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THEORETICAL STUDIES OF THE TECHNOLOGICAL PROCESS OF HARVESTING CHICORY ROOT CROPS

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Summary. *The decrease in the production of chicory root crops, which are valuable raw materials for the production of various products, is restrained by the low level of mechanization of their harvesting processes and unsatisfactory indicators of losses and contamination by impurity components. The purpose of the work: reduction of the second supply of impurities during the collection of chicory roots due to the development and analysis of analytical dependencies that functionally describe the process of collection of chicory roots by the working bodies of a combined single-disc digger. Based on the analysis of graphical dependencies, it was established that: the second supply of general impurities varies from 5 to 18 kg/s; second supply of loose soil – in the range from 4 to 15 kg/s; second supply of vegetable additives – from 0.06 to 0.1 kg/s. The obtained mathematical models are the initial dependencies for further substantiation of the parameters and modes of operation of the transport and cleaning working bodies of the root-harvesting machines.*

Key words: *chicory roots, process, slicing of ghee, impurities, remains of ghee, spherical disc, cleaning shaft, model, second feed.*

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Statement of the problem. Roots of chicory as an important technical crop are a valuable component for the food and pharmaceutical industries. Currently, in the country's agrarian sector, the sown area of chicory root crops has decreased due to the imperfection of root harvesting machines and the inconsistency of the quality of their work with agrotechnical requirements [1, 2]. Analysis of the work of known diggers showed that they significantly damage large root crops and have losses in small root crops of chicory. In addition, on these types of diggers, it is structurally impossible to combine two technological operations of harvesting – digging up root crops with simultaneous separation of husk remains [3, 4]. Tests and operation of chicory root pulp cleaners have shown that the technological process of removing tops has a number of significant drawbacks: high energy costs for the interaction of the cleaning blade with the head of the root crop; significant knocking out of roots from the soil, which leads to losses during harvesting [5, 6]. The criteria for the acceptability of modern requirements for the operation of digging tools of root-harvesting machines are primarily indicators of the completeness (losses) of root digging, their damage and the mass of impurities that enter their cleaning transport technological systems [7].

One of the reserves for increasing the technological indicators of the quality of the work of root equipment is the improvement of the technological process of harvesting chicory roots by using combined diggers that combine a passive spherical disk system and a shaft installed above it containing cleaning elements. Intensification of the process occurs due to specific kinematic and dynamic factors arising from the simultaneous interaction of cleaning elements with the head of root crops and the dug root crop [8, 9]. It can be concluded that the installation of a drive shaft with blades allows simultaneously digging up root crops and separating the remaining tops, reducing the intake of impurities by cleaning the contact interaction of the blades with the dump components [10].

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Materials and methods. Objective of work is to increase technological process indicators of haulm harvesting of chicory root crops through the development and substantiation of working parameters of haulm harvesting machines.

A large number of created designs of working tools, digging tools assemblies and layout schemes requires a differentiated approach in the selection, calculation, design, research and implementation of new developments into production [11]. Therefore, classified approach taking into account peculiarities of working bodies, layout schemes and methods of operation, provide the opportunity for analysis and synthesis of the necessary structural and technological scheme of combined digger for specific conditions of work. The root diggers design schemes variety connected directly with the process of harvesting and with structural and technological requirements to digging quality, roots cleaning and transportation [12]. On the basis of carried out identification (analysis and synthesis) of analogues of existing digging tools the advanced designs of combined root diggers, combining simultaneously all the advantages and benefits of the existed spherical single plate digger and possibility of use in conditions of excessive soil moisture and weed-infested crops, were submitted [13].

The structural model of algorithm of design and construction of a combined digger shown in Fig. 1 [14].

Combined digger consists of two spherical discs 1 set at an angle α to the axis of root row. Disks 1 freely planted on their axes of rotation 2. On the front area of the working edge of each spherical disc 1 the root directing device 3 is set. Above the discs, perpendicular to the direction of the speed of the motion of the digger ϑ_k , a horizontal drive shaft 4 is set. The horizontal drive shaft includes a reel 5 that bears flanges 6. The reel of the horizontal shaft made of three sections. The axis 7, 8, 9 are set adherently between the flanges of the reel on its axis range; flat elastic blades 10, 11 are fixed on them. Axis 7 and 8 of two end sections 12, 13 form a truncated cone, the end sections 12, 13 are directed to each other by smaller bases. Axis 9 of the intermediate section 14 forms a cylinder. The planes that pass through the axis 7, 9 or 8, 9 of contiguous sections 12, 14 or 13, 14 set at an obtuse angle. When the digger moves, root directing device 3 shifts knocked out of the row roots to its center and spherical disc 1 digs roots.

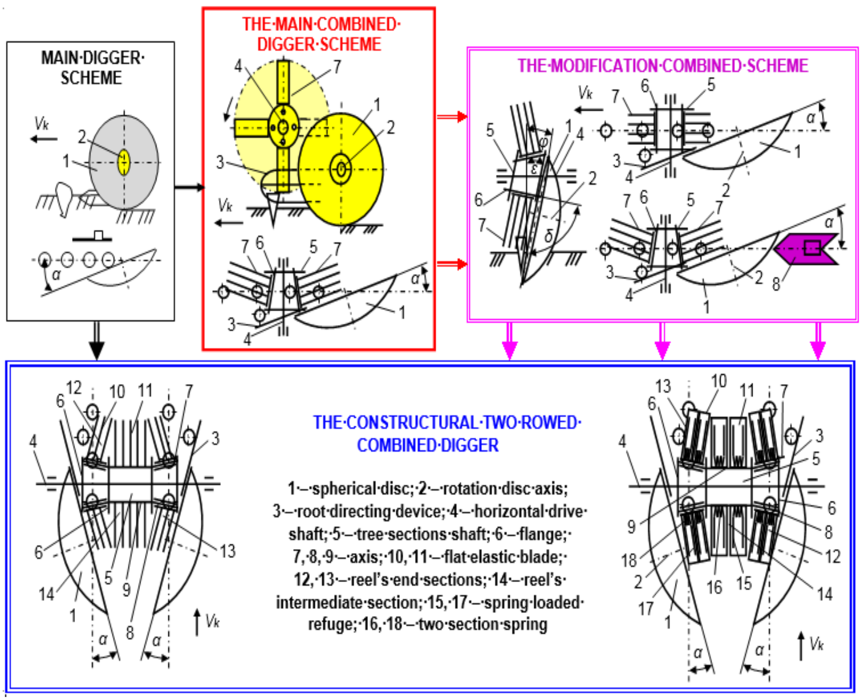

Figure 1. The development process identification of the combined digger structural and layout scheme

Along with digging roots by rotating the drive shaft 4 flat elastic blades 10, 11 of the two end sections 12, 13 interact with the heads of roots, while simultaneously cleaning of heads of roots from residue tops of two adjacent rows and destruction of lumps of soil occur.

In addition, flat elastic elements of intermediate section 14 simultaneously interact with roots and lumps of soil, purify the surface of roots of adhering soil and destroy clumps of soil, push heap, located in the space of spherical disks, which speeds up its supply to the following transport technology systems of root harvesting machinery.

and discussion. The technological efficiency of the operation of root harvesting machines when harvesting fodder beets depends on the following main criteria [15, 16, 17]:

- functional indicators of work quality;
- bandwidth of the main transport and technological systems (TTS), which determine the performance of the machine.

The second criterion is characterized by the ability of the TTS or the possibility of ensuring them to dig, transport and process the excavated heap of root crops without its accumulation on the surfaces of the working bodies of the TTS under the following conditions [18, 19]:

- at the specified required operating speed of the root harvesting machine;
- for receiving to the working bodies the corresponding number of components of the dug pile of root crops, that is, the corresponding second supply [20, 21].

The main criteria for evaluating the technological efficiency of the root crop digging process are the reduction of the total second supply Q_{2S} of the components of impurities that enter the cleaning system of the root harvesting machine after it is dug by the spherical disk 1 (Fig. 1) of the combined digger, or the adequate total mass M_{2S} of the components of impurities that are dug by disk 1 for a period of time Δt = 1 s compared to the identical performance indicators Q_{1S}, M_{1S} of the basic single-disc spherical digger [22].

To optimize the technological efficiency of the process of digging up root crops with a combined single-disc spherical digger, let's consider the complex scheme for calculating the technological process of digging up impurities from a pile of root crops, which is shown in Fig. 2. Then, in the process of movement of the digger, which is set relative to the direction of the working speed ϑ_k at the angle of attack α at the depth of the stroke h (Fig. 2) during the time interval Δt = 1 s, the spherical disc 2 moves from point B to point B_1 and cuts a groove in the soil with a length of L.

The arithmetic sum of these impurity components is equal to the corresponding total second supply of impurity Q_1, or the adequate total mass of impurity M_1, which is excavated by the disk in 1 s (here and in the future – from one row of root crops)

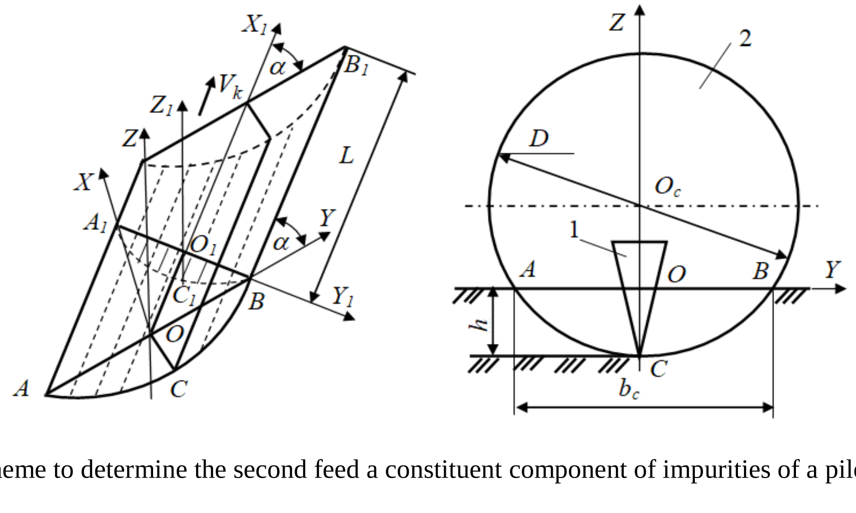

Figure 2. Scheme to determine the second feed a constituent component of impurities of a pile of root crops

$$Q_{1S} = M_1 t = \left(M_{1\rho} + M_{1n} + M_{1v} + M_{1z}\right) t, \tag{1}$$

where Q_{1S}, $M_{1\rho}$, M_{1n}, M_{1v}, M_{1z}, respectively, the total second supply of impurities, the mass of loose and adhered soil, free plant impurities, the remains of the humus on the heads of root crops, which are dug up with a disk in 1 s, kg/s.

The technological efficiency of the combined digger is expressed in terms of efficiency coefficients [23]–[24], which regulate the degree of reduction of its work quality indicator relative to the similar indicator of the basic digger: the total second feed Q_{2S}, or the total mass M_{2S} of impurities of a pile of root crops; the masses of the constituent components of $M_{2\rho}$, M_{2n}, M_{2v}, M_{2z} heap impurities.

At the same time, the total efficiency coefficient k and the efficiency coefficients k_ρ, k_n, k_v, k_z, which take into account the degree of reduction of the constituent component of impurities, are expressed as the ratio of the masses of impurities that enter the subsequent cleaning TTS of the root-harvesting machine with a combined and basic digger

$$Q_{2S} = M_{2S} t = \left(M_{2\rho} + M_{2n} + M_{2v} + M_{2z}\right) t = M_1 k t = \left(M_{1\rho} k_\rho + M_{1n} k_n + M_{1v} k_v + M_{1z} k\right) t_z, \tag{2}$$

where Q_{2S}, M_{2S}, respectively, the total second supply of impurities and the mass of impurities, which are supplied by the combined digger to the next cleaning TTS of the root harvesting machine in 1 s, kg/s; $M_{2\rho}$, M_{2n}, M_{2v}, M_{2z}, respectively, the mass of free and adhered soil, free plant impurities and the remains of scum on the heads of the body of root crops, which are fed by a combined digger to the next cleaning of the TTS of the root harvesting machine in t = 1 s, kg/s; k is the general coefficient, which takes into account the degree of reduction in the mass of impurities that are fed by the combined digger to the subsequent cleaning TTS of the root harvesting machine in t = 1 s relative to the mass of impurities that are excavated by a one-sided spherical disk; k_ρ, k_n, k_v, k_z coefficients that take into account the degree of reduction of the respective masses of the components of the impurity component of the pile of root crops.

To determine the theoretical and calculated values of Q_{1S}, M_{1S} and the masses of the constituent components of impurities $M_{1\rho}$, M_{1n}, M_{1v}, M_{1z}, which are excavated by one spherical disc, consider the diagram for determining the volume of the groove, Fig. 3.

In Fig. 3 relative to Fig. 2, the *OXYZ* coordinate system is turned to the angle of attack of the disc *α*, i.e., the *OX* axis is directed in the direction of translational movement of the digger, while the *OY*, *OZ* axes are directed in the transverse and vertical directions. According to [25], the projection of the helical line described by an arbitrary point of the outer cutting edge of the spherical disk onto the cross-sectional plane of the groove $Y_1O_1Z_1$ is an ellipse, i.e., the groove $A_1A_1'C_1'B'BC_1A_1$ of length L formed by the spherical disk (Fig. 2) has the cross-sectional shape of the segment of the ellipse A_1C_1B.

The mass of free soil located in the space of the $A_1A_1'C_1'B'BC_1A_1$ groove formed by a one-sided spherical disk during its movement t = 1 s will be

$$M_{1\rho} = \rho\left(V_L - \sum_{i=1}^{n} V_{n.k_i}\right) - M_{1n} = \rho\left(V_L - \sum_{i=1}^{n} V_{n.k_i} - \sum_{i=1}^{N} V_{n_i}\right), \tag{3}$$

where ρ is specific mass of soil, kg/m^3; V_L is groove volume, m^3; $\sum_{i=1}^{n} V_{n.k_i}$ is the total volume of underground parts of root crops 1 (Fig. 3), which are in the space of the groove, m^3; $\sum_{i=1}^{n} V_{n_i}$ is the total volume of adhered soil on the body surfaces of root crops 1, which are in the space of the groove, m^3.

The total mass of adhered soil, which is located on the lateral surface of the bodies of root crops, in the general case according to [26] is determined

$$M_{1n} = \sum_{i=1}^{n} V_{n_i}\rho = V_{1n}N = \rho V_{1n} n_k j_p = \rho S_n \delta n_k j_p = \\ = 2\pi n_k j_p \int_a^b \rho(Z)\delta(Z)\left[f(Z)\right]\sqrt{1+\left[f'(Z)\right]^2}\,dZ , \quad (4)$$

where V_{1n} is the volume of the layer of sticky soil of one root crop, m^3; S_n is the area of the lateral surface of the body of one root crop, on which there is adhering soil, m^2; δ is the thickness of the layer of uniformly distributed soil on the side surface, m.

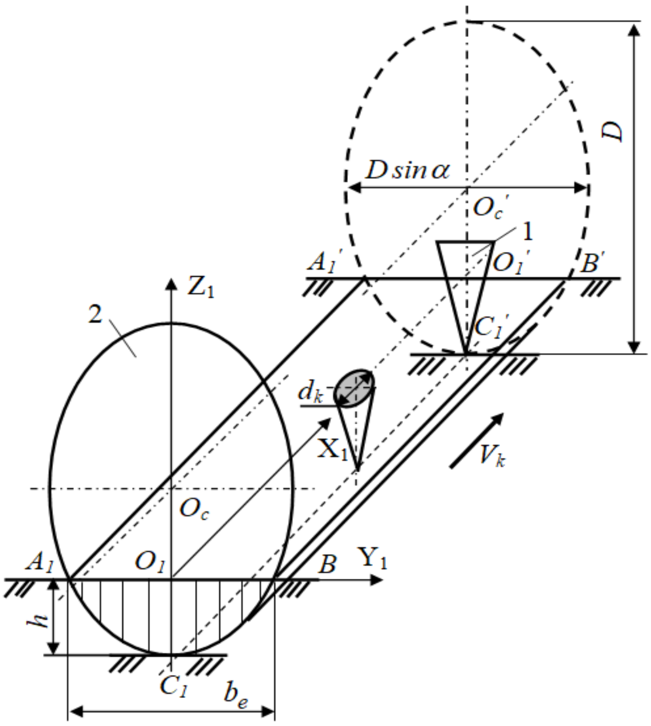

Figure 3. Scheme for calculating the volume of the groove: 1 – root crop; 2 – spherical disc

The total mass of free plant impurities M_{1v}, which is excavated by a one-sided spherical disk in t = 1 s, consists of the mass of weeds M_{1b} and the mass of sedge M_{1g}, which was lost in the process of its cutting by the working bodies of the sedge harvester.

According to the initial requirements for the technological process of the operation of root harvesting machines, which are intended for harvesting fodder beets [27], the specific mass of weeds at the time of harvesting root crops should not exceed $M_{1b} \leq$ 0.1 kg/m^2.

The mass of the lost gorse M_v and the mass of the remaining gorse on the heads of root crops M_z depend on the yield of the gorse and the quality of the work of the gorse harvesting machine. According to the original requirements [27]:

- the specific mass of lost gorse on an area of 1 m^2 should not exceed 10% of the yield of gorse;
- the length of the remaining gorse on the heads of root crops after cutting it with a gore harvester should not be more than 4 cm;
- the total specific mass M_{1v} / F_L of buckwheat residues on an area of 1 m^2 should not exceed 8% of the yield of buckwheat.

For further analysis, we accept the maximum values of the indicated indicators, according to agrotechnical requirements.

Then, the mass of free plant impurities M_{1v} and the remains of the ghee on the heads of root crops M_{1z} will be determined

$$\left.\begin{aligned} M_{1v} &= M_{1b} + M_{1g} = 0.1F_L + 0.1W_g F_L = 0.1F_L\left(1+W_g\right); \\ M_{1z} &= 0.08W_g F_L \end{aligned}\right\}, \tag{5}$$

where F_L is the area of the figure $A_1A_1'B'B$ at the level of the ground surface, which is formed by one spherical disk in a time of 1 s, m^2/s; W_g is the productivity of root crops, kg/m^2.

With:

- the volume of the $A_1A_1'C_1'B'BC_1A_1$ groove according to in the general case is equal to

$$\begin{gathered} V_L = F_c L = \left(ab\cdot\arccos\frac{z_1}{a} - z_1 y_1\right)\cdot \vartheta_k^{/}; \\ V_L = V_k \sin\alpha\left(0.25D^2 \arccos\frac{h}{D} - 2h\sqrt{h\left(D-h\right)}\right); \end{gathered} \tag{6}$$

$$F_c = 0.25D^2 \sin\alpha\cdot\arccos\frac{h}{D} - hb_e;\ b_e = 2\sin\alpha\sqrt{h\left(D-h\right)}, \tag{7}$$

where D is the diameter of the spherical disk, m; α is the angle of attack of the spherical disk, degrees; h is the depth of the groove, or the depth of the stroke of the spherical disk, m; b_e is the width of the groove, or the width of the base of the segment A_1C_1B of the ellipse, m; F_c is the cross-sectional area of the groove $A_1A_1'C_1'B'BC_1A_1$, or the area of the segment A_1C_1B of the ellipse, m^2; a, b, z_1, y_1 is respectively the major and minor semi-axes of the ellipse and running coordinates, m.

The most common varieties of fodder beet root crops are root crops that have conical and cylindrical shapes. According to the assumption adopted by us, we will determine the volume of the body of the underground parts of the formalized spatial form of fodder beet root crops.

$$\sum_{i=1}^{n} V_{n.k_i} = V_{1n.k}N = V_{1n.k} n_k j_p = n_k j_p \int_a^b \left[f(Z)\right]^2 dZ, \tag{8}$$

where $V_{1n.k}$ is the volume of the underground part of one root crop, m^3; N is the number of root crops on the path L, pcs.; n_k is the average value of the number of fodder beets per 1 linear meter of a row, pcs.; j_p is the number of linear meters that the digger passes in t = 1 s, running meters.

At the same time, the volume of the underground part of one root crop will be equal to: for a conical root crop according to [4] and for a root crop of cylindrical shape according to [8]:

$$V_{1n.k}^{k} = \frac{1}{3}\pi r_k^2 h_\rho = \frac{1}{3}\pi h^3 tg^2\left(\varphi/2\right); \qquad (9)$$

$$\begin{aligned} V_{1n.k}^{ц} &= V_{1k} + V_{1ц} = \frac{1}{12}\pi D_k^2 h_{k\rho} + \frac{1}{4}\pi D_k^2 h_{ц\rho} = \\ &= \frac{\pi D_k^2}{12}\left(h_{k\rho} + 3h_{ц\rho}\right) = \frac{\pi D_k^2}{12}\left(h + 2h_{ц\rho}\right) \end{aligned}, \qquad (10)$$

where $V_{1n.k}^{k}$ is the volume of the underground part of one conical root crop, m^3; r_k is the radius of the body of the root crop at the level of the soil surface, m; h_ρ is the depth of the root crop in the soil, m; φ is root crop growth cone angle, degrees; $V_{1n.k}^{ц}$, V_{1k}, $V_{1ц}$, respectively, the total volume of the underground part of the root crop of a cylindrical shape, the volume of the tail (conical) part of the root crop, and the volume of the cylindrical part of the root crop body [4, 8], m^3; D_k is root head diameter, m; $h_{k\rho}$, $h_{ц\rho}$, respectively, the height of the cone of the tail part of the root crop and the height of the cylindrical part of the body of the root crop, which lies in the soil, m.

The volume of the layer of sticky soil, which is located on the lateral surface of the body of one fodder beet root in a formalized form, will be:

- respectively, for a conical root crop and for a cylindrical root crop:

$$V_{1n}^{k} = S_n^k\delta = 0,5\pi d_k l_k \delta = \frac{\pi d_k^2 \delta}{4\sin\left(\varphi/2\right)} = \frac{4\pi h_\rho^2 tg^2\left(\varphi/2\right)\delta}{4\sin\left(\varphi/2\right)} = \frac{\pi h^2 tg\left(\varphi/2\right)\delta}{\cos\left(\varphi/2\right)}; \qquad (11)$$

$$V_{1n}^{ц} = S_n^k\delta + S_n^ц\delta = 0,5\pi D_k l_k \delta + \pi D_k h_{ц\rho}\delta = \pi D_k \delta\left(\frac{D_k}{4\sin\left(\varphi/2\right)} + h_{ц\rho}\right), \qquad (12)$$

where V_{1n}^{k} is the volume of the layer of adhering soil on the body surface of one conical root crop, m^3; S_n^k is the lateral surface of the body of one conical root crop, m^2; l_k is generating cone, m; $V_{1n}^{ц}$ is the volume of the layer of adhering soil on the surface of the body of one root crop of a cylindrical shape, m^3; $S_n^ц$ is the side surface of the body of one cylindrical root crop, m^2.

Substituting (11), (12) into equation (4) and after simplifying the expression, we obtain the dependence for determining the theoretically calculated total mass of adhering soil M_{1n} on the surface of formalized bodies of root crops that lie in the space of the groove $A_1A_1'C_1'B'BC_1A_1$:

- respectively, for conical root crops and for root crops of cylindrical shape:

$$M_{1n}^{k}=\frac{\pi n_k j_p h^2 tg\left(\varphi/2\right)\delta\rho}{\cos\left(\varphi/2\right)};\ M_{1n}^{ц}=\pi n_k j_p D_k \delta\rho\left(\frac{D_k}{4\sin\left(\varphi/2\right)}+h_{ц\rho}\right). \qquad (13)$$

Then, by substituting values (9), (10) into formula (3) and after simplifying the expression, we obtain the dependence for determining the theoretically calculated mass of free soil $M_{1\rho}$, which is excavated by a spherical disk in time t = 1 s and enters the following cleaning TTS of the root harvesting machine:

- respectively, for conical root crops and for root crops of cylindrical shape:

$$M_{1\rho}^{k}=\rho\vartheta_k\sin\alpha\left[0.25D^2\arccos\frac{h}{D}-2h\sqrt{h\left(D-h\right)}-\frac{\pi n_k j_p h^2 tg\left(\varphi/2\right)}{V_k\sin\alpha}\left(\frac{4h\sin\left(\varphi/2\right)+3\delta}{12\cos\left(\varphi/2\right)}\right)\right]; \qquad (14)$$

$$M_{1\rho}^{ц}=\rho\vartheta_k\sin\alpha\left[0.25D^2\arccos\frac{h}{D}-2h\sqrt{h\left(D-h\right)}-\frac{\pi n_k j_p D_k}{V_k\sin\alpha}\left[\frac{D_k\left(h+2h_{ц\rho}\right)}{12}+\delta\left(\frac{D_k}{4tg\left(\varphi/2\right)}+h_{ц\rho}\right)\right]\right]. \qquad (15)$$

Taking (5) and into account that $F_L=2L\sin\alpha\sqrt{h\left(D-h\right)}$ we will obtain a theoretical-calculation dependence for determining the mass of free plant impurities M_{1v} and the mass of the remains of chaff M_{1z} on the heads of root crops, which are dug up and fed by a one-sided spherical disk to the following cleaning TTS of the root harvesting machine

$$M_{1v}=0.2\vartheta_k\sin\alpha\sqrt{h\left(D-h\right)}\left(1+W_g\right);\ \ M_{1z}=0.16\vartheta_k W_g\sin\alpha\sqrt{h\left(D-h\right)}. \qquad (16)$$

Comparing equations (1), (3) and (4), we can write that

$$M_{1S}=\rho\left(V_L-\sum_{i=1}^{n}V_{n.k_i}-\sum_{i=1}^{n}V_{n_i}\right)+\sum_{i=1}^{n}V_{n_i}\rho+M_{1v}+M_{1z}=\rho\left(V_L-\sum_{i=1}^{n}V_{n.k_i}\right)+M_{1v}+M_{1z}=Q_{1S}t. \qquad (17)$$

By substituting (11), (14), (15) and (23) into equation (24) and after simplifying the expression, we obtain a theoretical-calculation dependence that characterizes the change in the second supply of general impurities Q_{1S} to the following cleaning TTS after their excavation by a one-sided spherical disk depending on from the design parameters of the disc, size and mass characteristics of root crops and the operating conditions of the root harvesting machine:

- when digging up conical and root crops of a cylindrical shape:

$$Q_{1S}^{k}=\rho\vartheta_k\sin\alpha\left[0.25D^2\arccos\frac{h}{D}-2\sqrt{h\left(D-h\right)}\left(h-\frac{0.1+0.17W_g}{\rho}\right)-\frac{\pi n_k j_p h^3 tg^2\left(\varphi/2\right)}{3\vartheta_k\sin\alpha}\right]; \qquad (18)$$

$$Q_{1S}^{ц}=\rho\vartheta_k\sin\alpha\left[0.25D^2\arccos\frac{h}{D}-\sqrt{h\left(D-h\right)}\left(2h-\frac{0.2+0.36W_g}{\rho}\right)-\frac{\pi n_k j_p D_k^2}{12\vartheta_k\sin\alpha}\left(h+2h_{ц\rho}\right)\right]. \qquad (19)$$

Respectively (2), (16), (18) and (19), we obtain a theoretical-calculation dependence that characterizes the change in the second supply of general Q_{2S} impurities after their digging by the combined digging working body to the following cleaning TTS of root-harvesting machines, depending on the structural and kinematic parameters of the disk, size and mass characteristics of root crops and operating conditions of the root harvesting machine:

- when digging up conical and root crops of a cylindrical shape:

$$Q_{2S}^{k} = k\rho\vartheta_k \sin\alpha \left[0.25D^2 \arccos\frac{h}{D} - 2\sqrt{h(D-h)}\left(h - \frac{0.1+0.17W_g}{\rho}\right) - \frac{\pi n_k j_p h^3 tg^2(\varphi/2)}{3\vartheta_k \sin\alpha} \right]; \qquad (20)$$

$$Q_{2S}^{ц} = k\rho\vartheta_k \sin\alpha \left[0.25D^2 \arccos\frac{h}{D} - 2\sqrt{h(D-h)}\left(h - \frac{0.1+0.17W_g}{\rho}\right) - \frac{\pi n_k j_p D_k^2}{12\vartheta_k \sin\alpha}\left(h + 2h_{ц\rho}\right) \right]. \qquad (21)$$

At the same time, the total second supply of plant impurities Q_{2p} according to (16) will be equal to the sum of the second supply of free plant impurities Q_{2v} and the second supply of the remaining humus on the heads of root crops Q_{2z}, or

$$\begin{aligned} Q_{2p} &= Q_{2v} + Q_{2z} = Q_{2v} = 0.2k_v\vartheta_k \sin\alpha\sqrt{h(D-h)}\left(1+W_g\right) + 0.16k_z\vartheta_k W_g \sin\alpha\sqrt{h(D-h)} = \\ &= 0.2\vartheta_k \sin\alpha\sqrt{h(D-h)}\left[k_v\left(1+W_g\right) + 0.8k_z W_g\right] \end{aligned}. \qquad (22)$$

Under the initial conditions α = 30^0, h = 0.09 m, ρ = 1500 kg/m^3, n_k = 4 pcs., W_g = 0.6 kg/m^2, D_k = 0.15 m, δ = 0.005 m, φ = 12^0, $j_p \cong \vartheta_k^{/}$ running meters graphical dependences of changes in the second supply of impurities during digging root crops were constructed fodder beets of conical and cylindrical shape by a combined digging working body: according to (20), (21) of the second supply of general impurities $Q_{2S}^{k} = f(D,k)$, $Q_{2}^{ц} = f(D,k)$, which are shown, respectively, in Fig. 4, Fig. 5; according to (22) the second supply of free plant impurities and the remains of lye on the heads of root crops $Q_{2p} = f(D,k_p)$, which are shown in Fig. 6, at the same time, we accept that $k = k_v = k_z$.

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

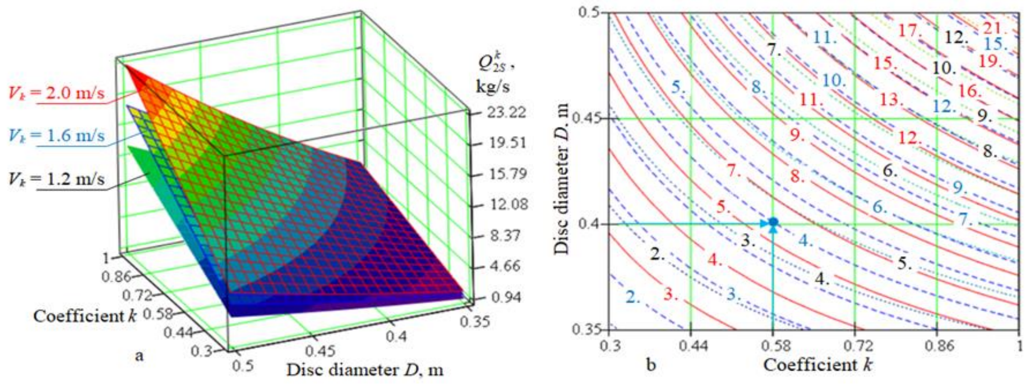

Figure 4. Graphical interpretations: a – the dependence of the change in the second supply of general impurities for conical root crops as a function of $Q_{2S}^{k} = f(D,k)$; b – nomogram for determining Q_{2S}^{k}

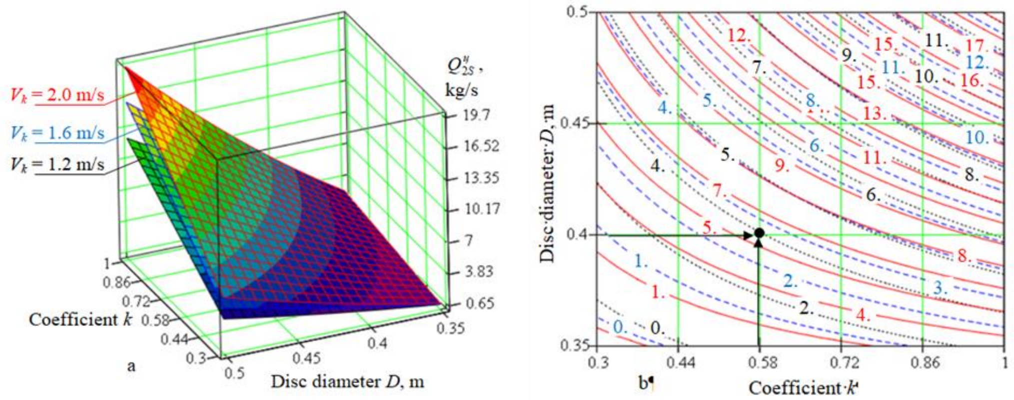

Figure 5. Graphical interpretations: a – dependence of the change in the second supply of general impurities for root crops of a cylindrical shape as a function of $Q_{2S}^{ц} = f(D, k)$; b – nomogram for –determining $Q_{2S}^{ц}$

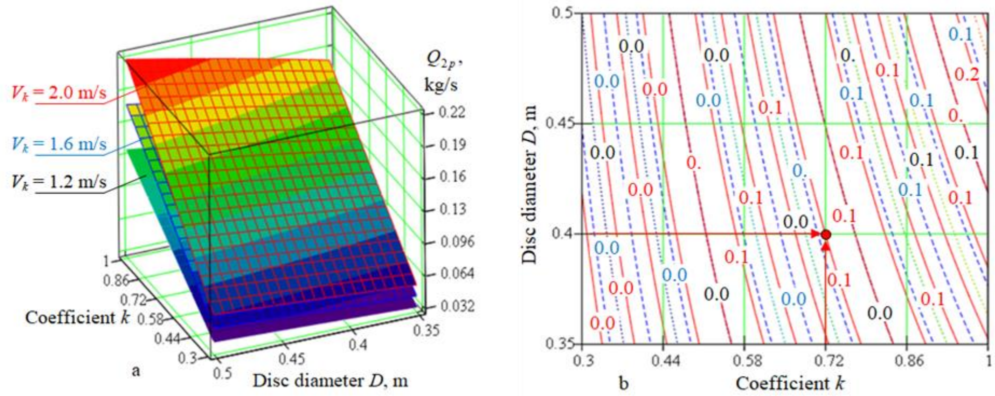

Figure 6. Graphical interpretations: a – dependence of the change in the second supply of general plant impurities for root crops of conical and cylindrical shape as a function of $Q_{2p} = f(D, k)$; b – monogram for determining Q_{2p}

- the theoretical and calculated second supply of general impurities by the combined digging working body from one row of fodder beet root crops of a conical shape is described by a deterministic mathematical model (20), and of fodder beet root crops of a cylindrical shape – by a deterministic mathematical model (21);
- the developed deterministic mathematical models (20) and (21) characterize the interrelationship of changes in the arrival of general impurities to the following TTS of the root harvesting machine depending on the parameters of the spherical disk;
- it was established that the theoretical and calculated value of the second supply of general impurities, depending on the diameter of the spherical disk *D* and the efficiency coefficient *k*, is within the limits for changes in the working speed of the digger from 1.2 to 2.0 m/s: when digging conical root crops from 0.9 to 23.2 kg/s; when digging up cylindrical root crops from 0.65 to 19.7 kg/s;
- the theoretical and calculated second supply of general plant impurities by the combined digging working body from one row of root crops of fodder beets of conical and cylindrical shape is described by a deterministic mathematical model (22);
- it was established that the theoretical and calculated value of the second supply of general plant impurities depending on the diameter of the spherical disk *D* and the efficiency coefficient *k* when digging conical and cylindrical root crops is in the range from 0.03 to 0.2 kg/s for changes in the working speed of the digger from 1.2 to 2.0 m/s.

At the values of the movement speed of the digger ϑ_k = 1.8 m/s or the root harvesting machine, which is regulated by the indicators of agrotechnical requirements, the diameter of the spherical disk D = 0.45 m and the average value of the efficiency coefficient k = 0.6...0.8, the following theoretical –calculated values of second feed of impurities:

- when digging up root crops of fodder beets of a conical shape, the total impurities vary from 10.3 to15.1 kg/s;
- when digging up root crops of fodder beets of cylindrical shape, the total impurities vary from 8.9 to11.9 kg/s;
- when digging up root crops of conical and cylindrical shape, the general plant impurities change in the range from 0.16 to 0.18 kg/s.

Conclusion. Thus, on the basis of the conducted theoretical analysis of the technological process of digging chicory root crops with a combined digging working body and a basic single-disc spherical digger, the following results were obtained:

- theoretical and calculated deterministic mathematical models that describe the relationship between the second supply of impurities excavated by the disk and the parameters of the excavation process;
- theoretical dependencies of the coefficients of the technological efficiency of the work of the combined excavating working body, which take into account the degree of reduction of the second supply of general impurities to the subsequent cleaning TTS of the root-harvesting machine in comparison with the corresponding performance indicators of the basic single-disk spherical digger.

The theoretically calculated total second supply of general impurities from one row at a digger movement speed of 1.8 m/s and a spherical disk diameter of 0.45 m and a value of the total coefficient of impurities of 0.6...0.8 is in the range from 10.3 to 1 from 8.9 to 11.9 kg/s, respectively, for conical and cylindrical root crops.

The real values of the coefficients k, k_ρ, k_n, k_v, k_z, which take into account the degree of reduction of general impurities and the corresponding constituent components of general impurities, will be determined based on the results of conducting and processing comparative field experimental studies of the combined excavating working body and the single-disc spherical digger.

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ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ЗБИРАННЯ КОРЕНЕПЛОДІВ ЦИКОРІЮ

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Резюме. *Зниження виробництва коренеплодів цикорію, які є цінною сировиною для виробництва різнопланової продукції, стримується низьким рівнем механізації процесів їх збирання та незадовільними показниками втрат і забруднення компонентами домішок. Поліпшення якісних показників процесу механізованого збирання коренеплодів цикорію коренезбиральними машинами є науковою проблемою, або актуальним завданням сьогодення. Мета роботи: зменшення секундної подачі домішок під час збирання коренеплодів цикорію за рахунок розробки та аналізу аналітичних залежностей, що функціонально описують процес збирання коренеплодів цикорію робочими органами* *комбінованого однодискового копача. На основі аналізу технологічного процесу збирання коренеплодів цикорію отримано розрахункові математичні моделі, які дозволяють визначати та прогнозувати зміну секундної подачі загальних домішок і складових компонентів домішок (гички, залишків гички на їх головках, вільних рослинних домішок, вільних грунтових домішок, налиплого грунту на коренеплодах,) залежно від параметрів сферичного диска комбінованого копача (діаметра диска, кута атаки диска), розмірних параметрів і форми коренеплодів цикорію (діаметра коренеплоду, довжини коренеплоду, глибини залягання коренеплоду в грунті, конічної або циліндричної форми) та умов роботи коренезбиральної машини (швидкості руху коренезбиральної машини). На основі аналізу графічних залежностей встановлено, що: секундна подача загальних домішок змінюється від 5 до 18 кг/с; секундна подача вільного ґрунту – в межах від 4 до 15 кг/с; секундна подача рослинних домішок – від 0,06 до 0,1 кг/с. Отримані математичні моделі є вихідними положеннями або математичними моделями (залежностями) для подальшого обґрунтування раціональних параметрів і режимів роботи робочих органів транспортно-очисних технологічних систем коренезбиральних машин.*

Ключові слова: *коренеплоди цикорію, процес, зрізування гички, домішки, залишки гички, сферичний диск, очисний вал, модель, секундна подача.*

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