Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2024, № 4 (116) https://doi.org/10.33108/visnyk_tntu2024.04
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 631.361.2

OPTIMIZATION OF THE PARAMETERS OF WORKING BODIES ROOT PILE CLEANER

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Abstract. *Root crops are valuable technical crops, and their raw material processing ensures the production of food (sugar, alcohol, juicy fodder for livestock, inulin for the field of medicine) and technical (renewable energy sources – biofuel) products is one of the types of organic fertilizers. The use of modern self-propelled bunker root harvesters in Ukraine, which are built according to the block-module principle, is profitable under the condition of seasonal production on a minimum area of 300 hectares or more. Therefore, in the conditions of management of multi-branch agricultural enterprises that grow root crops on small areas, an urgent technical and economic problem is the payback of technically complex and too expensive (from UAH 350 to 750 thousand per unit) root harvesting machines in connection with the specifics of the work – limited climatic terms of their use during the year (about one calendar month) and on small areas - up to 20...50 ha. Reducing the content of general soil and plant impurities in raw root crops by 0.5...1.5% reduces the total costs of their processing by an average of 10 to 15%, and reducing sticky soil by 0.5...0.8% reduces the costs of its separation (washing, scraping, etc.) on average from 8 to 12%. At the same time, the yield of the final processing product of higher quality is significantly increased by an average of 10...20%. The maximum permissible values of the work quality indicator in accordance with agrotechnical requirements were obtained with the following compromise values of the input factors: fodder and sugar beets: for augers of round section: rotation frequency of augers 150...160 rpm; rotation frequency of elastic elements 500...700 rpm; soil moisture 20...22%; speed of movement of the root harvesting machine up to 5...6 km/h; for elliptical screws: screw rotation frequency 120...160 rpm; rotation frequency of elastic elements 500...700 rpm; soil moisture 20...22%; speed of movement of the root harvesting machine up to 6...7 km/h; root crops of chicory: rotation frequency of the screw conveyor 140...150 rpm; soil moisture 20...22%; speed of movement of the root harvesting machine up to 6...7 km/h. The obtained results are a further step in the improvement of the methodology, methods of development and optimization of parameters of the work processes of transport and technological systems of root harvesting machines.*

Key words: *root crops, root harvester, cleaning module, quality indicators, general impurities, sticky soil, damage to root crops, parameters, movement speed, rotation frequency, soil moisture.*

https://doi.org/10.33108/visnyk_tntu2024.04.038 *Received 28.11.2024*

1. INTRODUCTION

The proposed concept of the transition to a sustainable and effective post-war recovery and development of Ukraine's industry provides for the implementation of strategic approaches to building up and increasing the production of various products in the agro-industrial sector, including large root crops of sugar and fodder beets, root crops of chicory (hereinafter – oot crops) [1, 2]. Root crops are valuable technical crops, and their raw material processing ensures the production of food (sugar, alcohol, juicy fodder for livestock, inulin for the field of medicine) and technical (renewable energy sources – biofuel) products is one of the types of organic fertilizers [3, 4].

Achieving the goals approved at the state level is possible through the development and implementation of effective production technologies and advanced technical means of harvesting root crops in the plant branch of agriculture, which provide the main indicators of agrotechnical requirements – loss of root crops up to 1.5%, contamination with impurities up to 8%, damage to root crops up to 15%, of them severely damaged – up to 8% [4–6].

The use of modern self-propelled bunker root harvesters in Ukraine, which are built according to the block-module principle, is profitable under the condition of seasonal production on a minimum area of 300 hectares or more [7, 8].

Therefore, in the conditions of management of multi-branch agricultural enterprises that grow root crops on small areas, an urgent technical and economic problem is the payback of technically complex and too expensive (from UAH 350 to 750 thousand per unit) root harvesting machines in connection with the specifics of the work – limited climatic terms of their use during the year (about one calendar month) and on small areas – up to 20...50 ha [9].

The use of existing trailed 3-row, 4-row root harvesting machines does not allow obtaining the necessary indicators of the quality of harvesting root crops in different soil and climatic conditions of work, which are typical for Ukraine during the period of biological maturity of root crops – the total number of impurities in the collected root crops significantly exceeds the established limit according to with agrotechnical requirements and in some cases reaches up to 20% or more, including free plant impurities – up to 10...12%, and soil stuck on root crops – up to 3...5%. At the same time, despite the fairly large dimensions of the cleaners (the area of the cleaning surfaces reaches up to 10...15 m^2, or the total length – up to 8...10 m), together with the harvested crop, up to 10...15 cm of arable soil layer on an area of 100 hectares is irreversibly removed , which causes irreparable damage to soil fertility 10–14].

Reducing the content of general soil and plant impurities in raw root crops by 0.5...1.5% reduces the total costs of their processing by an average of 10 to 15%, and reducing sticky soil by 0.5...0.8% reduces the costs of its separation (washing, scraping, etc.) on average from 8 to 12%. At the same time, the yield of the final processing product of higher quality is significantly increased by an average of 10...20% [15, 16].

In order to solve the scientific and technical problem of increasing the quality indicators of harvesting large root crops in the difficult conditions of operation of root harvesting machines, a scientific hypothesis was adopted, the implementation of which will ensure the intensification of the process of separating the structural components of impurities from root crops by developing a structural and technological scheme and optimizing the parameters of the working bodies of cleaning transport and technological modules of trailers cars [17, 18]

The resolution of the indicated direction is a further step in the improvement of the methodology, methods of development and optimization of parameters of the transport and technological systems of root harvesting machines, both in the fundamental (development of mathematical models) and practical (implementation in production) plan, which is a further step in the development of agricultural science both theoretically and empirically [19].

2. EXPERIMENTAL METHODS

When conducting field research, the functional nature of the change in performance indicators of the proposed cleaning transport-technological modules (CTTM) (Fig. 1) as part of root harvesting machines was determined: general impurities GI_k (circular augers) and GI_e (elliptical augers); masses of stuck soil on root crops SS_k (circular augers) and SS_e (elliptical augers); damage to root crops DR_k (circular augers) and DR_e (elliptical augers).

Determination of the quality indicators of the CTTM as part of the root harvesting machine based on the results of field experimental studies was carried out in accordance with the standard method of processing the experimental array of data [20]: CTTM (Fig. 1a,b) on sugar beet crops, Fig. 2; CTTM (Fig. 1c) on fodder beet crops, Fig. 3; CTTM on chicory root crops, Fig. 4 [21, 22].

The model of the implementation of experiments to determine the functional nature of changes in the quality indicators of the CTTM during the harvesting of fodder and sugar beets is carried out according to the structural diagram (Fig. 5), where the levels of variation by factors are given in the table 1.

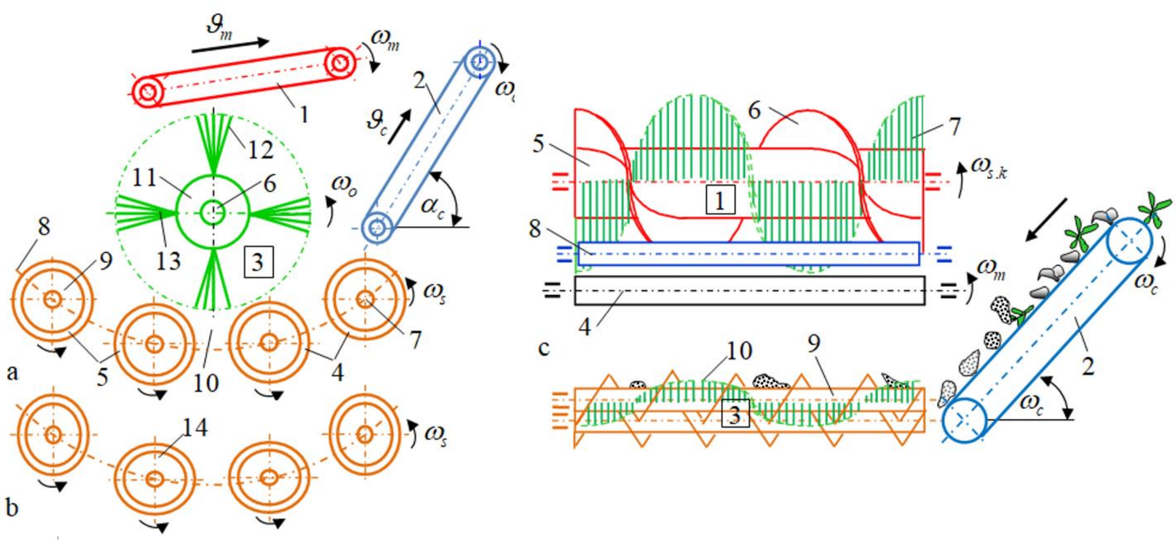

Figure 1. Structural and constructive schemes of CTTM. a, b: 1 – inclined conveyor; 2 – cleaning finger slide; 3 – combined working body; 4, 5 – respectively, the right and left system of screws; 6 – cleaning shaft; 7 – auger shaft; 8 – the lower branch of the ellipse; 9 – cleaning screws of round section; 10 – chute of the working channel; 11 – drum; 12 – elastic cleaning elements; 13 – bundles of pile; 14 – elliptical screws; c: 1 – combined working body; 2 – cleaning finger slide; 3 – combined working body; 4 – horizontal conveyor; 5 – screw conveyor; 6 – screw turn; 7 – elastic cleaning elements; 8 – roller; 9 – cleaning screws; 10 – cleaning shaft

The model of the implementation of experiments to determine the functional nature of the change in the performance quality indicators of the CTTM during the collection of chicory root crops was carried out according to the developed structural scheme (Fig. 6), where the levels of variation by factors are given in the table 2.

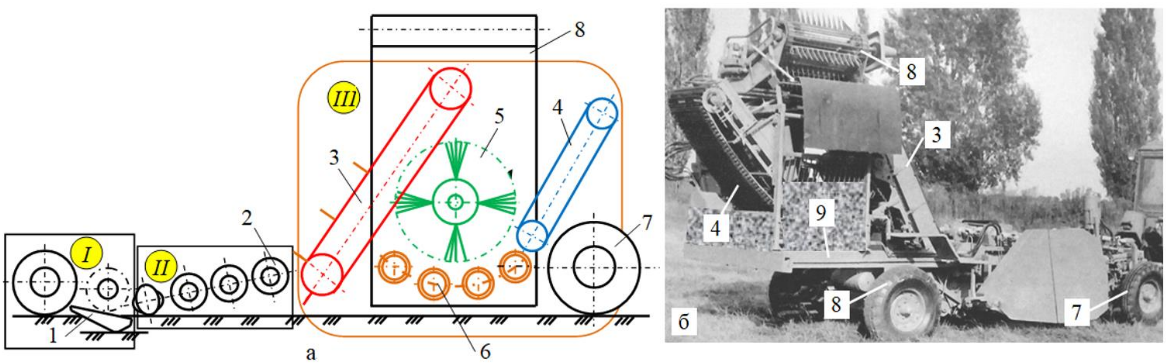

Figure 2. Modernized trailed root harvesting machine MPK-4: a – structural diagram; b – general appearance; I – root crop digging module; II - cleaning system; III – CTTM; 1 – vibrating digger; 2 – screw; 3 – inclined conveyor; 4 – hill; 5 – cleaning shaft; 6 – screw system; 7, 8 – supporting wheel; 9 – frame

Table 1

Factors and levels of variation by PFE 4^3 factors

Name of the factor	Natural marking	Coded designation / Levels of variation		
		Lower	Null	Upper
The speed of movement of the root harvester, km/h	ϑ_M	-1/5	0/6	+1/7
Screw rotation frequency, prm	n_s	-1/100	0/150	+1/200
Frequency of rotation of elastic elements, prm	n_e	-1/300	0/500	+1/700
Soil moisture, %	w_ρ	-1/18	0/22	+1/26

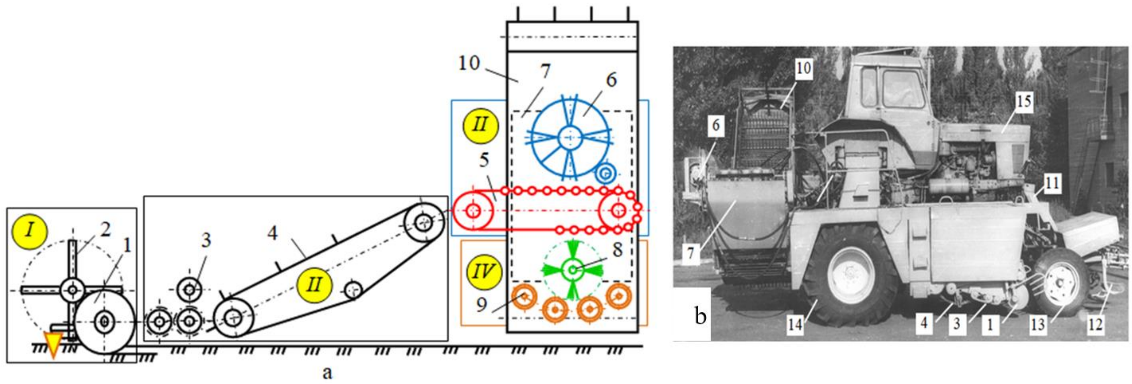

Figure 3. Modernized self-propelled root harvesting machine MKK-6A: a – structural diagram; b – general appearance; I – root crop digging module; II – cleaning system; III, IV – respectively, combined working body 1 and 2 CTTM; 1 – single-disc digger; 2 – horizontal cleaning shaft; 3 – screw cleaner; 4 – inclined bar conveyor; 5 – horizontal bar conveyor; 6 – screw conveyor; 7 – cleaning slide; 8 – drive horizontal shaft with cleaning elastic elements; 9 – systems of cleaning screws; 10 – unloading conveyor; 11 – frame; 12 – row control system; 13 – copying wheel; 14 – support wheel; 15 – tractor

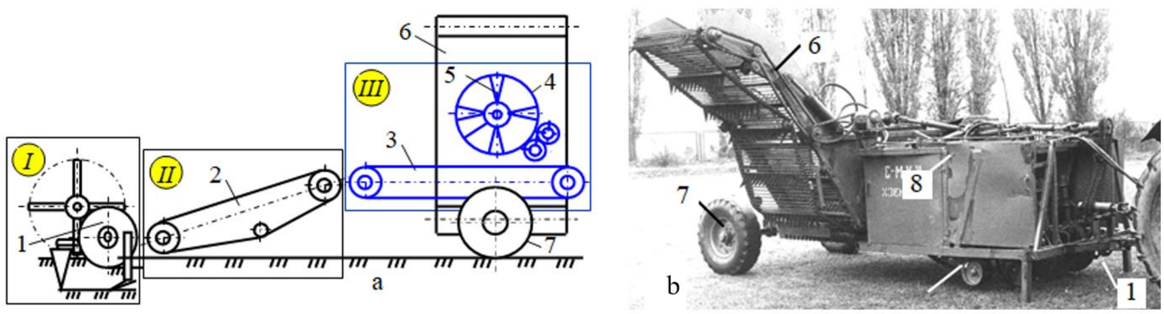

Figure 4. Trailed root harvesting machine: a – structural diagram; b – general appearance; I – root crop digging module; II – cleaning system; III – CTTM; 1 – digger; 2, 3 – inclined and horizontal conveyor; 4 – screw conveyor; 5 – cleaning elements; 6 – unloading conveyor; 7 – supporting wheel; 8 – frame

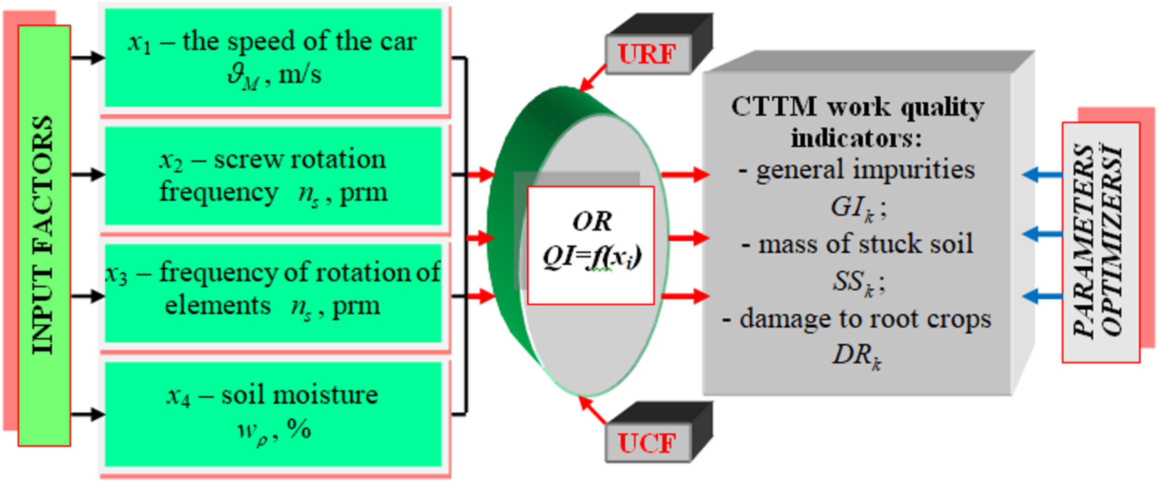

Figure 5. Model of implementation of experiments to determine performance indicators of CTTM during harvesting of fodder and sugar beets

During the experimental studies, the methodology of planned factorial experiments such as PFE 4^3 and PFE 3^3 was used. When conducting PFE 4^3, a randomized asymmetric Box-Benkin matrix plan was used [22].

Indicators of the quality of OTTM work are determined by the formula:

$$GI_i = \left(M_{GI} / M_R\right) 100\%;\ SS_i = \left(M_{SS} / M_R\right) 100\%;\ DR_i = \left(M_{DR} / M_R\right) 100\%, \tag{1}$$

Table 2

Factors and levels of variation by PFE 3^3 factors

Name of the factor	Natural marking	Coded designation / Levels of variation		
		Lower	Null	Upper
The speed of the car, km/h	ϑ_M	-1/1,5	0/1,7	+1/1,9
Rotation frequency of the screw conveyor, prm	$n_{s.k}$	-1/100	0/150	+1/200
Soil moisture, %	w_ρ	-1/18	0/21	+/24

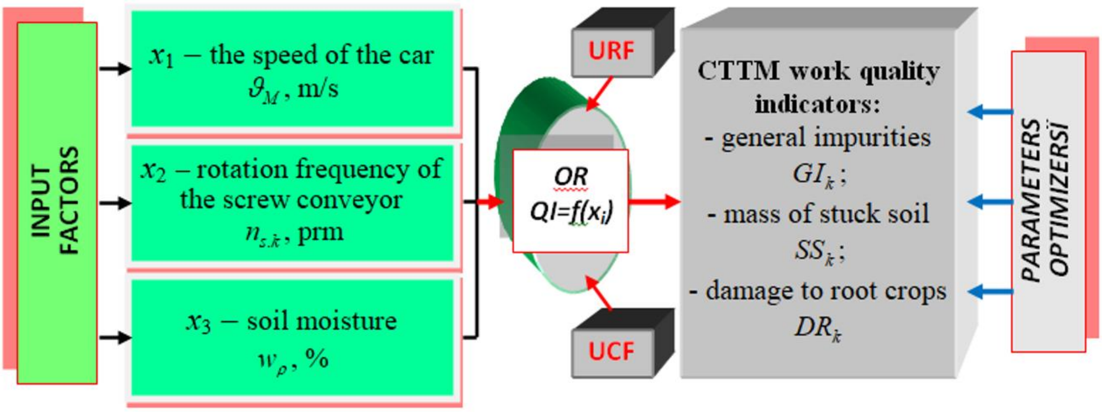

Figure 6. Model of the implementation of experiments to determine the quality indicators of CTTM work during the collection of chicory root crops

where M_{GI}, M_{SS}, M_{DR} and M_R are, respectively, the mass of total impurities, sticky soil, damaged root crops and the mass of root crops from the collected pile after digging by machine from one counting section of the field, kg.

The processing of the experimental data array during the determination of technological indicators and performance quality indicators of CTTM was carried out in accordance with the generally accepted method of processing experimental data, while: the unknown functional dependence of the indicators $\Pi_j = f_\Pi(x_1;x_2;x_i)$ for the approximation of the experimental data array was found by sorting known algebraic functions according to the largest value of the numerical coefficient determinations D_i of the corresponding algebraic dependence; the variability of the function was estimated by the standard deviation and the correlation coefficient; unknown coefficients of the regression equation of the functional dependence of $\Pi_j = f_\Pi(x_1;x_2;x_i)$ were determined with the help of an applied computer program package; the adequacy of the model and the significance of the coefficients of the regression equation were determined by Fisher's F-test and Student's – test [23, 24].

3. RESULTS AND DISCUSSION

According to the results of statistical processing of the obtained experimental array of data on the quality indicators of the CTTM as part of the root-harvesting machines, it was established that the largest value of the coefficients of numerical determination (D_{GIkk} = 0.940; D_{GIek} = 0.938; D_{SSkk} = 0.790; D_{SSek} = 0.962; D_{RKkk} = 0.965; D_{RKek} = 0.816) corresponded to mathematical model of a complete polynomial of the second degree [25].

After checking the significance of the coefficients of the regression equation and the adequacy of the model, the final empirical regression equations in natural factors were obtained, which characterize the functional dependence of the change:

- general impurities GI_c (circular augers) and GI_e (elliptical augers);
- masses of stuck soil on root crops SS_k (circular augers) and SS_e (elliptical augers);
- damage to root crops DR_k (circular augers) and DR_e (elliptical augers):
- during the harvesting of sugar beets with the MPK-4 machine, Fig. 2:

$$\begin{aligned} GI_{cs} &= 220,4 - 15,78\vartheta_M - 0,32n_s - 0,014n_e - 12,53w_\rho + 0,014\vartheta_M n_s + 0,33\cdot10^{-2}\vartheta_M n_e + \\ &+ 0,57\vartheta_M w_\rho + 0,3\cdot10^{-4} n_s n_e - 0,37\cdot10^{-3} n_e w_\rho - 0,058\vartheta_M^2 + 0,67\cdot10^{-3} n_s^2 - 0,74\cdot10^{-5} n_e^2 + 0,21w_\rho^2 \end{aligned}; \quad (2)$$

$$\begin{aligned} GI_{es} &= 217,6 - 15,52\vartheta_M - 0,32n_s - 0,97\cdot10^{-2} n_e - 12,45w_\rho + 0,014\vartheta_M n_s + 0,29\cdot10^{-2}\vartheta_M n_e + \\ &+ 0,57\vartheta_M w_\rho + 0,28\cdot10^{-4} n_s n_e - 0,36\cdot10^{-3} n_e w_\rho - 0,07\vartheta_M^2 + 0,65\cdot10^{-3} n_s^2 - 0,86\cdot10^{-5} n_e^2 + 0,21w_\rho^2 \end{aligned}; \quad (3)$$

$$\begin{aligned} SS_{cs} &= 14,8 + 1,36\vartheta_M - 0,13\cdot10^{-2} n_s - 0,12\cdot10^{-2} n_e - 1,55w_\rho - 0,25\cdot10^{-2}\vartheta_M n_s - \\ &- 0,35\cdot10^{-3}\vartheta_M n_e - 0,036\vartheta_M w_\rho + 0,51\cdot10^{-4} n_s^2 + 0,27\cdot10^{-5} n_e^2 + 0,04w_\rho^2 \end{aligned}; \quad (4)$$

$$\begin{aligned} SS_{es} &= 12,38 + 1,49\vartheta_M + 0,017n_s + 3,51\cdot10^{-3} n_e - 1,58w_\rho - 2,59\cdot10^{-3}\vartheta_M n_s - \\ &- 3,9\cdot10^{-4}\vartheta_M n_e - 0,038\vartheta_M w_\rho - 1,75\cdot10^{-5} n_s n_e + 0,16\cdot10^{-4} n_s^2 + 0,04w_\rho^2 \end{aligned}; \quad (5)$$

$$DR_{cs} = -103,2 + 36,1\vartheta_M + 0,52n_s - 0,43\cdot10^{-2}n_e - 2,77w_\rho - 0,07\vartheta_M n_s - 0,44\cdot10^{-2}\vartheta_M n_e - \\ -0,11\vartheta_M w_\rho + 0,13\cdot10^{-2}n_s w_\rho + 0,25\cdot10^{-3}n_e w_\rho - 1,77\vartheta_M^2 - 0,34\cdot10^{-3}n_s^2 + 0,25\cdot10^{-4}n_e^2 + 0,07w_\rho^2; \quad (6)$$

$$DR_{es} = 9,5 + 10,5\vartheta_M - 0,09n_s - 0,02n_e - 2,01w_\rho + 0,02\vartheta_M n_s - 0,13\vartheta_M w_\rho + \\ +0,13\cdot10^{-2}n_s w_\rho + 0,28\cdot10^{-3}n_e w_\rho - 0,77\vartheta_M^2 - 0,86\cdot10^{-4}n_s^2 + 0,93\cdot10^{-5}n_e^2 + 0,05w_\rho^2; \quad (7)$$

- during the harvesting of fodder beets with the MKK-6 machine, Fig. 3:

$$GI_{cf} = 139,8 - 0,94\vartheta_M - 0,29n_s - 10,16w_\rho + 0,45\cdot10^{-2}\vartheta_M n_s - 0,13\cdot10^{-2}\vartheta_M n_e + \\ +0,64\cdot10^{-2}\vartheta_M w_\rho + 0,23\cdot10^{-4}n_s n_e + 0,16\vartheta_M^2 + 0,77\cdot10^{-3}n_s^2 - 0,16\cdot10^{-5}n_e^2 + 0,23w_\rho^2; \quad (8)$$

$$GI_{ef} = 133,5 - 0,75\vartheta_M - 0,29n_s - 0,57\cdot10^{-2}n_e - 9,82w_\rho + 0,6\cdot10^{-2}\vartheta_M n_s - 0,17\cdot10^{-2}\vartheta_M n_e + \\ +0,63\cdot10^{-2}\vartheta_M w_\rho + 0,28\cdot10^{-4}n_s n_e + 0,94\cdot10^{-4}n_e w_\rho + 0,13\vartheta_M^2 + 0,7\cdot10^{-3}n_s^2 - 0,78\cdot10^{-5}n_e^2 + 0,22w_\rho^2; \quad (9)$$

$$SS_{cf} = 27,5 - 0,22\vartheta_M - 0,5\cdot10^{-2}n_s - 0,01n_e - 2,08w_\rho - \\ -0,25\cdot10^{-5}n_s n_e + 0,16\cdot10^{-4}n_s^2 + 0,72\cdot10^{-5}n_e^2 + 0,047w_\rho^2; \quad (10)$$

$$SS_{ef} = 23,9 - 0,032n_s - 0,42\cdot10^{-2}n_e - 1,7w_\rho + 0,25\cdot10^{-2}\vartheta_M n_s - \\ -0,25\cdot10^{-5}n_s n_e + 0,38\cdot10^{-3}n_s w_\rho + 0,31\cdot10^{-4}n_s^2 + 0,31\cdot10^{-5}n_e^2 + 0,037w_\rho^2; \quad (11)$$

$$DR_{cf} = 11,6 + 2,55\vartheta_M + 0,05n_s - 0,41\cdot10^{-2}n_e - 1,41w_\rho + 0,15\cdot10^{-2}\vartheta_M n_s - 0,12\cdot10^{-2}\vartheta_M n_e - \\ -0,11\vartheta_M w_\rho - 0,88\cdot10^{-3}n_s w_\rho + 0,37\cdot10^{-3}n_e w_\rho + 0,12\vartheta_M^2 + 0,31\cdot10^{-4}n_s^2 + 0,31\cdot10^{-5}n_e^2 + 0,044w_\rho^2; \quad (12)$$

$$DR_{ef} = 37,9 - 1,82\vartheta_M - 0,047n_s - 0,11n_e - 1,66w_\rho + 0,02\vartheta_M n_s - 0,14\vartheta_M w_\rho + \\ +0,14\cdot10^{-2}n_s w_\rho + 0,27\cdot10^{-3}n_e w_\rho + 0,28\vartheta_M^2 - 0,22\cdot10^{-3}n_s^2 + 0,33\cdot10^{-5}n_e^2 + 0,045w_\rho^2; \quad (13)$$

- during the harvesting of chicory root crops with a trailed three-row machine, Fig. 4:

$$GI_{cr} = 20,5 - 5,62\vartheta_M + 0,017n_{s.\kappa} + 0,89w_\rho + 0,35\cdot10^{-2}\vartheta_M n_{s.\kappa} + \\ +0,017\vartheta_M w_\rho - 0,11\cdot10^{-2}n_{s.\kappa}w_\rho + 0,42\vartheta_M^2 + 0,2\cdot10^{-3}n_{s.\kappa}^2 - 0,022w_\rho^2; \quad (14)$$

$$SS_{cr} = 21,6 + 0,25\vartheta_M - 0,67\cdot10^{-2}n_{s.\kappa} - 1,98w_\rho + 0,15\cdot10^{-2}\vartheta_M n_{s.\kappa} + \\ +0,17\cdot10^{-3}n_{s.\kappa}w_\rho - 0,049\vartheta_M^2 - 0,3\cdot10^{-4}n_{s.\kappa}^2 + 0,047w_\rho^2; \quad (15)$$

$$DR_{cr} = 208,4 - 3,07\vartheta_M - 0,057n_{s.\kappa} - 18,4w_\rho - 0,4\cdot10^{-2}\vartheta_M n_{s.\kappa} + \\ +0,82\cdot10^{-2}\vartheta_M w_\rho + 0,33\cdot10^{-2}n_{s.\kappa}w_\rho + 0,37\vartheta_M^2 + 0,11\cdot10^{-3}n_{s.\kappa}^2 + 0,43w_\rho^2. \quad (16)$$

The criterion for optimizing the rational parameters of the working bodies of the CTTM of root-harvesting machines is the minimum values of the work quality indicators, i.e.

$GI_i \to \min$, $SS_i \to \min$, $DR_i \to \min$, which are regulated by agrotechnical requirements.

Based on the results of field research, the parameters of the CTTM working bodies were determined, under which the values of the work quality indicators are minimal.

1. General impurities $GI_i \to \min$:

- sugar beets $GI_{is} \to \min$: augers of round cross-section – $GI_{cs} \to \min$ = 5.5% at the speed ϑ_M of the machine up to 6.0 km/h, the rotation frequency of the augers n_s 130...180 rpm, the rotation frequency n_e of the cleaning elements 650...700 rpm, soil moisture w_ρ from 20 to 22%; elliptical augers – $GI_{es} \to \min$ = 3.5% at the speed of movement ϑ_M of the machine up to 6.0 km/h, the rotation frequency of the augers n_s 120...200 rpm, the rotation frequency n_e of the cleaning elements 600...700 rpm, soil moisture w_ρ from 20 up to 22%, Fig. 7 a;

- fodder beets $GI_{if} \to \min$: augers of round cross-section – $GI_{cf} \to \min$ = 5.5% at the speed of movement ϑ_M of the machine up to 5.5 km/h, the rotation frequency of the augers n_s 140...180 rpm, the rotation frequency n_e of the cleaning elements 650...700 rpm , soil moisture w_ρ from 21 to 23%; elliptical augers – $GI_{ef} \to \min$ = 3.5% at the speed ϑ_M of the machine up to 6.0 km/h, the rotation frequency of the augers n_s 130...200 rpm, the rotation frequency n_e of the cleaning elements 600...700 rpm, soil moisture w_ρ from 20 up to 22%, Fig. 7 a;

- chicory roots – $GI_{cr} \to \min$ = 6.5% at the speed of movement ϑ_M of the machine up to 6.0 km/h, frequency $n_{s.\kappa}$ of rotation of the screw conveyor 100...170 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7 a.

2. Sticky soil on root crops $SS_i \to \min$:

- sugar beets $SS_{is} \to \min$: augers of round cross-section – $SS_{cs} \to \min$ = 0.5% for movement speed ϑ_M up to 6.5 km/h, rotation frequency of augers n_s 100...200 rpm, cleaning elements n_e 550...700 rpm, soil moisture w_ρ 20...22%; elliptical augers – $SS_{es} \to \min$ = 0.4% for machine speed ϑ_M up to 6.5 km/h, auger rotation frequency n_s 100...200 rpm, cleaning element rotation frequency n_e 650...700 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7b;

- fodder beets $SS_{if} \to \min$: augers of round cross-section – $SS_{cf} \to \min$ = 0.6% at machine speed ϑ_M up to 5.5 km/h, rotation frequency of augers n_s 100...160 rpm, rotation frequency of cleaning elements n_e 500...700 rpm, soil moisture w_ρ from 20 up to 22%; elliptical augers – $SS_{ef} \to \min$ = 0.5% at machine speed ϑ_M up to 6.0 km/h, auger rotation frequency n_s 100...180 rpm, cleaning element rotation frequency n_e 600...700 rpm, soil moisture w_ρ 20...22%, Fig. 7 b;

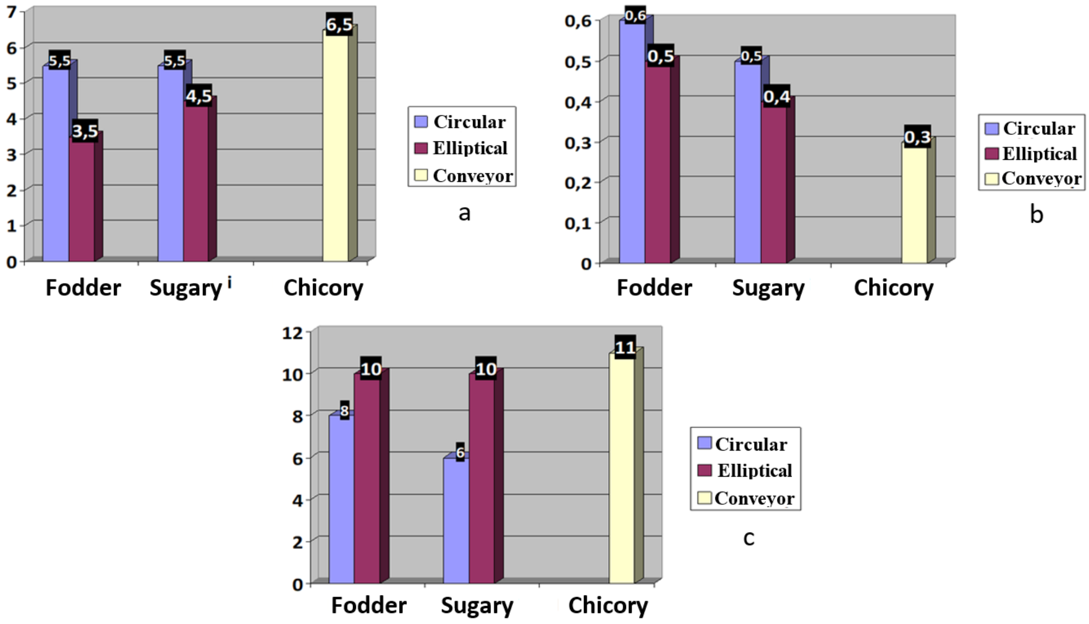

Figure 7. Diagram of minimum values: a – general impurities ($GI_i \to \min$); b – sticky soil ($SS_i \to \min$); c – damage to root crops ($DR_i \to \min$)

- chicory root crops – $SS_{cr} \to \min$ = 0.3% at machine speed ϑ_M up to 6.0 km/h, screw conveyor speed $n_{s.\kappa}$ 180...200 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7b.

3. Damage to root crops $DR_i \to \min$:

- sugar beets $DR_{is} \to \min$: augers of round cross-section – $DR_{cs} \to \min$ = 6.0% at a machine speed ϑ_M of up to 6.5 km/h, rotation frequency of augers n_s 100...150 rpm, rotation frequency of cleaning elements n_e 300...700 rpm, soil moisture w_ρ from 20 up to 22%; elliptical augers – $DR_{es} \to \min$ = 10.0% at the speed ϑ_M of movement of the root-harvesting machine up to 5.5 km/h, the rotation frequency of the augers n_s 100...120 rpm, the rotation frequency of the cleaning elastic elements n_e 300...700 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7 c;

- fodder beets $DR_{if} \to \min$: augers of round cross-section – $DR_{cf} \to \min$ = 8.0% at machine speed ϑ_M up to 5.5 km/h, rotation frequency of augers n_s 100...120 rpm, rotation frequency of cleaning elements n_e 300...700 rpm, soil moisture w_ρ from 20 up to 22%; elliptical augers – $DR_{ef} \to \min$ = 10% at a machine speed ϑ_M of up to 5.0 km/h, auger rotation frequency n_s 100...110 rpm, cleaning element rotation frequency n_e 300...700 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7 c;

- root crops of chicory – $DR_{cr} \to \min$ = 11.0% at the speed ϑ_M of the machine up to 7.0 km/h, the rotation frequency of the screw conveyor $n_{s.\kappa}$ 100...150 rpm, soil moisture w_ρ from 20 to 22%, Fig. 7 c.

However, the values of the parameters of the working organs of the CTTM and the speed of movement of the root-harvesting machine, at which the indicators of the quality of their work during the collection of large root crops are minimal, will provide the necessary throughput capacity of the CTTM, or the required performance of the work of the harvesting complex, or the productivity of the root-harvesting machine, which regulates the efficiency of the technical – economic indicators of feasibility of its industrial application.

Based on the analysis of the obtained results of the approximate values according to empirical models (2)–(16) and the graphical interpretation of the results of the functional change of the work quality indicators of CTTM and taking into account the influence of all active factors, it was established that the maximum permissible values of the function or the work quality indicator in accordance with agrotechnical requirements (of total impurities $GI_i \leq$ 8.0% (fodder and sugar beets), $GI_{cr} \leq 6.0$% (chicory roots), mass of stuck soil $SS_i \leq 1.5$% (fodder and sugar beets), $SS_{cr} \leq 1.0$% (chicory roots) and root damage $DR_i \leq 150$% (fodder and sugar beets), $DR_{cr} \leq 10.0$% (roots of chicory), obtained with the following compromise values of input factors:

- fodder and sugar beets: for augers of round section: rotation frequency of augers n_s 150...160 rpm; rotation frequency of elastic elements n_e 500...700 rpm; soil moisture w_ρ 20...22%; vehicle speed ϑ_M up to 5...6 km/h; for elliptical screws: screw rotation frequency n_s 120...160 rpm; rotation frequency of cleaning elements n_e 500...700 rpm; soil moisture w_ρ 20...22%; vehicle speed ϑ_M up to 6...7 km/h;
- chicory root crops: rotation frequency of the screw conveyor $n_{s.\kappa}$ 140...150 rpm; soil moisture w_ρ 20...22%; speed ϑ_M of movement of the root harvesting machine up to 6...7 km/h.

4. CONCLUSIONS

1. Regression equations (2)–(16) obtained as a result of experimental studies are empirical models that characterize the functional change in performance quality indicators of CTTM root-harvesting machines during harvesting of large sugar beets, fodder beets and chicory roots within the following limits of changes in input factors: speed movements of the root harvesting machine $5 \leq \vartheta_M \leq 7$ km/h; rotation frequency of screws $100 \leq n_s \leq 200$ prm; frequency of rotation of cleaning elastic elements $300 \leq n_e \leq 700$ prm; rotation frequency of the screw conveyor $100 \leq n_{s.\kappa} \leq 200$ prm; soil moisture $18 \leq w_\rho \leq 26$%.

2. In the context of the obtained research results, the following basic parameters of the working bodies of CTTM for production are recommended: speed of movement: root harvesting machine – $\vartheta_M = 7$ km/h; horizontal and inclined conveyor – $\vartheta_m = 1.6$ m/s; screw conveyor diameter – $D_{s.k} = 0.6$ m; diameter of screws (round/elliptical) – $D_s = 0.2/0.18$ m; rotation frequency of the screw conveyor and screws – $n_s = 180$ rpm; the slide installation angle

is $\alpha_c = 55$ degrees; speed of movement of the slide – $\vartheta_c = 1.3$ m/s; the rotation frequency of the cleaning elements is n_e = 700 rpm.

3. As separate transport and technological modules, which are the proposed CTTM, it is necessary to use for the modernization of the cleaning systems of the existing trailed (mounted) 3-, 4- and 6-row root-harvesting machines and pick-up loaders, which implement two-phase (direct or rolling) method of harvesting root crops with different types of machines.

4. CTTM with elliptical augers is advisable to use when harvesting large root crops by technology, when the collected root crops are not subject to storage.

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УДК 631.361.8

ОПТИМІЗАЦІЯ ПАРАМЕТРІВ РОБОЧИХ ОРГАНІВ ОЧИСНИКА ВОРОХУ КОРЕНЕПЛОДІВ

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Резюме. *Коренеплоди є цінними технічними культурами, а переробка їх сировини забезпечує виробництво харчової (цукор, спирт, соковиті корми для худоби, інулін для медицини) й технічної (відновлювані джерела енергії – біопаливо) продукції є одним із видів органічного добрива. Досягнення затверджених на державному рівні цілей можливе шляхом розроблення та впровадження ефективних технологій виробництва та прогресивних технічних засобів збирання коренеплодів у рослинницькій галузі землеробства, які забезпечують основні показники агротехнічних вимог – втрати коренеплодів до 1,5%. %, засміченість домішками до 8 %, пошкодження коренеплодів до 15%, з них сильно пошкоджені – до 8%. Зниження вмісту загальних грунтових і рослинних домішок у сировинних коренеплодах на 0,5…1,5% зменшує загальні витрати їх переробки в середньому від 10 до 15%, а зниження налиплого грунту на 0,5…0,8% зменшує витрати на його відокремлення (відмивання, зіскрібання тощо) в середньому від 8 до 12%. При цьому значно підвищується вихід кінцевого продукту переробки вищої якості в середньому на 10…20%. Максимально допустимі значення показника якості роботи згідно з агротехнічними вимогами отримано за таких компромісних значень вхідних факторів: кормові та цукрові буряки: для шнеків круглого перерізу: частоти обертання шнеків 150…160 об/хв; частоти обертання пружних елементів 500…700 об/хв; вологості грунту 20…22%; швидкості руху коренезбиральної машини до 5…6 км/год. Для еліпсних шнеків: частоти обертання шнеків 120…160 об/хв; частоти обертання пружних елементів 500…700 об/хв; вологості грунту 20…22%; швидкості руху коренезбиральної машини до 6…7 км/год. Коренеплоди цикорію: частоти обертання шнекового конвеєра 140…150 об/хв; вологості грунту 20…22%; швидкості руху коренезбиральної машини до 6…7 км/год. Отримані результати є подальшим кроком удосконалення методології, методів розроблення та оптимізації параметрів процесів роботи транспортно-технологічних систем коренезбиральних машини як у фундаментальному (розроблення математичних моделей), так і практичному (упровадження в виробництво) плані, що забезпечує розвиток аграрної науки як на теоретичному, так і емпіричному рівнях.*

Ключові слова: *коренеплоди, коренезбиральна машина, очисний модуль, показники якості, загальні домішки, налиплий грунт, пошкодження коренеплодів, параметри, швидкість руху, частота обертання, вологість грунту.*

https://doi.org/10.33108/visnyk_tntu2024.04.038 *Отримано 28.11.2024*