Theoretical investigation of the removal of halfrums from sugar beet root heads

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Abstract. *Removal of the haulm from the heads of sugar beet to the roots during their harvesting (cutting the main mass) or separation of its residues (when finishing the heads) is a complex technological process associated with either a significant loss of sugar-bearing mass (low cut), or not complete removal of residues (high cut), which significantly degrades the quality of root crops. Therefore, ways to find a complete removal of haulm and its residues from the heads of root crops require research and development of such devices capable of performing this process qualitatively. However, first it is necessary to determine theoretically and experimentally the basic initial conditions under which high quality indicators will be achieved, and losses of sugar-bearing mass during cutting the haulm will be minimal, with the remaining haulm being as small as possible (or they will be absent at all). This paper theoretically and experimentally investigates and determines the loss of sugar mass and remnants of the bud on the heads of sugar beet roots during the separation of the bud and its remnants. It is established that in the interval of working heights of a cut which is equal to 20 ... 60 mm deviation of theoretical calculations from experimental does not exceed on the average 1%.*

KEYWORDS: *SUGAR BEET, ROOT, ROOT HEAD, HICK, MATHEMATICAL MODEL.*

1. Introduction

When performing the technological process of cutting the main mass of haulm and cleaning the heads of sugar beet roots, the basic requirements of the current agro-technological requirements for harvesting sugar beets are not always met. Numerous studies of haulm harvesting have been conducted, but they do not reveal methods for determining the rational height of a no-copy haulm cut from the waste sugar mass and haulm residue on root crops that meet the requirements. This circumstance is an important scientific and technical problem, since reducing the waste of sugar-bearing mass during cutting directly reduces harvest losses, and the high content of haulm in the root crop pile also deteriorates the quality indicators, as well as reduces the sugar yield in their processing.

The most fundamental studies of sugar beet haulm cutting methods were obtained [1, 2]. It was in these works thoroughly determined the height of sugar beet haulm cutting without pinch, at which it would be possible to optimize the waste of sugar-bearing mass going into the cut haulm. In these works, the distribution of heights of sugar beet rootstock appearances is approximated by the normal law, and the shape of the rootstock heads can be given by different shapes. Наприклад, конусом, зрізаним конусом або сферою. For example, a cone, a truncated cone or a sphere. However, these studies are quite approximate and difficult to use to model the process of copyless cutting.

Therefore, in order to reduce the loss of sugar mass and, accordingly, increase the productivity of machines for the separation of the tops, it is necessary to develop basic provisions for determining the rational height of the copyless cut. It is necessary, first of all, to develop a mathematical model of the technological process of copyless cutting of the bud at the root of sugar beet roots. This will give grounds to further theoretically determine the dependences of sugar loss and remnants of the bud on the heads of root crops on the height of the copyless cut for different agrophysical characteristics of crops and varieties of sugar beet roots. Next, it is necessary to carry out experimental testing of this mathematical model of the specified technological process and to determine the limits of its practical application to optimize the parameters of working tools used to cut the haulm from the heads of root crops.

2. Materials and Methods

Preliminary studies carried out by A.A. Vasilenko, P.F. Volk, M.M. Zuev, L.V. Pogorely, M.V. Tatianka proved that there are linear relationships between the height of sugar beet root head appearance above the soil surface and the size parameters of its body. It was also proved that the main part of sugar beet root heads has the shape of a cut cone. The maximum diameter, which is more than 80% of the roots, is below the level of the soil surface.

It is also found that at the very head of the rootstock the haulm is so densely arranged that it can be modeled as a homogeneous cylindrical body. Therefore, with a known distance from the top to the base of the green leaves, it is possible to determine the diameter of the haulm cylinder. According to the known law of distribution of the height of appearance of the heads of root crops above the soil surface and the functional dependences of the head and haulm parameters on the height of appearance of the root crops head, we can describe the patterns of distribution of their masses relative to the soil surface..

This allows the construction of a mathematical model of the technological process of copierless cutting of the haulm with subsequent justification of the optimal cutting height. However, the main thing, first of all, is to build first the geometric model of sugar beet root ball head, which will simulate the most common type of sugar beet root ball before their harvesting.

Constructed model of sugar beet root ball head, which is above the soil surface level, is shown in Fig. 1.

This model shows the head of sugar beet root in the form of a cut cone, the base of which is located on a horizontal straight line (conditional level of the soil surface), and the height is designated as *h*. Also characteristic points and linear and angular dimensions are given, the nature of which is clear Fig. 1.

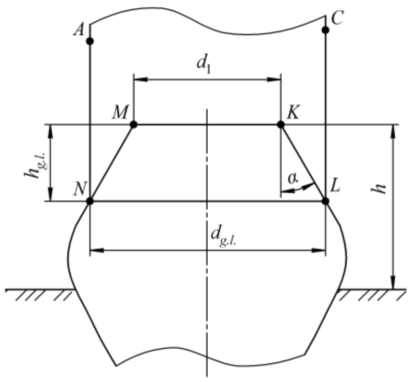

Figure 1. *Geometric model of sugar beet root head*

Based on this geometric model, we can formulate analytical relationships for the parameters of the sugar beet root and haulm, having the following form:

$$\left.\begin{aligned} h_{gl} &= a \cdot h + b; \\ d_1 &= m \cdot h + n; \\ d_{gl} &= d_1 + 2 \cdot h_{gl} \cdot \tan\alpha \end{aligned}\right\}, \qquad (1)$$

where h_{gl} – the distance from the top of the head to the base of the green leaves; h – the height of the head above the level of the soil surface; d_1 – the diameter of the top of the root head; d_{gl} – haulm diameter; α – half the angle of the taper of the head; a, b, m, n – constants.

Analyzing the location of root crops relative to the soil surface, six groups of characteristic location of the bud and root heads were identified (Fig. 2).

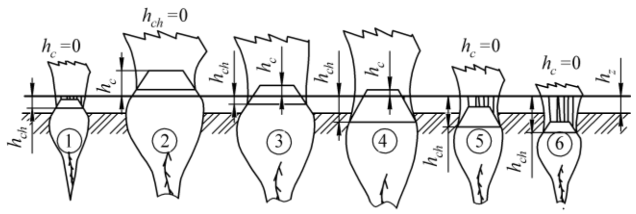

Figure 2. *Characteristic 6 cases of root and haulm location above the soil surface: h_c, h_{ch} – respectively the height of the tops and the head of the root crop*

We obtained analytical relationships to determine the location of the root and haulm relative to the soil surface, the passage of the cutting plane relative to the top of the head and the base of the green leaves, the height of the head and haulm cut, the amount of sugar loss and residual haulm. But the cutting height of the heads h_z of root crops and the cutting height of the haulm h_{ch} according to different cutting planes (and there can also be 6 such planes, according to these cases) can be described by the following dependencies:

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_z \geq h_i$:

$$h_c = 0; \; h_{ch} = h_{gl} - h_c - h_z; \qquad (2)$$

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_i > h_z \geq \left(h_i - h_{gl}\right)$:

$$h_c = h_i - h_z; \; h_{ch} = h_{gl} - h_i - h_z; \qquad (3)$$

– location of the root crop $h_i > 0$, $h_i \geq h_{gl}$; passing the plane of the cut $h_i > h_z < \left(h_i - h_{gl}\right)$:

$$h_c = h_i - h_z; \; h_{ch} = 0; \qquad (4)$$

– location of the root crop $h_i \leq h_{gl}$; passing the plane of the cut $h_z \geq h_i$:

$$h_c = 0; \; h_{ch} = h_{gl} - h_c - h_z; \qquad (5)$$

– location of the root crop $h_i \leq h_{gl}$; passing the plane of the cut $h_z < h_i$:

$$h_c = h_i - h_z; \; h_{ch} = h_{gl} - h_i - h_z; \qquad (6)$$

– location of the root crop $h_i \leq 0$;

– passing the plane of the cut $h_i \leq 0$:

$$h_c = 0; \; h_{ch} = h_{gl} - h_c - h_z; \qquad (7)$$

Accordingly, for each of these cases, we analytically obtained calculated expressions for calculating the volumes: cut root V_r and cut haulm V_q. They look as follows:

– case 1:

$$V_r = 0; \; V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{ch} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (8)$$

– case 2:

$$V_r = \frac{\pi \cdot h_c \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12};$$

$$V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot \left(h_{ch} - h_c\right) \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (9)$$

– case 3:

$$V_g = 0; \; V_r = \frac{\pi \cdot h_c \cdot \left(d_{dl}^2 + d_{gl} d_c + d_c^2\right)}{12}, \qquad (10)$$

– case 4:

$$V_r = 0; \; V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{gl} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (11)$$

– case 5:

$$V_r = \frac{\pi \cdot h_c \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12};$$

$$V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot \left(h_{ch} - h_c\right) \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}, \qquad (12)$$

– case 6:

$$V_r = 0; \; V_g = \frac{\pi \cdot h_{ch} \cdot d_{gl}^2}{4} - \frac{\pi \cdot h_{ch} \cdot \left(d_1^2 + d_1 d_{gl} + d_{gl}^2\right)}{12}. \qquad (13)$$

Losses of sugar-bearing mass and haulm residues for root crops of a given height interval of performances above the ground surface are determined by the formula:

$$M_i = F\left(h_i; h_c\right) \cdot P\left(h_i; h_{i+1}\right) \cdot N_{i,}, \qquad (14)$$

where $F(h_i, h_c)$ – loss of sugary mass or haulm residue, for root crops; $F(h_i, h_c) = V_r \cdot \rho$, for the tots $F_c(h_i, h_{ch}) = V_q \cdot \rho_g$, where V_r, ρ and V_q, ρ_q – volume and density of sugar beet root and haulm, respectively; N_i – the number of root crops of a given interval per crop unit area; $P(h_i, h_{i+1})$ – the probability of occurrence of a given interval of heights of protruding heads of root crops above the soil surface, determined according to this expression:

$$P\left(h_i; h_{i+1}\right) = \frac{1}{\sigma\sqrt{2\pi}} \int_{h_i}^{h_i+1} \exp\left(-\frac{\left(h-m\right)^2}{2\sigma^2}\right) dh. \qquad (15)$$

In this expression, the integral cannot be defined in quadrature, so we determine the probability of occurrence of beet roots of a given height interval by numerical integration using the Simpson formula. Summing the haulm residues and losses of sugar mass for all height intervals of performances, we obtain the total haulm residues *BM* and losses of sugar mass *GM* per unit area using these analytical expressions:

$$BM = \sum_{i=a}^{b}\left[N \cdot F\left(\frac{h_i + h_{i+1}}{2}; h_c\right) \cdot \left(\frac{h_{i+1} - h_i}{3m} \sum_{j=0}^{m} c_j \cdot f(h)\right)\right], \qquad (16)$$

$$GM = \sum_{i=a}^{b}\left[N \cdot F_c\left(\frac{h_i + h_{i+1}}{2}; h_c\right) \cdot \left(\frac{h_{i+1} - h_i}{3m} \sum_{j=0}^{m} c_j \cdot f(h)\right)\right], \qquad (17)$$

where m – number of intervals: $m = 2U$; $U = 1, 2, 3, 4, ...$; c_j – coefficient for the values of the subintegral function at the corresponding points, c_j = 1, 2, 3, 4, 2, 4,…,2, 4, 1.

3. Results and discussions

Verification of the correctness of the theoretical studies can be carried out using the results of the experimental study of the process of rootless cutting, published in [1]. In the conducted experimental studies, the distribution of heights of protruding heads of root crops relative to the soil surface, waste of sugar mass and haulm residue on the root crop when setting the knife of the cutting unit relative to the soil surface at a height of 10 - 50 mm with an interval of 10 mm was determined. Root crop yield was also determined. According to the data of experiments, it is possible to carry out mathematical modeling of a copierless cut on PC with the help of a composite program. Using the distribution of the heights of the protruding heads of root crops, we determined the mathematical expectation m standard deviation σ. By determining the dependences of the head apex diameter and the height of the green leaf zone on the height of the performance, as well as the head taper angle, we obtained the simulation results and compared them with the experimental data. A comparison of theoretical and experimental studies of the no-taper cutting process is shown in Fig. 3.

Comparing the results of experimental and theoretical studies, we can conclude that the theoretical model generally reflects the trends in the dependence of sugarcane waste and haulm residues on the height of the no-tillage cut obtained experimentally.

To verify this mathematical model, experimental investigations were carried out. The initial characteristics of sugar beet roots and the beet field on which the research was conducted were determined: crop capacity 0.5 t·ha^{-1}, mathematical expectation $m = 55.4$ mm, standard deviation $\sigma = 16.9$ mm, the average value of the taper angle of the root head 78 deg, the diameter of the top of the head $d_1 = 0.58h + 14.2$, height of the zone of green leaves $h_{gl} = 1.02h + 11$.

The results of the comparison of theoretical and experimental studies are shown in Fig. 3.

Determination of quality indicators was carried out by the methodology of the Institute of bioenergy crops and sugar beet NAAS, quite accurate, but characterized by a large amount of labor intensity than it is limited by the number of experiments required. We determined the differences between the theoretical and experimental data (Table 1).

Theoretical calculations compared to experimental studies deviate as follows:

– sugar waste according to the research of other scientists from -1.4% to + 4.7%, according to our research – from -0.3% to + 1.8%;

– haulm residues according to studies by other scientists from -1.2% to 3.6%, according to our own studies from -0.3% to 0.7%.

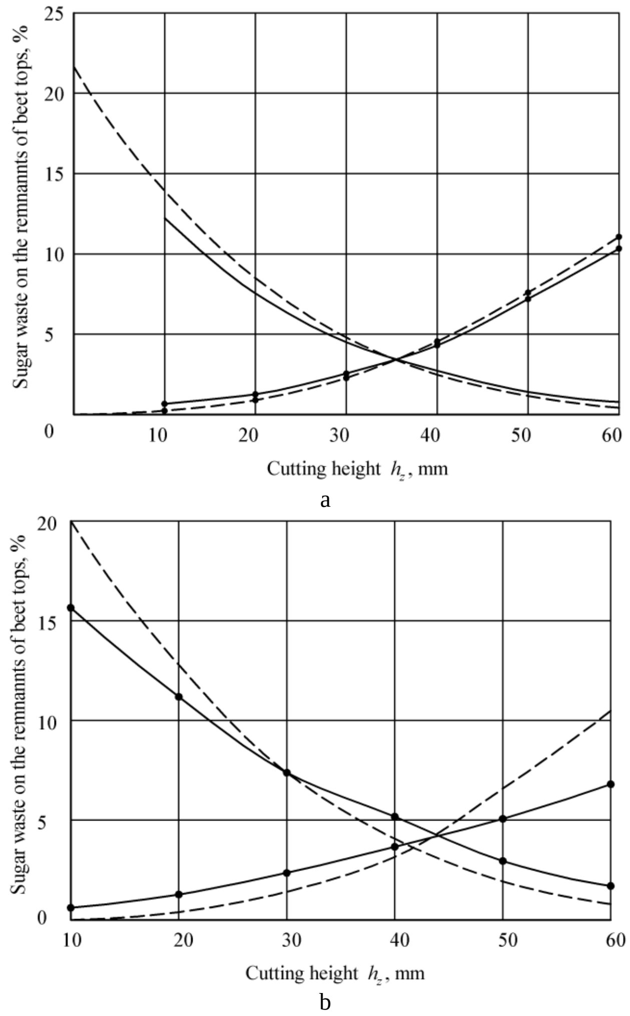

Figure 3. *Dependence of losses of sugar-bearing mass (a) and haulm residues (b) on the height h_z of the haulm cut from the heads of sugar beet roots*

Tabel 1. *Deviation of the results of theoretical and experimental research*

h_z, mm	10	20	30	40	50	60	10	20	30	40	50	60
							According to other researchers					
Weight loss, %	1.8	0.9	0.3	-0.2	-0.2	-0.3	4.7	1.1	0.2	-1.4	-0.6	-0.9
Leaves of the tops, %	-0.3	-0.2	-0.2	0.3	0.4	0.7	-0,6	-1.2	-1.0	-0.2	1.4	3.6

We found that one of the reasons for the deviation of the results of theoretical and experimental studies is not considered in the mathematical model of the additional cleaning of the haulm and damage to the roots, which occur in the technological process of digging sugar beet bodies from the root harvesting machines.

With sugarcane residues from 1% to 5%, close to the agrotechnical requirements, the deviation of the results of theoretical studies from the experimental ones does not exceed 0.7% for haulm residues and 0.5% for sugarcane residues. Therefore, this mathematical model can be used to predict sugarcane residues and haulm residues of different sugar beet varieties.

By constructing on the basis of the characteristics of the dependencies of the obtained analytical relationships, we can determine the height of the peakless cut with the predicted waste sugar mass and haulm residues.

4. Conclusion

A mathematical model of the process of separating the main mass of the haulm leaves by means of a birchless cut and an algorithm have been developed, which makes it possible to determine the optimal height of installation of the birchcutter above the ground level in accordance with the minimum allowable losses of sugar-bearing mass and the agrophysical characteristics of crops and root crops. As a result of the research it was found that for existing agrophones (σ = 10...30 mm, m = 40...60 mm) the cutting plane should pass not higher than 60 mm above ground level.

The dependence of losses of sugar-bearing mass and haulm residues on the height of the pickerless cut was determined experimentally. When comparing with theoretical calculations, it was found that in the interval of cutting height 20-60 mm above the soil level, the deviation of the results of theoretical studies from the experimental data does not exceed 0.7% for haulm residues and 0.9% for losses of sugar mass. Therefore, the proposed mathematical model can be used to justify the cutting height.

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