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# JUSTIFICATION FOR THE CHOICE OF A ROOT CROP HARVESTING WORKING BODY

*The efficiency of using modern chicory harvesting machines often remains unsatisfactory, particularly under difficult soil conditions. The primary factors limiting digging quality are increased root crop damage, their incomplete extraction from the ground, and a high content of impurities in the harvested mass. These indicators significantly depend on both the physical properties of the soil and the geometric parameters of the root crop itself, as well as the design features of the diggers.*

*To solve this urgent scientific and technical problem, it is necessary to develop analytical-empirical approaches to justify the design-kinematic parameters and operating modes of an improved combined digger. When designing such equipment, real operating conditions should be taken into account, including soil-climatic harvesting conditions and specific agrophysical characteristics of chicory.*

*Chicory is a valuable raw material for the food and pharmaceutical industries. Its tops can be used as an organic fertilizer that enriches the soil with nutrients, while the root crops themselves serve as an environmentally safe source of renewable energy for bioethanol production.*

*In terms of morpho-physiological characteristics, chicory is close to fodder carrots, while its cultivation technology and the appearance of its above-ground part have much in common with sugar beets. The quality of the harvesting technological process is determined primarily by the agrotechnical requirements for the crop, the design of the machines, and the layout of their working bodies. The foundation for designing new harvesting equipment must be the systematization of data on the variability of the agrophysical characteristics of chicory (both root crops and tops), as these fluctuations directly affect the design of the working units.*

*Despite the steady demand for chicory and its processed products, the sown areas for this crop are declining. The main reason for this trend is the insufficient level of mechanization in cultivation and harvesting. It is also important to consider that the accumulation of top mass and dry matter in the roots continues throughout the entire growing season; however, the intensity of this process (in particular, the formation of the rosette) is not constant. It depends on a number of factors: varietal characteristics, weather conditions, planting density, plant nutrition area, and the chosen cultivation technology.*

***Key words:*** *root crops, tops, digger, spherical disk, loosener, soil layer, classification, sugar beets, carrots, harvesting, root crop cleaning, cleaning blade, root crop head cleaner.*

**Statement of the problem.** An important limiting factor in the harvesting of chicory roots, compared to sugar beet roots, is their fragility and the total length of the roots, which is 5...10 cm longer. The working bodies of existing root harvesting machines, which are designed for harvesting sugar beet with the appropriate digging depth of roots (digging depth), do not sufficiently meet the quality of harvesting chicory roots [1-4].

The aim of this work is to increase the

efficiency of the chicory root harvesting process by improving the design and justifying the parameters of the working bodies of a combined harvesting machine.

**Materials and methods.** The processes of increasing the biomass of chicory root crops differ significantly from the dynamics of development of other crops (in particular, carrots or various types of beets). These differences are due to specific agrobiological features that change throughout the entire cycle of growth and formation of plants [4]. The dynamics of development of chicory root is influenced by a complex of factors: varietal composition, selected agricultural technology, soil type, climatic conditions of the region, etc.

The specificity of chicory development consists in intensive growth of stem mass in the initial period of vegetation and the formation of a powerful, branched root system that penetrates to a considerable depth. The final yield of chicory depends on many components: soil fertility, the quality of predecessors, the effectiveness of the fertilizer system, compliance with the timing of field work, as well as the density and uniformity of sowing [5-7]. It has been scientifically proven that to maximize the yield of root crops and tops, it is critically important to ensure optimal plant placement in the field.

The distribution of biomass by vegetation period is uneven: during the first two months, the plant directs the main resources (over 50%) to the development of the tops, while in the third and fourth months there is an intensive accumulation of dry matter directly in the body of the root crop [8].

The morphological parameters of chicory have the following indicators: the length of the tops is 25–40 cm, and the number of stems in a bundle on the head of the root crop is from 20 to 35 pieces [8]. The dimensions of the root crop itself can vary widely: the mass is from 150 to 450 g, the length is up to 40 cm, and the diameter is from 3 to 12 cm [9, 10]. The typical shape of the chicory root is cylindrical or hemispherical in the upper part, which gradually narrows towards the tail, acquiring a conical appearance. The taper angle of such roots is 20–35° [11].

It is worth noting that the proportion of the head mass in chicory is smaller than in sugar or fodder beets. According to research [12-14], the head occupies approximately 7.4%, the tail part - 7%, and the main part (body) of the root - about 85% of the total weight. Agrobiological parameters of chicory with a row spacing of 45 cm are systematized in Table. 1 [15].

**Table 1 - Agrobiological characteristics of chicory root crops (row spacing 45 sm)**

| Average indicators | Distance between root crops, $S_p$, sm | | | | |
|---|---|---|---|---|---|
| | 5…10 | 10…20 | 20…30 | 30…40 | 40…50 |
| Root mass mk, g | 300 | 363 | 408 | 449 | 503 |
| Root diameter Dk, mm | 54,0 | 60,1 | 62,6 | 64,3 | 85,0 |
| Root length Lk, mm | 221 | 235 | 245 | 254 | 266 |
| Root yield Uk, c/ha | 130 | 250 | 230 | 210 | 190 |
| Average specific load on root rupture Pp, kg/sm$^2$ | 5,5…8,4 | | | | |

The distribution of root crops by their diameter and technical length and the lateral deviation of root crops from the row line obeys the law of the Laplace-Gauss normal distribution [11].

The distance between plants in rows and their placement on the area also significantly affect the agrophysical parameters of chicory roots and, accordingly, its yield. Uneven placement of plants in rows leads to an increase in substandard chicory roots (with a diameter of less than 3 cm or a mass of less than 100 g), the number of which at different plant densities varies from 5.3 to 12.7%. With an increase in plant density, the number of chicory roots weighing from 100 to 200 g increases significantly [16].

The dispersion of lateral deviations of root heads relative to the conditional axis of the row varies from 0 to 40 mm. Up to 92.8% of root heads are located directly within the axis of the row (0…20 mm).

The degree of lateral scattering of root heads is related to the distance between chicory plants in a row at the time of harvesting: with a decrease in the interval between plants by 9 times (from 45 to 5 cm), the zone of lateral scattering of root heads relative to the conditional axial line of the row increases by 3.4 times - from 12.8 to 43.4 mm.

The main mechanical properties of the root tops of chicory are given in Table 2[17].

**Table 2 Mechanical properties of chicory root tops**

| Indicator | Condition of the tops | | |
|---|---|---|---|
| | At (+t°C) | At (-t°C) | In the thawed state at (+t°C) |
| Tension (by force), N | 1 | 1,39 | 1,01 |
| Bending (by force), N | 1 | 1,5 | 0 |
| Compression and shear (by force), N | 1 | 0,96 | 0,65 |
| Deflection (by deflection) | 1 | 0,5 | ∞ |
| Hardness (by penetration depth) | 1 | 0,35 | 0,74 |

The mass of the chicory root, covering its upper and middle zones, is approximately 85% of the total. The chemical composition of the plant is distributed heterogeneously: the concentration of monosaccharides increases in the direction from the head to the tail, varying from 5.79 to 9.12%. At the same time, the minimum proportion of inulin is recorded precisely in the head, while in the remaining parts of the root this indicator stabilizes at the level of 49.6–50.7% of dry matter. Studies have confirmed the correlation between the size of the root and the concentration of inulin: larger specimens accumulate it in higher quantities [13-16].

The works of the authors [10-16] indicate a direct relationship between the geometric parameters of the root and the effort required to extract it from the soil. In particular, the elongation of the root crop by 1 cm requires an increase in the pulling force by an average of 1.5 kg/sm, while the critical threshold of the tensile strength of the root crop tissues is from 5.5 to 8.4 kg/sm$^2$.

An important factor determining the efficiency of the harvesting units is the spatial arrangement of plants in the row. Significant deviations from the uniformity of sowing lead to an increase in the proportion of substandard products [16]. Many years of experience in harvesting row crops (such as beets) show that it is impossible to completely avoid crop losses with existing harvesting methods. This is due to both the design limitations of the equipment and the variability of soil and climatic conditions (changes in humidity, mechanical composition and soil hardness), as well as difficulties in complying with agrotechnical requirements for separating the tops and digging up root crops without mechanical injuries. For chicory, the problem is complicated by the lack of specialized high-tech harvesting complexes both in Ukraine and abroad, as well as the low level of mechanization of the technological cycle of growing this crop [16].

In-depth study of the agrobiological properties and physical and mechanical qualities of chicory is a fundamental basis for further design of effective working bodies of digging machines [16]. The current single-phase harvesting technology does not meet the current quality criteria: the level of contamination with impurities and residues of the tip reaches 8–15%, the loss of the main mass with trimmings is 7–9%, and mechanical damage in the form of chips reaches 15%. Such indicators significantly reduce the profitability of raw material processing, which makes the task of improving root harvesting equipment extremely relevant [16].

Results and discussion. The evolution of technical means intended for harvesting chicory roots is closely related to the main aspects of the development of technologies and methods of their harvesting, as well as to the improvement of technological operations for harvesting roots: harvesting the main mass of the tops and trimming its remains on the heads of chicory roots; digging, forming a roll of dug roots; cleaning the dug pile of roots from impurity components; loading the cleaned roots into a vehicle or a hopper of a root harvesting machine [16].

The BM-6 machine is used for harvesting tops, which is an original trailed design that copies the device with an active disk knife. The root harvester was based on an American beet harvester with two passive disk diggers, improved by Ukrainian designers into a self-propelled root harvester of the KS-6 type, which was produced in several modifications.

According to the results of [15] research, empirical relationships were obtained that allow predicting the future yield of chicory roots based on their actual agrobiological parameters and the distance between plants in a row for the harvesting period:

$$P_k = 281,65+4,93\, S_p; \quad D_k = 48,41+0,78\, S_p; \qquad (1)$$

$$L_k = 216,95+1,09\, S_p; \quad S_n = 45,0\, S_p; \qquad (2)$$

$$k = 0,02\, S_p^{-0,0015}; \quad C = 2222,84\, S_p^{-1}; \quad U_k = 451,67\, S_p^{-0,7739}, \qquad (3)$$

where $S_p$ is the distance between root crops in a row, mm.

With increasing interval between plants, the height of the heads of root crops above the soil surface increases, with the maximum height of the heads protruding above the soil surface reaching $x_{max}$ = 50 mm, and the height $h_b$ of the distribution of root crops above the soil surface is approximated by the equation [15]

$$h_в = 5,59 + 0,766\, S_p. \qquad (4)$$

The lateral deviation $S_b$ of the placement of root crops within the center line of the row is described by a logarithmic curve, and the distribution pattern obeys the normal law. [15]:

$$S_b = 65{,}483 - lg(S_p). \quad (5)$$

In [16], optimization mathematical models were obtained that characterize the change in the total supply of root crop heaps $M$, serving root croops$M_k$, total supply of soil impurities $M_{\rho\partial}$ and plant impurities $M_p$ from the disk parameters, dimensional characteristics of root crops and operating conditions of the root harvesting machine, while the total supply of heap from one row varies within 10…13 kg/s:

$$M = V_м \left\{ \begin{array}{l} \dfrac{0{,}125\rho_{гр} K_{в.\rho_2} \sin\alpha}{h}\left[S - 8h\left(j_1 V'_{k_\rho 1} - j_2 V'_{k_\rho 2} - \ldots - j_n V'_{k_\rho n}\right)\right] + \\ + \rho_k K_в \left(j_1 V_{k1} + j_2 V_{k2} + \ldots + j_n V_{kn}\right) + \\ + 2K_{в.р2} \sin\alpha \sqrt{a(D_д - a)}\left[U_г\left(\overset{i}{\mu} + \overset{i}{\eta}\right) + \overset{i}{\lambda}\right] \end{array} \right\}; \quad (6)$$

$$M_{\rho д} = \rho_{гр} V_м K_{в.\rho_1} \sin\alpha \left\lfloor S_\rho - \left(j_1 V'_{k_a 1} + j_2 V'_{k_a 2} + \ldots + j_n V'_{k_a n}\right)\right\rfloor; \quad (7)$$

$$M_p = 2V_м K_{в.p_2} \sin\alpha \sqrt{a(D_д - a)}\left[U_г\left(\overset{i}{\mu} + \overset{i}{\eta}\right) + \overset{i}{\lambda}\right], \quad (8)$$

where $V_м$ – translational speed of the root harvester, m/s; $\alpha$ – angle of installation of the spherical disk relative to the axis of the root crop row, degrees; $K_{в.\rho_2}$, $K_{в.p_2}$ – respectively, a coefficient that takes into account the degree of removal of soil and plant impurities per 1s; $\rho_{гр}$ – specific gravity of soil, kg/m³; $V_{k_\rho 1}, V_{k_\rho 2}, \ldots, V_{k_\rho n}$ – volume of the underground part of one *i-th* root crop of the corresponding dimensional and mass characteristics, m³; $j_1, j_2, \ldots, j_n$ – number of *i-th* root crops of corresponding dimensional and mass characteristics per 1 linear meter of row, pcs.; $h$ – depth of spherical disk (m); $R_c$ – radius of sphere, m; $R_д$ – radius of spherical disk, m; $a$ – depth of travel of spherical disk, m; $U_г$ – yield of tops, kg/m².

The degree of cleaning of the root crop head decreases when the free ends of the blade are placed above or below the surface of the connection of the tip with the head during impact. Also in [16], analytical dependences were derived to determine the force of interaction of the working body of the cleaner with the root crop head and the critical scraping force was determined.

$$\boldsymbol{P_{scr.} = \delta \cdot \Delta L\sigma_{pr} + E_r \cdot h_{pt}^2/2h(1 + \mu f \cos\alpha) + fP_{sp.}} \quad , \quad (9)$$

where $\delta$ – plate thickness; $\Delta L$ – plate length; $\sigma_{pr}$ – destructive contact stress for the tops; $E_r$ – elastic modulus of the tops; $h$ – thickness of the tops layer by which the plate is deepened; $h_{pt}$ – the amount of deepening of the plate into the tip, when stress $\sigma_{pr}$; $P_{sp}$ – spring pressure force on the plate; $f$ – friction coefficient; $\mu$ – Poisson's ratio for the tip.

The general fundamental shortcomings of the operation of existing and technically implemented types of diggers (ploughshare, fork, double-disk, vibratory), which are mainly equipped with mounted, trailed and self-propelled root harvesting machines, are as follows: a relatively significant second-by-second supply of loose and stuck soil on the surface of the root crop body (7…10 kg/s), topsoil residues on the heads of root crops (from 0.5 to 1.5 kg/s) from one linear meter of row at an operating machine speed of 1.6 m/s, with up to 70% of the total amount being the mass of loose and stuck soil, up to 10% – topsoil residues on the heads of root crops, which led to an increase in the length and structural complexity of the cleaning systems [16]. In addition, the analysis of the design and technological processes of the machines showed that the objective reason for the technological imperfection of existing diggers is that they are structurally and technologically impossible to simultaneously combine two technological operations into one during harvesting - digging and cleaning of root crops with the simultaneous removal of the remains of the tip on their heads. To increase the technological efficiency of the chicory root crop harvesting process, we have proposed a technical means for digging up root crops (Fig. 1), which will increase the completeness of digging up root crops and reduce their damage by intensifying the process of destruction of the pericarp and the occurrence of additional dynamic effects that provide an increase in the force of pushing the root crops out of the soil.

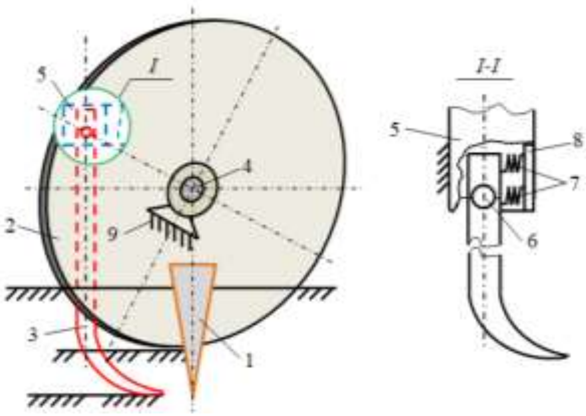


**Fig. 1 Structural diagram of a combined digger: 1 – root crop; 2 – spherical disk; 3 – ripper; 4 – disk rotation axis; 5 – ripper mounting bracket; 6 – ripper rotation axis; 7 – spring; 8 – thrust plate; 9 – frame.**

During the movement of the combined digger along the rows of chicory roots, the loosener 3 and the spherical disk 2 destroy the pericarp soil environment and the connections of the root crop in it due to the rotation of the spherical disk with angular velocity $\omega_\partial = d\vartheta_\partial / dt$ and the movement of the loosener (i.e., the disk) with translational velocity. In this case, such a phenomenon (process) occurs as the movement of the excavated soil layer along the spherical surface of the disk and, accordingly, its further movement to the following working bodies of the root harvesting machine.

**Conclusion.** Using the new combined digging mechanism, it becomes possible to intensify the chicory harvesting process (by increasing the speed of the unit) while meeting all the requirements for the quality of digging. As a result, the overall technological efficiency of the process increases: the degree of purification of raw materials from impurities improves, and crop losses associated with mechanical injury and breaking off of the underground tail part of the roots are minimized.

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## ОБГРУНТУВАННЯ ВИБОРУ РОБОЧОГО ОРГАНУ ДЛЯ ЗБИРАННЯ КОРЕНЕПЛОДІВ

*Основними критеріями, які характеризують незадовільну ефективність використання існуючих типів копачів для викопування крихких коренеплодів типу цикорію, особливо у важких умовах роботи, є значна ступінь залежності якості повноти викопування коренеплодів і їх пошкодження, забрудненості викопаного вороху домішками від фізичного стану грунту, параметрів коренеплодів і конструктивного виконання робочих органів копачів.*

*Вирішення важливої науково-технічної задачі полягає у розроблені аналітично-емпіричних методів обгрунтування технологічних, конструктивно-кінематичних параметрів і режимів роботи робочих органів удосконаленого комбінованого копача коренезбиральних машин із врахуванням реальних умов експлуатації, зокрема агрофізичних характеристик коренеплодів цикорію і грунтово-кліматичних умов збирання.*

*Коренеплоди цикорію є цінною харчовою та лікарською культурою. Гичка коренеплодів цикорію є одним із джерел повернення поживних речовин після її розкидання на зібране поле та заробки в грунт, а коренеплоди – це екологічно чисті продуктивні відновлювальні джерела енергії для виробництва біоетанолу [2].*

*Коренеплоди цикорію за технологією вирощування та зовнішніми ознаками схожі на коренеплоди цукрових буряків, а за фізіологічними й морфологічними властивостями – на кормову моркву.*

*Технологічний процес збирання коренеплодів цикорію регламентується в основному агротехнічними властивостями врожаю, конструкцією робочих органів і компонувальних схем коренезбиральних машин і пристроїв. Перший етап розробки техніки для збирання коренеплодів цикорію повинен базуватися на систематизації агрофізичних характеристиках коренеплодів і гички цикорію кореневого, варіювання і мінливість яких має суттєвий вплив на конструктивні особливості робочих органів.*

*Незважаючи на зростання попиту на цикорій і продукти його переробки, посівні площі під ним неухильно скорочуються через низьку механізацію технологічного процесу вирощування і особливо збирання урожаю.*

*Накопичення маси гички та сухої речовини в коренеплодах цикорію відбувається протягом усього періоду вегетації, але характер і інтенсивність накопичення, особливо стеблової маси та форми розетки гички, з початку і до кінця вегетації безперервно змінюється залежно від зовнішнього впливу погодних умов, площі живлення та густоти насадження рослин, сортових особливостей і елементів технології вирощування культури*

***Ключові слова:*** *коренеплоди, гичка, копач, сферичний диск, розрихлювач, шар грунту, класифікація, цукрові буряки, морква, збирання, очищення коренеплодів, очисна лопать, очисник головок коренеплодів.*

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