Experimental study of operation quality of a root head cleaner with rubber blades

Volodymyr Bulgakov[1]; Myroslav Budzanivskyi[2]; Ivan Holovach[1]; Yevhen Ihnatiev[3]; Ivan Chibichik[3]

[1]*National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine*
[2]*Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine*
[3]*Dmytro Motornyi Tavria State Agrotechnological University, Ukraine*
E-mail: vbugakov@meta.ua, yevhen.ihnatiev@tsatu.edu.ua

Abstract. *Modern technologies for harvesting sugar beet tops provide for the so-called two-stage cut, when the main continuous cutting is first carried out from the heads of root crops, as a rule, by rotary top-cutting mechanisms and subsequent cleaning or trimming of the heads of root crops from the remains of tops on the vine. It is this haulm harvesting technology that provides the highest quality continuous cutting and collection of green mass, which can be used as feed for livestock or as a raw material for biogas production and cleaning of root crop heads from haulm residues, eliminating the loss of sugar-bearing mass. We have developed a new design of the head cleaner from the remnants of the tops, the production tests of which showed good results. Such a cleaner of heads of root crops consists of two drive horizontal shafts, on which cleaning elastic blades are hinged in the radial direction. At the same time, the shafts, as it were, wrap around each row of root crops and the blades, applying elastic blows to the heads from two opposite sides, effectively clean the spherical surfaces of the heads of sugar beet root crops from the remains of tops. A new experimental setup was also created, which makes it possible to simulate the operation of this cleaner in the field and conduct its experimental studies. We have developed a program and methodology for conducting a field multifactorial experiment for this cleaner of heads of sugar beet root crops from the remains of tops on the vine, to determine the quality indicators of its work. The obtained results of the research, processed using a PC, showed that improving the quality of the technological process of cleaning the heads of sugar beet roots from the remains of tops by a cleaner with two drive horizontal shafts can be achieved by increasing the angular velocity of the drive shafts of the cleaner and reducing the installation height of the blades above the soil surface by small its forward speed. Based on the analysis of the obtained functional and graphical dependencies, it has been established that the rational values of the operating modes of the studied sugar beet root heads cleaner from haulm residues, in which the most high-quality work will be carried out to remove haulm residues from the spherical surfaces of root crop heads, are: 1) the speed of the progressive movement of the cleaner – 1.5...2.5 m·s^{-1}; 2) angular speed of rotation of drive shafts – 55...80 rad·s^{-1}; 3) installation height of the blades of the cleaner above the level of the soil surface – 0...2.5 cm*

KEYWORDS*: BEETROOT, TOPS, HEAD CLEANER, EXPERIMENTAL SETUP, MEASUREMENT RESULTS, PC PROCESSING*

1. Introduction

Modern sugar beet harvesting technologies involve separate harvesting of the tops and root crops, namely, the cutting of the tops on the vine and the subsequent extraction of root crops from the soil. In this case, the removal of the tops is carried out in two stages: a continuous main cut of the green mass of tops at an elevated height and subsequent cleaning of the heads from the remains of the tops or cutting off the heads. All the listed haulm harvesting operations are carried out on the vine, i.e. when the bodies of sugar beet root crops are found in the soil.

Numerous studies have established that when cutting the heads of root crops after a continuous main cut of the tops, despite the fact that this operation can be successfully carried out with simple designs of trimmers, it has a significant drawback – significant loss of body weight of root crops (cut heads remain in the field), and, hence the sugar mass. Numerous measurements also found that, along with the irretrievable losses of cut heads of root crops, a potentially possible sugar yield from each hectare of sugar beet crops is lost, sometimes reaching 8...10%.

In this regard, the exclusion of the operation of cutting the upper heads of root crops from the technology of harvesting sugar beet tops is more than justified.

Thus, it is the additional cleaning of the heads of root crops from the remnants of tops on the vine that is an actual, economically justified operation, which allows, with a high quality of the feedstock, to significantly save the yield of the final product per unit of harvested area.

We have developed a new design of the sugar beet root heads cleaner from the remains of the tops on the vine, after an increased continuous cut of the tops array with a rotary top cutter. The design feature of this cleaner is the presence of two driven cleaning shafts with horizontal axes of rotation, which cover each row of sugar beet root crops from two sides. These cleaning shafts, of a given length, can be arranged in parallel, or can be installed at an angle to each other, creating a so-called cleaning channel, which is larger in the front part, and smaller in the rear part. Elastic cleaning blades are hinged on the shafts in radial directions with the help of special holders in such a way that the blades are fixed on each shaft along its length with a certain pitch. In this case, the shafts with the specified clips (cleaning blades) are mounted on the frame so that the ends of the radially fixed blades of one shaft are located opposite the gaps between the blades of the second shaft. Shafts have the ability to rotate either in one direction or in opposite directions of rotation.

To study the technological and energy parameters of this head cleaner from the remains of tops on the vine, we developed a field experimental setup that allows us to simulate the operation of a single sample of this type of root head cleaner under real conditions of a sugar beet field. This field experimental unit is aggregated with a class 1.4 wheeled tractor and allows cleaning of haulm residues from one prepared row of sugar beet root crops, from which the main mass of haulm was previously cut, but some residues remained on the heads of root crops.

2. Preconditions and means for resolving the problem

Purpose of research. Experimentally determine the rational values of the design and kinematic parameters of a new head cleaner for sugar beet root crops from the remains of tops on the vine, ensuring the high quality of this technological process.

Program and methodology of experimental research. In order to study the process of operation of the root crop head cleaner with horizontal shafts, laboratory and field experimental studies were carried out, the program of which included an experimental study of the degree of cleaning of the root crop heads from the remains of tops on the vine with a wide range of changes in the operating modes of the working bodies of the root head cleaner, statistical analysis of the results of experimental studies and determining the factors most influencing the degree of cleaning of root crops, as well as substantiating the rational operating modes of the cleaner. When conducting experimental studies, generally accepted methods were used and partial methods were developed.

Materials and Methods. In order to ensure the conduct of experimental studies and obtain adequate experimental data, the initial requirements for cleaners of heads of sugar beet root crops were substantiated: the tops on sugar beet roots should be removed without additional cleaning by a haulm machine; the cut of the head

must be straight, smooth, without chips; the cutting plane must pass not lower than the level of the base of the green cuttings and not more than 20 mm from the top of the head of the root crops. At the same time, the cropped mass of root crops with tops should not exceed 5%; the total loss of green mass of tops, including free, on highly pruned and unpruned sugar beet roots in a heap and lost on the soil surface, should not exceed 10% of its yield; the number of damaged root crops should not be more than 20%, including severely damaged up to 5%.

A qualitative indicator of the work of the cleaner heads of root crops from the remains of tops on the vine was determined by the mass of residues of tops on all heads of sugar beet root crops, which were located on one linear meter of the area of the experimental plot.

When conducting experimental studies, the variation of the operating modes of the cleaner in the established range was carried out:

– forward speed: by shifting the implement tractor's gearbox in accordance with the set operating speed range. When aggregating the cleaner with wheeled tractors, the lower limit of the forward speed was 0.75 m·s^{-1}, upper bound – 2.5 m·s^{-1}, average value – 1.5 m·s^{-1};

– angular speed of rotation of the drive shafts of the cleaner: by changing the gear ratio in the elements of its drive (by replacing drive sprockets with a different number of teeth). The maximum value of this factor is: lower limit – 34.8 rad·s^{-1}, upper bound – 78.4 rad·s^{-1}, average value – 54.2 rad·s^{-1};

– the height of the end of the cleaning blade relative to the level of the soil surface: the position of the gauge wheels on the frame of the experimental setup on which the cleaner is installed. The range of variation in the height of the location of the ends of the blades was chosen taking into account the possibility of compensation by the blades of the unevenness of the soil surface. The minimum value of the height was taken as 0 m, which corresponds to the level of the soil surface, the average value – 0.02 m (2 cm), and the maximum height – 0.04 m (4 cm). The value of the maximum height takes into account the possibility of protrusion of the upper heads (parts) of sugar beet roots above the soil surface.

Experimental studies were carried out under the following field conditions: soil type in terms of mechanical composition – chernozem; soil hardness – 1.1...1.9 MPa; soil moisture – 22.0…22.5%; weed infestation in the field – 3 pcs.·m^{-2} height up to 90 cm; field relief – flat; haulm yield – 35 h·(ha)$^{-1}$.

Field experiments were carried out in five repetitions at the appropriate values of the installation height of the blades relative to the soil surface, the operating speeds of the cleaner and the modes of rotation of the horizontal drive shafts of the cleaner according to the standard plan matrix.

The experimental setup (Fig. 1) consists of the main frame 3, which is hung on the tractor-aggregator 1 with the help of a hitch 2. The main frame 3 is necessary for hanging the cleaning working bodies 7 on the horizontal drive shafts 6 with the help of spokes 8. The shafts 6 are placed at an angle alpha to each other and receive a rotational movement using the drive elements 4. The operation of the field test installation is carried out in a floating position, and the height of the installation of the cleaning working bodies (the ends of the rubber cleaning blades) is adjusted using the sensitive wheels 5. The position of the sensitive wheels 5 relative to the frame 3 can be changed due to the screw mechanisms for attaching them to the frame 3.

For experimental studies of the quality indicators of the work of the cleaner of the heads of sugar beet root crops from the remains of tops on the vine, a field experimental installation was developed, which allows in the field to investigate the operating modes of the cleaner with a new type of working body installed (Fig. 2) made from a more rigid material.

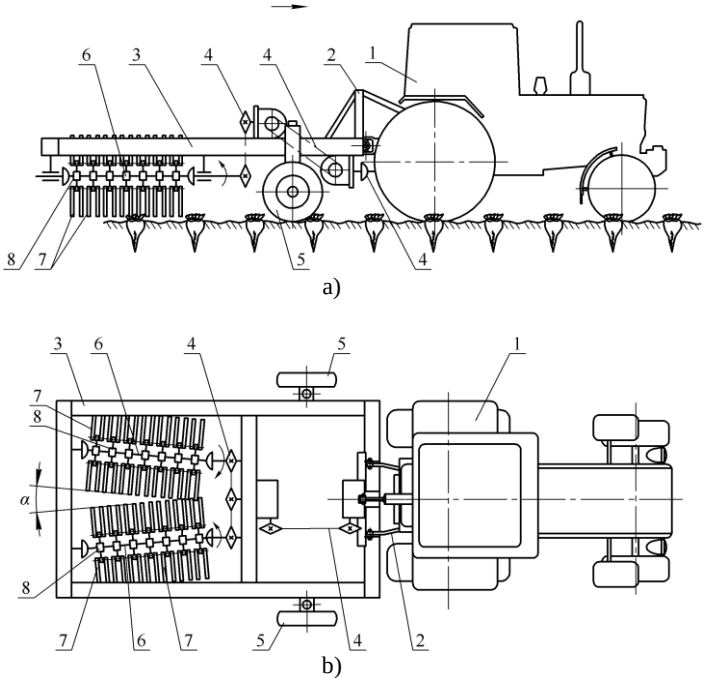

Figure 1. Structural scheme of the experimental setup:
a) side view; b) top view: 1 – tractor; 2 – hitch; 3 – main frame; 4 – drive elements; 5 – sensing wheels; 6 – drive shafts; 7 – working bodies; 8 – spokes

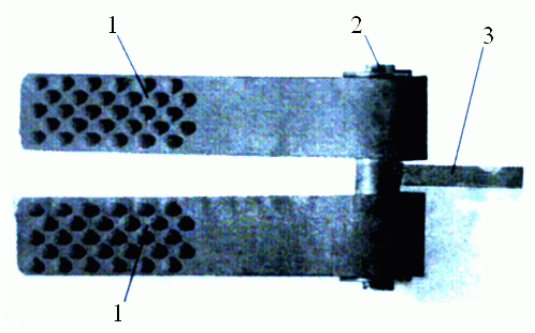

Figure 2. General view of the working body of the experimental plant for cleaning the heads of root crops from the remains of the tops with two horizontal shafts:
1 – rubber cleaning blade; 2 – axis; 3 – bracket

The drive shafts of the cleaning working bodies are driven by a cardan gear 8 from the power take-off shaft of the aggregating tractor through a bevel gearbox 6. Then, a gearbox 7 is driven from it using a chain drive, which is fixed on a rotary beam 3, thanks to which, by transmission through chain 9 and cardan 10 transmissions are driven by cleaning working bodies 11.

The quality of cleaning the heads of root crops from the remnants of tops at each repetition was carried out by manually removing the remnants of the tops from the heads of each root in the accounting area and weighing them on electronic scales.

3. Results and discussions

As a result of a complete three-factor experiment, which was implemented according to a standard plan, experimental data were obtained (table), processed by the methods of statistical, regression and correlation analyzes.

Table. The results of experimental studies of the quality of the work of the cleaner heads 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

As a result of the analysis of the data obtained experimentally and processed with the help of a PC, functional dependences of the haulm residues (Y) on the angular speed of rotation of the horizontal drive shafts of the cleaner (X_1) and the installation height of the cleaner blades above the soil surface (X_2) were obtained at a given translational speed wiper movement in the form of a polynomial dependence of the 2nd degree:

– for movement speed 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 movement speed 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 movement speed 2.5 m·s^{-1}:

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

As a result of the analysis of the obtained dependencies, it was found that the best approximation of the experimental data on the influence of the forward speed of the cleaner, the angular speed of rotation of the cleaner's drive shafts and the height of the cleaner blades above the soil surface on the quality of haulm residue removal corresponds to a polynomial dependence of the 2nd degree. The most significant factor here is the height of the blades of the cleaner above the level of the soil surface X_2.

Graphical interpretation of the results of experimental studies is presented in the form of response surfaces of the dependence of the mass of haulm residues on the angular speed of rotation of the horizontal drive shafts of the cleaner and the height of the blades above the soil surface at the forward speed of the cleaner: 0.75 m·s^{-1} (Fig. 3), 1.5 m·s^{-1} (Fig. 4), 2.5 m·s^{-1} (Fig. 5).

An analysis of the obtained functional and graphical (Fig. 3-5) 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 installation height of the blades relative to the level of the soil surface, a decrease in the remains of tops on the spherical surfaces of the heads of sugar beet root crops is mainly observed, which corresponds to a better performance of the cleaning process. However, at values of the forward speed of the cleaner equal to 1.5 m·s^{-1} dependence is more complex and ambiguous.

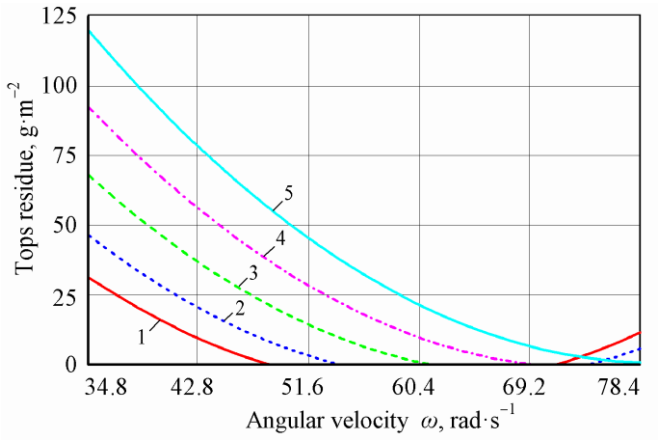

Figure 3. Dependence of haulm residues on the angular velocity of the drive shafts of the cleaner at the translational speed of the cleaner equal to 0.75 m·s^{-1} and installation height of the blades above the level of the soil surface:
1 – 0 cm; 2 – 1 cm; 3 – 2 cm; 4 – 3 cm; 5 – 4 cm

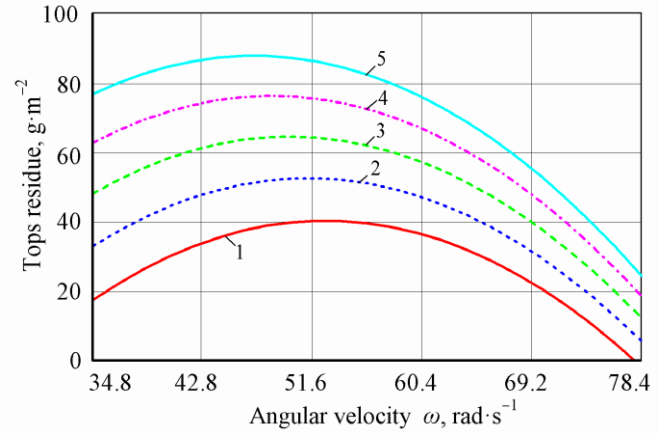

Figure 4. Dependence of haulm residues on the angular velocity of the drive shafts of the cleaner at the translational speed of the cleaner equal to 1.5 m·s^{-1} and installation height of the blades above the level of the soil surface:
1 – 0 cm; 2 – 1 cm; 3 – 2 cm; 4 – 3 cm; 5 – 4 cm

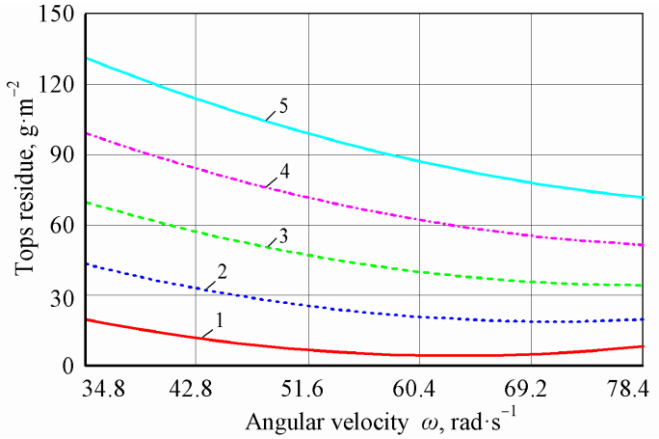

Figure 5. Dependence of haulm residues on the angular velocity of the drive shafts of the cleaner at the translational speed of the cleaner equal to 2.5 m·s^{-1} and installation height of the blades above the level of the soil surface:
1 – 0 cm; 2 – 1 cm; 3 – 2 cm; 4 – 3 cm; 5 – 4 cm

As for the influence 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 drive shafts equal to 54.2 rad·s^{-1} and 78.4 rad·s^{-1} there is first a gradual increase in the mass of residues of tops on the heads of sugar beet root crops in the speed range 0.75...1.5 m·s^{-1} with a subsequent increase in the mass of the

remains of the tops on the heads of root crops in the range of speeds 1.5...2.5 m·s^{-1}.

At the frequency of rotation of the drive shafts of the cleaner 40…55 rad·s^{-1} at speed 1.5 m·s^{-1} 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 remains of tops on the heads of root crops 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 blades are installed at a height of 2 cm relative to the level of the soil surface, the mass of tops remaining on the heads of root crops is 35…40% more than when the blades are installed at a height of 0 cm and the angular velocity of rotation of the blades is 54.2 rad·s^{-1} and 78.4 rad·s^{-1}. But when the blades are installed at a height above the level of the soil surface equal to 4 cm with an increase in the forward speed of the cleaner, the mass of haulm residues is intensively reduced to 50%.

In general, it can be concluded that the improvement of the quality of the technological process by the cleaner of the heads of 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 blades above the soil surface at high translational speeds of the cleaner. At low speeds up to 1 m·s^{-1} with a blade installation height of 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 dependencies, it has been established that the rational modes of operation of the studied sugar beet root heads cleaner from the remains of standing tops with horizontal drive shafts are:

– cleaner forward speed – 1.5...2.5 m·s^{-1};

– angular speed of rotation of drive shafts – 55...80 rad·s^{-1};

– installation height of the blades of the cleaner above the soil surface – 0...2.5 cm.

At the specified values of the cleaner operation modes, its most high-quality work will be on removing the remains of tops from the spherical surfaces of the heads of sugar beet roots, from which the bulk of the tops is cut.

4. Conclusion

1. We have developed a new design of a head cleaner for sugar beet root crops from residues of tops on the root, which consists of two drive cleaning shafts with hinged elastic blades that cover a row of sugar beet roots on both sides and, applying side impacts, clean the spherical surfaces of the heads from residues.

2. To study the process of operation of the cleaner of the heads of root crops from the remains of tops on the root with horizontal drive shafts and substantiate its rational modes of operation on the basis of standard and developed methods, field experimental studies of the effect of the cleaner's operating modes on the degree of cleaning of root crops were carried out.

3. To conduct experimental studies of the influence of the main operating modes of the cleaner on the quality indicators of the technological process, according to the accepted plan-matrix, a special experimental installation was developed and manufactured.

4. As a result of the analysis of experimental data processed using a PC, it was found that improving the quality of the technological process of cleaning the heads of sugar beet root crops from the remains of tops with a cleaner with two horizontal drive shafts can be achieved by increasing the angular velocity of the drive shafts of the cleaner and reducing the installation height of the blades above the soil surface at sufficiently high forward speeds of its movement.

5. Based on the analysis of the obtained functional and graphical dependencies, it has been established that the rational values of the operating modes of the studied cleaner of the heads of sugar beet roots from the remains of the tops, in which there will be the highest quality work to remove the remains of the tops from the spherical surfaces of the heads of the roots.

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