EXPERIMENTAL RESEARCH ON QUALITY FUNCTIONING OF HAULM RESIDUE REMOVER FROM SUGAR BEET EPICOTYL

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Abstract: The modern technology of sugar beet haulm harvesting assumes the so-called double-stage cutting. First, the basic continuous cutting of the haulm residues from the epicotyl is carried out by using rotor haulm-cutting mechanisms. Then there follows clearance or cutting the residues from the epicotyl. This technology allows continuous, superior quality cutting and green matter harvesting. The green matter can be used as cattle fodder or a raw material for the production of biogas and clearance of haulm from root crops, eliminating the loss of sugary mass. We have developed a new structure of the epicotyl remover of haulm residues; the production tests have yielded positive results. The remover comprises two driving horizontal cylinders, on which cleaning elastic blades are fixed with a toggle in the radial direction. The machine's shafts clasp each row of root crops, and the blades produce elastic bumps to the epicotyl from two opposite sides, thus cleaning effectively the spherical surfaces of the sugar beet epicotyls from the haulm residues. We have also developed new experimental equipment that allows modeling the work of the remover in field conditions, and we further pursue the experimental research of the machinery and tools. We have designed a program and methods to facilitate a field multifactorial experiment with a remover of haulm residues from the epicotyl of sugar beet roots and to determine the relevant quality indicators. The acquired results, processed by a PC, showed that the quality of the technological process that employs a remover with two driving horizontal cylinders to extract the haulm residues from the epicotyl of sugar beet can be improved via an elevated circumferential speed of the remover's driving cylinders and a reduced height of the fixed blades above the level of the soil surface at a low gradual speed of the machine motion. Based on an analysis of the acquired functional and graphic dependences, we claim that the rational significance of the functioning modes of the studied remover of haulm residues from sugar beet epicotyl, which delivers the highest quality operation in order to remove the haulm residues from the spherical surfaces of the epicotyls of root crops, involves: 1) the speed of the gradual motion of the remover – 1.5...2.5 $m \cdot s^{-1}$; 2) the circumferential speed of the rotation of the driving cylinders – 55...80 $rad \cdot s^{-1}$; 3) the height of fixing the blades of the remover over the soil surface level – 0...2.5 cm.

Keywords: sugar beet, haulm, epicotyl remover, experimental equipment, measurement results, PC processing.

Introduction

The modern technology of sugar beet harvesting assumes a separate harvest of the haulm and root crops, in particular, cutting the haulm at the root and subsequently pulling the roots from the soil. The haulm removal is carried out in two phases: continuous cutting of the green mass of the haulm at an increased height, and clearing the haulm residues from the epicotyl, namely, epicotyl cutting. All of the described haulm harvesting operations are performed on the root, i.e. the sugar beet corpus still rests in the soil.

Multiple examinations have proved that a principal drawback lies in considerable losses of the root crop corpuses (the cut epicotyls stay in the field) and the associated loss of the sugar mass; these issues occur in the process of cutting the epicotyls after the continuous haulm cutting. Based on previous experience and processing outcomes, the structural arrangement of the harvesting machinery presently appears to constitute a significant precondition for successful final removal of the crop from the field. The various measurements also verified that along with irretrievable losses of the cut root crop epicotyls there also emerges a loss of the possible sugar yield, at 8…10% out of each hectare of the sown sugar beet. From a rather general perspective, the importance of the above-mentioned aspects and other related factors is discussed in, for example, articles [1-10]; the cultivation preconditions and modeling that facilitate fruitful harvesting procedures and improve the yield rate are then outlined within articles and research reports [2-5; 7; 8; 11; 12]. In this connection, prospective innovations in harvesting the haulm appear to promise a very beneficial impact. Thus, additional cleaning of the root crop epicotyls from the haulm residues on the root has become a topical, economically rationalized operation which enables us to economize significantly the yield of the final product from a unit of harvested area along with a high quality of the original raw material. The novel structure of the remover of haulm residues from the epicotyls of sugar beet on the root relies on enhanced continuous cutting of the haulm mass by a haulm cutting rotor mechanism. The structural specialty of the remover is the presence of two driving cutting cylinders with horizontal rotating axes, which clasp each row of sugar beet from two sides. These cutting cylinders of a particular length can be placed in parallel, and they can be fixed to each other under an angle. The cylinders form a cleaning channel with a large size in the front part and a smaller size in the rear sector. On the cylinders of a radial direction, cleaning elastic blades are fixed by using a special collar and toggle. On each shaft, the blades are fixed along its length of a particular span. The cylinders with the collars (cleaning blades) are fixed to the frame so that the ends of the attached blades, radially in each cylinder, are placed opposite to the gaps between the blades of the second cylinder. The cylinders can rotate either in one way or in the opposite direction of rotation. The enhanced main mechanical structures and relevant complementary tools were designed in response to and considering previous approaches, such as those presented within studies [6; 7; 14; 19].

In order to study the technological and energy parameters of the remover of haulm from epicotyls of root crops on the root, we have developed experimental field equipment to model the functioning of the standard prototype of the remover under the real conditions of a sugar beet field. This type of equipment aggregates with a wheel-type tractor of the 1.4 class, and it facilitates cleaning the haulm residues from one prepared row of sugar beet, where the basic haulm mass had been cut before; despite these facts, however, residues are still left on the epicotyls of root crops.

Materials and methods

To determine experimentally the rational significance of the construction and kinematic parameters of the new remover of haulm residues from the epicotyl of sugar beet on the root, we employed solutions that result in a high quality of the technological process. The above-outlined laboratory and field experimental research was carried out in order to study the process of the remover functioning with the horizontal cylinders to cut the epicotyls of root crops. The exploration assumed and involved the following stages: an experimental observation of the level of cleaning the root crop epicotyls from the haulm residues on the root along with a wide range of measurements of regimes of the operating components of the remover; a statistical analysis of the results of the experimental studies; and justification of the rational regimes of the remover functioning. The studies utilized used the generally accepted and partial methodologies [3-6; 8-13; 15; 20].

The works [14; 21] are devoted to the study of the technological process of removing the remains of tops from the heads of the root crops on the cleaner with shafts, installed at an angle to one another, and the use of thin polyurethane blades. In order to pursue the experimental research and to acquire adequate data, we set the initial requirements for the sugar beet epicotyl removers as follows: the haulm on the sugar beet must be removed without complete cutting by the haulm cutter; the cutting of the epicotyl must be direct, smooth, without any residues; the cutting plane must not cross the level of the base of the green shoots and must not be higher than 20 mm from the top of the epicotyl of the root crops. The cut mass of the root crops with the haulm cannot be higher than 5%; the total losses of the green mass of the haulm must not exceed 10% of the yield, including the sugar beet roots cut high and uncut in bunch, and left on the soil surface; and the quantity of damaged roots must not exceed 20%, the overall volume of heavily damaged ones being required to range below 5%.

The evaluation of the conditions of the experiment included the characteristics of the soil-climate conditions and seeding, the conditions of the machine functioning, and the characteristics of the quality indicators of the operation.

Based on an analysis of the literature, the results of the preliminary theoretical research, and expert evaluation, we determined the principal factors of the experimental studies:

1. The speed of movement of the remover, $m \cdot s^{-1}$;
2. The rotational speed of the driving cylinders of the remover, $rad \cdot s^{-1}$;

3. The height of the fixing blades of the remover above the soil surface, cm.

The quality indicator to define the functioning of the remover was the quantity of the haulm mass on all epicotyls of the sugar beet, which grew at one meter of the area of the test bed.

Fig. 1 below presents a view of the sugar beet row where the base haulm mass was harvested (in the higher cut); here, however, the haulm residues that grow at the soil surface level or in the interseeding have remained, as is apparent from the image. In order to study the impact of the remover functioning regimes on the epicotyl cleaning quality, multifactorial experiments have been carried out to respond to the elaborated scheme of the studies.

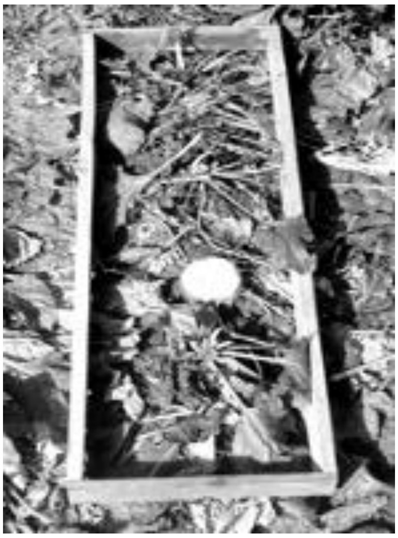

Fig.1. **Sugar beet testing bed of 1 linear meter; the basic haulm mass was cut from the epicotyl of the root crop**

The variation of the functioning regimes of the remover was carried out at a particular interval during the experimental research, as is obvious from these two factors.

1. The speed of operation: by changing over of the speed-change box of the aggregate tractor in accordance with the scale of the determined speed of operation. In the aggregation of the remover with a wheel tractor, the lower limit of the speed of operation was 0.75 $m \cdot s^{-1}$, the upper limit equalled 2.5 $m \cdot s^{-1}$, and the average speed reached 1.6 $m \cdot s^{-1}$. Regarding the rotational speed of the cleaner's driving cylinders, the variation proceeded via changing the transmissive number in the elements of the driving mechanism (by changing the driving chain gear with different number of cogs). The maximum significance of this factor is: the lower limit, 34.8 $rad \cdot s^{-1}$; the upper limit, 78.4 $rad \cdot s^{-1}$; the interval relevance 56 $rad \cdot s^{-1}$.
2. The fixing height of the cleaning blade's end in relation to the soil surface level: placing the tracing wheels on the frame of the experimental equipment, on which the cleaner is located. The scale of the height change of the blades' ends was chosen according to the blades' ability to compensate the soil surface bumps. The minimal height was 0 m, corresponding to the soil surface level; the average height reached 0.02 m (2 cm); and the maximum height equalled 0.04 m (4 cm). The significance of the maximum height takes into consideration the ability of ascent of the upper epicotyls (parts) of the sugar beet above the soil surface. The experimental research was performed under the following field conditions: soil type according to the mechanical characteristics – black soil; soil firmness 1.1…2.0 MPa; soil humidity 22.1…22.6%; bracken infestation 4 $pieces \cdot m^{-2}$ of height up to 100 cm; soil relief – flat; haulm yield 23 $t \cdot (ha)^{-1}$. The field tests were repeated five times with the appropriate significance of the blades' height in relation to the soil surface, the speed of operation, and regimes of the rotation of the driving horizontal cylinders of the cleaner in accordance with the plan matrix.

In order to pursue the experimental tests centred on the quality indicators of the remover of haulm residues from the epicotyl of sugar beet, we developed the above-introduced field experimental equipment, allowing us to model the functioning of the remover in the field (Fig. 2).

Fig. 2. **Overall view of the experimental equipment: the remover with two horizontal cylinders**

Fig.3 presents a view of two rubber cleaning blades, mounted pivotally on the axis. In addition, each rubber blade has at the end, on the working surface, protrusions of a hemispherical shape, the height of which does not exceed 0.5 cm.

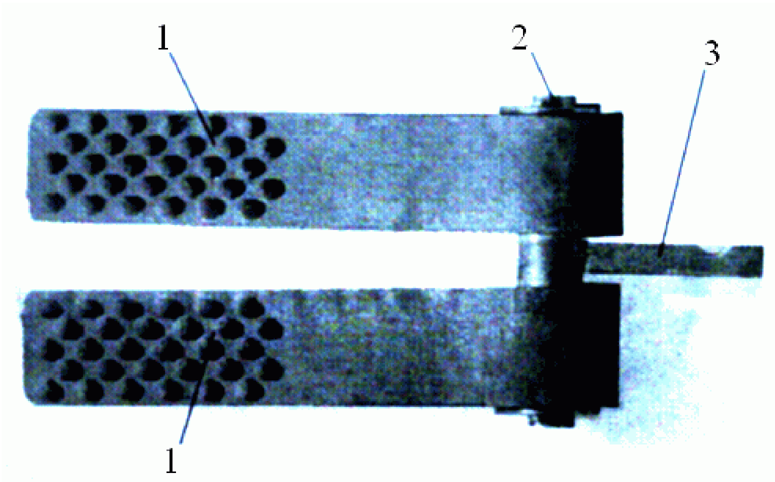

Fig. 3. **Rubber vanes, mounted in cages on horizontal cleaning rollers:** 1 – ends of the blades with hemispherical protrusions; 2 – axis of the pivotal blades; 3 – axle leash

The experimental equipment (Fig. 4) consists of a basic frame (1), which is hung on the aggregate tractor via a towing device (4). On the basic frame (1) is fixed a revolving frame (2) by means of a rotating balk (3). The revolving frame (2) is necessary for suspending the cleaning working mechanism with the horizontal driving cylinders to cut the epicotyl of the root crops. The frame can be installed through the rotating balk (3) under different angles to the surface of the sugar beet field. The field experimental equipment is operated in a floating position, and the height of the cleaning working apparatus (the ends of the elastic cleaning blades) is controlled by tracing wheels (5). The position of the tracing wheels in relation to the frame (1) can be changed through the construction of the bolt mechanism fixed to the frame.

The driving cylinders of the working mechanism are set into the rotating movement by a cardan-shaft transmission (8) from the power take-off shaft of the aggregated tractor through a conical reducer (6). Then, another reducer (7) moves on from the former one by the chain gear. This reducer is fixed on the rotating balk (3) and through it a chain gear and cardan-shaft transmission (10) drive the cleaning working mechanism (11).

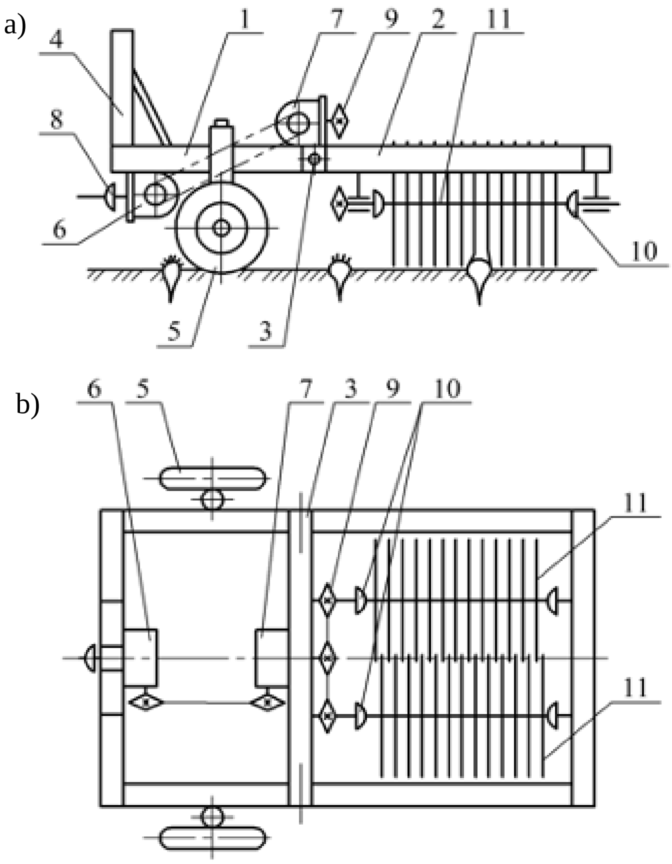

Fig.4. **Structural scheme of the experimental equipment:** a – side projection; b – top view

The quality of cleaning the haulm residues from the epicotyl of each beet was monitored by hand cutting in each repetition on the research field; this stage was followed by weighting with electronic scales.

Results and discussion

As a result of the analysis of the data, obtained experimentally and processed, using a PC, there were obtained functional dependences of the leaves of the tops (Y) upon the angular speed of rotation of the horizontal drive shafts of the cleaner (X_1) and the installation height of the ends of the rubber blades of the cleaner relative to the level of the soil surface (X_2) at a particular forward speed of the cleaner in the form of a polynomial dependence of the 2nd degree:

- for forward speed of the movement 0.75 m·s^{-1}:

$$Y = 192.8 - 6.82 \cdot X_1 + 37.3 \cdot X_2 + 0.058 \cdot X_1^2 - 0.592 \cdot X_1 \cdot X_2 + 1.46 \cdot X_2^2, \quad (1)$$

- for forward speed of the movement 1.5 m·s^{-1}:

$$Y = -141.9 + 6.91 \cdot X_1 + 22.2 \cdot X_2 - 0.066 \cdot X_1^2 - 0.189 \cdot X_1 \cdot X_2 - 0.253 \cdot X_2^2, \quad (2)$$

- for forward speed of the movement 2.5 m·s^{-1}:

$$Y = 76.8 - 2.30 \cdot X_1 + 31.4 \cdot X_2 + 0.018 \cdot X_1^2 - 0.273 \cdot X_1 \cdot X_2 + 1.43 \cdot X_2^2. \quad (3)$$

The test data (Table 1) originated from the completed three-factor experiment, which had been performed according to the standard plan. The data were processed via statistical, regressive, and correlation analyses.

As a result of the analysis of the obtained dependences, it was established that the best approximation of the experimental data of the effect of the forward speed of the cleaner, the angular speed of rotation of the cleaner drive shafts and the height of the cleaner rubber blades above the soil surface (the location of the ends of the rubber blades in the working position relative to the soil surface) on the quality of residue removal tops corresponds to a polynomial dependence of the 2nd degree. The most significant factor in this case is the installation height of the ends of the rubber blades of the cleaner above the level of the soil surface X_2.

Graphical interpretation of the results of the experimental studies is presented in the form of response surfaces of the dependence of the mass of the haulm residues upon the angular velocity of rotation of the horizontal drive shafts of the cleaner and the installation height of the ends of the rubber blades above the level of the soil surface at the forward speed of the cleaner: 0.75 m·s^{-1} (Fig. 5), 1.5 m·s^{-1} (Fig. 6), 2.5 m·s^{-1} (Fig. 7).

Table 1

Results of the experimental studies of the quality of work of the cleaner of root crops with two horizontal shafts

Rotational speed of the driving cylinders, rad·s^{-1}	**Operational speed of the remover motion**								
	0.75 m·s^{-1}			1.5 m·s^{-1}			2.5 m·s^{-1}		
	Height of the cleaning blades fixing above the soil surface level, cm								
	0	2	4	0	2	4	0	2	4
	Tops residue, g·m^{-2}			Tops residue, g·m^{-2}			Tops residue, g·m^{-2}		
78.4	2.8	3.8	4.4	1.7	10.2	12.9	4.1	52.1	77.4
	2.7	3.9	4.5	6.2	11.8	12.8	9.3	50.1	73.2
	6.1	8.5	9.7	4.8	10.9	11.5	9.2	30.9	58.3
	5.8	7.9	7.4	8.1	13.4	14.5	10.4	36.8	49.9
	2.7	8.7	8.9	6.7	12.8	13.3	8.9	42.7	57.4
54.2	5.9	3.4	12.6	9.7	34.6	104.2	8.9	13.7	99.7
	10.3	12.6	13.8	14.8	74.3	100.3	13.7	12.9	113.2
	12.6	18.3	20.4	17.3	68.5	101.2	10.8	16.8	121.3
	13.5	18.2	21.1	16.8	82.2	100.1	10.7	12.7	130.2
	8.2	12.7	18.4	21.7	90.1	100.9	14.5	16.4	131.2
34.8	14.6	51.1	121.2	31.6	32.8	51.6	12.2	76.4	128.7
	12.8	58.4	155.3	37.2	36.6	68.7	13.9	80.6	118.3
	14.5	61.1	140.4	38.4	48.2	70.9	12.8	101.3	124.3
	26.6	60.4	110.3	28.4	46.7	71.6	9.8	102.8	96.9
	28.8	52.4	121.7	37.3	44.3	89.3	16.2	89.9	98.7

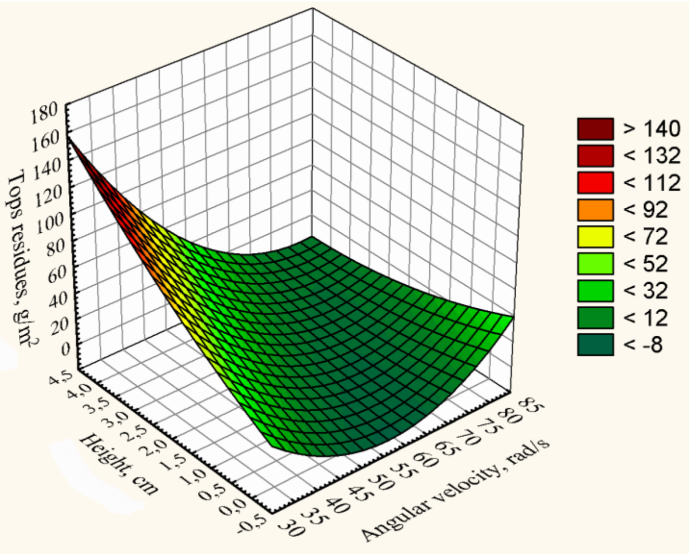

Fig. 5. **Response surface of the dependence of the haulm residues on the angular velocity of the drive shafts of the cleaner and the height of the rubber blades above the level of the soil surface at a forward speed of the cleaner, equal to 0.75 m·s^{-1}**

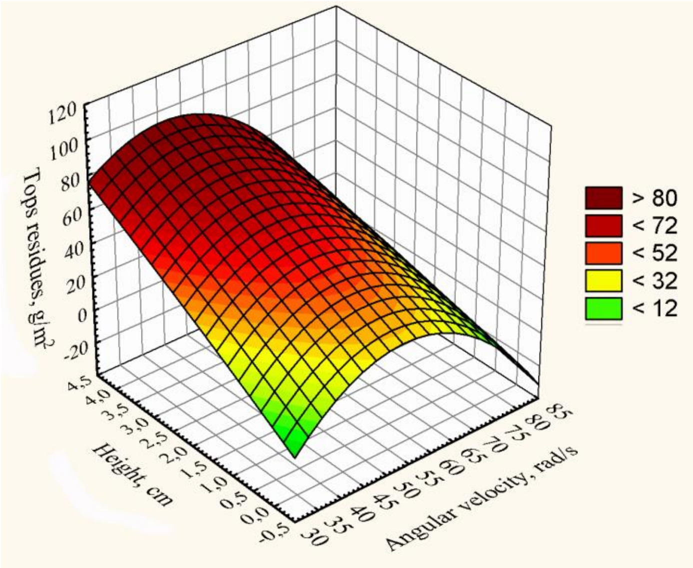

Fig. 6. **Response surface of the dependence of the haulm residues on the angular speed of rotation of the drive shafts of the cleaner and the height of installation of the rubber blades above the level of the soil surface at a forward speed of the cleaner, equal to 1.5 m·s^{-1}**

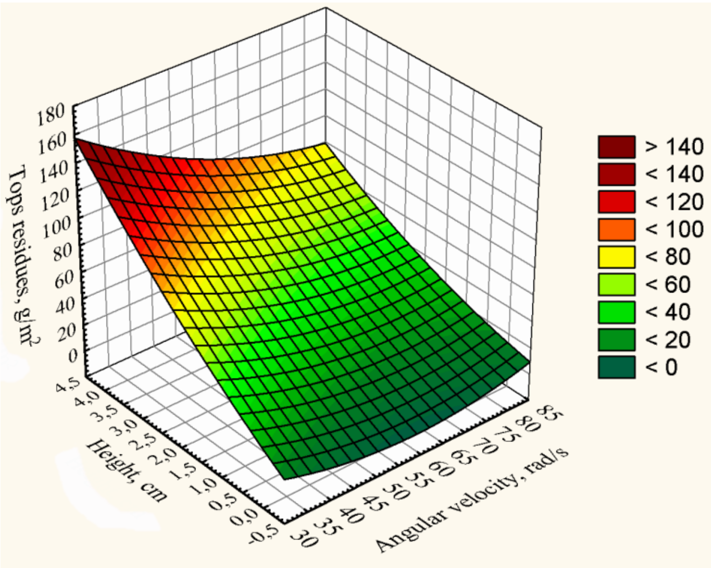

Fig. 7. **Response surface of the dependence of the haulm residues on the angular velocity of rotation of the drive shafts of the cleaner and the height of installation of the rubber blades above the level of the soil surface at a forward speed of the cleaner, equal to 2.5 m·s^{-1}**

Analysis of the obtained functional and graphical (Fig. 5-7) dependencies indicates that, with an increase in the angular speed of rotation of the horizontal drive shafts of the cleaner and a decrease in the height of the installation of the ends of the rubber blades relative to the level of the soil surface, a decrease in the remains of tops on the spherical surfaces of the heads of the sugar beet root crops is mainly observed, which corresponds to a better performance of the cleaning process. However, at the values of the forward speed of the cleaner, equal to 1.5 m·s^{-1}, the dependence is of more complex and ambiguous nature. As for the effect of the forward speed of the cleaner on the quality of its work, it should be noted that at an angular speed of rotation of the cleaner's drive shafts, equal to 54.2 rad·s^{-1} and 78.4 rad·s^{-1}, a gradual increase in the weight of the top residues on the sugar beet heads is first observed in the speed range of 0.75...1.5 m·s^{-1}, followed by an increase in the mass of the haulm residues on the heads of the root crops within the speed range of 1.5...2.5 m·s^{-1} At a frequency of rotation of the drive shafts of the cleaner 40…55 rad·s^{-1} at a speed of 1.5 m·s^{-1}, the nature of its influence on the quality indicators of the cleaner is changeable. At the installation height of the cleaning blades relative to the level of the soil surface, equal to 0 cm, with an increase in the forward speed of the cleaner within 0.75...1.5 m·s^{-1}, the mass of the top residues on the root crop heads decreases. However, in the speed range of 1.5...2.5 m·s^{-1}, there is a certain increase in this performance indicator. When the height of the ends of the rubber blades relative to the level of the soil surface is 2 cm, the mass of the top residues on the heads of the root crops is 35–40% more than when the height of the ends of the blades is 0 cm, and the angular velocity of rotation of the rubber blades is 54.2 rad·s^{-1} and 78.4 rad·s^{-1}. But, when the installation height of the ends of the rubber blades above the level of the soil surface is equal to 4 cm with an increase in the forward speed of the cleaner, the mass of the haulm residues is intensively reduced to 50%. On the whole, it can be concluded that the improvement of the quality of the technological process by the cleaner of the heads of the root crops from the remains of the tops with horizontal drive shafts can be achieved by increasing the angular speed of rotation of the drive shafts of the cleaner and reducing the installation height of the ends of the rubber blades above the soil surface at high forward speeds of the cleaner. At a low speed of movement up to 1 m·s^{-1} at a height of installation of the ends of the blades up to 2.5 cm, the angular speed of rotation of the drive shafts practically does not affect the quality of the technological process.

As a result of the analysis of the obtained dependences, it was found that the rational modes of operation of the investigated cleaner of sugar beet heads from the the residues without extraction of the beets from the soil with horizontal drive shafts are:

- the forward speed of the cleaner is 1.5...2.5 m·s^{-1};
- the angular speed of rotational movement of two horizontal drive shafts – 55...80 rad·s^{-1};
- the installation height of the ends of the rubber cleaning blades above the level of the soil surface – 0...2.5 cm.

With the indicated values of the cleaner operation modes, its most high-quality work will be in removing the top residues from the spherical surfaces of the sugar beet heads, from which the basic mass of the tops is cut.

Conclusions

1. A new design of a head cleaner for sugar beet root crops from the top residues without extracting the beets from the soil has been developed, which consists of two drive cleaning shafts with pivotal rubber blades that cover a row of sugar beet roots from two sides and, applying lateral impacts, clean the spherical surfaces of the heads from the top residues. The rubber blades are mounted on axles, fixed on clips and contain hemispherical protrusions at their ends.
2. To study the process of operation of the cleaner of the root crop heads from the residues of tops without extracting the heads from the ground with horizontal drive shafts and rubber blades, and substantiate its rational operating modes on the basis of standard and developed methods, field experimental studies were conducted of the influence of the operating modes of the cleaner upon the degree of cleaning of the heads of root crops from the residues of tops.
3. To conduct experimental studies of the impact of the main operating modes of the cleaner upon the quality indicators of the technological process, according to the accepted plan-matrix, a special experimental installation was developed and made.
4. As a result of analysis of the experimental data, processed using a PC, it was found that improving the quality of the technological process of cleaning the sugar beet heads from the residues of tops with a cleaner having two horizontal drive shafts can be achieved by increasing the angular speed of rotation of the drive shafts of the cleaner and reducing the installation height of the ends of the rubber blades above the level of the soil surface at sufficiently high forward speeds of its movement.
5. Based on the analysis of the obtained functional and graphical dependences, it has been established that the rational values of the operation modes of the studied cleaner of the sugar beet heads from the top residues with rubber blades, which will ensure the highest quality of removing the remains of the tops from the spherical surfaces of the root crop heads, will be:
   - the cleaner forward speed – 1.5...2.5 m·s^{-1};
   - the angular speed of the drive shafts – 55...80 rad·s^{-1};
   - the installation height of the ends of the rubber blades of the cleaner above the level of the soil surface – 0...2.5 cm.

6. The use of rubber blades with hemispherical protrusions at the ends, 0.5 cm high, improves the quality of cleaning the beet heads from the haulm residues by an average of 8...10% in comparison with the blades made of polyurethane.

Author contributions

Conceptualization, V.B., methodology, S.I. and M.B., software, M.Z. and M.K., validation, I.B. and B.O; formal analysis, V.B and P.D.., investigation, V.B., S.I., M.Z. and M.K; data curation, A.B., D.O. and P.D., writing – original draft preparation, V.B., writing – review and editing, A.A. and V.B., visualization, Y.I., V.N., project administration, V.B., funding acquisition, S.I. All authors have read and agreed to the published version of the manuscript.

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