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EXPERIMENTAL STUDIES OF PRUNING THE HAULM OF CHICORY ROOT TOPS

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Summary. *Chicory roots are a valuable technical and strategically important crop for the leading sectors of the Ukrainian economy. The processing of raw materials from chicory roots allows to obtain energy (biofuel), food (coffee) and pharmaceutical (inulin) products. The low level of mechanization of harvesting chicory root crops (significant losses, damage) does not allow to meet the needs of raw materials for its processing. The purpose of the study is to increase the quality indicators of the cutting of burdock from the heads of root crops by substantiating the rational parameters of the working organs of the improved trimmer. According to the results of field experimental studies, regression equations were obtained that describe the functional change in the number of chicory root crops that have fallen from the ground and the number of damaged root crops depending on the speed of the copier, the stiffness coefficient of the spring of the vertical thrust of the copier and the angle of installation of the copier relative to the horizon. The following values of the rational parameters of the trimmer were obtained: speed of movement of the trimmer 1.6...1.8 m/s; the weight of the moving parts of the cutter is 6...7 kg; the angle of installation of the copier relative to the horizontal plane is 30...35 degrees, the stiffness coefficient of the spring of the copier's vertical thrust cup is up to 45 N/m.*

Key words: *chicory root crops, chickpea residues, process, fallen root crops, damage, model, factors, regression equation, parameters.*

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Statement of the problem. Root chicory is a technical crop from the raw materials of which valuable pharmaceutical (inulin, various types of acids), food (coffee, vitamins) and bioenergy (bioethanol, biodiesel) products of its processing are produced [1]. The cut haulm, which is scattered and worked into the soil after rotting, is an element of organic fertilizers that contribute to increasing the yield of crops and the processes of restoring soil fertility [2, 3]. The use of existing technical means for the mechanized harvesting of chicory root crops, including those that cut the haulm of chicory from their heads, leads to significant losses (falling out and damage) of root crops or losses of raw materials. This reduces the profitability of the production of chicory roots and their processing products in general [4].

The basis for reducing the number of chicory root crops that have fallen from the ground and reducing their damage is a scientific hypothesis, which involves the development of improved designs for the cutters of the haulm of the chicory, which are a component of the modules for collecting the chicory of modern root-harvesting machines [5, 6].

The need for developed and improved technical means for cutting the haulm of gorse from the heads of root crops arose in the process of introducing a two-stage method of cutting haulm in the late 50s of the last century [7].

This method involved cutting the main massif of the gorse with the subsequent trimming of the haulm of the haulm from the heads of root crops. According to the principle or method of cutting the remains of the pulp from the heads of root crops, the main four types of trimmers, which are built according to the design of the working bodies, were developed or introduced into production: «active copier-active knife»; «active copier-passive knife»; «passive copier-active knife»; «passive copier-passive knife» [8, 9].

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From the point of view of a rational approach, it is necessary to conduct an analysis of those constructions of the cutters of the haulm of the gorse, which are used on modern root-harvesting machines.

These are cutters that are made according to the fourth «passive copier-passive knife» scheme and which implement the second stage of common harvesting technologies, both of the main mass of gorse and trimming the remains of gorse from the heads of root crops [10]. These modern technologies are implemented by six-row self-propelled bunker harvesters of the world's leading companies, which are built according to the block-modular system of the location of working bodies [11].

The aim of the work is to increase the quality indicators of trimming the remains of the haulm from the heads of chicory root crops by improving the design and substantiating the rational parameters of the trimmer.

Materials and methods. To implement the experiments, a structural diagram of the experimental research model was developed based on the basic principles of the «black box» concept, Fig. 1. The structure and principle of operation of the improved cutter are given in the work [12].

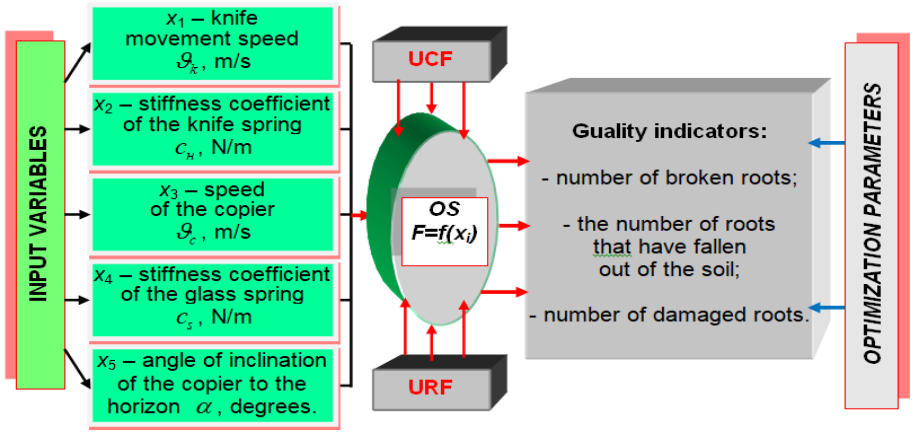

Figure 1. Structural diagram of the model of experimental studies of the trimmer: NRF, NCF – unregulated and uncontrollable input factors

The relationship between the input variable factors, which include the structural and kinematic parameters of the cutter and the parameters of chicory root crops, and the output parameters (optimization parameters) is a functional empirical dependence $F = f(x_i)$, where i = 1, 2,..., n- input factors.

Experimental studies on the determination of the number of root crops fallen from the soil and the number of damaged chicory root crops were carried out in field conditions using an improved trimmer for the remains of chicory from the heads of chicory root crops on crops of chicory root crops of the Umanskyi 99 variety.

The nature of the functional dependence, which described the change in the number K_{dr} of root crops fallen from the soil and the number K_{fr} of damaged chicory roots in the process of their contact interaction with a passive copier and a spring-loaded flat knife, depending on the variable factors: the speed of movement ϑ_c of the copier (or the adequate speed of movement of the shearing machine), the coefficient stiffness c_s of the spring of the moving thrust of the glass and the angle of inclination α of the copier to the horizon [12].

That is, the nature of the change in the empirical function $K_{dr} = f(\vartheta_c; c_s; \alpha)$ and $K_{fr} = f(\vartheta_c; c_s; \alpha)$ was determined. To obtain an experimental data set of the empirical function,

a three-factor experiment was implemented at three levels of variation by the factors, or a planned experiment of the PFE 3^3 type. The characteristics of the input factors of the three-factor experiment of the PFE 3^3 type are given in table. 1.

For the implementation of field experimental studies on the determination of the number of root crops that have fallen from the soil and damage to root crops of chicory, the following were used: a three-row gusset cutting machine (Fig. 2) for cutting the main mass of gusset [13]; the improved design of the trimmer for the remains of the chicory root heads, Fig. 3.

Table 1

Characteristics of input factors

Name of the factor	Marking		Variation interval	Levels of variation, natural/encoded		
	Natural	Encoded				
Speed of the copier ϑ_c, m/s	x_3	X_3	0,3	1,5/-1	1,8/0	2,1/+1
Coefficient of stiffness of the glass spring c_s, N/m	x_4	X_4	15	35/-1	50/0	65/+1
The angle of inclination of the copier to the horizon α, degr.	x_5	X_5	10	20/-1	30/0	40/+1

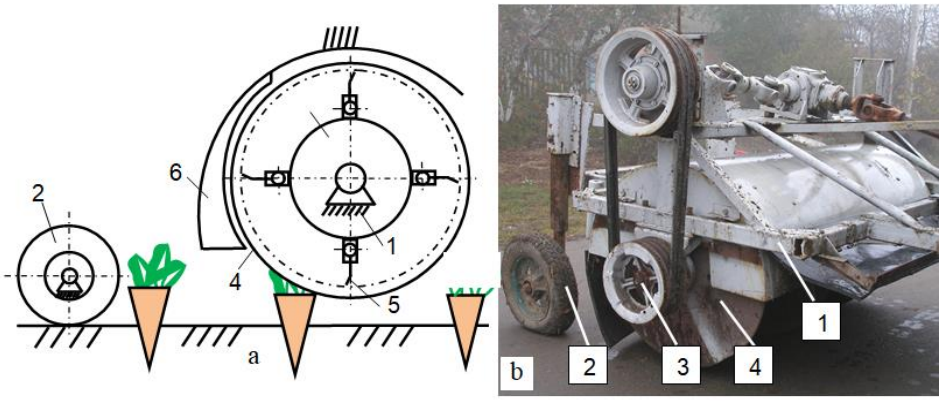

Figure 2. Scheme (a) and general view of the die-cutting machine (b): 1 – main frame; 2 – adjusting wheel; 3 – rotary cutter; 4 – dividing disk; 5 – flat L-shaped knife; 6 – casing

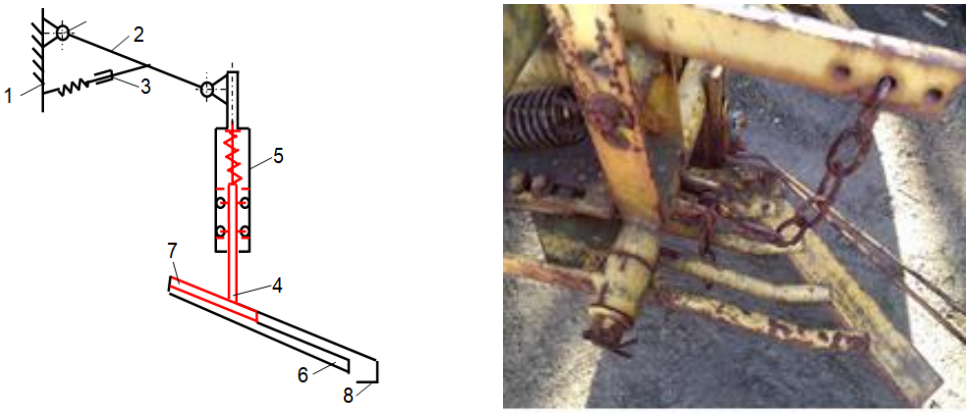

Figure 3. Structural diagram (a) and general view (b) of the improved trimmer: 1 – frame of the trimmer; 2 – parallelogram mechanism; 3 – traction is adjustable; 4 – vertical thrust; 5 – glass; 6 – copier; 7 – shock absorber; 8 – a knife

At the first stage, the main array of sedges was cut from the heads of chicory root crops with a three-row sedge cutting machine (Fig. 2) according to the principle of cutting without cutting on tall roots.

The total weight of the moving parts of the cutter was 8 kg.

The length of the course of the scoring section of one repetition was equal to 25 m.

Fallen and damaged root crops were culled from the 3 rows formed.

At the second stage, the improved cutter was brought into working position, and the drive of the rotary brush cutter was turned off by disconnecting the power take-off shaft of the tractor.

The number of fallen root crops from the soil K_{dr}, the number of damaged root crops K_{fr} was determined in % relative to the total mass of cut root crops $M_r^{(1)}$ of one repetition according to the formulas:

$$K_{dr} = \frac{m_{dr}^{(1)}}{M_r^{(1)}} 100; \quad K_{fr} = \frac{m_{fr}^{(1)}}{M_r^{(1)}} 100, \tag{1}$$

where K_{dr}, K_{fr} is respectively, the number of root crops fallen from the soil and the number of damaged chicory root crops, %; $m_{dr}^{(1)}$, $m_{fr}^{(1)}$ – mass of root crops of the corresponding quality indicator, kg; $M_r^{(1)}$ – total weight of cut root crops of one repetition, kg.

The mass of root crops, the corresponding quality indicator and the total mass of cut root crops of one repetition were determined by weighing on scales, the accuracy of weighing is ± 1.0 kg.

The obtained experimental array of data on the number of fallen root crops from the soil and the number of damaged chicory root crops was processed according to the standard method [14, 15].

Results and discussion. Experimental studies of the improved cutter of the remnants of gorse were carried out with the aim of establishing a functional empirical model that describes the behavior of changes in the number of K_{dr} root crops fallen from the soil and the number K_{fr} of damaged chicory roots in the process of their contact interaction with the passive copier (Fig. 3) depending on variable factors (table 1): the speed of movement ϑ_c of the copier, the stiffness coefficient c_c of the spring of the cup of the vertical movable thrust and the angle α of the inclination of the working surface of the copier to the horizon.

The sequence of conducting the first and subsequent experiments was established according to the randomized plan-matrix of the planned factorial experiment of the PFE 3^3 type.

Mathematical calculations of statistical indicators of the experimental data set of the number of chicory root crops fallen from the soil and the number of damaged root crops, or the processing of the experimental data set was carried out according to standard methods.

At the same time, it was established: calculated coefficients of the regression equation (empirical model) in natural values, which are given in the table 2; the mathematical form of the functional dependence of $K_{dr} = f(\vartheta_c; c_s; \alpha)$ and $K_{fr} = f(\vartheta_c; c_s; \alpha)$, which is written in the form of a polynomial of the second degree according to the largest value of the coefficient of multiple determination, respectively, D = 0.973 and D = 0.956.

The statistical significance of the coefficients of the regression equation of the relevant input factors was checked by the Student's t-test, while all the coefficients of the regression equation are significant.

The adequacy of the empirical mathematical model, which is written in the form of a polynomial of the second degree, was confirmed by Fisher's *F*-criterion, while the coefficient of multiple determination, respectively, *D* = 0.973 and *D* = 0.956 is significant with probability *P* = 0.94989 and *P* = 89341 at the level of significance *p* = 0.95.

Table 2

Natural values of the b_i coefficients of the regression equation of the number of K_{dr} and K_{fr} quality indicators

Marking	Natural values of the coefficients of the regression equation				
$K_{dr} = f(\vartheta_c; c_s; \alpha)$	b_0	b_1	b_2	b_3	b_{12}
	6,44	-0,75	-0,35	-0,54	0,61
	b_{13}	b_{23}	b_{11}	b_{22}	b_{33}
	-0,02	-0,02	0,32	-0,001	0,01
$K_{fr} = f(\vartheta_c; c_s; \alpha)$	b_0	b_1	b_2	b_3	b_{12}
	40,59	0,35	-1,04	-1,04	1,63
	b_{13}	b_{23}	b_{11}	b_{22}	b_{33}
	-0,97	-0,05	-5,51	-0,004	0,07

Thus, the regression equation that describes the functional nature of the change in the number of chicory root crops that have fallen from the soil and the number of damaged root crops in the implementation of experiments of the PFE 3^3 type is written in the form:

$$K_{dr} = 6,44 - 0,75\vartheta_c - 0,35c_s - 0,54\alpha + 0,61\vartheta_c c_s - \\ -0,02\vartheta_s\alpha - 0,02c_s\alpha + 0,32\vartheta_c^2 - 0,001c_s^2 + 0,01\alpha^2 ; \quad (2)$$

$$K_{fr} = 40,59 + 0,35\vartheta_c - 1,04c_s - 1,04\alpha + 1,63\vartheta_c c_s - \\ -0,97\vartheta_c\alpha - 0,05c_s\alpha - 5,51\vartheta_c^2 - 0,004c_s^2 + 0,07\alpha^2 ; \quad (3)$$

According to the data of the experimental array and regression equations (2) and (3), a graphical interpretation was constructed in the form of a response surface and a two-dimensional section of the response surface (Fig. 4, Fig. 5, Fig. 6, Fig. 7), which describe the functional change of the optimization parameter, or the number K_{dr} of fallen root crops from of soil and the number K_{fr} of damaged chicory root crops from the range of changes in input factors:

- the speed of the copier in the range of $1.5 \le \vartheta_c \le 2.1$ m/s;
- the coefficient of stiffness of the spring of the vertical copier thrust cup within $35 \le c_s \le 65$ N/cm;
- the angle of installation of the copier relative to the horizon within $20 \le \alpha \le 40$ degrees.

Based on the analysis of graphical dependencies (Fig. 4, Fig. 5, Fig. 6, Fig. 7), it can be stated that:

- the number of fallen chicory root crops as a function of $K_{dr} = f(\vartheta_c; c_s)$ varies in the range from 1.5 to 5.0%, while the dominant factor that most affects the optimization parameter K_{dr} is the stiffness coefficient of the spring c_s of the vertical thrust cup of the copier, Fig. 4;

- the number of fallen chicory root crops as a function of $K_{dr} = f(\vartheta_c; \alpha)$ varies in the range from 2.5 to 5.5%, while the dominant factor that most affects the optimization parameter K_{dr} is both factors ϑ_c and α, Fig. 5;

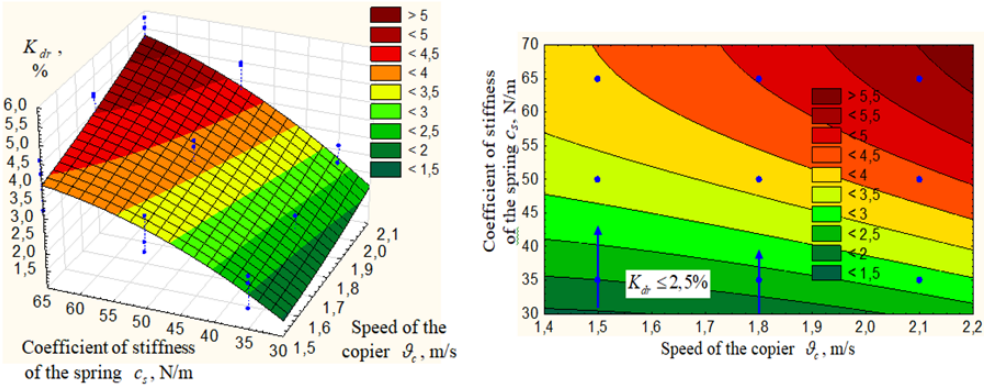

Figure 4. Response surface and two-dimensional section of the functional change surface $K_{dr} = f(\vartheta_c; c_s)$ of the number of fallen chicory roots

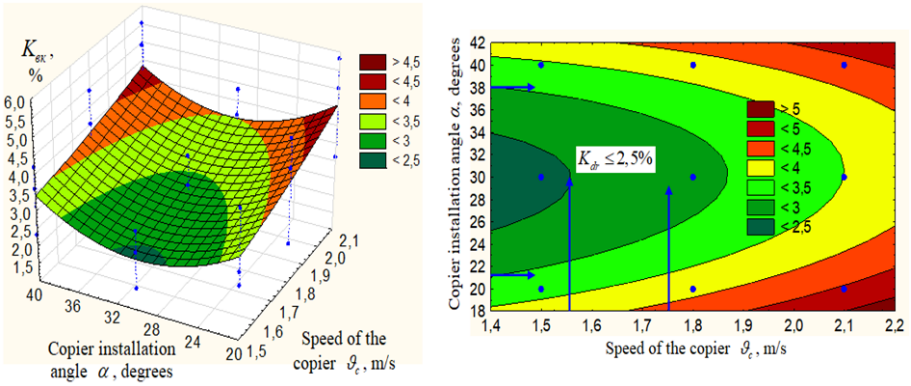

Figure 5. Response surface and two-dimensional section of the functional change surface $K_{dr} = f(\vartheta_c; \alpha)$ of the number of fallen chicory roots

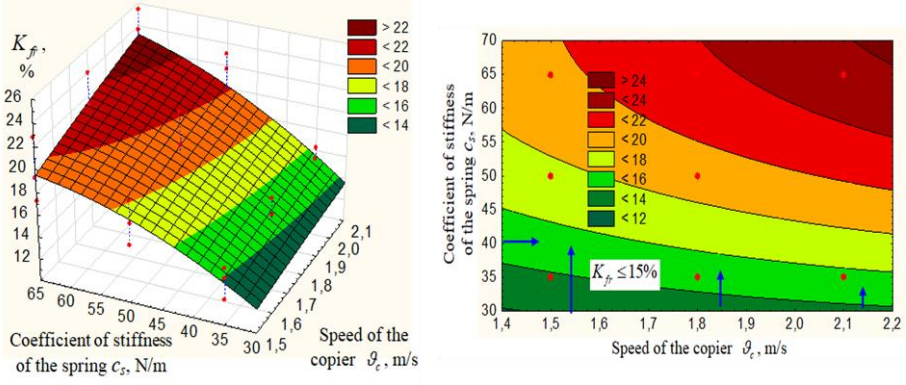

Figure 6. Response surface and two-dimensional section of the functional change surface $K_{fr} = f(\vartheta_c; c_s)$ of the number of damaged roots

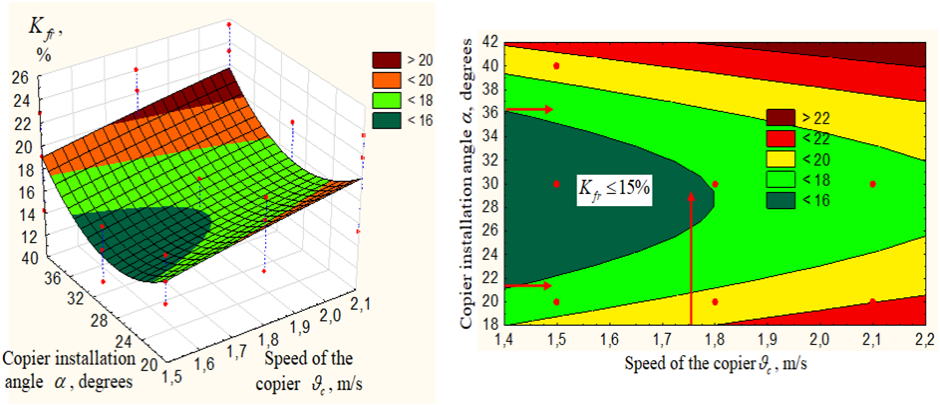

Figure 7. Response surface and two-dimensional section of the functional change surface $K_{fr} = f(\vartheta_c; c_s)$ of the number of damaged roots

- the number of damaged chicory root crops as a function of $K_{fr} = f(\vartheta_c; c_s)$ varies in the range from 11 to 23%, while the dominant factor that most affects the optimization parameter K_{fr} is the stiffness coefficient c_s of the cup of the vertical thrust of the copier, Fig. 6;

- the number of damaged chicory roots as a function of $K_{fr} = f(\vartheta_c; \alpha)$ varies in the range from 14 to 21%, while the dominant factor that most affects the parameter K_{fr} is both factors ϑ_c and α, Fig. 7.

The functional change of the initial parameters of the optimization, or the number K_{dr} of root crops fallen from the soil and the number K_{fr} of damaged root crops due to an increase in the stiffness coefficient c_s of the spring of the vertical thrust cup within the range of the change of the input factor $35 \le c_s \le 65$ N/m has a parabolic character, while:

- the minimum value of the optimum of the function $K_{dr} = f(\vartheta_c; c_s)$ and $K_{fr} = f(\vartheta_c; c_s)$, which is equal to, respectively, $K_{dr} = f(\vartheta_c; c_s) \to \min$ (1.3%) and $K_{fr} = f(\vartheta_c; c_s) \to \min$ (13.9%), obtained at the speed of movement ϑ_c of the copier no more than $\vartheta_c \le 1.8$ m/s, the stiffness coefficient c_s of the spring vertical thrust glass of no more than $c_s \le 45$ N/m and the angle α of the copier installation relative to the horizon equal to $\alpha = 30$ degrees.

Functional change of the initial optimization parameters, or the number K_{dr} of root crops fallen from the ground and the number K_{fr} of damaged root crops for increasing the angle α of the copier installation relative to the horizon within the range of the input factor change from $20 \le \alpha \le 40$ degrees has a parabolic character, at the same time:

- the minimum value of the optimum of the function $K_{dr} = f(\vartheta_c; \alpha)$ and $K_{fr} = f(\vartheta_c; \alpha)$, which is, respectively, $K_{dr} = f(\vartheta_c; \alpha) \to \min$ (2.3%) and $K_{fr} = f(\vartheta_c; \alpha) \to \min$ (13.9%), obtained at the angle α of setting the copier relative to the horizon within $25 \le \alpha \le 35$ degrees. and the movement speed ϑ_c of the copier is no more than $\vartheta_c \le 1.8$ m/s.

Taking into account the obtained results of experimental studies of indicators K_{dr} (number of root crops fallen from the soil) and K_{fr} (number of damaged root crops) and agrotechnical requirements [14] for the process of harvesting root crops, according to

which the working speed of the root harvesting machine should be at least 1.5 m/s, the number of chicory root crops that have fallen out of the ground with a head trimmer is no more than 2.5%, the number of damaged root crops should not be more than 15%, it can be stated that the established indicators of and K_{fr} tend to their minimum or optimal values ($K_{dr} \rightarrow optimum$ (≤ 2.5 %), $K_{fr} \rightarrow optimum$ (≤ 15 %)) are observed under the following cutter parameters:

- the speed of movement ϑ_c of the copier (or root harvesting machine) is less than or equal to 1.8 m/s;
- the stiffness coefficient c_s of the spring of the copier vertical thrust cup is less than or equal to 45 N/m;
- the installation angle α of the copier relative to the horizontal plane is from 30 to 35 degrees.

Conclusion. According to the results of the obtained indicators of the quality of the work process of the improved trimmer of the remains of the root crops from the heads of root crops, it can be stated that with a constant total mass of the moving parts of the trimmer m_c = 8 kg and the stiffness coefficient of the spring of the adjusting thrust c_a = 30 N/m, the nature of the change in the number of fallen K_{dr} root crops from the soil and the amount of K_{fr} of damaged root crops is as follows: the percentage increase in the number K_{dr} of root crops fallen from the soil and the number K_{fr} of damaged root crops due to an increase in the stiffness coefficient c_s of the cup of the vertical thrust of the copier within the change of the input factor from 35 to 65 N/m increases on average, respectively, by 3.0–3.5% and by 10–13%; an increase in the speed of movement ϑ_c of the copier within the limits of the change of the factor from 1.5 to 2.1 m/s does not significantly change the indicator of the number K_{dr} of root crops fallen from the soil and the indicator of the number K_{fr} of damaged root crops – respectively, K_{dr} and K_{fr} increase on average by 0, 4–0.6% and by 2.5–3.1%.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ЗРІЗУВАННЯ ГИЧКИ З ГОЛОВКИ КОРЕНЕПЛОДІВ ЦИКОРІЮ

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Резюме. *Коренеплоди цикорію є цінною технічною та стратегічно-важливою культурою для провідних галузей економіки України. Переробка сировини з коренеплодів цикорію дозволяє отримувати продукти енергетичного (біопаливо), харчового (кава) та фармацевтичного (інулін) характеру. Низький рівень механізації збирання коренеплодів цикорію (значні втрати, пошкодження) не дозволяє забезпечувати потреби сировини для її переробки. Мета дослідження – підвищення показників якості зрізування гички з головок коренеплодів шляхом обгрунтування раціональних параметрів робочих органів удосконаленого обрізника. За результатами проведених польових експериментальних досліджень отримано рівняння регресії, які описують функціональну зміну кількості вивалених коренеплодів цикорію з грунту та кількості пошкоджених коренеплодів залежно від швидкості руху копіра, сумарної маси рухомих частин обрізника, коефіцієнта жорсткості пружини стакана вертикальної тяги копіра та кута установлення копіра відносно горизонту. Порядок проведення експериментів і опрацювання експериментальних даних проводили згідно з відомою методикою планування та опрацювання результатів багатофакторних експериментів. Домінантними факторами, які суттєво впливають на показники оптимізації, є кут встановлення копіра до горизонту та сумарна маса рухомих частин обрізника. Зі збільшенням цих факторів у межах, відповідно, від 1,5 до 2,1 м/с та від 6 до 12 кг показники кількості вивалених коренеплодів з грунту та пошкоджених коренеплодів збільшуються в середньому в 1,4 раза. Отримано такі значення раціональних параметрів обрізника: швидкість руху обрізника – 1,6…1,8 м/с; маса рухомих частин обрізника 6…7 кг; кут встановлення копіра відносно горизонтальної площини – 30…35 град., коефіцієнт жорсткості пружини стакана вертикальної тяги копіра до 45 Н/м. Отримані результати дозволяють прогнозувати показники якості роботи гичкозбиральних модулів коренезбиральних машин.*

Ключові слова: *коренеплоди цикорію, залишки гички, процес, вивалені коренеплоди, пошкодження, модель, фактори, рівняння регресії, параметри.*

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