CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216
DOI: 10.3303/CET1758038

A Theoretical Study of Haulm Loss Resulting from Rotor Topper Oscillation

Volodymyr Bulgakov[a], Valerii Adamchuk[b], Margus Arak[c], Jüri Olt[c]

[a]National University of Life and Environmental Sciences of Ukraine, 15 Heroyiv Oborony Str., UA 03041 Kyiv, Ukraine
[b]National Scientific Centre, Institute for Agricultural Engineering and Electrification, 11, Vokzalna Str., Glevaкha-1, Vasylkiv District, UA 08631 Kiev Region, Ukraine
[c]Estonian University of Life Sciences, Institute of Technology, 56 Kreutzwaldi Str., EE 51014 Tartu, Estonia
jyri.olt@emu.ee

This theoretical study aims to detail haulm loss that is caused by rotor topper oscillation in the longitudinal vertical plane. The study has been undertaken with regard to the new design for a multi-purpose haulm gatherer which has been developed by us, and which performs the all-over feeler-free cutting of haulm stock from the crowns of standing sugar beet roots. By basing our work on the superimposition of the trajectories for rotor topper oscillation in the longitudinal vertical plane, along with the surface irregularities in the soil in which the roots stand, we have analytically determined the rates of haulm loss during all-over topping work. The results from the modelling were used to plot a graphical representation of the relationship between the haulm loss rate on the one hand, and the phase displacement between rotor topper oscillation and the soil surface irregularities on the other hand, all of which was observed at different values of the topper's preset elevation above the conventional surface of the sugar beet field. The technique which was produced for the analytical determination of haulm loss in all-over feeler-free haulm cutting - as carried out during haulm gathering with the use of a haulm gatherer which was front-mounted on a tractor - can be applied when it comes to discovering similar loss levels of herbage that could be caused by other types of harvesting implement.
Keywords: sugar beet root, beet tops, rotor topping unit, oscillation.

1. Introduction

The sugar beet harvesting that is carried out by state-of-the-art sugar beet harvesters targets the high quality topping and scalping of standing root crowns, followed by the lifting of the roots from the soil whilst ensuring that they are neither lost or damaged (Pogorely and Tatyanko, 2004; Bentini et al., 2005; Gruber, 2005; Gu et al., 2014). Thanks to these requirements, the work process that is carried out by haulm gatherers (or the topping modules of sugar beet combines) must first of all ensure the maximum possible all-over removal of herbage (haulm) from the root crowns, and then must carry out the normal scalping of crowns (in order to reduce the possible loss of sugar-bearing stock), while at the same time avoiding any damage to the root bodies or dislodging them from the soil, while also providing for the complete collection of the sheared-off herbage (or its proper chopping and even spreading over the harvested area of the field) (Schulze Lammers, 2011). As can be seen, high quality harvesting of sugar beet haulm is quite a complex task for the sugar beet industry.

The two-stage gathering procedure for sugar beet haulm has recently gained the widest levels of acceptance around the world (Wang and Zhang, 2013; Wu et al., 2013). This includes the first stage, in which rotor toppers shear off the bulk of the haulm stock (support and feeler-free all-over topping) at an increased height, followed by the second stage of scalping the root crowns with the use of passive or active scalpers, which involves feeling each sugar beet root. Meanwhile, it has to be noted straight away that the main stage in all-over shearing off the bulk of haulm includes its collection, transportation, and loading into a lorry, while the final stage of scalping the very root crowns is inevitably associated with the loss of sheared-off segments, which is equivalent to the practically non-recoverable loss of sugar-bearing stock.

The work processes involved in operating the new haulm gatherer (Figure 1) proceeds as follows: the rotor topper 3 carries out the main work in all-over cutting of haulm across the whole working span. The cutting

Please cite this article as: Bulgakov V., Adamchuk V., Arak M., Olt J., 2017, A theoretical study of haulm loss resulting from rotor topper oscillation, Chemical Engineering Transactions, 58, 223-228 DOI: 10.3303/CET1758038

height is controlled by two gauge wheels 2 which are located at the front and by moving in the spacings between the rows of growing sugar beet. After being sheared off by the topper's bow-shaped blades, haulm stock is collected across the whole working span with the use of a transverse auger conveyor, which transports haulm to one of the ends at which a vane spinner 4 and feeding spout 5 convey it into the transport vehicle which maintains its position alongside. An alternative mode of operation for the haulm gatherer is arranged by dismantling the spinner 4 and feeding spout 5, after which the sheared-off haulm (or mowed grass) is discharged sideways, directly onto the harvested area of the field. The final topping of the root crowns is carried out by the passive scalpers 6 which are equipped with comb feelers and flat blades and are installed on each planted row of sugar beet roots.

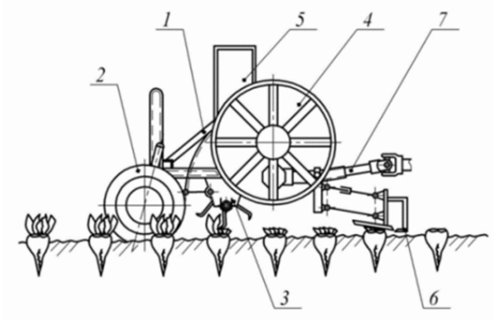

Figure 1. Design and process flow schematic model: 1 - frame; 2 - pneumatic gauge wheels; 3 - rotor topper; 4 - auger conveyor and vane spinner; 5 - feeding spout; 6 - root crown scalper; 7 - tool drive

The study aims to analytically discover the levels of loss in haulm that result from the oscillation of the rotor topper in the longitudinal vertical plane in relation to any soil surface irregularities.

2. Material and methods

When our developed haulm gatherer is front-mounted on a tractor, it performs three-dimensional motions which are determined by the soil relief in any sugar beet field (in the spacings between rows of planted sugar beet within the working span), as well as by the location of the gauge wheels with respect to the implement's suspension system, the flexible nature of the suspension system, translational velocity, and other influences. The use of pneumatic gauge wheels in the design of this haulm gatherer entails the oscillation of the rotor topper in the longitudinal vertical plane, which has a major impact on the performance quality of the work process, ie. the uniform shearing-off of haulm from sugar beet root crowns across the whole working span. Therefore, said oscillation, which causes the non-uniform cutting of haulm from root crowns in regard to the cutting height, causes a significant loss of haulm during its gathering, as stated above.

In search of a resolution for this problem, the analytical determination of haulm loss rate in relation to the amplitude and frequency of the rotor topper's oscillation allows the structural and kinematic parameters of the haulm gatherer to be researched, which will allow the aforementioned loss of haulm yield to be reduced.

Meanwhile, in order to discover the rate of haulm loss that results from the oscillation of the rotor topper in the longitudinal vertical plane, it is necessary to analytically examine two possible cases:

- soil surface irregularities are found only in the spacings between rows of planted sugar beet roots, while the vast majority of root crowns which are located in the rows all stand at the same level;
- soil surface irregularities are found in the spacings between the rows of planted sugar beet roots. Therefore, in the rows themselves, the root crowns rise to different heights above the conventional line of the field's surface.

We assume that in accordance with Zhang et al. (2013), the soil surface irregularities in the spacings between the rows of planted sugar beet vary following the cosine law, which can be represented by the following analytical expression:

$$Y_o = h_o \cos\frac{2\pi}{l_3} X \qquad (1)$$

where l_3 is the spacing for soil surface irregularities; h_o is the height of soil surface irregularities; X is the instantaneous coordinate.

Based on the results of our theoretical investigation Bulgakov (2011), the period of oscillation for the rotor topper's centre of mass (in practice, this being the rotor topper blade tips) is approximately two times smaller than the spacing of soil surface irregularities. Accordingly, it can be assumed that any oscillation of the tips of the rotor topper blades takes place under the following law:

$$Y_1 = h_1 \cos\frac{4\pi}{l_3}X \qquad (2)$$

where h_1 is the oscillation amplitude for the rotor topper in the longitudinal vertical plane.

Let's begin with a consideration of the first of the aforementioned cases. First we draw up a schematic model of the placement of sugar beet roots in the longitudinal vertical plane (Figure 2). A system of coordinates, *OXY*, is set up so that the root crowns stand along axis X, while the axis itself represents the conventional line of the soil's surface, ie. the conventional line of the sugar beet field. The centre lines of the sugar beet roots themselves, five items in total, are positioned vertically in the diagram and with equal spacing within the interval which is equal to the soil surface irregularity spacing distance which has been designated as l_3 and equal to l_3 = 0.5m.

Now we assume that *H* is the height at which the blades (or at least the blade tips) on the rotor topper move above the conventional line of the sugar beet field surface. Obviously, in such a case the cosine curve for rotor topper oscillation is situated higher than the conventional line of the field's surface by *H*. Then we designate X_1 as the centre line for the cosine curve of the rotor topper oscillation.

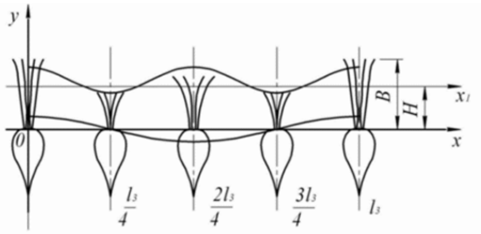

Figure 2. Schematic model showing the placement of sugar beet roots in soil and the haulm cutting height, taking into account soil surface irregularities and rotor topper oscillation

According to the schematic model presented here, the haulm cutting height *B* above the soil's surface for sugar beet root which is located at a distance of *X* from point *O* will be:

$$B = Y + H + Y_1, \qquad (3)$$

or, using expressions (1) and (2), we will have:

$$B = h_o \cos\frac{2\pi}{l_3}X + H + h_1 \cos\frac{4\pi}{l_3}X. \qquad (4)$$

Now we are going to find the cutting height for roots that stand in soil as shown in Figure 1 in accordance with expression (4). This will be as follows:

at $X = 0$: $B = h_o + H + h_1$; at $X = l_3/4$: $B = H - h_1$; at $X = l_3/2$: $B = - h_o + H + h_1$;

at $X = 3l_3/4$: $B = H - h_1$; at $X = l_3$: $B = h_o + H + h_1$.

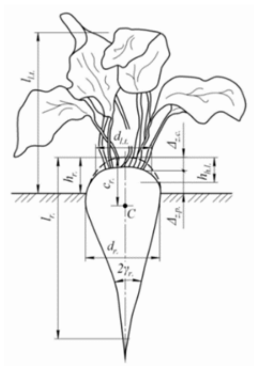

Figure 3. Main dimensions of the haulm and crown of a sugar beet root: d_r is the root diameter; l_r is the root length; $d_{l.t.}$ is the haulm bundle diameter; $l_{l.t.}$ is the length of the sugar beet top bundle; h_r is the rise of the root crown above the soil's surface level; $h_{h.l.}$ is the root crown's height; $\Delta_{z.p.}$ is the thickness of the 'latent eye' zone; $\Delta_{z.c.}$ is the thickness of the higher root crown zone; $c_{r.}$ is the coordinates for the centre of gravity; $2\gamma_r$ is the angle of taper.

Taking into account the fact that the sugar beet root crown surpasses the conventional line of the soil's surface (and therefore the field's general surface level) by a height of $h_{r.}$ (Figure 3), the height of uncut haulm on this sugar beet root will be equal to $B - h_{r.}$ In a more general case, when the phase of the rotor topper's oscillation is displaced by an unknown number which is represented by P residing in the interval ($0 \le P \le l_3/2$), relation (4) acquires the following form:

$$B = h_o \cos\frac{2\pi}{l_3} X + H + h_1 \cos\left(\frac{4\pi}{l_3} X - P\right). \quad (5)$$

Furthermore, let's consider the second case. The height of any uncut haulm for roots standing at a distance of X from point O will be:

$$B = H + h_1 \cos\frac{4\pi}{l_3} X - h_o \cos\frac{2\pi}{l_3} X. \quad (6)$$

We will also find the root cutting height in accordance with expression (6). This will be as follows:
at $X = 0$: $B = H + h_1 - h_o$; at $X = l_3/4$: $B = H - h_1$; at $X = l_3/2$: $B = H + h_1 + h_o$;
at $X = 3l_3/4$: $B = H - h_1$; at $X = l_3$: $B = H + h_1 - h_o$.
With the displacement of the phase of rotor topper oscillation, expression (6) will take the following form:

$$B = H + h_1 \cos\left(\frac{4\pi}{l_3} X - P\right) - h_o \cos\frac{2\pi}{l_3} X. \quad (7)$$

Furthermore, we will find the minimum height above the soil's surface at which the rotor topper can be set to ensure the normal root crown cutting pattern. According to the agrotechnical requirements, the haulm cutting height above the soil's surface B has to meet the following conditions:

$$h_{r.} + 2 \ge B \ge h_{r.} - \left(\Delta_{z.p.} + \Delta_{z.c.}\right), \quad (8)$$

where h_r is the height of any protrusion of the root above the soil's surface level; $\Delta_{z.p.}$ is the thickness of the 'latent eye' zone; $\Delta_{z.c.}$ is the thickness of the higher root crown zone. The designations mentioned above have been assigned according to Pogorely et al. (1983), and are shown in Figure 3. As the low cutting of the root crown is undesirable according to current agrotechnical requirements, because that is a case, when the loss of sugar-bearing stock becomes significant, we will set a limiting condition of the normal cutting, which will have the following form:

$$B = h_{r.} - (\Delta_{z.p.} + \Delta_{z.c.}). \quad (9)$$

If the cosine curve of the rotor topper's oscillation is displaced, relative to the cosine curve of the specified oscillation shown in Figure 2, to the left or to the right by a value of $l_3/4$ then the lowest root cutting height will be observed at point $X = l_3/2$ and this will be equal to:

$$B = H - h_1 - h_o. \quad (10)$$

Overall, this is the lowest cutting height possible with these cosine curves (1) and (2). By substituting expression (10) in expression (9), we obtain:

$$H - h_1 - h_o = h_{r.} - (\Delta_{z.p.} + \Delta_{z.c.}), \quad (11)$$

From here, we can define the permissible elevation of the rotor topper above the soil's surface level, ensuring the normal cutting of the haulm:

$$H = h_o + h_1 + h_{r.} - (\Delta_{z.p.} + \Delta_{z.c.}). \quad (12)$$

In the case of there being an optimal magnitude of H, none of the sugar beet roots will be cut too low, but a considerable proportion of the roots can be cut too high. It is clear that a reduction in high cutting could be achieved by reducing the value H. At the same time, this will result in some roots being cut too low. If we reduce the H value by h_o, ie. if:

$$H = h_1 + h_{r.} - (\Delta_{z.p.} + \Delta_{z.c.}), \quad (13)$$

then some roots will be cut at the lowest level as defined by expression (10) above.
These will be the sugar beet roots which have been cut by the topper at its lowest position due to soil surface irregularities and the oscillation of the topper itself. Apparently, such positions will be relatively few in number; therefore, the number of sugar beet roots that suffer the lowest cut will also be sparse. For the purpose of calculating the haulm loss rate, we have assumed that the preset height for the rotor topper above the conventional soil surface level is defined by the expression (13). Clearly, if we take such a value of H that is lower than that defined by expression (13), then the number of sugar beet roots that are cut too low will rise significantly.

3. Results and discussion

According to Pogorely et al. (1983), we have assumed for the purpose of the calculations the following geometrical dimensions for sugar beet roots: $h_{r.}$ = 1.8-5.0 cm; $\Delta_{z.p.}$ = 0.8-2.14 cm; $\Delta_{z.c.}$ = 1.32-1.62 cm. Substituting the minimum, mean, and maximum values of the parameters listed above in expression (13), we obtain H = 3.7 cm, H = 4.5 cm and H = 5.2 cm, respectively. Hence, we can assume that the minimum value of H is within 4.0-6.0 cm.

Therefore, when carrying out the numerical calculations on a PC, it is necessary to input the values of H , meeting the condition: $H \geq 3.7$cm

Now we are going to calculate the loss figure of haulm when it is cut by a rotor topper. Let's assume that at least six roots stand within each running metre of a planted row of sugar beet. For each root we can calculate its cutting height as B_i in accordance with expression (4) by substituting the value of its coordinate X_i , while: $X_{i+1} = X_i + \Delta$,

where Δ is the distance between the symmetry axes of the adjacent sugar beet roots, $X_1 = 0$, $\Delta = 20$cm, $i = 1$, 2, and so on to 6.

Furthermore, taking into account the fact that the cut haulm bundle takes the form of a truncated cone, for each sugar beet root we will find the volume of haulm that remains after the initial topping:

$$V_i = \frac{1}{3}\pi\left(B_i - h_{r.}\right)\left[r_{l.1}^2 + r_{l.1}\cdot r_{l.2} + r_{l.2}^2\right], \quad (i = 1, 2, ..., 6), \tag{14}$$

where $r_{l.1}$ is the radius of the lower cone base of the sheared-off haulm bundle; $r_{l.2}$ is the radius of the upper cone base of the sheared-off haulm bundle.

Then the mass of the remaining tops for each root will be equal to:

$$m_i = \gamma \cdot V_i , \qquad (i = 1, 2, ..., 6), \tag{15}$$

where γ is the average density of the sheared-off haulm bundle.

The total mass of the uncut tops in each running metre will be equal to:

$$m_g = \sum_{i=1}^{6} m_i . \tag{16}$$

After this stage we will find the percentage of haulm remaining in one running metre after it has been sheared-off all-over with the rotor topper:

$$q = \frac{m_g}{6Q_{l.}} \cdot 100\% \tag{17}$$

where $Q_{l.}$ is the mass of the haulm bundle on top of the root before topping.

The calculation described will be repeated for each of the following values for the rotor topper oscillation's cosine curve phase displacement: $P_1 = 0$; $P_{i+1} = P_i + 0.05l_3$; $l_3 = 50$cm; $i = 1$, 2, and so on to 11.

In order to more comprehensively assess the loss of haulm during its harvesting, we have carried out numerical calculations on a PC for several values taken from the rotor topper's preset height above the conventional level of the sugar beet field's surface level H, specifically: $H = 3.7$cm, $H = 4.0$cm, $H = 5.0$cm and $H = 7.0$cm.

The data for calculations have been taken in accordance with Pogorely et al. (1983). They are as follows: $R_{l.1} = 3$cm, $r_{l.2} = 6$cm, $\gamma = 0.15$g/cm^3, $Q_{l.} = 500$ g, $h_{r.s.} = 2$cm.

After developing the numerical calculation algorithm and compiling the programme for a PC, numerical modelling was carried out, which provided the basis for plotting the graph (Figure 4) covering haulm loss q as a function of phase displacement P_k at different values for the rotor topper's preset height above the conventional level of the sugar beet field surface H.

It can be concluded from the data in the diagram presented above (Figure 4) that at $H = 3.7$cm the haulm loss percentage q depends appreciably on the phase displacement between the cosine curves of the rotor topper oscillation and the soil surface irregularities, and varies within 3.5% and 6.0%.

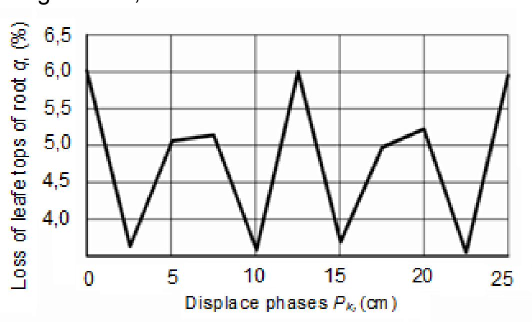

Figure 4. Loss of haulm q (%) as a function of phase displacement P_k (cm) between the rotor topper oscillation cosine curve and the soil surface irregularity cosine curve (at H = 3.7cm)

The results of all of the theoretical calculations for haulm loss as a function of the rotor topper's preset height above the soil surface level are summarised in the Table 1 below.

Table 1. Loss of haulm on one running metre of a row of sugar beet roots in relation to preset the height of the rotor topping unit

Preset height of topping unit above conventional field surface *H*, cm	Loss of haulm per running metre of planted row of roots *q*, %
3.7	3.532-6.000
4.0	4.126-6.597
5.0	6.105-8.570
7.0	10.063-12.535

The data presented in the table support the results of previous analytical calculations and prove that the minimum haulm loss rates (those which serve to meet agrotechnical requirements) will be achieved when the topping unit is set at a height that is between 4.0cm and 6.0cm above the soil's surface level.

4. Conclusions

1. A technique has been developed for the analytical determination of the loss of haulm during its all-over feeler-free cutting, as carried out with the use of a haulm gatherer which is front-mounted on a tractor, taking into account the oscillation of the rotor topping unit and the soil's surface irregularities.
2. The minimum height above the soil's surface at which the rotor topper can be set, taking into account the agrotechnical requirements for sugar beet harvesting and ensuring the normal root crown cutting pattern, has been determined analytically. According to the calculation results, the height setting value should remain within the range of 4.0cm to 6.0cm.
3. The results of the calculations have facilitated the plotting of graphs that represent the relation between the haulm loss rate on the one hand, and the phase displacement between the rotor topper oscillation and the soil's surface irregularity pattern on the other hand. The results of numerical modelling have shown that it is possible to find the values for phase displacement, which ensure a minimal loss of haulm, these specifically being: P = 2.5cm; 10cm; 15cm; 20.5cm.
4. The percentage values for haulm loss q (%) as a function of the preset height H (cm) for the topping unit above the conventional sugar beet field surface have been obtained - these vary within the range of 6.0% and 12%t.

Reference

Bentini M., Caprara C., Rondelli V. 2005. Mechanical properties of sugar beet roots. *Transactions of the American Society of American Engineers* 48(4), 1429–1439.

Bulgakov V.M. 2011. *Sugar beet harvesting machines*. Kiev: Agricultural Science. 245 pp.

Gruber W. 2005. Trends in sugar beet harvesting. *Landtechnik.* 60 (6), 320–321.

Gu F., Hu Z., Wu H., Peng B., Gao X., Wang S. 2014. Development and experiment of 4LT-A staggered-dig sugar beet combine. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering* 30(23), 1–9.

Pogorely L.V., Tatyanko N.V. 2004. *Beet-harvesting machines: History, Construction, Theory, Prognosis*, Feniks, Kyiv, 232 pp. (in Ukrainian).

Pogorely L.V., Tatyanko N.V. & Bray V.V. 1983. *Beet-harvesting machines (designing and calculation)*. Tehnika, Kyiv, 168 pp.

Schulze Lammers P. 2011. Harvest and loading machines for sugar beet – new trends. *International Sugar Journal* 113(1348), 253–256.

Schulze Lammers P., Schmittmann O. 2013. Testing of sugar beet harvesters in Germany 2012. International Sugar Journal 115(1370), 100-106.

Wang F., Zhang D. 2013. Design and experiment of disc-dig sugar beet combine. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering* 29(13), 7–14.

Wu H., Hu Z., Peng B., Wang H., Wang B. 2013. Development of auto-follow row system employed in pull-type beet combine harvester. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering* 29(12), 17–24.

Zhang G., Xu W., Fan S. 2013. Analysis and parameter optimization of adjustable beet top cutting mechanism. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering* 29(18), 26–33.