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JUSTIFICATION OF CONSTRUCTION AND TECHNOLOGICAL PARAMETERS OF THE STRIP-TILL SECTION FOR STRIP TILLAGE WITH THE APPLICATION OF FERTILIZERS

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The STRiP-TiLL technology came from the USA, where at a certain stage, as a result of changes in the external environment, it was formed from the technology of direct seeding, or No-Till. This tillage technology is most suitable for row crops. Yes, it was primarily developed in North America specifically for corn. Gradually, it proved itself well during the cultivation of other row crops, in particular, sunflower, soybean, sugar beet, etc.

Strip cultivation, as a resource-saving technology with the prospect of its application in arid conditions, is quite promising in the cultivation of industrial crops. The key principles of implementing the strip-till technology are the separate type of its application, i.e. the formation of strips and sowing are spread over time, or combined - when the processes of forming strips and sowing are carried out simultaneously. World agricultural engineering offers various technical and technological solutions for the implementation of strip-till technology, based on the application of the principles of separate and combined methods of implementing this technology, in which they use: in the first version - separate machines for forming strips and sowing, in the second - about combine them into one unit and use one universal unit.

One of the features of strip tillage is the possibility of using various chemicals and mineral fertilizers at the same time as sowing seeds, which makes it possible to make the fertilizing process quite precise and targeted, placing active substances right near the roots of the plants.

Strip-Till allows you to integrate oxygen into the soil with part of the fertilizers when plants with a short growing cycle are planted. This improves plant development by eliminating stress. Passing the rollers on both sides of the seed line eliminates the air pocket left by the paws, promoting ideal plant growth. Loosening only the seed line limits or eliminates inter-row weed growth while creating a water storage area that will percolate to the roots of the harvested plants.

Key words: *strip-till, design parameters, application of fertilizers, soil, strip tillage.*
Eq. 19. Fig. 10. Ref. 8.

1. Formulation of the problem

Currently, plowing is the most common method of basic soil cultivation. Plows ensure bulk grinding, soil mixing and incorporation of plant residues. However, when plowing to a constant depth, the sole of the plow is formed and the soil is compacted.

To reduce soil compaction, clearing plows are used to retain moisture in the soil and retain the upper nutrient layer, while maintaining a core that restrains water and wind erosion. In addition, chisel tools are less energy-intensive than plows. However, the presence of surface abrasion requires the use of special tools for additional soil treatment.

2. Analysis of recent research and publications

One of the compromise options today is strip tillage. Thus, when processing strips, part of the surface remains untreated with plant remains and biota, which contributes to the recovery of the soil after processing, as well as the accumulation of moisture and loosening in the processed strips. This method of grant processing is increasingly used in farms, but its application raises a number of questions. One of the main ones is processing time. Opinions of experts and practitioners were divided. Some of them believe that cultivation should be done in the spring together or before sowing, while others say that it is necessary to cut the strips in the fall, and in the spring to sow the seeds in the pre-cut strips. The analysis of publications showed that depending on the condition of the soil, natural and climatic conditions and the availability of equipment, each of these options can be implemented. But each of them has its own terms of use [2].

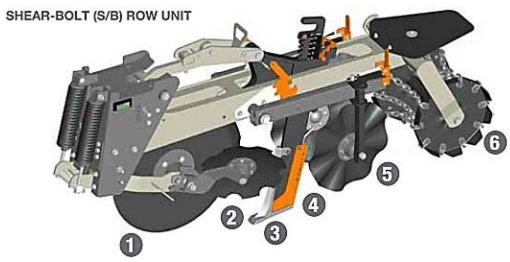
To date, a large amount of theoretical and practical material has been accumulated on the justification of the constructive and technological parameters of tillage machines and working bodies. These works are mainly aimed at the development and improvement of technical means used in technologies of continuous soil treatment. However, the presence of plant residues on the surface of the field, increased hardness and poverty of the soil significantly affect the processes of soil treatment, which must be taken into account when justifying the parameters and developing aggregates for strip cultivation. In order to substantiate the structural and technological design and parameters of the unit, it is necessary to consider the process of interaction of its working bodies with the soil.

Currently, there is no serial production of tillage units for strip cultivation in Ukraine. Foreign models of units for strip cultivation are very expensive and are developed without taking into account the soil and climatic conditions of Ukraine. In addition, the existing units do not allow volume application of fertilizers to the soil. In connection with this, an urgent task is the development and substantiation of the parameters of the unit for strip tillage for cultivated crops with the possibility of volumetric intra-soil fertilization.

Let's consider some foreign aggregates for strip-till technology.

The well-known Kuhn Gladiator tillage unit for tillage using Strip-till technology, which is presented in fig. 1.

a



b

Fig. 1. Kuhn Gladiator 1200 soil tillage unit:
a – general view; b – construction of the Gladiator 1200 tillage unit section

This unit of the French company Kuhn is manufactured from small to wide-grip versions, which allows you to process large fields. The section is made in the form of a parallelogram, which allows you to accurately withstand the specified depth. The KUHN Krause ST-PRO Row Unit system ensures constant contact of the rolling working bodies with the soil, but this system is very expensive. Also, the disadvantage of this section is its low working clearance, which can cause clogging with plant remains.

Fig. 2. Focus TD soil tillage unit manufactured by Horch

The advantages of this unit are a fairly large placement of working bodies from each other, racks for deep loosening have spring protection with an actuation force of 550 kg.

Disadvantages include the heavy weight of the unit, as a result of which a high tractor power is required for operation, which requires from 200 to 300 hp. for processing 3 m width of soil grip, depending on the configuration. This unit does not have a slotted disk, which is installed in front of the rack and row cleaners from plant residues, as well as side disks that limit the strip being processed.

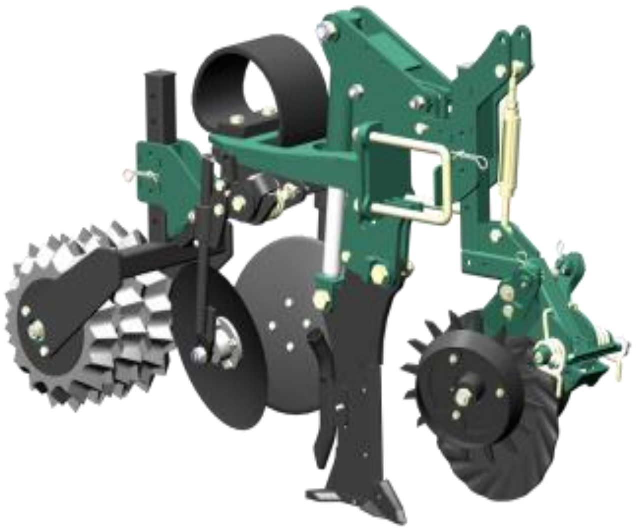


Fig. 3. Section of the Strip-Till Integral tillage unit from Duro-France

The advantages of this section are a relatively light construction for strip-till technology, the rear roller is located on a vibration stand and a high clearance of the frame, which is 64 cm.

There are also disadvantages of this section, among which the close location of the working bodies to each other, which can cause clogging with harvest residues, as well as poor copying of the topography of the field [8].

Taking into account all the positive and negative sides of the aggregates listed above, we offer a strip-till section that will combine the maximum possible number of positive characteristics and contain the minimum number of shortcomings in the conditions of Ukraine necessary for modern farms.

Characterization of the processes that occur during the interaction of various types of working bodies with the soil is the basis for differentiating the composition of tillage machines. A significant number of scientific works on agricultural mechanics are devoted to the issue of the interaction of working bodies with the soil, in particular by V.P. Goryachkin, P.M. Vasylenko, V.A. Zheligovskyi, L.V. Pohorily, O.N. Sokolovskyi, A.S. Kushnaryova, P.V. Sysolina, A.M. Panchenko, V. I. Vetokhin, V. O. Dubrovina and others. Sufficient attention has not been paid to the study of aggregates for strip tillage, their structural and technological parameters and the impact on quality and energy indicators in the conditions of Ukraine. That is why it is necessary to generalize research on the expediency of using strip tillage technology to obtain an effective production result, to determine its positive opportunities and negative consequences [3].

3. The purpose of the study

On the basis of analytical calculations of the tillage process, it is necessary to substantiate the structural and technological parameters of the proposed section for strip tillage.

4. Presentation of the main material

To substantiate the structural and technological parameters of the strip tillage section, a research program was developed, the scheme of which is presented in fig. 4.

The program includes three main stages of research:

- analysis of strip tillage technology (strip-till);
- modeling the process of processing the strip-till section and modeling the process of applying fertilizers, assessing the adequacy of models by experimental methods;
- analysis of research results.

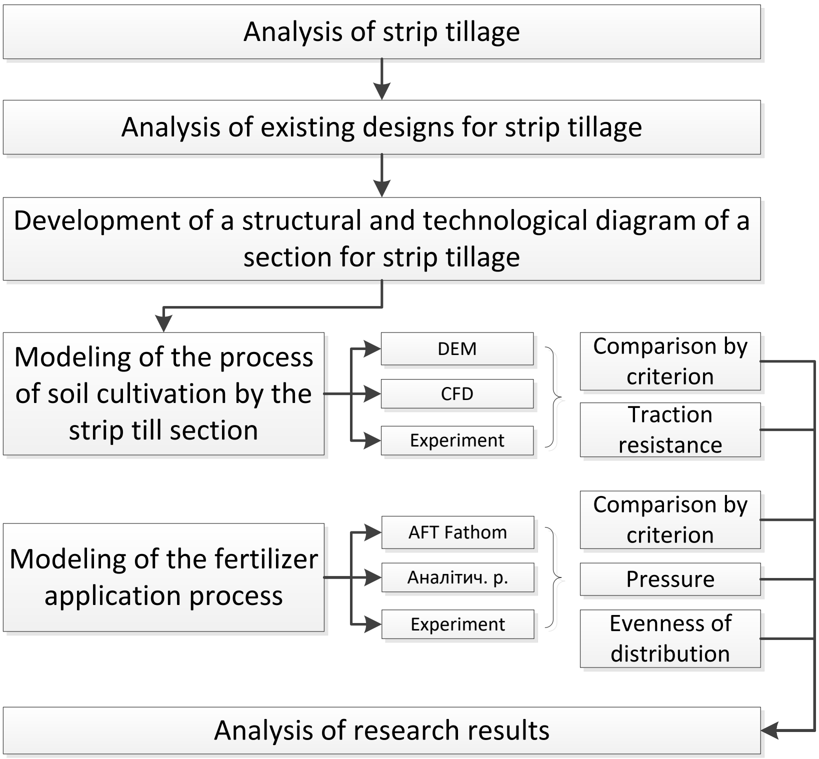


Fig. 4. Research program

We will conduct a constructive and technological justification of the developed scheme.

Figure 5 shows the estimated layout of the working bodies of the strip-till section. The diagram shows the structural parameters characterizing the position of the working bodies of the section in space relative to each other and the treated surface.

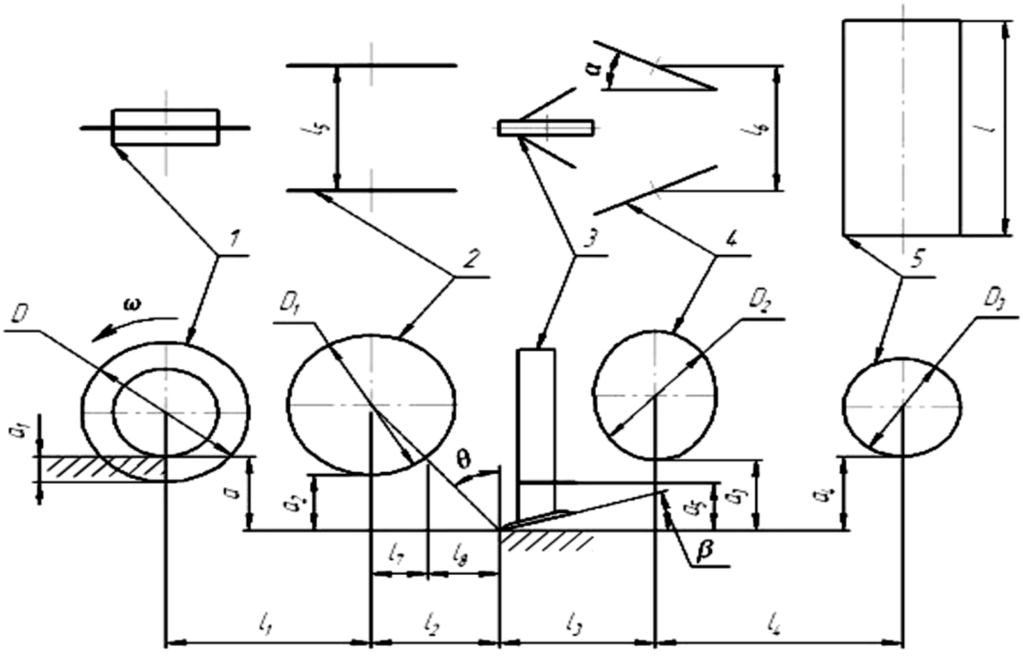


Fig. 5. Scheme of placement of working bodies on the section frame:

1 – front split disc; 2 – split rear discs; 3 – slitter with knives; 4 – spherical disks; 5 – slatted rink; l_1 – the distance between the axes of the front and rear cutting discs; l_2 – the distance between the tip of the slitter and the axis of the rear cutting discs; l_3 – the distance between the toe of the slitter and the axis of the spherical disks, which fill up; l_4 – the distance between the axes of the spherical discs and the slatted roller; l_5 is the distance between the rear spherical disks in the transverse direction

The calculation scheme for the installation of lateral vertical discs is presented in Fig. 6.

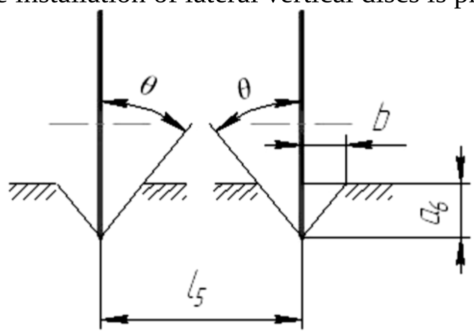


Fig. 6. Calculation scheme for installation of lateral vertical disks

Angle Θ depends on the physical and mechanical properties of the soil and varies within 18 to 42º [3].

Let's define (Figure 4) the distance between the traces of working bodies according to the following formula:

$$S=(S-S_n)+B_b+2\cdot(a-a_1)\cdot tg\theta_n \quad (1)$$

where B_b – the width of the grasp of the working body for applying fertilizer, m; a_1 – height of installation of knives, m; θ_n – the angle at which soil chipping occurs in the transverse-vertical plane.

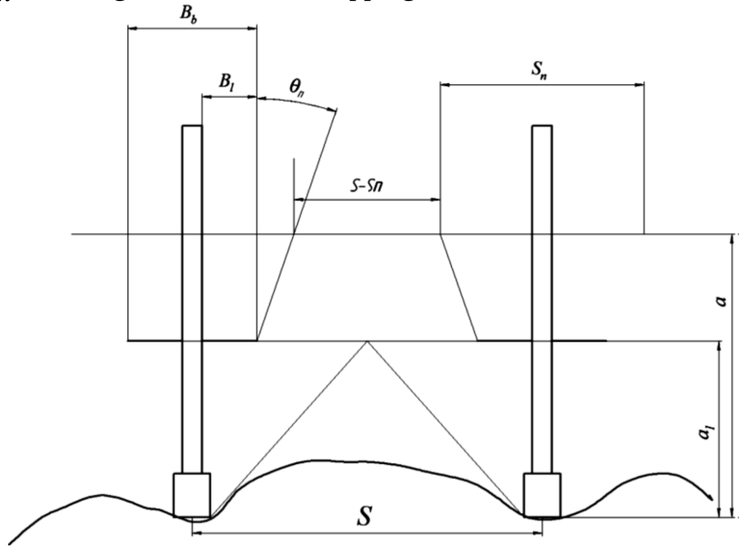


Fig. 7. Calculation scheme for determining the width of the working body for applying fertilizers

From formula (1), let's express the minimum width of the working body for applying fertilizers of the upper tier

$$B_b=S_n-2\cdot(\alpha-a_1)\cdot tg\theta_n. \quad (2)$$

At the depth of processing a=0,25 m, the height of the installation of the knives on the rack of the slitter a_1=0,15 m. and the maximum soil chipping angle θ_n =42° the width of the knives of the upper tier of cultivation and fertilizer application B_b = 0,18 m.

The position of the working body on the rack is determined based on the technological process of its interaction with the soil in the longitudinal plane (Figure 5). To reduce the energy intensity of the process, it is necessary to minimize the overlap of the deformation zones of the formation with the chisel of the slitter and the working body for applying fertilizers of the upper layer on each other. This condition will be ensured if the tip of the bit or the working body for applying fertilizer and the intersection of the cleavage line of the soil layer with the soil surface lie on the same vertical line.

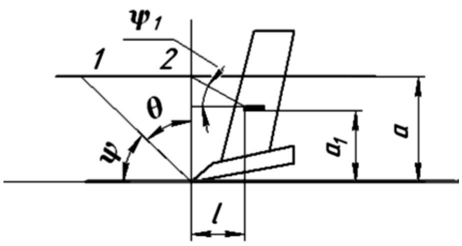


Fig. 8. Calculation diagram of the installation height of the knives on the rack of the slitter

To ensure the conditions described above, the distance from the knife to the tip of the bit is determined from the expression:

$$l=(a-a_1)/tg\psi_1 \quad (3)$$

where ψ_1 – angle of displacement of the soil of the upper tier, deg.

$$\psi_1 = \alpha+\varphi_2 \quad (4)$$

Justification of the distance between working bodies.

To eliminate clogging of soil and plant residues between the working bodies, the soil deformation zones of each of them should not intersect with each other.

According to the calculation scheme (Fig. 6), the distance between the working bodies is determined as follows.

The loosening working body is characterized by the following parameters: a – depth of processing, m (a = 0,25 m); β – the angle of placing the bit on the bottom of the furrow, degrees; в – bit grip width, m (в = 0,03 m); $в_g$ – the width of the loosening zone of the bit, m; l_1 – departure of the bit relative to the rack, m (l_1 = 0,05 m); l_2 – the distance between the disk and the loosening working body, m

$$l_2 = a\cdot(\alpha+\varphi) \quad (5)$$

where α – angle of collapse (α=20°), φ - angle of soil friction by bit material (φ>20…30°) [4].

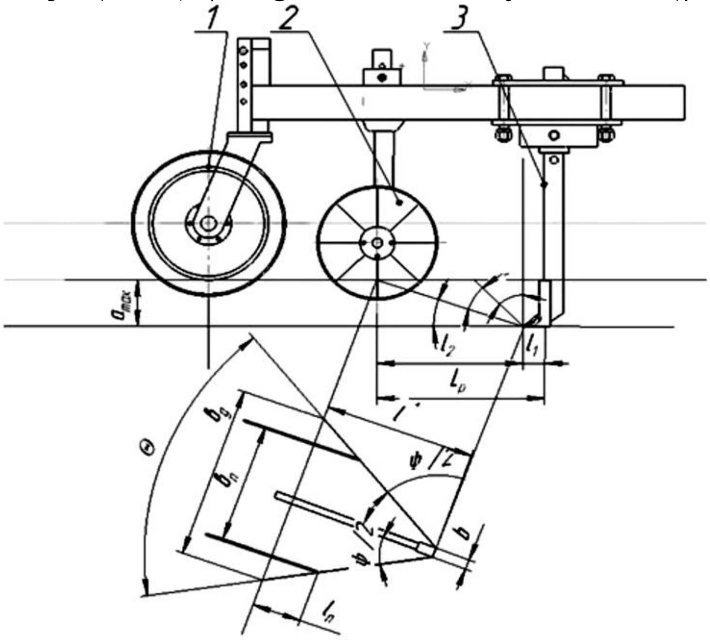


Fig. 9. Location of the working bodies of the section: 1 – split disc with ribs; 2 – cutting disks; 3 – baking powder

The zone of propagation of soil deformation in the longitudinal direction depends on the value of a, as well as on the angles α and φ. When reducing the distance from the chisel to the cutting discs, the soil can be jammed, and increasing the distance can lead to unjustified elongation of the structure. The deformation zone is determined from formula 9.

The angle characterizing the area of deformation in the transverse direction of the soil in the plane of chipping:

$$\theta=2\varphi_2 \quad (6)$$

The soil chipping angle can be determined by the formula of V.P. Horyachkina [5]:

$$\Psi=90°-(\alpha+\varphi_1+\varphi_2)/2 \quad (7)$$

where φ_1 – angle of soil friction by paw material, φ_2 – angle of internal soil friction. φ_1 =20°…30°, φ_2 =30°…40° [6].

$$\Psi = 90° - \frac{25°+25°+35°}{2} = 47{,}5° \quad (8)$$

It is necessary to determine the depth of deformation $l*$. It is determined by the following formula:

$$x = \sqrt{l^2 + a_{max}^2} = \sqrt{0{,}0036^2 + 0{,}25^2} = 0{,}3 \text{ m} \quad (9)$$

The distance between the slitter and the cutting discs Lp is defined as:

$$L_p=l_1+l_2 \quad (10)$$

$$L_p=(0{,}05+(0{,}25\cdot tg(25°+35°))=0{,}3 \text{ m} \quad (11)$$

To determine the deformation in the transverse direction, we use the formula

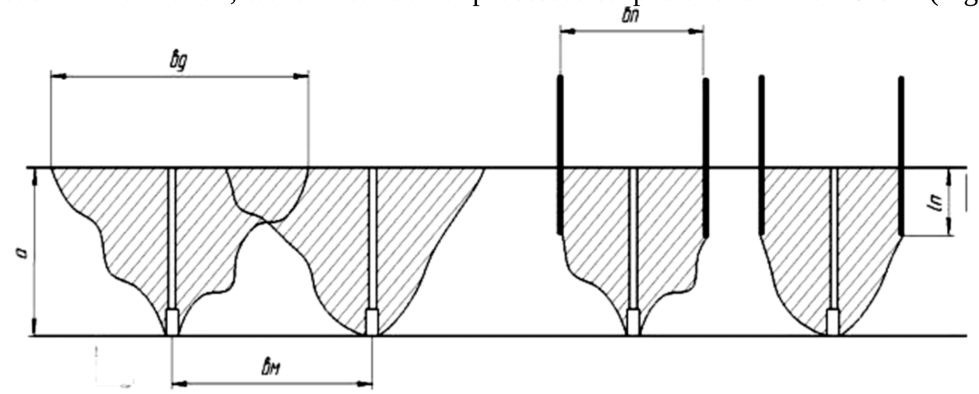
$$в_g = в + 2a \cdot tg2\varphi = 0{,}05 + 2 \cdot 0{,}25 \cdot tg26^{\circ} = 0{,}6 \text{ m} \quad (12)$$

Based on the results of formula 12, the deformation zone in the transverse direction is в_g= 0.6 m, from (Figure 7 a) it can be seen that, with the specified values, the deformation zone in the transverse direction intersects with the deformation of the neighboring working body, which is not permissible for the strip tillage technology. In order to achieve the formation of a raw strip, we install two cutting discs in parallel at the depth and distance:

$$l_n = 0{,}1 \text{ m} \quad (13)$$

$$в_n = 0{,}25 \text{ m} \quad (14)$$

with such an installation, we will leave an unprocessed strip with a width of 0.25 m (Figure 7 b).



a) *b)*

Fig. 10. Scheme of soil deformation by loosening agent:
a) deformation of soil by loosening agent, b) soil deformation using cutting discs

During operation, these cutting discs will cut the soil to a certain depth Ip to form vertical cuts. The soil deformation that will be generated from the loosener to the cut soil will not propagate further. This creates a strip of the required width vp and processing depth a.

Thus, on the basis of theoretical calculations, the following structural and technological parameters of the section for strip soil treatment were obtained:

- the width of the knives of the upper tier of processing and applying fertilizers B_b = 0.18 m;
- the distance between the slitter and the cutting discs p = 0.3 m;
- running depth of cutting discs l_n = 0.1 m;
- the distance between the cutting discs in = 0.25 m;

Theoretical definition of tensile strength of the section.

To choose an energy tool for aggregating the cultivator being developed, it is necessary to determine its traction resistance, which expresses the physical essence of the interaction of the working bodies with the soil.

The traction resistance of the R_{tyag} section can be defined as the sum of the component traction resistances of each working body.

$$R_{tyag} = P_{td} + 2 \cdot P_{rt} + P_{rs} + 2 \cdot P_{rs} + P_{rr} \quad (15)$$

where P_{td}– turbodisc drag, N; P_{rt} – resistance of cutting turbodiscs, N; P_{rs}– resistance of the slitter with knives, N; P_{rs} – resistance of spherical disks, N; P_{rr}– resistance of the roller, N.

Resistance of the turbo disc and cutting discs

$$P_{rt} = a \cdot k_d \quad (16)$$

where a – depth of processing, k_d – the calculated specific resistance of the knife at a depth of 1 cm with a back thickness of 10...17 mm is k_d = 5…9 N/cm.

The traction resistance of the loosening working body consists of the forces spent on cutting the soil layer with the chisel blade and the knife of the rack, on the friction of the soil against the bit and the rack of the working body, on lifting and loosening the soil. The value of these forces depends on the parameters of the bit and the rack.

Pulling resistance of the ripper (slitter):

$$P_{rs} = k \cdot b_d \cdot h \quad (17)$$

where k – specific tensile cutting resistance, N/m; b_d – bit width, m; h – depth of processing, m.

It is known that the traction resistance of disc working bodies is lower than that of loosening working bodies, because the forces of friction of the soil against the disc are transferred to the force of rolling.

When the soil is deformed by shear, the specific resistance of the soil to cutting

$$k=\tau_{max}\cdot\cos\varphi_1\cdot\sin(\alpha\cdot\varphi)/cos^2(\alpha+\varphi+\varphi_1)/2 \quad (18)$$

where α– the angle of installation of the bit to the bottom of the furrow; τ_{max} – net shear stress; φ and φ_1 – angle of external and internal soil friction.

Traction resistance of a wavy disk

$$P_{rs} = P_{td} /(tg(\alpha_{dm}+\varphi_{am})) \quad (19)$$

where α_{dm} – angle of installation of the knife to the direction of movement (α= 10..12), φ_{am}– the angle of (external) friction of the soil against the metal (φ=23..25).

As a result of calculations:

- drag resistance of the turbodisc 157 ... 193 N;
- tensile strength of the slitter 635 ... 775 N;
- traction resistance of a spherical disc 225...275 N;
- roller traction resistance 112...132 N;
- total tensile strength of the section 1668 ... 2036 N.

According to the obtained formulas, you can choose an energy tool for aggregating the cultivator.

5. Conclusions

Analytical calculations of the tillage process were carried out, and the structural and technological parameters of the proposed section for strip tillage were substantiated. As a result of the analysis of soil cultivation technologies, it was established:

- the position of the working body on the rack of the splitter has a significant effect on the quality of fertilizer application and the traction resistance of the tool;
- in order to increase the yield of agricultural crops, it is necessary to ensure volumetric intrasoil application of fertilizers to the depth of the treated layer;
- application of fertilizers to different depths directly into the soil helps to improve plant nutrition and allows to reduce plant feeding operations.
- the working body allows you to carry out the main processing of the soil on a strip width of 15 to 25 cm, while about 60% of the field area is not processed, which in turn leads to a decrease in energy costs.

References

[1] Dvornyk, A.V. (2023). Analytical modeling of movement of structural aggregate of soil through the working surface of chisel. *Bulletin of Sumy National Agrarian University. The Series: Mechanization and Automation of Production Processes*, *4 (50)*, 24–30. https://doi.org/10.32845/msnau.2022.4.4 [in English].

[2] Fylymonov, S.A., Batrachenko, A.V., Yashchenko, S.S., Fylymonova, N.V. (2020). Rozrakhunok syl, shcho vynykaiut pry stvorenni vibratsii za dopomohoiu smart piezoceramics, ta doslidzhennia yikh rozpodilu u pluzhnomu vidvali. *Visnyk Cherkaskoho derzhavnoho tekhnolohichnoho universytetu*, *2*, 21–28. DOI: 24025/2306-4412.2.2020.198180. [in Ukrainian].

[3] Sereda, L., Trukhanska, O., Shvets, L. (2020). Investigation of the hydraulic drive of the unit for strip tillage with simultaneous application of liquid fertilizers. *Vibratsii v tekhnitsi ta tekhnolohiiakh, 4 (99),* 67–72. [in English].

[4] Kaletnik, G.M., Goncharuk, I.V., Yemchyk, T.V., Lutkovskaya, S.M. (2020). *Agrarian policy and land relations.* Monographs published in Ukraine Vinnytsia: VNAU. [in Ukrainian].

[5] Veselovskaya, N.R., Ivanov, M.I., Rutkevich, V.S., Shargorodsky, S.A. (2019). *Hydraulics: Textbook.* Vinnytsia. [in Ukrainian].

[6] Sereda, L.P., Trukhanskaya, O.O., Shvets, L.V. (2019). Development and research of a tillage machine for strip-till technology with active milling working bodies. *Vibratsii v tekhnitsi ta tekhnolohiiakh*, *4 (95)*, 65–71. DOI: 10.37128/2306-8744-2019-4-8 [in Ukrainian].

[7] Duro-France. URL: https://www.duro-france.com/fr/gammes/strip-till/14-16.html#bloc_switch (date of application: 15.03.2024)

[8] STRiP-TiLL – technology of the future. URL: https://healthysoil.in.ua/strip-till-technology-for-future/ (date of application: 15.03.2024)

ОБГРУНТУВАННЯ КОНСТРУКЦІЇ ТА ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ СЕКЦІЇ STRIP-TILL ДЛЯ СМУГОВОГО ОБРАБІТКУ ҐРУНТУ ІЗ ВНЕСЕННЯМ ДОБРИВ

Технологія STRiP-TiLL прийшла із США, де на певному етапі у результаті зміни умов зовнішнього середовища утворилася з технології прямого посіву, або No-Till. Переважним чином ця технологія обробітку ґрунту якнайкраще підходить для просапних культур. Так, першочергово вона розроблялася в Північній Америці саме під кукурудзу. Поступово вона себе добре зарекомендувала під час вирощування інших просапних культур, зокрема соняшнику, сої, цукрових буряків тощо.

Смуговий обробіток, як ресурсозберігаюча технологія з перспективою її застосування в посушливих умовах, є досить перспективним при вирощуванні технічних культур. Ключовими принципами реалізації технології strip-till є відокремлений тип її застосування, тобто формування смуг та посів рознесено в часі, або ж суміщений – коли процеси формування смуг та посіву виконують одночасно. Світове сільськогосподарське машинобудування пропонує різні техніко-технологічні рішення для впровадження технології strip-till, засновані на застосуванні принципів відокремленого та об'єднаного способів реалізації цієї технології, при яких використовують: у першому варіанті – окремі машини для формування смуг та посіву, у другому – об'єднують їх в один агрегат і використовують один універсальний агрегат.

Однією з особливостей смугового обробітку, є можливість одночасного з посівом насіння, використання різного роду хімічних речовин та мінеральних добрив, що дозволяє зробити процес підживлення досить точним і цілеспрямованим, закладаючи діючі речовини прямо біля коренів рослин.

Strip-Till дозволяє інтегрувати кисень в ґрунт з частиною добрив, коли висаджуються рослини з коротким вегетаційним циклом. Це покращує розвиток рослин, усуваючи стрес. Проходження котків по обидва боки від лінії посіву усуває повітряну кишеню, залишену лапами, сприяючи ідеальному росту рослин. Розпушування тільки лінії посіву обмежує або усуває проростання бур'янів у міжряддях, одночасно створюючи зону зберігання води, яка буде просочуватися до коріння рослин, що збираються.

Ключові слова: *смуговий обробіток, конструктивні параметри, внесення добрив, ґрунт, смуговий обробіток ґрунту*

Ф. 19. Рис. 10. Літ. 8.

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