadvantages.

Thus, Yurov S. et al (1989) offered a coulter with a combined, adjustable in the vertical plane runner, which has a sharp angle of entry into the soil and is aimed at cutting a layer of high-density soil. In the bottom part, the runner has an obtuse angle of entry into the soil and forms a furrow. Depending on the seeding conditions, the coulter may have either a sharp or a combined angle of entry into the soil.

Bondarenko G. et al (1990) emphasizes that a combined coulter with different angles of the working surface can significantly reduce a draught and improve the process of furrow formation. He has offered a coulter, which in a front part has a tip with a sharp angle of entry into the soil to facilitate the deepening and increase of the movement stability, and in the bottom part has a depressor with an obtuse angle of entry into the soil that forms a furrow. In order to irrigate plant residues, in the rear part of the coulter are located runner blades.

Falola O. (1996), while examining the coulter furrow opener, came to a conclusion that the main elements that affect the quality of furrow formation are the shape and parameters of the furrow opener. He has offered a new furrow opener design. This design has elements of both obtuse and sharp angles of entry into the soil. The soil distortion by such a coulter is followed by a compaction of the lower soil layers (seedbed). These lower soil layers contact with the lower part of the furrow opener, and the upper soil layer is thrown aside by the upper part of the furrow opener, which has a sharp angle of entry into the soil. In the author's opinion, such types of coulters move more evenly and carry out furrow formation at a high-quality level.

During the development of such a technological process, Morozov I. (2003) offered a somewhat different type of a coulter. This type of a coulter has a combined furrow opener and a cut of sidewalls in the rear part. As a result of such a coulter operation, the top dry soil layer is thrown aside from the row axis and in a moist bottom layer is formed the seedbed with optimal quality criteria (density, structure, moisture content), which ensures favorable conditions for seed germination. Having said so, the vertical components of soil reactions applied to both parts of the furrow opener are directed in opposite directions. Thereby, the coulter moves more steadily in the longitudinal - vertical plane ensuring a sufficient seed distribution uniformity along the depth. It is the author's opinion that, the appliance of such elements in the designs of modern coulters will eliminate the main disadvantage of coulter furrow openers - the nonuniform seeds distribution along the row depth and the formation of the necessary germination conditions.

Bakum M. et al (2005), while conducting a research regarding coulters design improvement, points out that it is necessary to manufacture coulters with a combined angle, in which the upper and bottom parts have different angles of entry into the soil. This will balance the movement of the coulter in the longitudinal-vertical plane. The coulter moves more steadily and has an improved seed distribution uniformity in the soil. During the operation of such coulters, the upper part of the furrow opener with a sharp angle throws the top dry layer of soil aside, and the bottom part of the furrow opener forms a furrow and compacts the seedbed. This group of coulters is targeted at placing the seeds in a multilevel seed layer of the soil, and each level in its turn differs in density, structure and moisture content. Conditionally, the seed layer is divided into two layers: the top is dry and the bottom is moist. Such types of coulters are more stable in seed placement along the depth. They create optimal conditions for the seeds germination and development of plants, and unfavorable conditions for the development of weeds.

Murray, J. et al (2006) there has been conducted investigations of the constituent elements of various seed drills coulters. The main disadvantages that exist in the furrow openers with an obtuse angle of entry into the soil are as follows: with an increase in soil density, it is necessary to load the coulter more, and this can lead to over compaction of the seed bed, resulting into a deterioration of the conditions for seed germination; an coulter with an obtuse angle of entry into the soil does not work well on soils clogged with plant residue, pressing them into the soil during operation, which can worsen the coulter running depth; such coulter design does not work well on soils with a high content of clay and on moist soils. Also, there were identified the disadvantages of coulters with an sharp angle of entry into the soil, which include: lifting and washover on the surface of the furrow of the lower moist soil layer; the presence of plant residues in the sowing layer of soil when they are washovered by the coulter to the surface of the furrow results in additional opening of the furrow and deterioration of the seedbed formation; openers with a sharp angle of entry into the soil are more suitable for sowing at greater depths. The research concludes that coulter furrow openers can be more cross functional if the furrow opener design will be combined and will include advantages of both types of coulters or seed drills need to be equipped with additional elements to improve their operation.

Zhang Xiangcai et al (2016) studying the design of the coulter furrow opener of a direct grain crops seed drill, note that the design of the front part of the furrow opener has a significant influence on the character of furrow formation and the qualitative indicators of operation. Four variants of furrow openers have been investigated during the research. All of these furrow openers have different angles of entry into the soil and different design of the working surface. It has been determined that the most suitable for use on coulters of direct seed drill is a furrow opener with a curved working surface and a sharp angle of entry into the soil.

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. The top layer of plant residues, during the operation of such a coulter, is minimally moved to the sides, which most contributes to the formation of conditions for quick germination of seeds.

Kuş, E. and Yıldırım, Y. (2020), upon conducting experimental researches of precision seed drills coulters, emphasize – that the design of the working surface of the coulter has a significant impact on the quality of sowing seeds (distribution along the depth of the furrow). It is being noted that, the working surface of the coulter has an angle of entry into the soil, which corresponds to the angle of entry into the soil of the disc coulter. A substantial impact on the quality of seed distribution in the furrow is being played by the drop height of the seeds and the depth of its wrapping. The authors make up a conclusion that the placement of seeds in the furrow directly affects the speed of plant emergence on the day surface.

The conducted review of the baseline conditions of scientific researches regarding the determination of rational design of the working surface of the coulter furrow opener, made it possible to reveal that there is needed a 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 furrow opener and must fully meet the requirements of agricultural technology towards sowing of cultivating crops.

Grounding of Design Features of Coulter Furrow Opener Aimed at Sowing of Cultivating Crops

The analysis of the existing designs of the precision seed drills coulters has shown that they lack multi purposefulness. They do not allow carrying out several operations in one passage. They also have a high draught and do not ensure the seeding at a required level. In light of this, there is a need to continue the further research of the coulter furrow opener of a precision seed drill, as a major element, which influences on the formation of the furrow.

For justification of the coulter furrow opener of a precision seed drill, it is necessary to determine the functions that should be performed during the technological process (Figure 2).

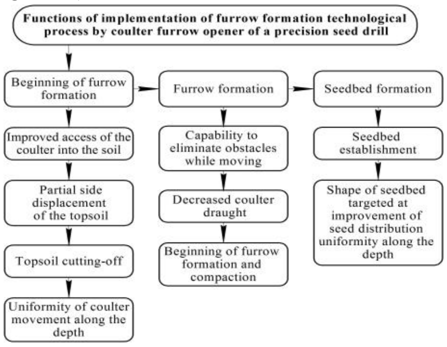

Figure 2. The functions that should be performed during the technological process of the coulter furrow opener of a precision seed drill

In furtherance of the stated functions of the technological process performance, we have developed the improved coulter (Artemenko D. et al, 2019). This improved coulter has a combined wedge furrow opener, 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 (Figure 3). 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.

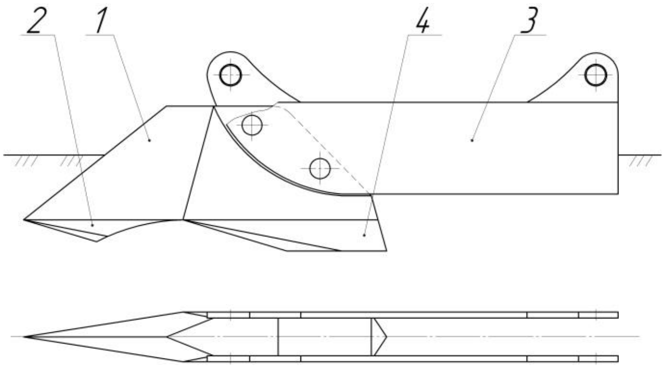

Figure 3. Precision seed drill coulter with improved coulter: 1 – upper part of wedge furrow; 2 – lower part of furrow opener; 3 - sidewalls; 4 – compactor

The offered coulter is working in the following way: moving at the level of furrow 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. Compactor, located in the rear part of the furrow opener 4, 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.

Results and Discussion

Determination of the Angle of Entry into the Soil of the Upper Part of the Furrow Opener

As follows from the originated scheme of the precision seed drill coulter design, there are defined the main structural and technological parameters which directly influence the quality of the furrow formation process: the angles of entry into the soil of the upper and lower parts of the coulter in a vertical plane that affect the draught of the coulter, 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 angle of tip of the furrow opener in the horizontal plane, which affects the distance of throwing some part of upper dry soil layer aside, easing the movement of the coulter at a depth; the taper angle of a coulter furrow opener compactor, which forms the seedbed and influences on the seed distribution uniformity along the furrow depth.

When specifying the rational value of the angle of entry in the soil of the upper coulter part, it is necessary to define under what conditions the draught of the coulter will be the lowest. Forasmuch as, during cultivated crops seeding, there is carried out seedbed preparation. As the result of such a preparation, soil becomes well-loosened and granular, that's why we are going to consider the interaction of the coulter upper part with the soil as the interaction of an inclined plane with a fraction in the vertical plane (Figure 4).

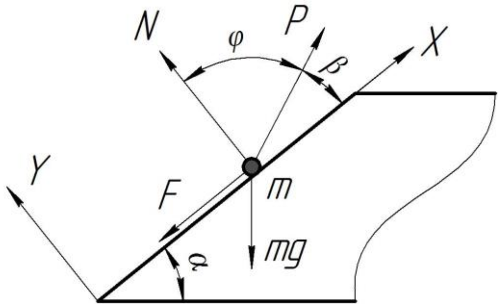

Figure 4. Interaction scheme of the coulter upper part with a sharp angle of entry in the soil in the vertical plane

On some part of the soil m, which is located on the top of the coulter with angle of tip α is acting an active pushing force P at an angle β. From this active force, from the furrow opener surface, is acting perpendicular to it normal reaction, force N and parallel relatively to the plane, which is directed against the friction force movement F. The friction force is related to the normal force as represented in the following equation:

$$F \le tg\varphi N\,, \quad (1)$$

where φ - friction angle.

The equations of mass movements in projections on the axis X i Y are as follows:

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

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

where W_X - acceleration along the axis X.

While solving these equations upon the condition that $F = kN$, where $k = tg\varphi$ with respect to mW_X and N, we get:

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

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

As follows from equation (4) in order the grain of the soil would be located at a plane, it is necessary and sufficient that the force N would be positive, that is:

$$N = mg\cos\alpha - P\sin\beta \ge 0\,. \quad (6)$$

In other words, force P should not exceed:

$$P \le \frac{mg\cos\alpha}{\sin\beta}\,. \quad (7)$$

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:

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

In other words, force P should exceed:

$$P \ge \frac{mg\sin\alpha + kmg\cos\alpha}{k\sin\beta + \cos\beta}\,. \quad (9)$$

This condition must be hold only for $k = tg\varphi$.

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

$$P \ge \frac{mg\sin\alpha + kmg\cos\alpha}{k\sin\beta + \cos\beta} = \frac{mg(\sin\alpha + tg\varphi\cos\alpha)}{tg\varphi\sin\beta + \cos\beta} = \frac{mg\sin(\alpha+\varphi)}{\cos(\beta-\varphi)} \quad (10)$$

The obtained equation shows that the greater the angle of tip of the plane, the greater magnitude of the force P is needed in order to ensure the movement of the soil grain along the furrow opener surface.

Determination of the Angle of Entry into the Soil of the Lower Part of the Furrow Opener

To determine the rational value of the angle of entry into the soil of the lower part of the furrow opener, it is necessary to define under what conditions the draught of the coulter will be the smallest. Which is why we consider the interaction of the lower part of the furrow opener with the soil, as the interaction of an inclined plane with a part in the vertical plane. The forces acting in the vertical plane on the lower part of the furrow opener are shown in Figure 5.

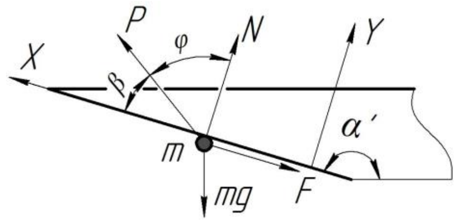

Figure 5. Scheme of interaction with the soil of the lower part of the furrow opener in the vertical plane

Mass movement equation in projections on the axis X and Y are as follows:

$$-mg\sin\alpha' - F + P\cos\beta = mW_X\,; \quad (11)$$

$$mg\cos\alpha' + P\sin\beta + N = 0\,. \quad (12)$$

Solving this equation upon the condition that $F = kN$ relatively to mW_X and N, we arrive at:

$$N = -mg\cos\alpha' - P\sin\beta ; \quad (13)$$

$$mW_X = -mg\sin\alpha' - k\left(-mg\cos\alpha' - P\sin\beta\right) + P\cos\beta \quad (14)$$

As follows from equation (13) in order the grain of the soil would be located at a plane, it is necessary and sufficient that the force N would be positive, that is:

$$N = -mg\cos\alpha' - P\sin\beta \geq 0 . \quad (15)$$

In other words, force P should not exceed:

$$P \leq -\frac{mg\cos\alpha'}{\sin\beta} . \quad (16)$$

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:

$$mW_X = -mg\sin\alpha' - k\left(-mg\cos\alpha' - P\sin\beta\right) + P\cos\beta \geq 0 \quad (17)$$

In other words, force P should exceed:

$$P \geq \frac{mg\sin\alpha' - kmg\cos\alpha'}{k\sin\beta + \cos\beta} . \quad (18)$$

This condition must be hold only for $k = tg\varphi$.

Substituting this equation into a dependence (18) and rearranging, we obtain:

$$P = \frac{mg\sin(\alpha' - \varphi)}{\cos(\beta - \varphi)} . \quad (19)$$

The obtained equation shows that the greater the angle of tip of the plane, the smaller the amount of force P is required to ensure the movement of a soil grain on the surface of the coulter furrow opener.

Analyzing the obtained equations (10) and (19), and taking into account that a friction coefficient of a black soil against a metal equals 0,6 then the theoretical angle change range α and α' will be: $\alpha \geq 40^\circ$, $\alpha' \leq 160^\circ$. In order to determine the angles of the upper and lower parts of the furrow opener in the vertical plane more accurately, it is necessary to know the material from which it is made and the area of use, insomuch as these parameters directly affect the coulter draught. To allow further experimental researches in the prospect of defining the optimal value of angles of entry of a coulter furrow opener, we consider an angle of tip of the coulter upper part to be $\alpha = 40...60^\circ$, an angle of tip of the coulter lower part and a compactor fall within the limits of $\alpha' = 120...160^\circ$. The improved value of these angles can be declared only after further laboratory follow-up study.

Determination of Angle of Tip of a Furrow Opener Lateral Surface

In order to assert an angle of tip of a furrow opener in a horizontal plane γ, let's consider the interaction of its lateral surface with the soil. We consider that the edge shape is of the form of a dihedral wedge (Figure 6), the soil is well loosened and is represented as granular soil.

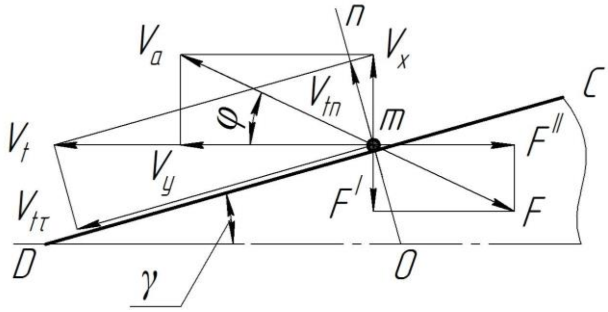

Figure 6. Interaction scheme of the soil part with a lateral surface of a furrow opener in a horizontal plane

While a precision seed drill coulter is moving, the interaction of a soil grain with a lateral surface of a furrow opener occurs in the form of a breakout. When the furrow opener is moving at a speed of V_t, 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.

$$V_{tn} = V_t \cdot \sin\gamma , \qquad V_{tn} = V_a \cdot \cos\varphi .$$

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

$$V_a = V_t \cdot \sin\gamma / \cos\varphi , \quad (20)$$

Where V_t - coulter travel speed;

φ - angle of friction.

A formula (20) shows that if angle γ decreases, the absolute speed of grains throwing is decreasing. Let's decompose the grain absolute speed into two components: along the coulter movement V_t and perpendicular to it V_x. The distance of a grain being thrown aside depends on the component V_x and is defined by the expression:

$$V_x = V_a \cdot \cos(\gamma + \varphi) . \quad (21)$$

Substituting (20) into (21) and rearranging, we obtain:

$$V_x = \frac{V_t \cdot \sin\gamma \cdot \cos(\gamma + \varphi)}{\cos\varphi} . \quad (22)$$

To determine a maximum magnitude of a lateral component of an absolute speed, expression (22) has been tested for extremum (upon condition that dif V_y to dif γ equals zero). Upon conduction of appropriate rearrangements, we have obtained the following dependence:

$$2 \cdot \gamma + \varphi = \pi / 2 + \kappa\pi . \quad (23)$$

We are considering the speed change in the interval [0; $\pi / 2$] so an equation (23) will appear as follows $\gamma = \pi / 4 - \varphi / 2$ and makes it possible to determine that that the lateral component of the absolute speed will be maximum and the throwing of the soil aside by the means of lateral surface of the furrow opener will be greatest.

From Figure 7 can be seen that the lateral component V_x as the angle increases, it first increases and then decreases.

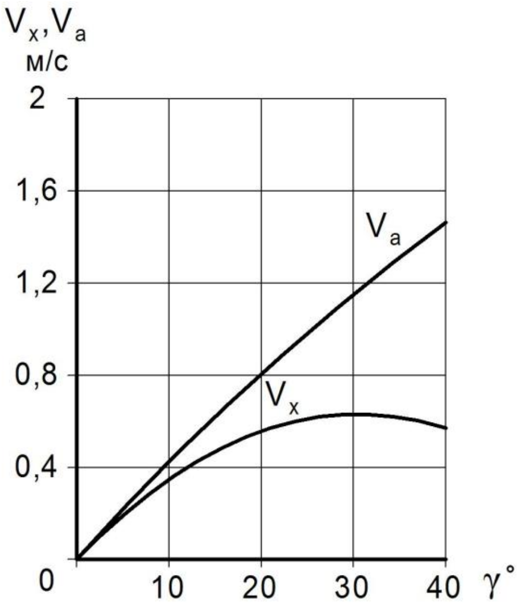

Figure 7. Dependence of speeds V_a and V_x changes on the angle of tip of furrow opener working surface

In the process of furrow formation, the upper part of the furrow opener throws the top dry layer of soil aside. Therefore, 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 furrow opener.

Let's assume that with the maximum value of the lateral throwing aside speed, the soil grain moves away from the surface of the furrow opener and moves along the surface of the field with the initial speed V_{xo}.

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

Then the differential equation of soil grain movement towards the direction V_x will be:

$$m\frac{d^2 S(t)}{dt^2} = -f_2 \cdot mg\cos(\gamma+\varphi). \quad (24)$$

On integrating the expression (24) with respect to t, we get:

$$V_x = V_{xo} - t \cdot f_2 g\cos(\gamma+\varphi), \quad (25)$$

$$X(t) = V_{xo}\cdot t - f_2 g\cos(\gamma+\varphi)\cdot\frac{t^2}{2}. \quad (26)$$

The terminal speed of the grain equals zero, we deduce from equation (25) the time t of grain movement:

$$t = \frac{V_{xo}}{gf_2\cos(\gamma+\varphi)}.$$

Substituting the value t in the expression (26), we get:

$$L = \frac{V_t^2 \cdot \sin^4\gamma \cdot (ctg\gamma - tg\varphi)^2}{2\cdot f_2 \cdot g\cos(\gamma+\varphi)}. \quad (27)$$

Equation (27) shows that the lateral throwing of soil grains aside is a square-law to the travel speed of the machine and depends on the camber angle of deflector device and the physical - mechanical properties of the soil. In Figure 8 is shown a graphical analysis of equation (27).

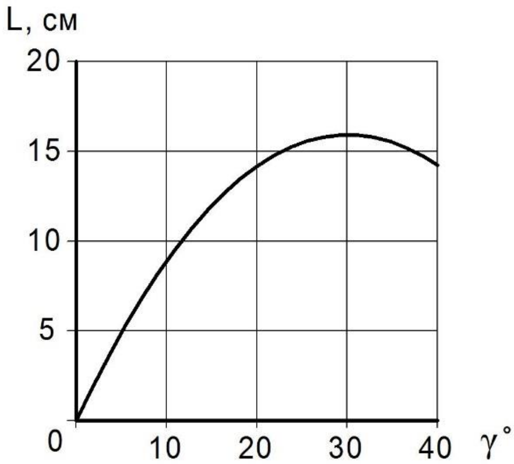

Figure 8. Dependence of soil grain throwing range on furrow opener camber angle

Upon the results of conducted analysis, 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 (Figure 8). The reason for this is that with the further angle increase γ lateral speed V_x is decreasing. In this way, at angles of tip of a furrow opener working surface up to 30° soil lateral throwing range will be maximum. Analyzing the conditions in which the coulter works during seeding and taking into account the agro-technical requirements for furrow formation, it is necessary that the lower moist layers would be place on the soil surface in a minimum quantity, that's why for further researches, we consider $\gamma = 10...20^\circ$.

In the research, which has been carried out by us (Artemenko D. et al., 2010), are considered the parameters of sharpening angle of a device targeted at seedbed formation by precision seed drill coulter and is obtained a dependency (Artemenko D. et al., 2010, dependence 20) 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 a new precision seed drill coulter with a combined angle of entry into the soil and defined its main technological parameters. In the future, it is planned to carry out a service-simulating test of new coulter operation using application programs. Thereafter, the manufacture of advanced coulter pre-prototypes and its experimental testing by the procedure of full factor testing, in order to optimize the theoretical values of its technological parameters.

Conclusions

On the ground of carried out analytical and research work regarding the improvement of the design of the precision seed drill coulter, it was determined that an upcoming trend of existing coulters designs improvement is a combination of sharp and obtuse angles of entry into the soil in front of part of a furrow opener. This makes it possible to combine all the advantages of all types of coulters and minimize their disadvantages.

Arising from the development of an improved design of a coulter furrow opener of a precision seed drill, there was proposed a combined wedge furrow opener, 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 has a working surface with an obtuse angle of entry into the soil. The obtained analytical dependencies (10), (19), (27) make it possible to theoretically substantiate the values of the main constructional and technological parameters of the elements of the improved furrow opener.

Theoretically justified: the angle of entry into the soil of the upper part of the coulter is within $\alpha = 40...60^\circ$ range; the lower part of the coulter and a compactor is within $\alpha' = 120...160^\circ$ range; in the rolling plane, the angel of tip of a compactor is within $\alpha_б = 25...35^\circ$ range; the angle of tip of the furrow opener in the horizontal plane is within $\gamma = 10...20^\circ$ range. The obtained data can be used to manufacture experimental samples of coulters for further researches.

References

Artemenko, D. at al. 2019. Patent 133540, Opener. MPC A01C 7/20 (2006.01); u 201811332; declared 11.19.2018; publ. 04.10.2019, Bull. Number 7. Kyiv/Ukraine. http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=257399&chapter=description

Artemenko, D., O. Mahopets, and P. Solomashenko. 2010. Research and working out of an advanced design steel seeders. *Construction, production and operation of agricultural machinery: nationwide. intern. scientific-technical Sat.* KNTU, 40, part 1. 136-142. – Kirovograd/Ukraine. http://dspace.kntu.kr.ua/jspui/bitstream/123456789/1795/1/26.pdf

Bakum, M. et al. 2005. Agricultural machinery. Kharkiv National Technical University of Agriculture. Petra Vasilenko. KHTUSH. Part 3: Seeding machine. Kharkiv/Ukraine.

Bondarenko, G., V. Bescherevnykh, E. Chumakov, and M. Matukevich. 1990. A.S. 1575990 USSR, MKI A01C 7/20. Opener (USSR); Applicant and patent holder Rostov-on-Don Institute of Agricultural Engineering. - No. 4493333 / 30-15; declared 08.16.88; publ., 07.07.90, Bull. Number 25. Moscow /USSR. http://patents.su/3-1575990-soshnik.html

Brunotte, J., K. Sommer, B. Gattermann. 2005. Architektur moderne Pflanzen. AMAZONEN-WERKE H. Dreyer GmbH & Co. KG. Hasbergen. GmbH/Germany. http://seyalka.com/catalog/arhitektura_sovremennogo_rastenievodstva.html

Falola, O. 1996. The study of the technology of applying seeds to the soil and finding the optimal parameters of the oral coulters. KHTUSH. Kharkiv/Ukraine. http://tekhnosfera.com/view/518682/a?#?page=1

Gaspardo. SP Range. 2017. Pneumatic precision seed drills. Italy. https://www.maschio.com/assets/Uploads/Leaflet-SP-RANGE-17-2017-09-W00230043R-EN.pdf

Kuhn. Planter 3. 2015. Precision seed drills. Kuhn farm machinery (UK). http://www.kuhn.co.uk/uk/range/seeding/pneumatic-precision-seed-drills/planter-3-m-single-bar.html

Kuş, E. and Y. Yıldırım. 2020. Effects of Seed Drop Height and Tillage System on the Emergence Time and Rate in the Single Seed Planters. *Alinteri Journal of Agriculture Sciences*, 35(1): 69-76. https://doi.org/10.28955/alinterizbd.739387

Kverneland. 2017. Monopill - mechanical precision seeder. Precise separation - not only for beets. Kverneland Group Germany. GmbH/Germany. https://www.kverneland.de/Saetechnik/Einzelkornsaemaschinen/Kverneland-Monopill-Monopill-e-drive-II

Melnyk, O. 2016. SESVanderhave seeds are the key to your successful beet growing. Seswenderhave Library. Kyiv/Ukraine. Available: https://sv-ukraine.com.ua/images/Technology_nasinya.pdf

Monosem. 2018. The precision Planter specialist. MECA V4. Ribouleau MONOSEM – FRANCE. https://www.monosem.com/Range/Planter-range/MECA-V4

Morozov, I. 2003. Technological and technical fundamentals of improving the design of seeders of grain seeders. Ternopil State Technical University. Ivana Pulia. Ternopil/Ukraine. http://base.dnsgb.com.ua/files/ard/2003/03mivszs.pdf

Mostypan, M. I., K. V. Vasylkovska, O. O. Andriyenko, and V. P. Reznichenko. 2017. Modern aspects of tilled crops productivity forecasting. *INMATEH - Agricultural Engineering, INMA. Vol. 53, No.3. pp. 35-40.,* Bucharest/Romania.

Murray, J. R., J. N. Tullberg, and B. B. Basnet. 2006. Planters and their components: types, attributes, functional requirements, classification and description. *ACIAR Monograph* No. 121. ISBN 1 86320 462 8.

Nanka, A. et al. 2019. Improving the efficiency of a sowing technology based on the improved structural parameters for colters. *Eastern-European Journal of Enterprise Technologies*. Vol 4, No 1 (100). Kharkiv/Ukraine. https://doi.org/10.15587/1729-4061.2019.174445

Nielsen, S. et al. 2017. Seed drill instrumentation for spatial coulter depth measurements. *Computers and Electronics in Agriculture*. 141. 207-214. Ed. Elsevier, London/U.K. https://doi.org/10.1016/j.compag.2017.07.014

Operating manual. Amazone. 2017. Precision airplanter. Amazonen-Werke H. Dreyer GmbH & Co. KG. Germany. http://et.amazone.de/files/pdf/mg5226.pdf

Product Catalog. 2016. Technology in harmony with the nature. Elvorti - Chervona zirka. Kropyvnytskyi/ Ukraine. https://www.elvorti.com/content/pdf/2016/KATALOG_2016_EN_SITE.pdf

Tatarov, G. 2016. Development of a ridge seeder with justification of the coulter parameters for multilevel sowing of seeds and fertilizers. Ulyanovsk State Agricultural Academy, pp. 35-44. Ulyanovsk/Russian. https://bsau.ru/upload/iblock/83f/Диссертация Татаров Г.Л.pdf

Vasylkovska, K. V., S. M. Leshchenko, O. M. Vasylkovskyi, and D. I. Petrenko. 2016. Improvement of equipment for basic tillage and sowing as initial stage of harvest forecasting. *INMATEH - Agricultural Engineering. INMA: Vol. 50, No.3. pp. 13-20.,* Bucharest/Romania.

Voitiuk, D., et al. 2005. Agricultural machinery. Fundamentals of theory and calculation. Higher education, pp. 141-142. Kyiv/Ukraine. https://studfiles.net/preview/5063474/page:25/

Volokha. M. P. 2015. Technological complex of machines for sugar beet production: row spacing. Theory, modeling, test results. [Monograph]: Center for Educational Literature, pp. 32-57. Kyiv/Ukraine. http://er.nau.edu.ua/handle/NAU/17399;

Yurov S., P. Shcherbina, N. Salamatin. 1989. A.S. 1496672. USSR, MKI A 01C 7/20. Crawler opener. (USSR); applicant and patent holder Krasnodar Research Institute of Agriculture named after P.P. Lukyanenko. - No. 4081462 / 30-15; declared 05/05/86; publ., 07/30/89, Bull. No. 28. Moscow /USSR. http://patents.su/3-1496672-polozovidnyjj-soshnik.html;

Zhang, X. C., H. W. Li, R. C. Du, S. C. Ma, J. He, Q. J. Wang, et al. 2016. Effects of key design parameters of tine furrow opener on soil seedbed properties. *Int J Agric & Biol Eng.*, 9(3): 67—80. https://doi.org/10.3965/j.ijabe.20160903.2259