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DETERMINING THE EFFECT OF THE DIRECTION OF INSTALLING THE CUTTING EDGES OF SHREDDER ROLLER BLADES ON PROCESS PARAMETERS

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This paper reports a study aimed at increasing the intensity of grinding of the stems of coarse-stemmed crops by establishing the influence of the orientation of the cutting edge of the cutter-shredder knives on the quality of the technological grinding operations.

Analytical dependences of the planar movement of the roller-shredder were established and it was determined that for rollers with knives, the cutting edge of which is directed in the direction opposite to the direction of rotation:

– exceeding the value of the vertical components of the total forces of resistance of the knives, which made it possible to increase the values of forces, and, as a result, more intensive destruction of the layer of plant remains;

– exceeding the values of the driving force of the knives based on the dependence of the driving force on structural and kinematic parameters (roller weight, drum radius, blade height, blade inclination angle, acceleration).

Experimental studies have established an excess of up to 20 % of the quality indicators of milling sunflower and corn stems with roller knives, the cutting edge of which is directed in the direction opposite to the direction of rotation.

The average number of crushed pieces of corn stalks in the range of less than 50 mm is 13.6 % higher in the combined unit, the cutter blades of which are directed with the cutting edge in the direction opposite to the direction of rotation.

It was established that with zero and 3.92 kN (400 kg) additional loading, an increase in speed from 7.45 km/h to 13.6 km/h leads to a decrease in the values of the average traction resistance. The highest value of traction resistance was set at a speed of 13.6 km/h and an additional load of 7.84 kN (800 kg). The lowest value of traction resistance was established at zero additional load and a speed of 22.0 km/h, which is 21.5 % less than at a speed of 7.45 km/h and 14.1 % less than at a speed of 13.6 km/h

Keywords: shredder roller, cutting edge of a blade, analytical dependences of the planar motion of shredder roller, traction resistance of shredder roller

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1. Introduction

Shredder rollers are increasingly used by land users. The solo version of the shredder roller:

1) carries out preliminary grinding and partial wrapping of the stems of plant residues;

2) eliminates surface irregularities;

3) creates more favorable conditions for performing the subsequent technological operations of grinding and working plant residues into the soil.

In addition to corn stubble, sunflower, it is advisable to carry out operations of grinding and making siderates,

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processing of rapeseed stubble, grain crops, technical hemp, etc. A shredder roller in combination with a disc harrow is an effective tool on such an agricultural background as it enables not only the crushing of plant residues but also obtaining a well-mulched top layer of soil with an agronomically valuable structure.

Due to high passability and workability on backgrounds with a large amount of plant remains, combined disc units containing shredder rollers are among the most effective and used means of mechanization of soil cultivation after growing coarse-stemmed crops. This is explained by the successful addition and expansion of the functional capabilities of the combined unit, owing to the use of the advantages of each tool included in its composition.

It is known that the disc harrow in the solo version grinds the remains with discs and mixes them with the soil. However, mainly only those plant stems located in the direction perpendicular to the movement of the tool are crushed. The stems of the plants, which are oriented in the direction of movement, are almost not crushed by the tools and are unsatisfactorily wrapped in the soil. This problem is solved by combined units, which, in addition to the disk harrow, include a shredder roller. Under these conditions, the blades of the blade-shaped working body of the roller-shredder are located perpendicular to the direction of movement and the plane of rotation of the discs. The implementation of such a technical solution makes it possible in one pass of the unit to precisely grind those stalks that are located in the direction of movement and are not crushed by discs. In general, this improves the quality of planting plant residues into the soil in one pass of the unit.

That is why comprehensive studies are relevant to determine the influence of the orientation of the cutting edge of the cutter-shredder knives on the quality of the technological operations of grinding plant residues of rough-stemmed crops.

2. Literature review and problem statement

Leading manufacturers of tillage equipment have carried out a number of important scientific research works and structural developments on the improvement of disc implements, as a result of supplementing their designs with rollers-shredders. Owing to such actions, it was possible to expand the functional purposes of the disk combined tool, which contains a shredder roller, and increase its productivity. Under such conditions, we note the lack of a general methodology for substantiating rational technological parameters for both combined machines containing disk rotary tools and crusher rollers, as well as crusher rollers in the form of a solo tool. As a result of the above, further serious miscalculations in the design and production of new machines and tools become possible [1–3].

The quality of processing is directly dependent on its intensity. Special combined units, the technological scheme of which included a flattener roller (Zünslerschreck) or a chopper roller (DalboMaxiCut, HORSCH Joker RT, VäderstadCarrierCrosscutter) have proven to be quite positive under the conditions of their use for crushing and burying stems of coarse-stemmed crops [2]. It should be noted that the authors of the cited studies did not indicate individual brands of machines and tools but rather used the mechanized concepts. Special machines, such as mulchers or shredder rollers, are very effective in destroying corn stalks. However, combined units, where the shredder roller is used in combination with working bodies for soil cultivation, make it possible not only to successfully solve this task but also to combine it with the simultaneous cultivation of plant residues. In addition, these machines solve a number of soil cultivation tasks and have a much wider range of applications. However, the authors did not provide the results of comparative studies of tools with different options for installing knives.

Uniform mixing of plant residues with the soil is also advisable from the point of view of their rapid decomposition, creation of favorable conditions for sowing and prevention of early clogging [4]. In addition to siderates, intensive grinding of plant residues in combination with surface treatment is very important under the conditions of rape stubble processing. A thin layer of mulch on the surface accumulates moisture well and is favorable for the rapid germination of carrion seeds. For farms with a high concentration of rapeseed, the shredder roller is as important a tool for maintaining a proper agricultural culture as it is for reliable grinding of corn stalks [5, 6].

The authors of [7] carried out modeling and developed an experimental model of the working body-straw-soil interaction based on the method of discrete elements. It was found that the average value of the torque of the cutter shaft was the smallest at the depth of soil cultivation of 200 mm, the rotation speed of the cutter shaft of 240 rpm, and the amount of straw per unit of 3.5 kg/m. Models of the simulated interaction of returning soil and returning soil straw were built. The average electricity consumption of the blade roller with straw was 12.1 % more than the consumption without straw. Average torque with straw was about 11.3 % higher than without straw. A comparative analysis revealed that the trend of the test value and the simulation value with or without straw was basically the same [7].

It was noted in [8] that the high water content and high viscosity of corn straw lead to a low level of proficiency of the traditional rotary blade return machine. Under such conditions, it can easily lead to straw blocking and thus affect the quality of the wheat crop. The authors proposed a cutting method based on the principle of a four-rod connection mechanism. Corn straw was crushed using the ground as a support. Based on the theoretical calculation and motion simulation, the dimensions of the 4-link mechanism of the cutting device were determined and the trajectory of the cutters was optimized. In the 4-link mechanism, the minimum angle of transmission was 70°, the maximum angle of rotation of the rocker arm was 20°. The eccentric distance of the eccentric wheel was 80 mm, and the lengths of the cutter bar (connecting rod) and rocker arm were 267.375 and 460.702 mm, respectively. The experimental results showed that the average straw length with the developed machine was 4.8 cm, the unqualified rate was 6 %, and the coefficient of variation was 0.209, which was better than that of the traditional machine. The depth of cutting with the new cutter reached an average of 7.71 cm, and the volume density of the soil at a depth of 0–10 cm decreased significantly. Experiments with wheat seeding found no straw blocking during seeding when the planter was operating on the surface on which the cutting straw return machine was operating. The seeding depth coefficient under such conditions was 92.5 %, which was significantly higher than the other [8].

Article [9] hypothesizes that the methods used to predict the forces on the soil that cut narrow paws can be applied to the rotary deep loosener. However, when using these methods, it is necessary to take into account the position of the working element in the soil and take into account the features associated with the rotary loosener. A new mathematical model has been built for predicting the torque for a rotary tiller in various soils. It is noted that there are no theoretical models describing the operation of rotary deep-fillers. Under such conditions, predicting the required torque can be very important for designers, as well as for other experts who use such machines in the field. The model constructed was tested in experiments conducted in soil channels, which confirmed its reliability [9].

Publications [7–9] do not provide the results of theoretical and experimental comparative studies of tools with different options for installing knives.

One should note a certain design feature of roller-shredders, which are equipped with blade-like working bodies. This structural feature applies to blade installation options. Some manufacturers install knives, orienting their cutting edge in the direction that coincides with the direction of rotation of the drum. Others, on the contrary, install the knives in such a way that their cutting edge is directed in the direction opposite to the direction of rotation of the roller drum. Theoretical and experimental studies on the justification of the advantages of one scheme over another have not yet been carried out in detail. That is why the task of forming a rational state of the mulch layer of plant remains of rough-stemmed crops by rollers-shredders, the working bodies of which contain reasonable structural parameters, needs to be solved.

3. The aim and objectives of the study

The purpose of this study is to substantiate the structural parameters of the shredder roller for the formation of a rational state of the mulch layer on the agro background of plant remains of coarse-stemmed crops.

To achieve the goal, the following tasks were solved:

– to analytically investigate the planar movement of the shredder roller, the blades of which are turned with the cutting edge in the direction of rotation of the drum and the cutting edge of which is turned in the direction opposite to the direction of rotation;

– to experimentally investigate the influence of the location of the cutting edge of the roller blade on the quality indicators of the operations of grinding sunflower and corn stalks;

– to investigate the traction resistance of the shredder roller.

4. The study materials and methods

The object of our research is the technological processes of crushing plant residues, coarse plant material, working bodies of the roller-shredder.

The subject of research is the interaction of the working bodies of the roller-shredder with plant material (corn stalks, sunflowers), the influence of the direction of installation of the cutting edge of the knives of the roller-shredder on process indicators.

The scientific hypothesis assumes that there are such technical and technological solutions, the implementation of which would enable the intensification of the technological process of grinding by the working bodies of the roller-shredder plant remains of rough-stemmed crops.

Analytical studies of the planar movement of a roller-shredder, the knives of which are turned with their cutting edge in the direction of rotation of the drum and whose cutting edge is turned in the direction opposite to the direction of rotation, were carried out using the methods of theoretical mechanics and mathematics.

The experimental sample of the shredder roller of plant residues was investigated at the experimental plots of the State Enterprise Experimental Farm «Olenivske», the National Research Center «Institute of Mechanization and Electrification of Agriculture» (Kyiv oblast).

Experimental studies were carried out using the designed and manufactured experimental sample of the shredder roller, in which the cutting knives are placed across the width of the gripper in a staggered order with the possibility of changing the angle of inclination to the axis of rotation of the drum [11]. The structural diagrams of the designed shredder roller with various options for installing knives, as well as the results of experimental studies into the quality of grinding parts of stems of coarse-stemmed crops (sunflower and corn) are described in detail in [11–13].

Determination of traction characteristics of the shredder roller was performed in accordance with DSTU ISO 789-9:2019 Agricultural tractors. Test procedures. Part 9. Determination of drawbar capacity (ISO 789-9:2018, IDT).

5. Results of studying the effect of the direction of installation of the cutting edge of the knives of the shredder roller on the process indicators

5. 1. Results of analytical studies of the flat motion of the shredder roller

Analyzing the nature of the interaction of the shredder roller blade with the plant-soil environment, several possible scenarios for the implementation of the process were noted:

a) the blade deforms, compacts, partially destroys the upper part of the plant layer. The extent of destruction is determined by the physical and mechanical properties of plants, the structure of plant residues, their composition, technical characteristics of the tool, etc. Under such conditions, the compacted layer of vegetation (h_{pl}) is greater than the height of the blade (h_t);

b) the rolling blade deforms the layer of plants and grinds them. However, the blade does not interact with the soil environment. Such a scenario is described by the condition:

$$h_{pl} \approx h_t.$$

From the point of view of the tasks of grinding plant residues, the above conditions are desirable to ensure the greatest effectiveness of the tool and the implementation of the technological grinding operation;

c) under the condition that the height of the blade exceeds the thickness of the deformed layer of the plant medium ($h_t > h_{pl}$) before the blade begins to interact with the soil. Under the conditions of the implementation of this scenario, the following possible options can be identified:

1) the depth of penetration of the blade into the plant-soil environment is equal to its height:

$$h_t = h_{pl} + h_d,$$

where h_d is the depth of penetration of the blade into the soil environment;

2) the blade does not penetrate the plant-soil medium to its full height, i.e., only its partial deepening $h_t > h_{pl} + h_d$ occurs.

Such a case is a consequence of the excess of the forces of resistance to penetration of the blade into the soil over the active forces. Partial penetration of the blade into the soil can be caused by the existence of longitudinal and transverse unevenness of the plant-soil environment.

The variant of interaction of the shredder roller blade only with the plant environment was considered (Fig. 1, *a, b*). Fig. 1, *a* shows the option of installing knives with the cutting edge turned in the direction of rotation of the drum (diagram 1), and Fig. 1, *b* shows the option of installing knives, the cutting edge of which is turned in the direction opposite to the direction of rotation (diagram 2). Fig. 2 shows an enlarged, superimposed schematic image of the interaction of the blade with the plant environment under the conditions of their installation according to scheme 1 and scheme 2.

It was assumed that the layer of plant residues is homogeneous in properties, uniform in thickness in the longitudinal and transverse planes.

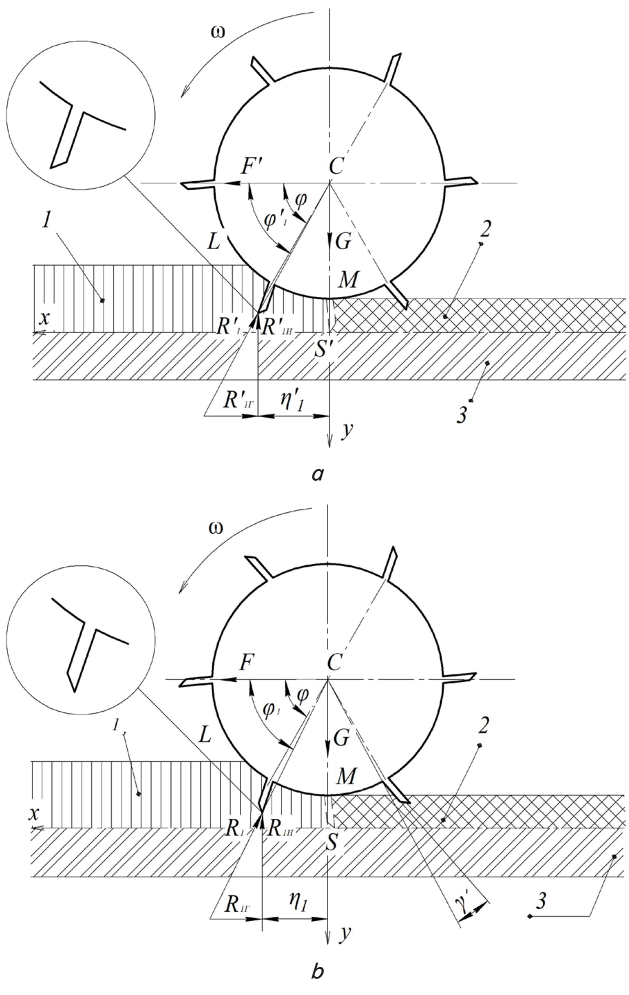

Fig. 1. The scheme of interaction of the shredder roller blade with the plant environment: 1 – plant remains; 2 – a layer of crushed plant remains; 3 – soil; *a* – the cutting edge of the blade coincides with the direction of rotation of the roller drum (assembly diagram 1); *b* – the cutting edge is installed in the direction opposite to the direction of rotation of the drum (assembly diagram 2)

During the rolling of the drum of the shredder roller along the plane, the layer of plant remains is deformed, which interacts with the blade along the arc *LM* (Fig. 1, *a, b*) of the drum. The total reaction R_1' (Fig. 1, *a*) of the resistance of the plant environment is applied to the extreme point of the knife blade at an angle φ_1' to the horizontal direction of action of the driving force F'. The total resistance reaction R_1 (Fig. 1, *b*) of the plant environment is applied to the extreme point of the knife blade at an angle φ_1 to the horizontal direction of action of the driving force *F*.

It follows from Fig. 2 that the angle φ_1 formed by the direction of action of the total reaction of the plant environment with a horizontal line according to diagram 2 exceeds the similar angle φ_1' in diagram 1. This excess is $\varphi_1-\varphi_1'=\Delta\varphi_1$.

The total reaction force R_1' (Fig. 1, *a*) is divided into normal R_{1N}' and tangential components R_{1h}'. The tangential component is the force of friction $R_{1h}'=F_f'$. The normal component of the reaction force is slightly shifted relative to the center of gravity of the drum in the direction of its rotation. For scheme option 1 (Fig. 1, *a*), this displacement is η_1', for scheme option 2 (Fig. 1, *b*) – η_1, respectively. It follows from Fig. 1, *a, b* that the weight *G* normal reaction R_{1N}' and the weight of the roller and the normal reaction R_{1N} (Fig. 2) form a pair of forces – a pair of rolling friction.

The arm of pair action η_1' – (Fig. 1, *a*), η_1 (Fig. 1, *b*) is called the coefficient of rolling friction. Thus, in contrast to the coefficient of friction *f*, which is a dimensionless quantity, the coefficients of rolling friction η_1', η_1 are measured in centimeters.

The direction of the *x* axis is specified (Fig. 1, *a, b*; Fig. 2). The *y* axis is directed vertically. The angle of rotation of the roller drum φ is counted in the counterclockwise direction. The angles φ_1' (Fig. 1, *a*) and φ_1 (Fig. 1, *b*) are determined under the conditions of rotation of the drum by the angle φ.

External forces are applied to the roller drum: *G* is the weight of the roller; *F* – driving force; R_{1N}', R_{1N} is the total normal reaction of the plant environment (Fig. 1, *a, b*), respectively. Let's direct the friction forces $F_f'=R_h'$, $F_f=R_h$ (Fig. 1, *a, b*) in the direction opposite to the direction of movement of the shredder roller.

The differential equations of planar motion for the blade installation option in scheme 1 take the following form:

$$\begin{cases} \dfrac{G}{g}\ddot{x}_c'=F'-F_f', \\ \dfrac{G}{g}\ddot{y}_c'=G-R_{1N}', \\ \dfrac{Gr^2}{2g}\ddot{\varphi}_1'=F_f'\cdot r-\eta_1'G, \end{cases} \tag{1}$$

where $\ddot{x}'$, $\ddot{y}'$ is the acceleration of the center of mass *C* of the roller in the horizontal and vertical planes, (m/s^2); F' – motive force, (*H*); *g* – acceleration of free fall, (m/s^2); $\ddot{\varphi}'$ – angular acceleration, (s^{-2}); *r* is the radius of rotation of the extreme point of the knife blade, (m).

The differential equation of the planar motion of a rigid body (a drum with shredder roller knives) for scheme 2 (Fig. 1, *b*) of installing knives takes the following form:

$$\begin{cases} \dfrac{G}{g}\ddot{x}_c=F-F_f, \\ \dfrac{G}{g}\ddot{y}_c=G-R_{1N}, \\ \dfrac{Gr^2}{2g}\ddot{\varphi}_1=F_f\cdot r-G\eta_1, \end{cases} \tag{2}$$

where $\ddot{x}$, $\ddot{y}$ is the acceleration of the center of mass C of the roller in the horizontal and vertical planes (m/s^2); F – driving force (H); $\ddot{\varphi}$ – angular acceleration.

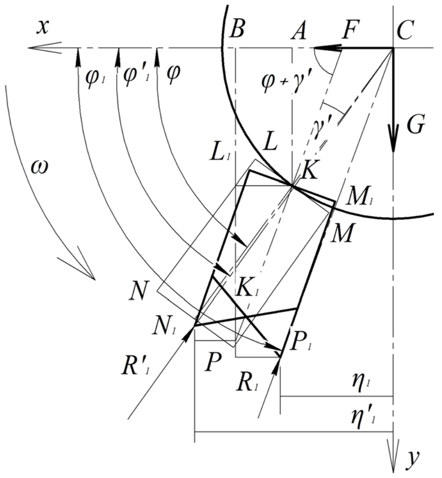

Fig. 2. Calculation scheme of superimposed images of the interaction of the blades of the shredder roller with the plant environment according to scheme 1 and scheme 2

As a result of simple transformations taking into account that $r=r_d+h_t\sin\gamma'$ where r_d is the radius of the roller drum, h_t is the height of the blade, γ' is the angle of inclination of the blade relative to the extension of the radius to the side that coincides with the direction of rotation, we obtain:

$$F' = G\left(\frac{3a}{2g} + \frac{\eta_1'}{r_d + h_t\cos\gamma'}\right), \tag{3}$$

$$F = G\left(\frac{3a}{2g} + \frac{\eta_1}{r_d + h_t\cos\gamma'}\right). \tag{4}$$

Equations (3) and (4) determine the dependence of the driving forces F' and F on acceleration, the coefficient of rolling friction η_1', η_1 and the structural parameters of the roller (roller weight G, drum radius r_d, blade height h_t, blade inclination angle γ'). It was assumed that the total reactions of the plant environment, both under the conditions of using rollers with scheme 1 and scheme 2, would be equal.

$$R_1' = R_1,$$

$$\begin{cases} R_1' = \sqrt{R_{1N}'^2 + R_{1h}'^2}, \\ R_1 = \sqrt{R_{1N}^2 + R_{1h}^2}. \end{cases} \tag{5}$$

Then horizontal projections:

$$R_{1h}' = R_1'\cos\varphi' = F_f' = G\left(\frac{3a}{2g} + \frac{\eta_1'}{r_d + h_t\cos\gamma'}\right),$$

$$R_{1h} = R_1\cos\varphi = F_f = G\left(\frac{3a}{2g} + \frac{\eta_1}{r_d + h_t\cos\gamma'}\right).$$

It follows from (5) that:

$$R_{1N}'^2 + R_{1h}'^2 = R_{1N}^2 + R_{1h}^2. \tag{6}$$

Since $F_f' > F_f$, due to meeting the conditions $\eta_1' > \eta_1$, in order to fulfill (6), it is necessary that $R_{1N} > R_{1N}'$.

This conclusion coincides with the results of the analysis of the static model of the interaction of knives with different installation schemes, given in [12]. That is, with a greater value of the vertical force (scheme 2 of installation of knives), a more intense destruction of the layer of plant remains will be observed.

Under conditions of rotation of the drum around the horizontal axis, the neutral axis of the drum (the axis passing through the middle of the cross-section of the thickness of the knife blade) will turn at angle φ. The blade occupies the $LMPN$ position under the conditions of its installation on the extension of the radius of the drum. If it is installed turned at angle γ' in the direction of the drum rotation, the blade will be in the $L_1M_1P_1N_1$ position. As can be seen from Fig. 2, actually the blade is turned relative to the vertical axis passing through the point K at angle γ'.

As a result of simple transformations, we get:

$$\begin{cases} \eta_1' = r_d\cos\varphi + h_t\cos(\varphi+\gamma') + \frac{b}{2}\sin(\varphi+\gamma'), \\ \eta_1 = r_d\cos\varphi + h_t\cos(\varphi+\gamma') - \frac{b}{2}\sin(\varphi+\gamma'), \end{cases} \tag{7}$$

where b is the blade thickness.

Then, taking into account (7), dependences (3) and (4) will take the form:

$$F' = G\left[\frac{3a}{2g} + \frac{r_d\cos\varphi + h_t\cos(\varphi+\gamma') + \frac{b}{2}\sin(\varphi+\gamma')}{r_d + h_t\cos\gamma'}\right], \tag{8}$$

$$F = G\left[\frac{3a}{2g} + \frac{r_d\cos\varphi + h_t\cos(\varphi+\gamma') - \frac{b}{2}\sin(\varphi+\gamma')}{r_d + h_t\cos\gamma'}\right]. \tag{9}$$

Fig. 3, 4 show graphical dependences based on (8), (9).

Dependences (8) and (9) for different blade installation schemes determine the corresponding values of the driving force F' and F on the structural and kinematic parameters. The noted parameters include the weight of the roller G, the radius of the drum r_d, the height of the blade h_t, the width of the blade b, the angle of inclination of the blade γ', the angle of rotation of the roller drum φ, the acceleration a.

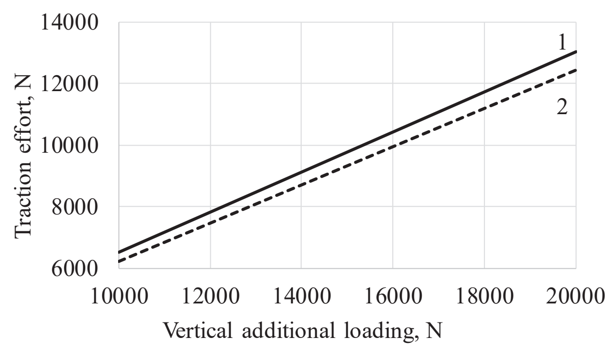

Fig. 3. Dependence of traction effort on vertical post-loading for blades: 1 — the cutting edge coincides with the direction of rotation of the roller drum (scheme 1); 2 — the cutting edge is set in the direction opposite to the direction of rotation (diagram 2) at a=0.3 m/s^2; g=9.81 m/s^2; r_d=165 mm; φ=50°; h_t=80 mm; γ'=12°; b=8 mm

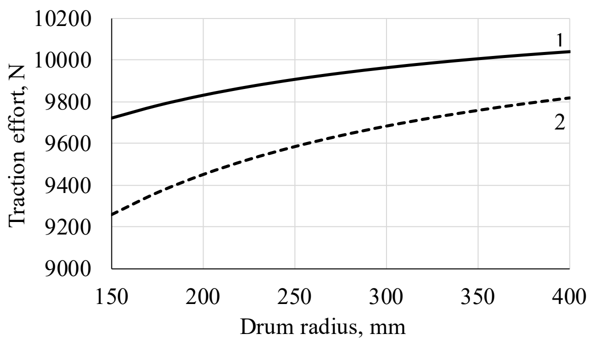

Fig. 4. Dependence of the traction force on the radius of the drum for blad: 1 – the cutting edge coincides with the direction of rotation of the roller drum (scheme 1); 2 – the cutting edge is set in the direction opposite to the direction of rotation (scheme 2) at a=0.3 m/s; g=9.81 m/s; φ=50°; h_t=80 mm; γ'=12°; b=8 mm; G=15000 N

Analyzing the obtained results of studies into the dynamics of the planar movement of the shredder roller, which includes a drum with blades that can be installed according to different schemes (scheme 1 and scheme 2), the following can be noted:

– the values of the vertical components of the total resistance forces of scheme 2 of installing blades exceed the similar values of the forces of scheme 1. Given this, other conditions being equal, greater values of forces are possible, and, as a resut, more intense destruction of the layer of plant remains;

– the values of driving force F, set for scheme 2 by dependence (9), all other conditions being equal, are always smaller than the corresponding values of driving force F' of the variant with scheme 1 of installing knives. Such a regularity is also valid in relation to the analysis of frictional forces. This is due to higher values of the rolling friction coefficient according to scheme 1 than scheme 2, $\eta_1 < \eta_1'$ (Fig. 2).

5. 2. Results of experimental studies into the influence of the location of the cutting edge of the roller blade on the quality indicators of grinding operations

A detailed description of the designed and manufactured shredder roller, as well as experimental studies of its crushing of plant stalks of sunflower and corn, are given in [11]. Below are some general conclusions from them.

Experimental studies of the technological process of grinding sunflower and corn stalks have established an excess of the quality of grinding by rollers with the compositional scheme 2 over the corresponding values of the indicators of the rollers with the compositional scheme 1. This excess, for individual indicators, reaches 20 %. It was established that in rollers whose cutting edge of blades is directed in the direction opposite to the direction of rotation:

– the highest total level of the percentage of chopped stalks in the range of 101–150, with an additional load of 800 kg, exceeded the corresponding indicators of the roller with an additional load of 600 kg by 1.58 times. For the shredder roller in the unit with a disc harrow, this excess was 1.33 times;

– the largest total value of the percentage of chopped stalks in the range of 0–200 mm under the conditions of additional loading of the roller of 800 kg was 1.13 times higher than the corresponding indicators of the roller with an additional load of 600 kg and 1.05 times of the roller in the unit with a disc harrow;

– under the conditions of additional loading of the roller with a weight of 600 kg, the highest total value of the percentage of stalk crushing in the range of 0–50 mm and 0–200 mm was established at a speed of 10.08 km/h, and under the conditions of an additional load of 800 kg – at a speed of 7.45 km/h.

In the range of 0–50 mm, the average value of the weight of the corn stalk particles in the roller whose cutting edge was directed in the direction opposite to the direction of rotation was greater than the corresponding indicators of the roller with the oppositely directed cutting edge. This excess in average weight was 0.042 g for the stem fraction sample, or 10 %.

In the combined unit with layout scheme 2, the average number of crushed parts of corn stalks in the range of less than 50 mm exceeded the corresponding indicators of the unit with layout scheme 1 by 13.6 %. On the surface of the soil, the percentage of crushed parts of corn stalks for the first scheme of installing knives was 39.16 %, for the second – 37.48 %, and in the soil these indicators were 47.18 % and 38.5 %, respectively.

Analyzing the range of 0–100 mm, it was established that the proportion of crushed corn stalks is:

– for rollers whose cutting edge is directed in the direction opposite to the direction of rotation – 36.68 %;

– for rollers whose cutting edge coincides with the direction of rotation –36.68 %.

5. 3. Studies to determine the traction resistance of a shredder roller

Experimental studies of the shredder roller in a unit with a T-150K tractor were conducted in the fields of the State Enterprise «Experimental Farm «Olenivske» (Kyiv oblast) after harvesting sunflowers. The hardness of the soil in the layer (0–15 cm) was 1.7–3.0 MPa, and the moisture content was 6.8–8.1 %.

Fig. 5 shows the graphical dependences of change in the average value of the traction resistance of the shredder roller depending on the additional vertical loading with a force of 7.84 kN (800 kg) and 3.92 kN (400 kg).

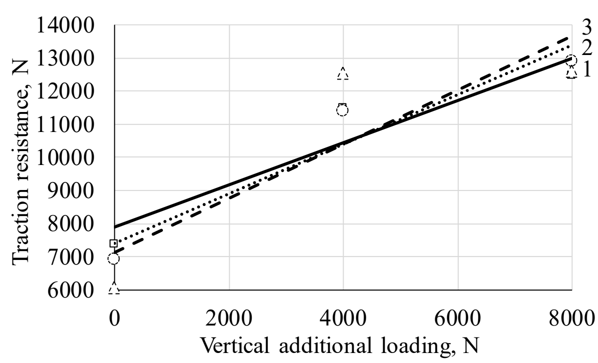

Fig. 5. Change in the traction resistance of the shredder roller depending on the vertical additional loading under conditions of movement at a speed of: 1 – 7.45 km/h; 2 – 13.6 km/h; 3 – 22.0 km/h

Based on the results of the analysis of the above dependences (Fig. 5), it was noted that at zero and 3.92 kN (400 kg) additional load, an increase in speed from 7.45 km/h to 13.6 km/h leads to a decrease in the values of the average traction resistance. With zero additional loading, this reduction was 6 %, for 400 kg – 1.5 %, respectively. The highest value of traction resistance was established at a speed of 13.6 km/h and an additional load of 7.84 kN (800 kg), which is 9.5 % higher than at a speed of 7.45 km/h and 2.4 % at a speed of 22.0 km/h The lowest value of traction resistance was established at zero additional load and a speed of 22.0 km/h, which is 21.5 % less than at a speed of 7.45 km/h and 14.1 % less than at a speed of 13.6 km/h.

Approximation of the results of experimental studies using the method of least squares has made it possible to obtain the regression equation. The dependences of change in the traction resistance of the shredder roller on vertical additional loading under conditions of movement at a speed of 7.45 km/h were obtained; 13.6 km/h; 22.0 km/h:

$$y\,(7.45)=0.8169x+7136.2,\ R^2=0.7576,$$

$$y\,(13.6)=0.7476x+7415.5,\ R^2=0.9253,$$

$$y\,(22.0)=0.6371x+7897.2,\ R^2=0.8866.$$

Increasing the working speeds of unit movement is one of the most attractive ways of improving the productivity of technological operations. However, in real operating conditions, its use has certain limitations. These restrictions may refer to the features of reducing the depth of penetration of the working body into the soil depending on the speed of the energy source. It was established that with zero additional load in the range of speed increase from 7.45 km/h to 22.0 km/h there was a decrease in traction resistance values by 21.4 %. That is, it seems natural that an increase in speed led to a decrease in the depth of penetration of the blades of the shredder roller into the plant-soil environment. The results of studies with additional loading of 3.92 kN (400 kg) and 7.84 kN (800 kg) at all speeds were characterized by stable values of traction resistance. Thus, for an additional load of 3.92 kN (400 kg), a change in speed from 7.45 km/h to 13.6 km/h led to a decrease in traction resistance by 1 %, and in the range of speeds from 13.6 km/h to 22.0 km/h, on the contrary, traction resistance increased by 9.1 %. For an additional load of 7.84 kN (800 kg)), changing the speed from 7.45 km/h to 13.6 km/h resulted in an increase in traction resistance by 3.5 %, and in the range of speeds from 13.6 km/h to 22 ,0 km/h, on the contrary, traction resistance decreased by 2.4 %.

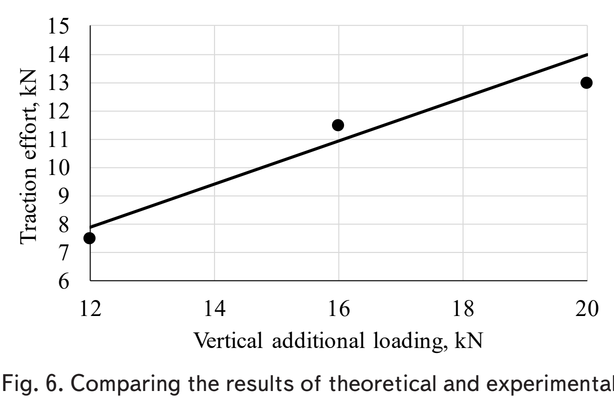

Fig. 6. Comparing the results of theoretical and experimental studies on the determination of traction resistance of the shredder roller: —— – theoretical dependence; • – experimental data

Fig. 6 shows a comparison of the results of theoretical studies with the experimentally established values of the traction force of the shredder roller. The deviation of the theoretical values of the driving force (Fig. 3) from the experimentally determined average values of the traction force (Fig. 6) at a speed of 13.6 km/h was 8.5 %.

6. Discussion of results of the study to determine the influence of the direction of installation of the cutting edge of blades in the shredder roller

This study is a logical continuation of previously conducted systematic studies, which relate to the determination of the influence of the location of the cutting edge of the blade on the indicators of the quality and efficiency of the technological operation – the technological process of grinding vegetable residues of sunflower [11], corn [12], and the cause-and-effect relationships of factors, which determine the system of formation of quality indicators.

The efficiency of the shredder roller design is determined by a number of factors. Among the main ones is the option of placing a blade-shaped working body, the justification of which would make it possible, all other conditions being equal, to create the greatest value of destructive force in the vertical plane. According to the results of the analysis of the obtained theoretical dependence (6), the greatest value of the vertical force is found in the blade, the cutting edge of which is directed in the direction opposite to the direction of rotation. These results were confirmed by experimental studies of grinding with a roller in the solo version of sunflower and corn stalks. It was noted that in the range of less than 50 mm, the percentage of crushed sunflower and corn stalks in the roller whose cutting edge was directed in the direction opposite to the direction of rotation was 20 % higher than the indicators of the roller with the opposite arrangement of knives. The achieved results are especially relevant for the grinding of corn stalks, where it is extremely important to maximize the percentage of stalks less than 50 mm long. In stems of such a length, the corn butterfly pest is unable to exist. That is, the more corn stalks less than 50 mm in length, the smaller the losses from the pest, and, accordingly, the greater the efficiency of crop cultivation [11].

Experimental studies of a combined unit containing a roller, the cutting edge of which is directed in the direction opposite to the direction of rotation, established that the average number of crushed parts of corn stalks in the range of less than 50 mm exceeded the corresponding indicators of the tool with the opposite scheme of fastening the knives by 13.6 %. Under such conditions, the percentage of crushed stem parts for the combined unit with the dominant arrangement of knives was 39.16 % on the soil surface, and 37.48 % with the opposite scheme, and in the soil these indicators were 47.18 % and 38.5 %, respectively [13].

Increasing the working speeds of unit movement is one of the most attractive ways of improving the productivity of technological operations. However, in real operating conditions, its use has certain limitations. These restrictions relate to the peculiarities of reducing the depth of penetration of the working body into the soil depending on the speed of movement of the power tool. That is, an increase in speed leads to a decrease in the depth of penetration, for example, of the knives of a shredder roller.

Performing operations at low speeds makes it possible to implement a scenario when the depth of penetration of the blade into the plant-soil environment is equal to its height.

However, such conditions of technological operation are characterized by certain features and complications. These include increased traction resistance, the formation of accumulations from the plant-soil environment, which make it difficult to move in the longitudinal direction. All the noted factors, together with the physical and mechanical properties of the soil environment, are difficult to calculate, which in general significantly complicates the process of mathematical representation of the movement model in the longitudinal direction. In addition, the noted factors, together with the physical and mechanical properties of the soil environment, complicate the calculation of the effort to roll the roller drum and the depth of penetration of its knives.

It should be noted that the process of movement in the longitudinal direction of the shredder roller, which contains a number of rows of blades, is quite complicated. This is due to the fact that it is not possible to implement a predefined, clearly defined scenario of movement of the drum with knives due to a number of factors. The main ones are the following: the plant-soil environment is characterized by various indicators and properties, heterogeneity, and unevenness. Deformation and destruction of the layer of plants, crumpling of the soil and the formation of a kind of rut, in front of the drum, accumulation of a mixture of plant and soil environment can occur. Under such conditions, the difference in the values of the density of the plant and soil environment and, as a result, the difference in the values of the speed of movement of the knives in them looks natural.

The results of theoretical and experimental studies have made it possible to determine the influence of the direction of installation of the cutting edge of the shredder roller knives on the indicators of the grinding process. Cutters, the cutting edge of which is directed in the direction opposite to the direction of rotation, in addition to the above-mentioned advantages in ensuring a high-quality picture of chopping plant stems, also have advantages in the energy evaluation of the process. The analysis of theoretical dependences (8), (9) established an excess of the values of the driving force of knives whose cutting edge is turned in the direction that coincides with the direction of rotation over the forces of knives whose cutting edge is directed in the opposite direction. That is, with less traction resistance, the design of the roller, the blades of which are directed with the cutting edge in the direction opposite to the direction of rotation, enable the intensification of the process of grinding plant remains.

It should be noted that the results of the theoretical studies were obtained under the condition that the blade of the shredder roller is in contact only with the plant layer. Analytical dependences did not predict contact with soil. Under actual operating conditions, it is extremely difficult to create such ideal conditions for the interaction of the working body with the plant and soil environment. Therefore, it is advisable to continue research on improving mathematical models of the interaction of blade-like working bodies not only with the plant but also with the soil environment. Mathematical models built under such conditions could make it possible to take into account the peculiarities of the structural composition of the vegetation layer and soil. It is advisable to continue experimental research with the aim of accumulating informational data, expanding and clarifying the obtained regularities of the influence of the direction of installation of the cutting edge of the shredder roller knives under the conditions of its interaction with the plant layer of various agricultural crops.

7. Conclusions

1. Analytical dependences of the planar movement of the shredder roller with different blade attachment schemes were established and determined:

– exceeding the values of the vertical components of the total resistance forces of the knives, the cutting edge of which is directed in the direction opposite to the direction of rotation, over the corresponding values of the forces of the knives, the cutting edge of which coincides with the direction of rotation. That is, at higher values of effort, a more intense destruction of the layer of plant remains becomes possible;

– dependence of the driving force on the structural and kinematic parameters of the roller (weight, radius of the drum, height of the blade, angle of inclination of the blade, acceleration). The obtained dependences made it possible to establish an excess of the values of the driving force of the knives, the cutting edge of which is turned in the direction that coincides with the direction of rotation, over the forces of the knives, the cutting edge of which is directed in the opposite direction.

2. Experimental studies have established an excess of up to 20 % of the quality indicators of milling sunflower and corn stems with roller blades, the cutting edge of which is directed in the direction opposite to the direction of rotation.

The average number of crushed pieces of corn stalks in the range of less than 50 mm is 13.6 % higher in the combined unit, the cutter blades of which are directed with the cutting edge in the direction opposite to the direction of rotation.

3. It was established that with zero and 3.92 kN (400 kg) additional loading, an increase in speed from 7.45 km/h to 13.6 km/h leads to a decrease in the values of the average traction resistance. With zero additional loading, this reduction was 6 %, for 400 kg – 1.5 %, respectively. The highest value of traction resistance was established at a speed of 13.6 km/h and an additional load of 7.84 kN (800 kg), which is 9.5 % higher than at a speed of 7.45 km/h and 2.4 % at a speed of 22.0 km/h. The lowest value of traction resistance was established at zero additional load and a speed of 22.0 km/h, which is 21.5 % less than at a speed of 7.45 km/h, and 14.1 % less than at a speed of 13.6 km/h.

The deviation of the theoretical values of the driving force from the experimentally determined average values of the traction force at a speed of 13.6 km/h was 8.5 %.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

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