INVESTIGATION OF QUALITY INDICATORS OF OPERATION OF EXPERIMENTAL ROOT HEAD CLEANER FROM HOLM RESIDUES

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Abstract. The task of high-quality separation of the remains of tops from root crops is of great relevance. Experimental research of the new design of the cleaner to determine the quality indicators of its work was carried out by the developed and manufactured field experimental design. The purpose of the work is experimental studies of the quality indicators of the operation of the experimental cleaner and determination of the optimal modes of operation of cleaning the root crop heads from the remains of the tops and determination of the optimal modes of operation. It has been established that the rational values of the operating modes of the investigated cleaner, in which the most high-quality performance is possible when removing the remains of the tops from the surface of the root crop heads, are: – the speed of the translational movement of the twin-shaft cleaner – 0.8...1.2 $m \cdot s^{-1}$; – the angular speed of rotation of its drive shafts – 63...78 $rad \cdot s^{-1}$; – the installation height of the blades of the cleaner above the level of the soil surface – 0...2 cm.

Keywords: head cleaner, experiments, quality, speed.

Introduction

Beet growing is an important branch of agriculture in many European countries [1; 2]. In the technology of production of sugar and fodder beets, the most labour-intensive and expensive technological process is harvesting. Harvesting accounts for about 60% of the cost of beet production [3-5]. In addition, harvesting also determines the quality of the resulting product, its safety over time, as well as the losses of the grown biological mass. The safety of beet root crops is affected by the presence of haulm residues, because the tops, compared with the roots, are more perishable and can cause crop rotting. But, on the other hand, the tops can be used as feed for livestock, for production of biogas, etc. Obtaining clean root crops and minimal leaf loss is an important task of the harvesting process. Therefore, the task of high-quality separation of the remains of tops from root crops is of great relevance. Many investigations have been devoted to the problem of cleaning the heads of the root crops from the top remains [6-9].

The initial requirements for sugar beet root head cleaners are the following: the tops on the sugar beet roots must be cut off without additional cleaning by a haulm harvester; 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 higher than 20 mm from the top of the head of the root crop. Beside that, the cropped mass of the root crops with the tops should not exceed 5%; the total loss of the green mass of the tops, including free one, on the highly cut and the uncut root crops in a heap and lost on the soil surface, should not exceed 10% of its yield; the number of the damaged root crops should not be more than 20%, including the severely damaged roots, up to 5% [10; 11].

More than 60 years have passed since the mass introduction of beet harvesting mechanisation, several generations of machines for harvesting have already been created [12-16]; however, the task to improve machines for implementation of this technological process still has a great practical need.

The purpose of the work is experimental studies of the quality indicators of the operation of the experimental cleaner and determination of the optimal modes of operation of cleaning the root crop heads from the remains of the tops and determination of the optimal modes of operation.

Materials and methods

Experimental research of the new design of the cleaner to determine the quality indicators of its work was carried out by the developed and manufactured field experimental setup which allows to simulate completely the operation of a two-shaft cleaner on the field. Fig. 1 shows a structural and technological scheme of the experimental setup with a new two-shaft cleaner of the sugar beet heads from the haulm residues. Fig. 2 shows a general view of the experimental plant with the installed head cleaner from the remains of the tops during the experimental field research. The developed experimental setup (Fig. 1) consists of the main frame 1, which is hung from behind on a wheeled aggregating tractor of class 1.4 by means of a hitch 4. A turning frame 2 is installed on the main frame 1, using a turning beam 3. The turning frame 2 is required for hanging the cleaning tools with horizontal drive shafts on it, and it can be installed, using the turning beam 3, at various angles to the surface of the beet field. The experimental field setup is aggregated in a floating position, and the installation height of the cleaning tools relative to the level of the soil surface is adjusted using gauge wheels 5. Each of the two cleaning shafts is driven by a cardan 8 from the power take-off shaft of the aggregating tractor through the bevel gear 6. Then, by means of a chain transmission, the gearbox 7 is actuated from it, which is fixed on a rotary beam 3, due to which the working tools are driven by transmission through the chain 9 and cardan 10 transmissions. The horizontal drive shafts have clips, fixed at certain distances along their lengths, on which flexible cleaning blades 11 are pivotally mounted with the help of hinges. In total, each clip has four cleaning blades 11. In addition, blades 11 of one drive shaft are located between the blades 11 of the other drive shaft.

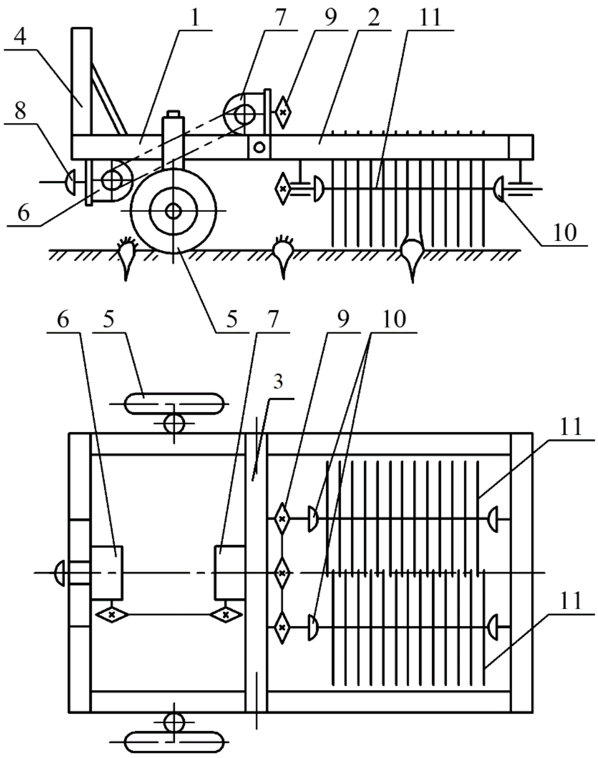

Fig. 1. **Structural and technological scheme of the experimental machine:** 1– main frame; 2 – turning frame; 3 – turning beam; 4 – hitch; 5 – gauge wheels; 6 – gear; 7 – gearbox; 8 – cardan; 9 – through chain; 10 – cardan transmissions; 11 – blades

Fig. 2. **General view of the experimental setup with a two-shaft cleaner of root crops heads from remains of tops**

The drive shafts with hinged flexible cleaning blades 11 have a counter rotational movement.

The technological process of cleaning the heads of the root crops from the remains of tops on the vine with a twin-shaft cleaner is performed in the following way. The cleaner, aggregated with a wheeled tractor, is installed along the axis of a row of the sugar beet roots, from which the main mass of tops has already been cut off (entire cut at a higher height). However, the remains of the tops have remained on the heads of the root crops in the form of short green and strong residues, as well as dry and lodged residues, which are mainly firmly connected with the heads of the root crops and are located between the rows of crops or in the row between adjacent root crops. Moving progressively in a row, the drive cleaning shafts cover the row of root crops from two sides, and their elastic blades 11 strike the heads, effectively knocking down (compressing and combing) the remains of the tops from the entire surface of the root crop heads.

The main parameters of the characteristics of the research conditions were as follows: deviation of the root crops from the theoretical straightness: ± 40 mm and more – 25.2%, ± 30 mm – 30.9%; up to ± 20 mm – 23.0%, placement of the root crop heads relative to the level of the soil surface: + 60 mm or more – 21.6%; + 40 mm ... + 60 mm – 11.4%; + 20 mm ... + 40 mm – 22.7%; 0... + 20 mm –36.4%, the row spacing – 45 cm; the planting density – 82.9 thousand pieces ha^{-1}, the root crop yield – 53.3 $t\cdot ha^{-1}$; the haulm yield – 13.3 $t\cdot ha^{-1}$.

To study the influence of the operating modes of the cleaner upon the cleaning quality of the root crop heads from the remnants of the tops, a field multifactorial experiment was conducted [17; 18]. In the experimental research as the input parameters were: V – the translational speed of a two-shaft cleaner, $m\cdot s^{-1}$; ω – the angular speed of the rotational movement of the driven cleaning shafts, $rad\cdot s^{-1}$; h – the installation height of the blades of the cleaner above the level of the soil surface, cm.

In addition, the output parameter, i.e. the quality indicator of the work of a twin-shaft cleaner of the root crop heads was the mass of the top residues per one square meter of the area of the experimental field of beets, on which a continuous cut of the top mass was already made, and the passage and additional cleaning of the root crop heads from the tops was done. In the experimental studies the translational speed of the twin-shaft cleaner was regulated by switching the gearbox of the wheeled aggregating tractor. When aggregating the twin-shaft cleaner of wheeled tractors, class 1.4, the lower limit of the forward speed was 0.8 $m\cdot s^{-1}$, the upper limit was 2.0 $m\cdot s^{-1}$, and the average value was 1.4 $m\cdot s^{-1}$. Adjustment of the angular speed of rotation of the driven shafts of the cleaner was made by changing the gear ratio of the drive. The maximum value of the angular speed of the rotational movement of the cleaner shafts was 34.8 $rad\cdot s^{-1}$, the maximum value was 78 $rad\cdot s^{-1}$, and the average value was 54 $rad\cdot s^{-1}$. The installation height of the cleaning blade above the level of the soil surface was regulated by changing the position of the gauge wheels of the twin-shaft cleaner. The minimum value of the installation height of the blades was taken equal to 0 (when the ends of the blades were strictly at the level of the soil surface without gaps), the average value of the installation height was 0.02 m, and the maximum value of the installation height of the blades above the soil surface was 0.04 m). The cleaning quality of the root crop heads from the remnants of the tops at each repetition of the experiment was made by manually removing the remnants of the tops from the heads of the root crops in the scoring area and weighing them on electronic scales according to the standard methodology [10]. The experimental field research was conducted in five repetitions at the corresponding values of the installation height of the blades relative to the level of the soil surface, different operating speeds of the cleaner and different modes of rotation of the cleaner shafts according to the standard plan matrix.

Results and discussion

As a result of a complete three-factor experiment, experimental data were obtained presented in Table. 1. Processing of the obtained experimental data was performed on a PC in accordance with the existing program of statistical calculations. There are obtained functional dependences of the amount of the haulm residues (Y) upon the translational speed of the cleaner (X_1), the angular speed of the rotational movement of the cleaner drive shafts (X_2) and the height at which the blades of the cleaner are installed relative to the level of the soil surface (X_3). These functional dependencies are described by the following regression equations:

- as a linear relationship

$$Y = 97.45 - 8.611X_1 - 1.102X_2 + 3.29X_3, \tag{1}$$

with the multiple determination coefficient $D = 0.416$, the multiple correlation coefficient $R = 0.645$;

- as a power dependence

$$Y = 33857\, X_1^{\,0.0138} \cdot X_2^{\,-1.8651} \cdot X_3^{\,0.0177}, \tag{2}$$

with the multiple determination coefficient $D = 0.453$, the multiple correlation coefficient $R = 0.673$;

- as exponential dependence

$$Y = 115.23 \cdot 0.991^{X_1} \cdot 0.967^{X_2} \cdot 1.055^{X_3}, \tag{3}$$

with the multiple determination coefficient $D = 0.416$, the multiple correlation coefficient $R = 0.645$

- as a logarithmic dependence

$$Y = 284.31 - 11.152\ln X_1 - 62.4\ln X_2 + 0.82\ln X_3, \tag{4}$$

with the multiple determination coefficient $D = 0.463$, the multiple correlation coefficient $R = 0.681$;

- as an inverse relationship

$$Y = -41.123 + \frac{11.111}{X_1} + \frac{3250}{X_2} - \frac{0.00001}{X_3}, \tag{5}$$

with the multiple determination coefficient $D = 0.495$, the multiple correlation coefficient $R = 0.704$;

- as a polynomial dependence of the 2nd degree

$$\begin{aligned} Y = {} & 209.38 - 6.34X_1 - 6.66X_2 + 61.16X_3 + 0.99X_1^2 + 0.05X_2^2 - \\ & -1.13X_3^2 + 0.28X_1X_2 - 28.98X_1X_3 - 0.7X_2X_3 + 0.34X_1X_2X_3, \end{aligned} \tag{6}$$

with the multiple determination coefficient $D = 0.707$, the multiple correlation coefficient $R = 0.841$.

As it is evident, the resulting regression equation (6) has the highest values of the coefficients of determination and correlation, which gives priority to its use for further calculations on the PC. The quadratic coefficients, included into this equation in subsequent calculations, will best reflect the relationship between the weight of the remains of the leaves g (parameter Y), and the forward speed (parameter X_1), the angular speed of the rotational movement of the cleaning shafts (parameter X_2), and the installation height of the cleaner blades above the soil surface (parameter X_3). The results of the experimental studies, depending on the parameters of the cleaner, are presented in Table 1.

Analysis of the above analytical dependences (1)-(6) shows that the best approximation to the experimental data of the impact of the forward speed of the cleaner, the angular speed of the rotational movement of the cleaner drive shafts and the height of the cleaner blades above the soil surface on the quality of removal of the haulm residues corresponds to a polynomial dependence of the 2nd degree. The most significant factor here is the angular velocity ω of the rotational movement of the drive shafts X_2.

According to the results of numerical calculations performed on a PC, graphs were constructed, presented in the form of response surfaces of dependencies of the mass of leaves of haulm upon the angular velocity ω of the rotational movement of the drive shafts of the cleaner and the installation height h of the blades above the soil surface at the translational speed V of the cleaner, which was equal to: 0.8 $m \cdot s^{-1}$ (Fig. 4), 1.4 $m \cdot s^{-1}$ (Fig. 5), 2.0 $m \cdot s^{-1}$ (Fig. 6).

Besides it is evident from the presented graphical dependencies that, with an increase in the angular velocity ω of the rotational movement of the drive shafts of the cleaner and a decrease in the installation height h of the blades above the soil surface level, a decrease in the top residue on the surfaces of the root crop heads is mainly observed. However, at values of the translational speed V of the cleaner equal to 1.4 m·s^{-1} and 2.0 m·s^{-1}, these dependences are of a more complex character.

In the range of speeds V of the translational movement 0.8...1.4 m·s^{-1} at angular velocities ω of rotational movement of the drive shafts of the cleaner 54 rad·s^{-1} and 78 rad·s^{-1}, at first, a gradual increase in the mass of the haulm residues on the heads of the root crops is noted, and then a subsequent decrease in the speed range 1.4...2.0 m·s^{-1}. At the angular speed ω of rotation of the drive shafts of the cleaner, equal to 34.8 rad·s^{-1}, the nature of the influence of the translational speed V of movement upon the quality indicators of performance is changeable. So, at a “zero” installation height of the blades $h = 0$, with an increase in the translational speed of the cleaner within 0.8...1.4 m·s^{-1}, the mass of the haulm residues decreases.

Table 1

Results of the experimental research of the performance quality of the twin-shaft root head cleaner from remnants of haulm

Angular speed of rotation of the driving shafts, rad·s^{-1}	**Speed of the movement of the twin-shaft cleaner**								
	0.8 m·s^{-1}			1.4 m·s^{-1}			2.0 m·s^{-1}		
	Installation height of the cleaning blades above the soil surface, 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}		
78.0	5.3	5.8	4.0	10.3	12.3	2.1	34.9	54.1	67.5
	3.4	6.9	4.2	9.4	16.8	2.5	26.2	49.1	23.4
	8.7	8.8	11.0	3.9	12.3	12.4	34.2	40.2	23.1
	6.6	12.6	6.2	14.8	24.5	6.3	10.7	34.8	23.1
	4.1	22.1	5.8	8.1	9.8	10.2	8.1	31.7	20.2
54.0	6.7	3.1	22.4	10.1	28.7	54.6	8.4	4.3	94.2
	12.1	22.9	12.1	23.1	14.2	67.2	16.1	10.1	83.1
	14.2	10.6	19.2	7.8	23.1	70.3	7.2	17.1	58.7
	3.7	8.1	10.2	7.4	12.4	103.1	7.8	10.4	32.1
	4.1	3.1	9.7	20.1	10.7	114.1	14.5	16.3	127.3
34.8	74.5	63.1	180.3	40.4	12.4	50.7	2.4	16.4	12.9
	62.9	70.9	164.5	27.2	26.4	79.5	3.9	10.6	8.4
	54.6	90.1	132.1	28.4	28.5	74.8	2.8	11.1	26.7
	36.7	62.8	97.9	28.9	16.2	72.1	3.8	10.8	22.5
	82.5	50.7	117.4	30.5	34.1	97.4	6.2	15.9	10.4

However, in the range of speeds 1.4...2.0 m·s^{-1}, a certain increase in this indicator is observed. At a blade installation height of 2 cm, the trends are similar to the installation height $h = 0$ and the angular speed of rotation 54 rad·s^{-1} and 78 rad·s^{-1}. But at the installation height of the blades of 4 cm, with an increase in the translational speed V of the cleaner, the mass of the haulm residues decreases intensively.

On the whole, improvement of the quality of the technological process by the cleaner of the root crop heads from the remains of the tops with horizontal drive shafts can be achieved by increasing the angular speed ω of the drive shafts of the cleaner, and reducing the installation height h of the blades above the soil surface at low translational speeds.

It is evident from Fig. 4 that at the lowest forward velocity V of the cleaner (0.8 m·s^{-1}), the lowest quality of cleaning takes place. An increase in the angular speed of rotation of the cleaning rollers ω , on the whole, reduces the amount of residues on the heads of the root crops and reaches a minimum at a rotation frequency of 60 rad·s^{-1}. Height h of location of the ends of the blades relative to the level of the soil surface in this case does not have a significant impact upon the amount of the leaves residues on the heads of the root crops. At a forward speed of the cleaner 1.4 m·s^{-1} (Fig. 5) the best cleaning quality indicators are achieved at an angular speed of rotation of the cleaning shafts ω 50-60 rad·s^{-1}.

Reduction of the height *h* also leads to an increase in the quality of cleaning the heads of sugar beet roots from the remains of tops. At a maximum value of the forward speed *V* of the cleaner 2.0 m·s^{-1} (Fig. 6) the value of the haulm residues may reach 60 g·m^{-2}. From the other parameters high quality can be achieved at a height *h*, equal to 3.4 cm, and an angular velocity, taking a maximum value of 80 rad·s^{-1}.

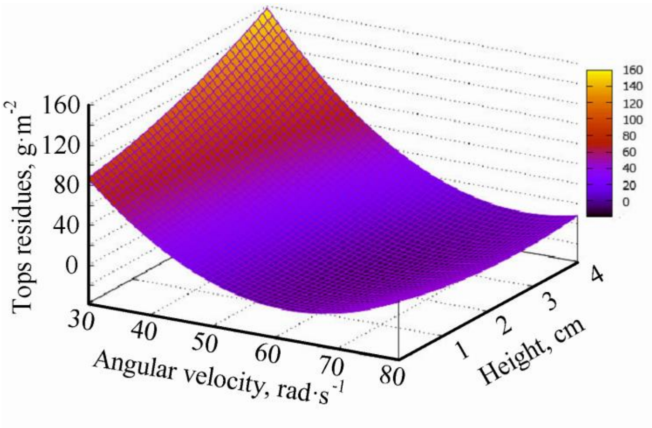

Fig. 4. **Response surface of dependence of haulm residues upon the angular speed of rotational movement of the drive shafts of the cleaner and the installation height of the blades above the level of the soil surface at a translational speed of the cleaner 0.8 m·s^{-1}**

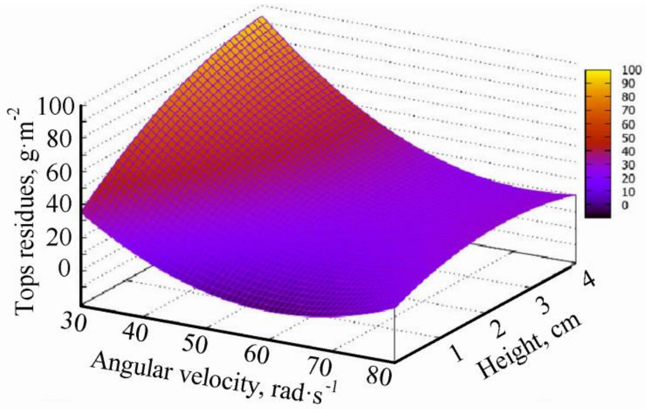

Fig. 5. **Response surface of dependence of haulm residues upon the angular speed of rotational movement of the drive shafts of the cleaner and the installation height of the blades above the level of the soil surface at a translational speed of the cleaner 1.4 m·s^{-1}**

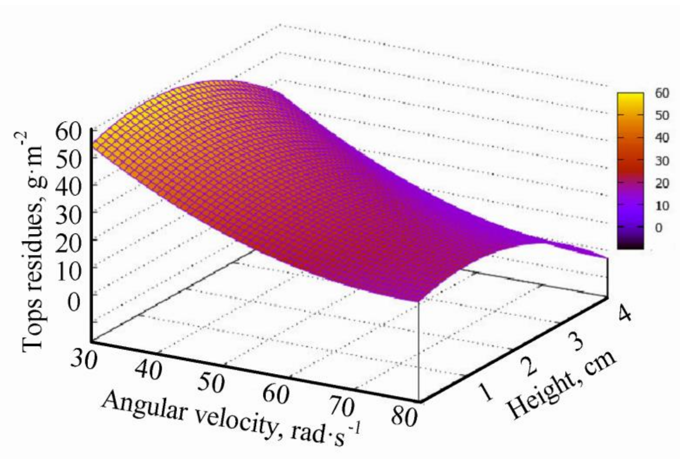

Fig. 6. **Response surface of dependence of haulm residues upon the angular speed of rotational movement of the drive shafts of the cleaner and the installation height of the blades above the level of the soil surface at a translational speed of the cleaner 2.0 m·s^{-1}**

According to the results of experimental field studies, the rational modes of operation of the investigated twin-shaft cleaner are: the speed *V* of the translational movement of the cleaner is equal to 0.8...1.2 m·s^{-1}; the angular speed ω of the rotational movement of the drive cleaning shafts is 63...78 rad·s^{-1}, and the installation height *h* of the cleaner blades above the level of the soil surface is 0...2 cm.

Conclusions

1. Improvement of the execution quality of the technological process by the cleaner of the root crop heads from the remains of the tops with horizontal drive shafts can be achieved by increasing the angular speed of the drive shafts of the cleaner and reducing the installation height of the blades above the soil surface at low translational speeds of the machine.
2. 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 investigated cleaner, in which the most high-quality performance is possible when removing the remains of the tops from the surface of the root crop heads, are: -the speed of the translational movement of the twin-shaft cleaner – 0.8...1.2 m·s^{-1}; -the angular speed of rotation of its drive shafts – 63...78 rad·s^{-1}; -the installation height of the blades of the cleaner above the level of the soil surface – 0...2 cm.

Author contributions

Conceptualization, V.B.; methodology, S.I. and I.H..; software, A.A.; validation, V.B.; formal analysis, V.B, S.I. and. Y.I.; investigation, V.B., S.I. and A.A.; data curation, A.A.; writing—review and editing, A.A. and S.I.; visualization, I.H.; 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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