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EXPERIMENTAL STUDIES OF THE WIDTH OF THE SWATH OF TOPS OF ROOT CROPS

Viktor Baranovsky[1]; Valentin Myronenko[2]; Vitalii Pankiv[1]

[1]Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
[2]Institute of Mechanics and Automatics of Agroindustrial production of the National Academy of Agrarian sciences of Ukraine, Glevakha, Ukraine

Summary. *The search for effective technical solutions and scientific directions for substantiating the rational parameters of the working bodies of thick-cutting devices, which ensure an increase in the production of strategically important for the leading processing industries of Ukraine's economy (energy – biofuel; food – sugar, coffee; pharmaceutical – inulin) of technical crops or root crops is relevant and a significant direction of research, both for science and practice. The article presents the results of testing the adequacy of the developed analytical model, which functionally describes the process of unloading the cut root crop pulp onto the surface of the harvested field by the transport element (screw conveyor) of the pulp cutting module depending on the parameters of the screw conveyor. On the basis of the processing of the experimental data array, the regression equation of the change in the width of the formed swath of cut chaff was obtained depending on the input parameters: the speed of the chaff harvesting module, the chaff yield and the rotation frequency of the screw conveyor. It was established that within the range of variation of the input factors, the speed of movement of the module from 1.6 to 2.4 m/s, the yield of root crops from 120 to 180 t/ha and the rotation frequency of the screw conveyor from 40 to 100 rpm, the width of the formed roll of chopped the width of the swath is in the range from 0.5 to 1.4 m. The difference between the experimental and theoretical values of the width of the formed swath is within 5...10%. The obtained results of scientific research are a further step in the improvement of the methodology of optimizing the rational parameters of the working bodies of root-harvesting machines.*

Key words: *root crops, process, cut tops, screw conveyor, model, factors, parameters.*

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Statement of the problem. Root crops (sugar and fodder beets, chicory roots, etc.) are strategically important technical crops from the raw materials of which processing enterprises produce the necessary products for consumption or use in various fields of production [1–3].

Losses of raw material during harvesting are caused both by losses of root crops (more than 1.5%), and by unsatisfactory indicators of the quality of work of harvesting machines that do not meet agrotechnical requirements: the total contamination by impurities significantly exceeds the established limit (up to 8%), while the contamination with the remains of ghee is 3...5%, and contamination with soil impurities – up to 4...8%; waste in the mass of cut heads – 7...9%; up to 15% of damaged root crops due to chipped heads, of which more than 6...8% are severely damaged [4–7].

One of the reserves for improving the quality indicators of the work of root-harvesting modules, and accordingly, the quality indicators of modern self-propelled root-harvesting machines in general, is the improvement of the technological process of harvesting root crops by improving and substantiating the rational structural and kinematic parameters of the working bodies that cut the main array of root crops from the heads of root crops.

A significant number of scientific works have been devoted to the theoretical and experimental analysis of the technological processes of cutting the main mass of root crop root crops by substantiating the rational structural and kinematic parameters of the working bodies of the root crop cutting apparatus [8–11].

They outline the main aspects that characterize the scientific approaches and methodology of description, development of mathematical analytical and empirical models, and analysis of the working processes of devices for cutting the main mass of gorse and trimming the remains of gorse from the heads of root crops with various types of cutters.

However, the issue of scientific research on the formation of the width of the formed swath of cut swath, which is placed on the surface of the harvested field, has not been fully and insufficiently investigated – the width of the swath of cut swath regulates the necessary width of the center distance between the wheels of vehicles that move next to the swath or root harvester by car [12]. That is why there was a need for further research and analysis of the work processes of the root-harvesting modules of the root-harvesting machines.

Setting objectives. The task of the research is the development of an empirical model that describes the nature of the change in the width of the formed swath of cut chaff, which is formed by unloading chaff onto the surface of the harvested field by the screw conveyor of the chaff harvesting module, depending on the main parameters of the process.

Materials and methods. In order to formalize the technological process of transporting crushed root vegetables and to justify the rational parameters of the screw conveyor, a scheme for calculating the width of the cut swath is considered, which is formed by unloading the cut swath with a screw conveyor (Fig. 1) and which combines one of the stages of the functional scheme of the technological process the work of the gizzard-harvesting module (Fig. 2).

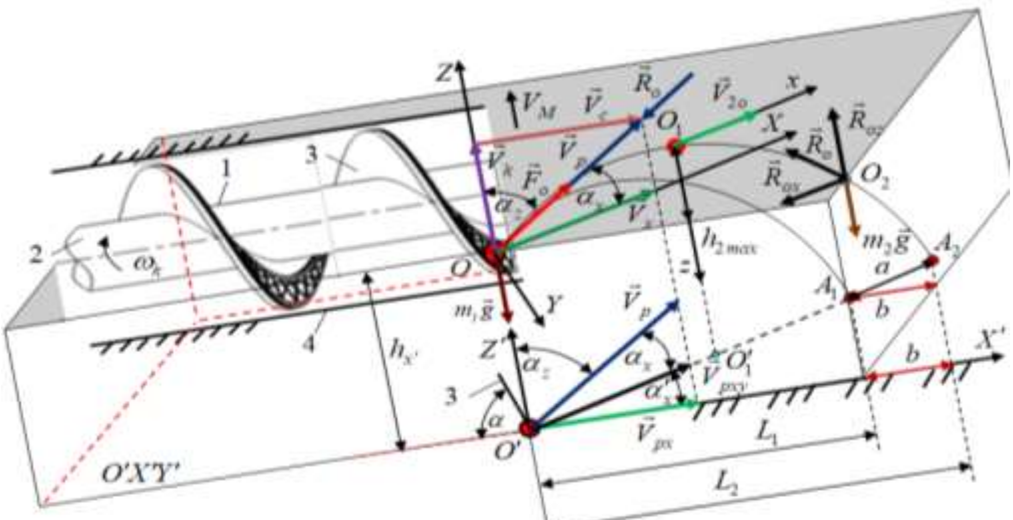

Figure 1. The scheme for calculating the width of a swath of cut root crops is formed:
1 – screw conveyor; 2 – drum; 3 – turn of the screw conveyor; 4 – casing

The width of the formed roll of sedge spread over the surface of the harvested field largely depends on the parameters and modes of operation of the screw conveyor 1 (Fig. 1), the instantaneous coordinates that determine the position of the point mass of the sedge relative to the spiral turn 3 at the moment of its exit from it, the resistance of the air medium, the mass of the shredded sorghum at the time of its exit from the auger coil, the physical state of the sorghum at the time of harvesting, etc [13–15].

After carrying out a theoretical analysis of the technological process of the chaff harvesting module (Fig. 2), an analytical model was obtained that describes the functional change in the width of the formed swath of cut chaff depending on the process parameters

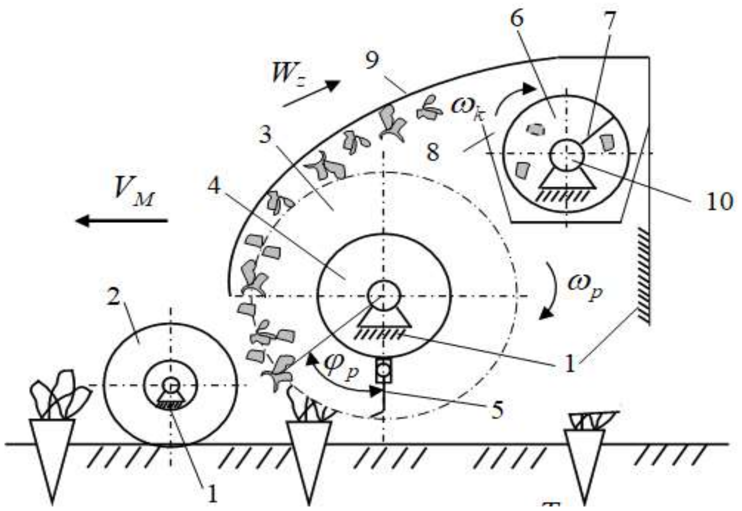

Figure 2. Schematic of the technological process of the work of the tops removal module:
1 – frame; 2 – support wheel; 3 – rotary cutter; 4, 10 – drum; 5 – a knife; 6 – screw conveyor; 7 – turn; 8 – gutter; 9 – casing; 11 – the output part of the auger

$$b=\frac{\pi n_k}{60}\frac{\Psi\sin\left(atctg\,\frac{n\pi_k}{tg\left(0,5\pi-\alpha_k\right)}\right)\cos\beta}{gk_om_i}\times$$
$$\times\left(1-\frac{\pi n_k k_o m_i\Psi\cos\left(arctg\,\frac{n\pi_k}{tg\left(0,5\pi-\alpha_k\right)}\right)}{60}\right)^{-1}e^{k_om_ig}\left(e^{t_{21}}-e^{t_{22}}\right), \qquad (1)$$

where $D^2+\left(Dtg\left(0,5\pi-\alpha_k\right)-\delta_v\right)^2k_a^2k_y^2=\Psi^2$ [13].

In order to check the adequacy of the theoretical provisions and statements of the developed model (1), which characterizes the dependence of the width of the formed roll b_e on the crushed chaff scattered on the surface of the soil, experimental studies of the laboratory installation were conducted, the structural scheme of which is shown in Fig. 2.

In order to obtain an empirical regression equation, which characterizes the change in the width of the formed swath b_e (m) cut by a rotary cutter, the plan of a three-factor planned experiment was chosen. At the same time, independent variable factors were taken (Fig. 3): the speed of movement V_M of the fiber-gathering module, which was coded with the index x_1, i.e. $V_M\to x_1$; the yield of root crops U_g, which was coded with the index x_2, i.e. $U_g\to x_2$; the rotation frequency of the screw conveyor n_k, which was coded with the index x_3, i.e. $n_k\to x_3$.

A three-factor planned experiment was conducted at three levels of variation with variable input factors, that is, a planned experiment of the PFE 3^3 type was implemented [16].

The results of factor coding and their variation levels are given in table. 1.

The sequence of conducting the first and subsequent experiments was established according to the numbered order of the randomized plan-matrix of the planned experiment of the PFE 3^3 type [17].

After the 6 rows of the counting area were passed through the smut collecting module, a roll of cut smut was formed.

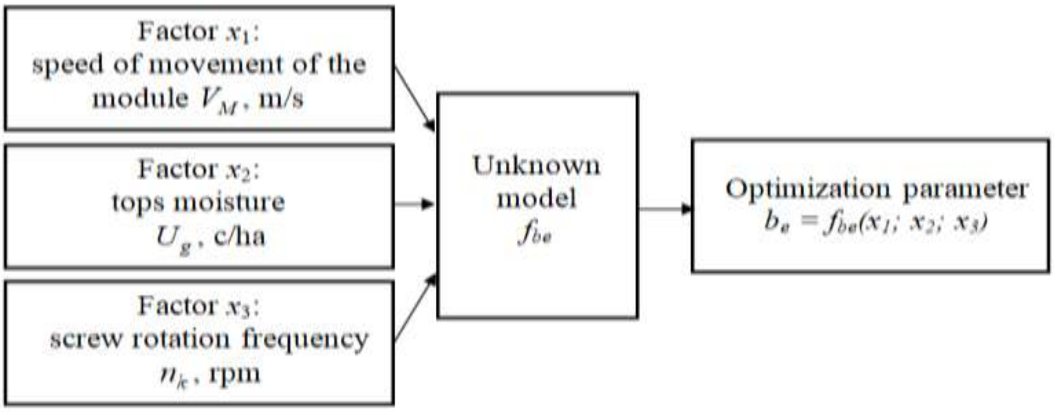

Figure 3. Scheme of the model of the planned factorial experiment of the PFE 33 type

The counting time t_b of conducting each experiment during the study was t_b = 2 s, while the length of the run L_b of the counting area of root crops from which each counting sample was taken was determined by the formula $L_b = V_M t_b$, that is, by V_M = 1.6; 2.0; 2.4 m/s the length of the race was L_b = 3.2; 4.0; 4.8 m. The numerical value of the rotation frequency n_k of the screw conveyor was set by rearranging the sprocket with the appropriate number of teeth.

Table 1

Results of factor coding and levels of their variation during experimental research

Name of the factor	Coded designation	Variation interval	Levels of variation, natural/encoded		
Module movement speed V_M, m/s	x_1	0,4	1,6/-1	2,0/0	2,4/+1
Tops moisture U_g, c/ha	x_2	30,0	120/-1	150/0	180/+1
Screw rotation frequency n_k, rpm	x_3	250	350/-1	600/0	850/+1

The width of the formed swath b_e on each length of the nth counting section was measured using a tape measure with an accuracy of ± 1 cm at intervals of 1 m and the average value was determined.

The approximating response function, or the optimization parameter (the width of the formed swath b_e, determined experimentally, was found in the form of a mathematical model of a logarithmic function

$$b_e = b_0 + b_1 \ln x_1 + b_2 \ln x_2 + b_3 \ln x_3, \quad (2)$$

where b_0, b_1, b_2, b_3 are the coefficients of the corresponding values;

x_1, x_2, x_3 – corresponding coded factors.

and discussion. After processing the obtained experimental array of data and carrying out an assessment of the statistical significance of the coefficients of the regression equation (Table 2) and checking the adequacy of the model [18], a regression equation was obtained that characterizes the change in the width of the formed swath b_e of cut hemlock on the field surface in natural values

$$b_e = -8,74 + 0,27\ln\left(V_M\right) + 1,21\ln\left(U_g\right) + 0,79\ln\left(n_k\right). \qquad (3)$$

According to the test results, all coefficients of the regression equation are significant, while the coefficient of multiple determinations is D = 0.995 at the 0.95 confidence level [19].

Table 2

Natural values of the coefficients b_i of the regression equation of the change in the width b_e of the formed top roll

Marking	Natural values of the coefficients of the regression equation			
	b_0	b_1	b_2	b_3
$b_e = f_b(V_M;U_g;n_k)$	-8,74	0,27	1,21	0,79

In Fig. 4–6 shows the response surface and a two-dimensional cross-section of the response surface of the functional change in the width of the formed swath b_e cut by a rotary swath cutter and laid on the collected field by a screw conveyor of crushed chicory root swaths, which are constructed according to the regression equation (3), obtained on the basis of the approximating empirical mathematical model $b_e = f_b(V_M;U_g;n_k)$, respectively:

- Fig. 4, Fig. 5 – as a function of $b_e = f_b(V_M;U_g)$;
- Fig. 6, Fig. 7 – as a function of $b_e = f_b(V_M;n_k)$;
- Fig. 8, Fig. 9 – as a function of $b_e = f_b(U_g;n_k)$.

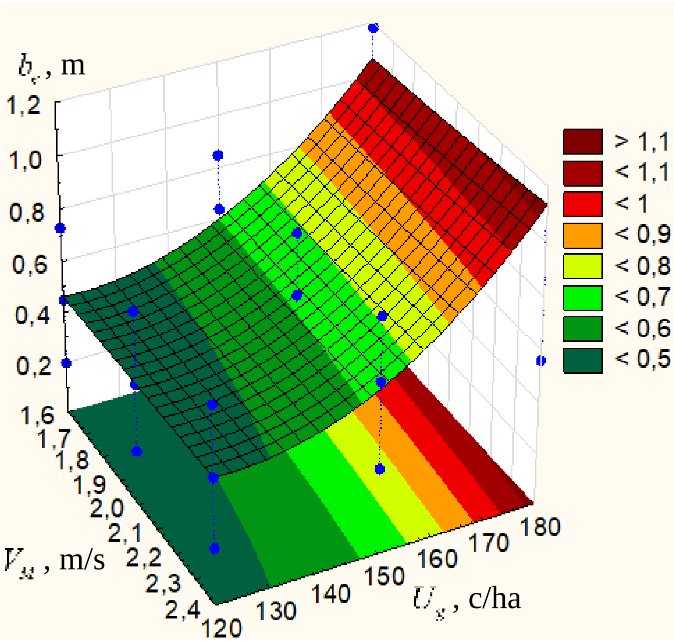

Figure 4. Change response surface width b_e of the formed roll as a function of $b_e = f_b(V_M;U_g)$

Within the given limits of variation of the variable input factors, the speed of movement of the module 1.6 $\leq V_M \leq$ 2.4 m, the yield of root crops 120 $\leq U_g \leq$ 180 c/ha and the rotation frequency of the auger 40 $\leq n_k \leq$ 100 rpm, the width b_e of the formed roll of chopped sedge is in the range from 0.5 to 1.4 m.

The functional change in the width b_e of the formed roll of shredded hemp depending on the change in the input factors is directly proportional – with an increase in V_M, U_g and n_k, the width b_e of the formed roll of shredded hemp also increases.

At the same time, the dominant factors that have a significant impact on the increase in the optimization parameter are the yield of root crop U_g and the frequency of rotation of the auger n_k (Fig. 4–9).

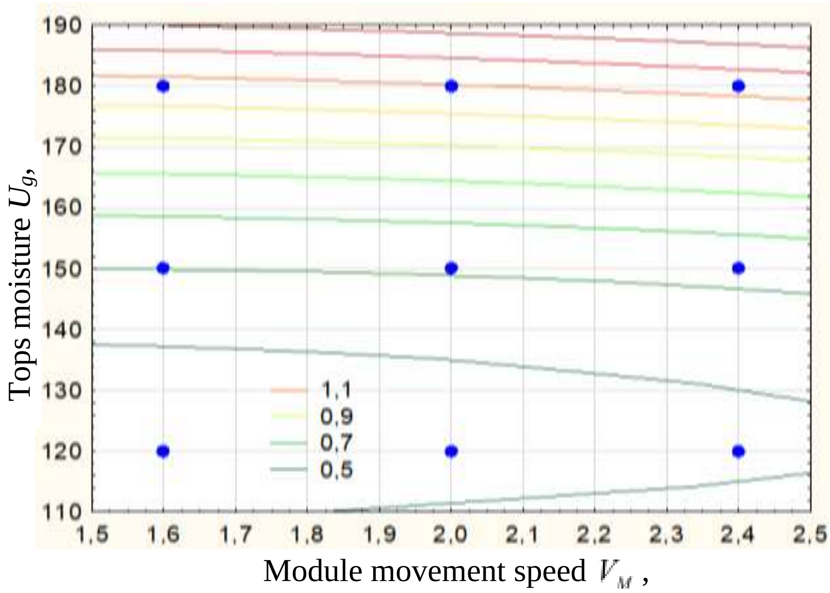

Figure 5. Two-dimensional section of the change response surface width b_e of the formed roll as a function of $b_e = f_b(V_M;U_g)$

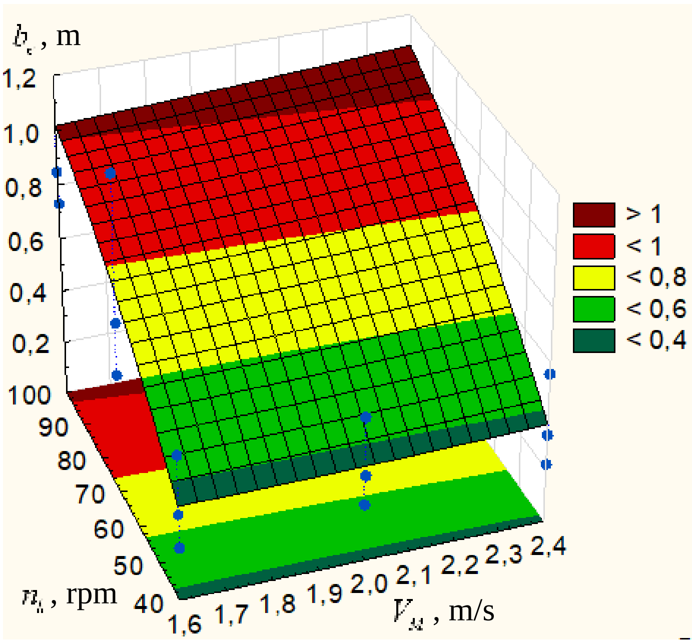

Figure 6. Change response surface width b_e of the formed roll as a function of $b_e = f_b(V_M;n_k)$

With an increase in the rotation frequency of the auger n_k from 40 to 100 rpm, the width b_e of the formed roll of crushed sedge laid on the surface of the soil increases by an average of 0.7 m (Fig. 4, 5, 8–10 a), and with an increase in the yield of sedge U_g of root crops from 120 to 180ct/ ha – by an average of 0.5 m (Fig. 6–9).

The increase in the width b_e of the formed roll of chopped straw laid on the surface of the soil within the limits of increasing the speed of movement V_M of the straw harvesting module from 1.6 to 2.4 m/s is insignificant – the average value of the increase b_e is within 0.05...0.1 m (Fig. 4–7, 10 b).

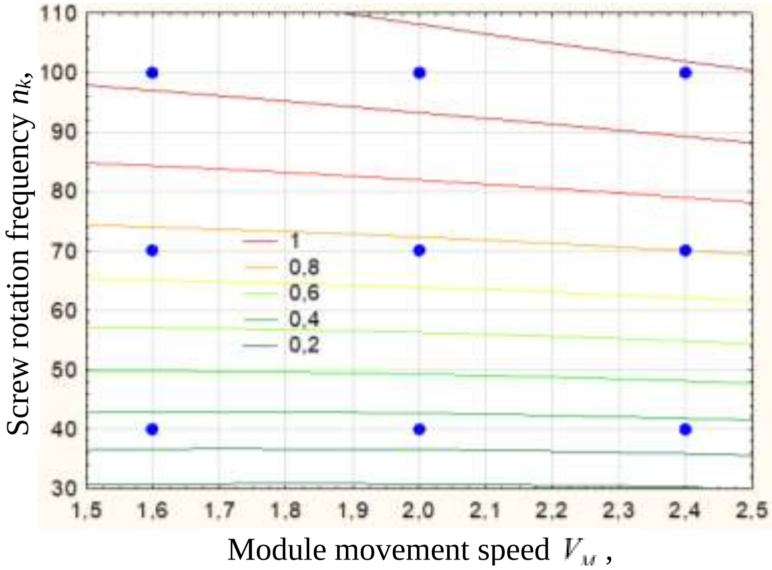

Figure 7. Two-dimensional section of the change response surface width b_e of the formed roll as a function of $b_e = f_b(V_M ; n_k)$

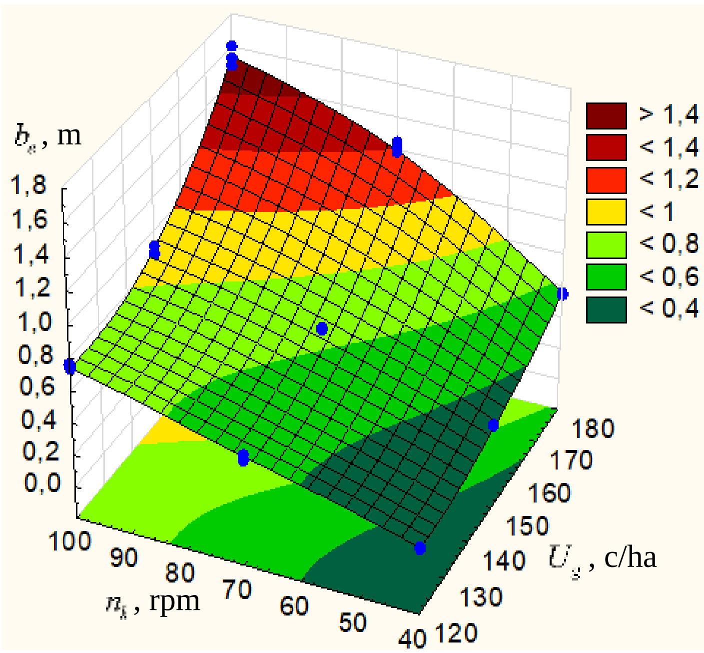

Figure 8. Change response surface width b_e of the formed roll as a function of $b_e = f_b(U_g ; n_k)$

From the point of view of a systematic analysis of the technological process of the operation of modern self-propelled root harvesting machines, which perform a single-phase method of harvesting root crops, it can be stated that the expediency of an experimental study of the width b_e of the formed roll laid on the harvested field by a screw conveyor of crushed root crops is regulated by:

- ensuring the manufacturability of the vehicles used to load dug root crops into the trailer;
- ensuring the manufacturability of machines that spread the formed windrow on the surface of the harvested field.
- partial unloading of harvested root crops from the filled hopper of the root harvesting machine without stopping it.

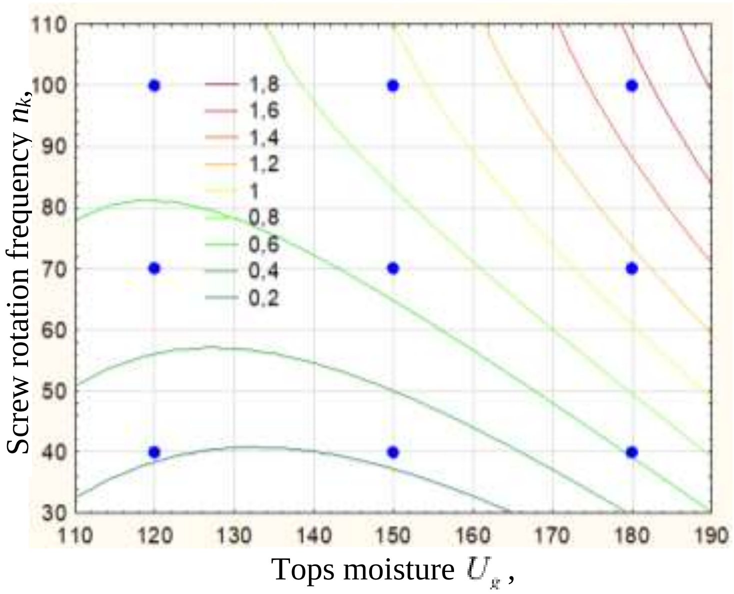

Figure 9. Two-dimensional section of the change response surface width b_e of the formed roll as a function of $b_e = f_b(U_g; n_k)$

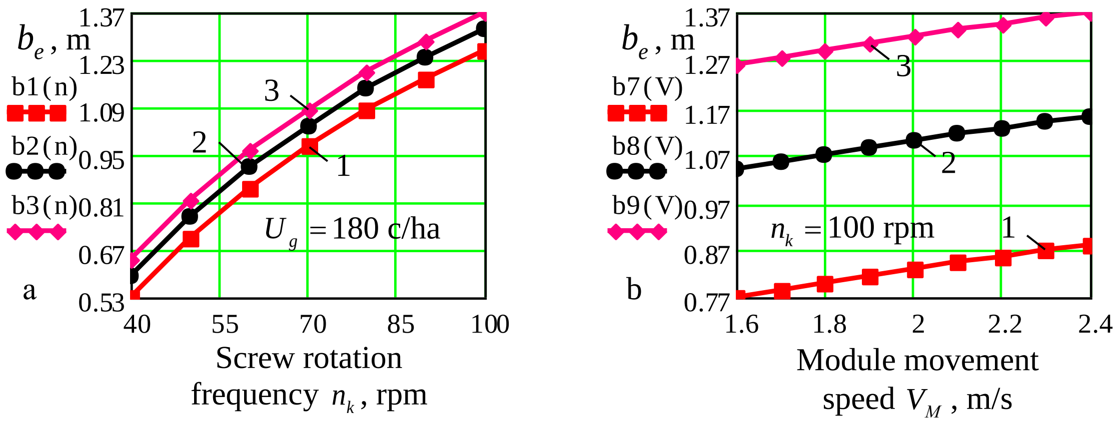

Figure 10. Dependence of the change in the width b_e of the formed roll as a function:
a – $b_e = f_b(n_k)$, 1, 2, 3 – respectively, V_M = 1.6; 2.0; 2.4 m/s;
b – $b_e = f_b(V_M)$, 1, 2, 3 – respectively, U_g = 120; 150; 180 c/ha

In this aspect, the value of the width b_e of the formed roll of shredded sorghum laid on the collected field is an important technological indicator of the technological process of the sorghum harvesting module, while in order to ensure the manufacturability of vehicles, the width b_e of the formed roll of shredded sorghum should not be greater than the interaxial distance of the vehicle's engines or the width transport track B_m.

In most cases and, as a rule, the width of the transport track of the technological transport during the harvesting of root crops is $B_m = 1.8$ m.

Then it can be stated that the obtained limit of change of the theoretical and experimental values of the width $b_{(i)}$ of the formed swath of crushed root crops $b_{(i)} \leq 1.6$ m does not exceed the width of the transport track of the technological transport $B_m = 1.8$ m, i.e. scattered over the surface of the harvested field, the crushed wheat will not interfere normal movement of the vehicle (absence of skidding of the vehicle's engines).

The difference between the experimental values of the width b_e of the formed swath of chopped straw laid on the collected field, which are constructed according to the regression equation (3) (dependencies b1(n), b3(n), b5(n)) and theoretical values b (dependencies b2(n), b4(n), b6(n)), obtained at the analytical level according to the mathematical model (1) is within 5...10%, Fig. 11.

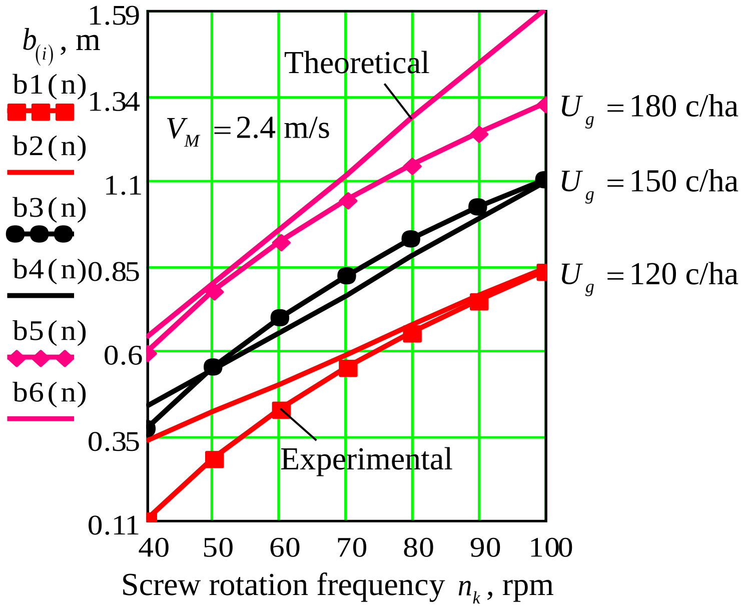

Figure 11. Dependence of the change in the width $b_{(i)}$ of the formed roll as a function $b = f_b(n_k)$

However, it should be noted that the ideal discrepancy between the theoretical and experimental values of the width of the formed swath of cut stubble, which is spread on the field surface by the screw conveyor, will be ideal under the permissible (normal) conditions of operation of the stubble harvesting module, or in the presence of wind, the direction and speed of which will not affect the increasing or decreasing the width of the formed roll.

Conclusion. On the basis of the conducted analysis, it can be stated that a theoretical model (1) has been developed, which functionally describes the change in the width b of the formed roll of shredded chaff laid on the collected field depending on the structural and kinematic parameters of the auger and the technological parameters of the chaff harvesting module in the general context at the analytical level adequately, or satisfactorily describes the real process of changing the width b_e of the formed roll of shredded sedge placed on the collected field, which is obtained at the empirical level according to the regression equations (2).

Within the limits of the variation of the input factors, the speed of movement of the module 1.6 $\leq V_M \leq$ 2.4 m, the productivity of root crops 120 $\leq U_g \leq$ 180 c/ha and the rotation frequency of the auger 40 $\leq n_k \leq$ 100 rpm, the width b_e of the formed roll of chopped sedge is in the range of 0.5 up to 1.4 m. These limits of the width B of the swath of cut and crushed root crops formed on the surface of the soil are optimal for ensuring uninterrupted operation of the technological transport for transporting the collected root crops.

The difference between the experimental and theoretical values of the width P of the formed roll is within 5...10%.

The obtained results are a further step in the improvement of the methodology for optimizing the parameters of the working bodies of the gizzard-harvesting modules and root-harvesting machines in general.

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ШИРИНИ ВАЛКА ЗРІЗАНОЇ ГИЧКИ КОРЕНЕПЛОДІВ

Віктор Барановський[1]; Валентин Мироненко[2]; Віталій Паньків[1]

[1]Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна
[2]Інститут механіки та автоматики агропромислового виробництва Національної академії аграрних наук України, Глеваха, Україна

Резюме. *Пошук ефективних технічних рішень і наукових напрямків розроблення нових і обґрунтування раціональних параметрів робочих органів гичкозрізувальних апаратів сучасних самохідних коренезбиральних машин, які забезпечують збільшення виробництва стратегічноважливих для провідних переробних галузей економіки України (енергетичної – біопаливо; харчової – цукор, кава; фармацевтичної – інулін) технічних культур, або коренеплодів є актуальним і значущим напрямком досліджень як для науки, так і практики. Метою роботи є обґрунтування раціональної ширини валка гички, який утворюється шляхом вивантаження витками шнекового конвеєра на зібране поле гички, яку зрізано та подрібнено ножами роторного гичкоріза гичкозбирального модуля. Наведено результати перевірки адекватності розробленої аналітичної моделі, яка функціонально описує кінематичний процес вивантаження зрізаної гички коренеплодів на поверхню зібраного поля транспортуючим елементом (шнековим конвеєром) гичкозрізувального модуля залежно від параметрів шнекового конвеєра та умов роботи гичкозбирального модуля. На основі опрацювання експериментального масиву даних отримано рівняння регресії зміни ширини утвореного валка зрізаної гички залежно від вхідних параметрів: швидкості руху гичкозбирального модуля, урожайності гички та частоти обертання шнекового конвеєра. Встановлено, що у межах варіювання вхідних факторів, швидкості руху гичкозбирального модуля від 1,6 до 2,4 м/с, урожайності гички коренеплодів від 120 до 180 ц/га і частоти обертання шнекового конвеєра від 40 до 100 об/хв ширина утвореного валка подрібненої гички в діапазоні від 0,5 до 1,4 м. Розбіжність експериментальних і теоретичних значень ширини утвореного валка знаходиться в межах 5...10%. Отримані результати наукових досліджень є подальшим кроком удосконалення методології оптимізації раціональних параметрів робочих органів гичкозбиральних модулів і коренезбиральних машин загалом.*

Ключові слова: *коренеплоди, процес, зрізана гичка, шнековий конвеєр, модель, параметри.*

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