FIELD INVESTIGATIONS OF THE EXPERIMENTAL CLEANER OF THE ROOT CROP HEADS FROM THE TOP RESIDUES

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Abstract
Despite the presence of a large number of technical solutions, the problem of improving the quality of harvesting root crops is still relevant. A new design of the working body for the top removal without extraction the beets from the soil has been developed and researched, and investigations have been carried out to substantiate the optimal parameters and operating modes. Based on the analysis of the obtained functional and graphical dependencies, rational values of the operating modes of the investigated cleaner have been established in which the most high-quality work is possible when removing the remains of the tops from the surface of the root crops heads. In comparison with the top-removing module of the serial Holmer beet harvester, the experimental equipment reduces the loss of the sugar-bearing mass by 37%.

Key words: *root crops, machine, cleaner, top residues.*

INTRODUCTION

Beet growing is an important branch of agriculture in many European countries (*Ivančan, Sito & Fabijanić, 2002; Bulgakov et al., 2016*). Thus the volume of the sugar beet production in 2017 in France amounted to 34.4 million tons, in Germany – to 34.0 million tons, in Poland – to 15.7 million tons, in Ukraine – to 14.9 million tons. In addition, the yield of the sugar beet in France was more than 80 tons ha^{-1}. In the technology of production of sugar and fodder beets the most labor-intensive and expensive technological process is their harvesting. Harvesting accounts for about 60% of the energy costs of the beet production (*Hoffmann, 2018*). In addition the beet gathering determines the quality of the resulting product, its storage properties over time, as well as the losses of the grown biological mass. Preservation of beet root crops is affected by the presence of the top residues since the tops, unlike the root crops, is a more perishable mass, and it can provoke the crop rotting. But, on the other hand, the tops can be used as livestock feed, for the biogas generation, etc. Obtaining clean root crops with minimal losses of the tops is an important task of the technological process of harvesting. Therefore the task of high-quality separation of the remains of the tops from the root crops is of great relevance. There are many investigations devoted to the problem of cleaning the heads of root crops from the top remnants (*Bulgakov et al., 2017; Hoffmann, 2018*). Initial requirements for the cleaners of the sugar beet heads: tops on the sugar beets must be cut off without additional cleaning by a bush harvester; the cut of the head must be straight, smooth, without chips; the cutting plane must pass not lower than the level of the green cuttings and not higher than 20 mm from the top of the head. Besides, the cropped mass of the root crops from the tops should not exceed 5%; the total losses of the green mass of the tops, including the free mass, on highly cut and uncut root crops in the pile 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 ones – up to 5%. Since the mass introduction of mechanization, beet harvesting has been over 60 years. During this time several generations of machines for its collection have already been created; however, the tasks of improving the machines for the implementation of this technological process are still of great scientific relevance and practical need. An important contribution to the theory and practice of this issue some time ago was made by the following scientists: Helemendik N., Pogorely L. and other researchers (*Helemendik, 1996; Bulgakov et al., 2015; Alami et al., 2021*). The purpose of this research is to determine the optimal design and kinematic characteristics of the developed experimental cleaner of the root crops heads to ensure high-quality work.

MATERIALS AND METHODS

When conducting experimental investigations, generally accepted and specially developed methods were used (*Bulgakov et al., 2017*). Assessment of the conditions for conducting the experimental research included determination of the soil and climatic conditions and characteristics of planting the root crops, substantiation for the operating modes of the machine, and determination of the quality indicators (*Helemendik, 1996*). The conditions for conducting the field experimental investigations were as follows: deviation of the root crops from the theoretical axis of the line – ± 22 mm; the average height of the protruding heads above the ground surface – 34 mm; the width of the main row spacing – 44.5 mm; density of root crops – 82.9 thousand pieces ha^{-1}; the biological yield of the tops – 13.3 t ha^{-1}; the biological yield of the beets – 53.4 t ha^{-1}. Conducting experimental research of the new design of the cleaner to determine the quality indicators of its work was carried out by an experimental setup that allows full simulation of the operation of the cleaner in the field. Fig. 1 shows a structural and technological scheme of the experimental setup with an installed experimental twin-shaft cleaner of the sugar beet heads from the top residues.

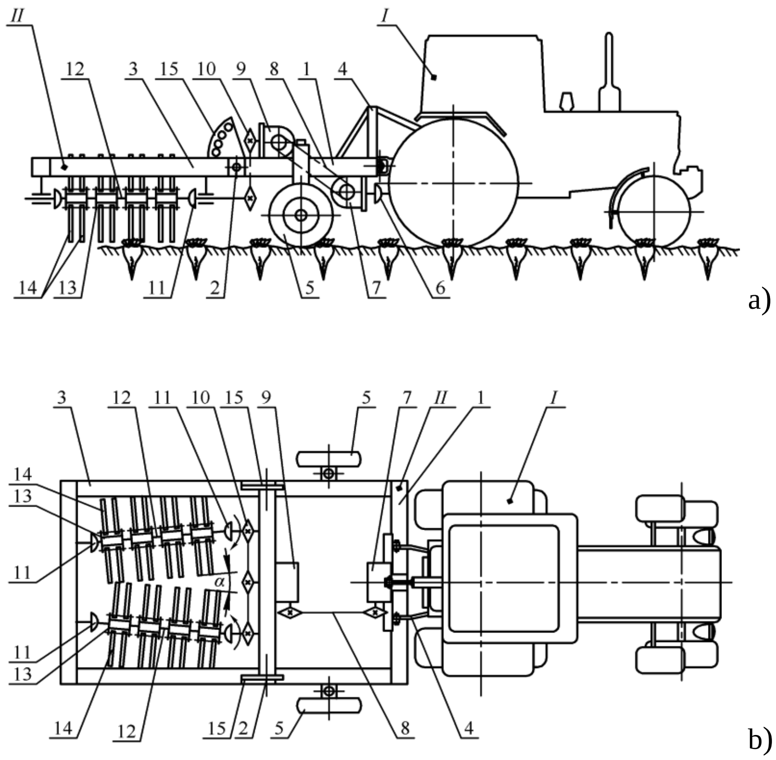

Fig. 1 Structural-technological scheme of the aggregate with an experimental setup, simulating a two-shaft cleaner of the root crop heads from the residues of the tops: a – a general side view; b – a top view: I – the wheeled aggregating tractor; II – the experimental setup: 1 – the main frame; 2 – the transverse beam; 3 – the rotary frame; 4 – the hitch; 5 – the gauge wheels; 6 – the cardan transmission from the tractor power take-off shaft; 7 – the bevel gear on the main frame; 8 – the chain drive; 9 – the gearbox on the transverse beam; 10 – the chain transmission for the drive of cleaning shafts; 11 – the cardan shafts; 12 – the cleaning shafts; 13 – the hinges on which the blades are installed; 14 – the flexible cleaning blades; 15 – the sector for setting the angles of inclination

The experimental setup (*Patent UA115404, 2017*) consists of the main frame 1 connected to the tractor, using hitch 4. On the main frame 1, the rotary frame 3 is installed with the help of a transverse beam 2 (Fig. 1). The rotary frame 3 is necessary for mounting the cleaning blades 14 of the hinges 11 with horizontal drive shafts 12 installed at an angle α to each other. Rotary frame 3 has an ability to be installed due to main frame 2 at different angles to the surface of the sugar beet field. The installation height of the cleaning working bodies relative to the level of the soil surface is adjusted using gauge wheels 5. Each of the two cleaning shafts 12 is driven by cardan 11 from the power take-off shaft 6 of the aggregating tractor through bevel gear 7. Then, by means of the chain drive 8, gearbox 9 is driven from it, which is mounted on the rotary frame 3, due to which shafts 12 with the blocks of the hinges with working bodies 13 are driven by transmission through chain 10 and cardan drive 11. The horizontal drive shafts 12 have hinges 13 fixed at certain distances along their lengths, on which flexible cleaning blades 14 are pivotally mounted with the help of hinges. In total, each hoop has four cleaning blades 14. Drive shafts 12 with the hinged flexible cleaning blades 14 make counter rotational movement. During operation the cleaner, aggregated with a wheeled tractor, is installed along the axis of the row of the sugar beets, from which the main mass of the tops have already been cut (entire cut at a higher height); however, the remains of tops in the form of short green and strong residues remained on the heads of the beets, as well as dry and dry fallen residues, which are mainly firmly connected with the heads of the root crops and are located in the spaces between the rows or in a row between adjacent root crops. Moving progressively along the row, the drive cleaning shafts cover the row of the root crops from two sides, and their flexible blades 14 strike the heads, effectively knocking down (crushing and combing) the remains of the tops from the entire surface of the root heads.

To study the influence of the operating modes of the cleaner upon the quality of cleaning the heads of root crops from the remnants of the tops, a multifactorial experiment was made (*Montgomery, 2013*). In this experiment the input parameters were: V – the speed of the forward movement of the two-shaft cleaner, m s^{-1}; ω – the angular velocity of the rotational movement of the driven cleaning shafts, rad s^{-1}; h – the installation height of the cleaner blades above the level of the ground surface, cm. The output parameter, that is, a quality indicator of the operation of the cleaner of the root crop heads, was the mass of the top residues per square meter of the experimental area of the sugar beet field, on which a continuous cut of the top mass was already made, and the passage and additional cleaning of the heads of the root crops from the top residues was completed. In experimental studies the speed of the forward movement of the two-shaft cleaner was regulated by switching the gearbox of a wheeled aggregating tractor. The lower limit of the forward speed of the movement was 0.8 m s^{-1}, the upper limit was 2.0 m s^{-1}, the average value was 1.4 m s^{-1}. Adjustment of the angular speed of rotation of the drive shafts of the cleaner was made by changing the gear ratio of the drive. The maximum value of the angular velocity of the rotational movement of the cleaner shafts was 34.8 rad s^{-1}, the maximum value was 78 rad s^{-1}, the average value was 54 rad s^{-1}. The installation height of the cleaning blade above the level of the ground surface was regulated by changing the position of the gauge wheels of the two-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 ground surface without gaps), the average value of the installation height was 0.02 m (2 cm), and the maximum value of the installation height of the blades above the level of the soil surface was 0.04 m (4 cm). The field experimental investigations were conducted in five repetitions at the appropriate values of the installation height of the blades relative to the level of the soil surface, various operating speeds of the cleaner and various modes of rotation of the cleaner shafts in accordance with the standard plan matrix. The quality of cleaning of the root crops heads from the residues of the tops at each repetition of the experiment was checked by manually removing the remnants of the tops from the root crop heads in the experimental area and weighing them on electronic scales. Processing of the obtained experimental data was performed on a PC in accordance with the existing program of statistical calculations Statistica 5.0.

RESULTS AND DISCUSSION

The results of the experimental investigations (based on a full three-factor experiment) of the quality of the experimental top cleaner under various operating modes are presented in Table 1.

There are obtained the functional dependencies of the amount of the top residues (Y) upon the forward speed of movement 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 equation in the form of a polynomial dependence of the 2nd degree:

$$Y = 209.38 - 6.34X_1 - 6.66X_2 + 61.16X_3 + 0.99X_1^2 + 0.05X_2^2 - \\ -1.13X_3^2 + 0.28X_1 \cdot X_2 - 28.98X_1 \cdot X_3 - 0.7X_2 \cdot X_3 + 0.34X_1 \cdot X_2 \cdot X_3 \quad (1)$$

at the coefficient of multiple determination D = 0.707, the coefficient of multiple correlation R = 0.841. This analytical dependence shows that its most significant factor is the angular speed of the drive shafts X_2. According to the results of the numerical calculations, performed on a PC, graphs were constructed and presented in the form of response surfaces of the dependences of the mass of the top residues 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 level of the soil surface at a forward speed V of the cleaner, equal to: 0.8 m s^{-1} (Fig. 2), 1.4 m·s^{-1} (Fig. 3), 2.0 m s^{-1} (Fig. 4).

Tab. 1 Results of the experimental investigations of the quality of the experimental top cleaner under various operating modes

Angular speed of rotation of the drive hafts, rad·s^{-1}	Speed of the movement								
	0.8 m·s^{-1}			1.4 m·s^{-1}			2.0 m·s^{-1}		
	Installation height of the cleaning blades above a flat surface of the field, cm								
	0	2	4	0	2	4	0	2	4
	Top residues, g·m^{-2}			Top residues, g·m^{-2}			Top residues, g·m^{-2}		
	5.3	5.8	4	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
78.0	8.7	8,8	11	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
	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
54.0	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
	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
34.8	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

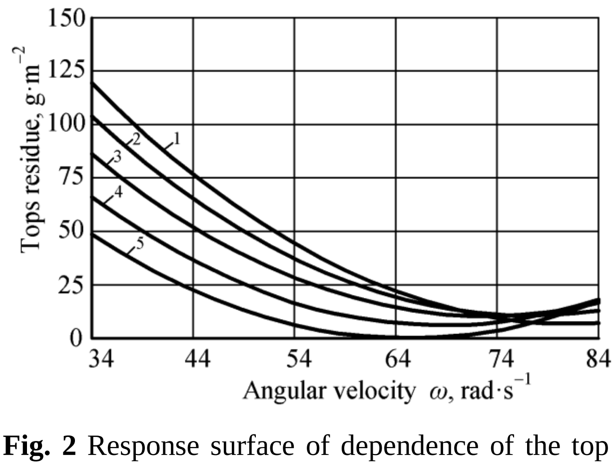

Fig. 2 Response surface of dependence of the top residues on the angular velocity of the rotational movement of the drive shafts of the cleaner and the installation height of the blades at the forward speed of the cleaner 0.8 m s^{-1}: 1 – h = 4 cm; 2 – h = 3 cm; 3 – h = 2 cm; 4 – h = 1 cm; 5 – h = 0 cm

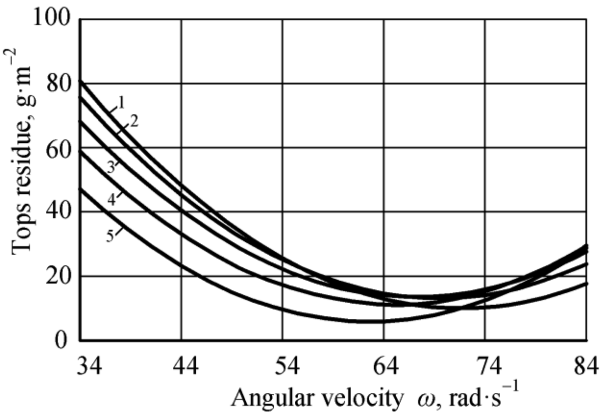

Fig. 3 Response surface of dependence of the top residues on the angular velocity of the rotational movement of the drive shafts of the cleaner and the installation height of the blades at the forward speed of the cleaner 1.4 m s^{-1}: 1 – *h* = 4 cm; 2 – *h* = 3 cm; 3 – *h* = 2 cm; 4 – *h* = 1 cm; 5 – *h* = 0 cm

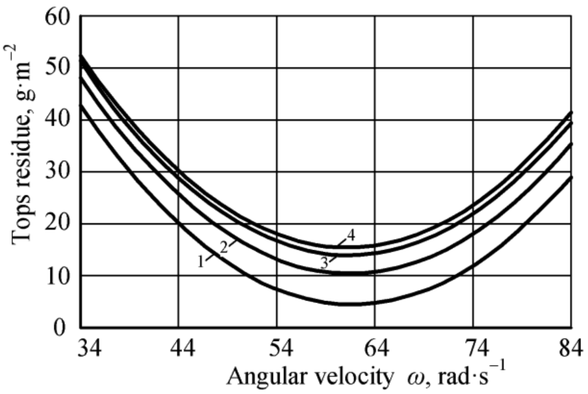

Fig. 4 Response surface of dependence of the top residues on the angular velocity of the rotational movement of the drive shafts of the cleaner and the installation height of the blades at the forward speed of the cleaner 2.0 m s^{-1}: 1 – *h* = 4 cm; 2 – *h* = 3 cm; 3 – *h* = 2 cm; 4 – *h* = 1 cm

In addition 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 level of the soil surface, a decrease in the top residue on the surfaces of the root crop heads is mainly observed. However, at the values of the forward speed *V* of the cleaner movement, equal to 1.4 m s^{-1}, the dependences are more complex, and at the speed of 2.0 m s^{-1}, on the contrary, an increase in height *h* leads to a decrease in the top residues. It is also evident from these graphical dependencies that within the range of speeds *V* of the forward movement 0.8...1.4 m s^{-1}, with an increase in the angular speed ω of the rotational movement of the cleaner drive shafts up to 70 rad s^{-1} and 64 rad s^{-1}, first, a gradual decrease in the mass of the top residues on the heads of root crops is observed, and then a slight increase. At a speed of 2.0 m s^{-1}, rapid growth of the top residues starts already at ω = 60 rad s^{-1}. At an angular speed of rotation of the drive shafts of the cleaner, equal to 34.8 rad s^{-1}, the nature of the impact of the forward speed *V* of movement upon the quality indicators of work is changeable. So, at the "zero" height of the installation of the blades *h* = 0, with an increase in the forward speed of the cleaner within 0.8…1.4 m s^{-1}, the mass of the top residues decreases. However, within the range of speed 1.4...2.0 m s^{-1}, a certain increase in this indicator is observed. At the blade installation height of 2 cm, the tendencies are similar to the installation height *h* = 0 and the angular velocity 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 forward speed *V* of the cleaner, the mass of the top residues decreases intensively. On the whole, raising the quality of the technological process by means of the cleaner of the root crop heads from the top residues with horizontal drive shafts can be achieved by increasing the angular velocity ω of the drive shafts of the cleaner and reducing the installation height h of the blades above the soil surface at a speed of up to 1.4 m s^{-1}. In the investigations by other authors, it is also indicated that an increase in the speed of more than 1.5 m s^{-1} leads to a decrease in the quality of harvesting the remains of sugar beet tops *(Kukhmazov & Zyabirov, 2008).* According to the results of the field experimental investigations of the two-shaft cleaner, the rational modes of its operation are: speed V of the forward movement of the cleaner is 0.8...1.2 m s^{-1}; the angular speed ω of the rotational movement of the driven cleaning shafts is 63…78 rad s^{-1} and the height h of the cleaner blades above the ground level is 0…2 cm.

To evaluate the efficiency of the experimental machine, research was made of five main indicators of the quality of work in comparison with the serial machines, used to perform this technological process. The loss of the mass of the root crop heads due to the removal of the tops when cut by the top-removing module of a serial Holmer beet harvester is 3.2%, but for the experimental equipment 2.0% (i.e., there is a decrease in the losses by 37%). In other mass-produced machines, common in Ukraine, this indicator of loss of mass is even greater *(Kukhmazov & Zyabirov, 2008).* The set of technical documentation for the experimental equipment of the top removal was transferred to the Ternopil Combine Plant (Ukraine) to be used in industrial production of the beet harvesting equipment.

CONCLUSIONS

1. Improving the quality of the technological process with a cleaner of the root crop heads from the top residues by means of 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 forward 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 cleaner to be studied under which the most high-quality work is possible when removing top residues from the surface of the root crop heads are: the speed of the forward movement of the two-shaft cleaner – 0.8…1.2 $m{\cdot}s^{-1}$; 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 ground surface – 0...2 cm.

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