EXPERIMENTAL LABORATORY INVESTIGATIONS OF OPERATING ELEMENT FOR SUGAR BEET TOP REMOVAL

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Abstract. A design of a new top remover with a rotary feeler, new laboratory equipment for conducting experimental investigations under laboratory conditions and a methodology for the research of the top removal process from the heads of sugar beet roots before their extracting from the soil have been worked out. Graphic dependencies have been obtained of the indicators showing interrelation of the top removal quality with the forward speed of the top removal apparatus, the projection height of the heads of the root crops above the surface level of the field and their deviation from the conditional axial line of the row. Using the results obtained during experimental laboratory investigations, rational values of the basic design and technological parameters were determined of the new top remover from the heads of root crops.

Keywords: root crop, head of the root crop, top remover, laboratory equipment.

Introduction

In sugar beet harvesting the presence of tops in the final pile has an adverse effect on the sugar output; therefore, high quality top removal is an urgent task.

The results of independent studies of the work of the top removing modules and the entire top removing machines presented in articles [1-6] showed that, when the traditional top removal technologies are applied, the agrotechnical requirements by the quality indicators are executed to a limited degree of the forward speeds. This creates technological incompatibility by the working speed between the top removal operation and extraction of the sugar beet roots from the ground. For instance, top removal is carried out at forward speeds up to 1.5 $m \cdot s^{-1}$ but extraction of the root crops from the ground – up to 2.5 $m \cdot s^{-1}$.

In the up-to-date top removing modules there are technologies widely used in which the tops are removed from the heads without a feeler with subsequent additional topping by means of a feeler, which allows to reduce the range of topping by means of a feeler and inertial load on the root crops heads, raises the precision of their feeling [7]. However, additional topping of the root crop heads involves remarkable growth of waste of the sugar-bearing mass. An experimental study was made of the impact of these technologies upon the waste of the mass and the remains of tops, and basic relationships established. It should be remarked right away that the agrophysical characteristics of sugar beets depend on many factors and considerably vary. On the whole, an impressive number of experimental investigations have accumulated at the present time of the agrophysical characteristics of the sugar beet crops, the waste of the sugar beet mass and the remains of the tops depending on different ways of topping [8-9].

In this connection a need arises to perfect the traditional technologies and create new operating elements, allowing quality execution of the top removal process at speeds over 2 $m \cdot s^{-1}$.

A significant part of investigations concerning the sugar beet harvesting were done under field conditions using newly developed and made, specialised and completely different by its complexity experimental equipment. Today a necessity arises also to work out versatile laboratory equipment for testing different types of operating elements for the top removal and simulating the conditions of "a mobile field" allowing, on the whole, to cut the costs of research at the expense of a reduced number of the required laboratory facilities.

Materials and methods

We propose a new combined top removing process from the heads of sugar beet roots [10-11]. This process includes topping of low roots without a feeler, topping of medium roots by means of a feeler, and topping tall roots of sugar beet without a feeler. In order to execute such a technological process, a new top remover with a rotary feeler was designed. Its basic parameters were substantiated by us theoretically [12-13].

The aim of the work: to substantiate under laboratory conditions the basic design and technological parameters, and rational limits of changes of the operating modes, as well as to confirm the theoretical provisions obtained in previous investigations. The tasks of the experimental laboratory investigation were also to determine rational values of such parameters as the initial vertical gap a, the speed of the forward movement V of the digger, and deviation δ of root crops from the conditional axial line of the row.

In order to check the previously obtained theoretical provisions and substantiate the cinematic and design parameters of the new top remover with a rotary feeler, we made special laboratory equipment simulating the work of the developed operating element for sugar beet topping. The laboratory equipment for the investigation of the top removal operating elements consists of: the operating element 1 (Fig. 2*a*), the angular reduction gear 2, the rotary part 3, the chain-and-slat variator 4, the V-belt drive 5, the tensioning device 6, the electric motor 7, the base 8, the drive mechanism of the frame of the “mobile field” 9, the frame of the “mobile field” 10, the frame of the mobile field 11, the root crop 12, struts 13. The drive mechanism of the frame of the “mobile field” consists of an electric motor, a reel for winding a rope connected with the frame 11. Natural roots of sugar beet with tops were used for experimental laboratory investigations. The root crop with a characteristically developed top was dug out (without damage to the body and the bunch of leaves), cleared of the remnants of soil and the tail piece of the root crop was cut off to the diameter of 10 mm. A mark was made on the lateral surface of the root crop by cutting a definite number of small holes with a diameter 3...4 mm and depth 5...10 mm indicating the projection of the root crop above the surface of the soil. One hole corresponded to a 10 mm projection.

a) b)

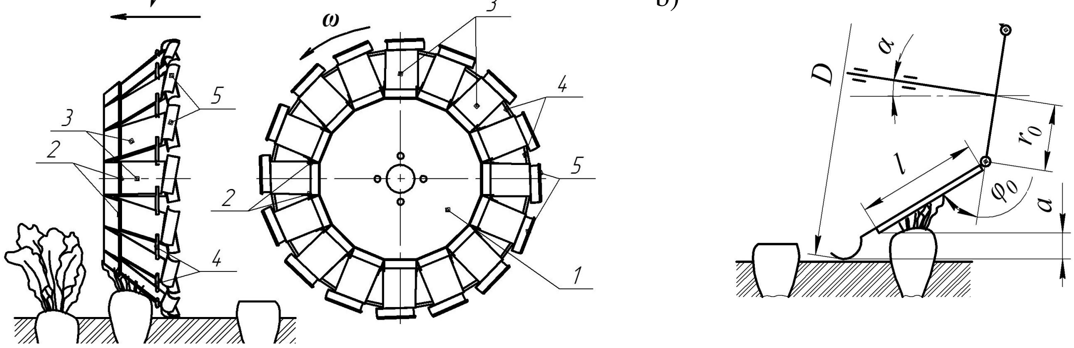

Fig. 1. **Operating element for sugar beet topping; a – scheme of operation; b – scheme of design parameters:** 1– disk; 2 – joints; 3 – rectilinear part of the operating element; 4 – supports for raising the operating element to a preset height of topping; 5 – cutting part of the operating element

a) b)

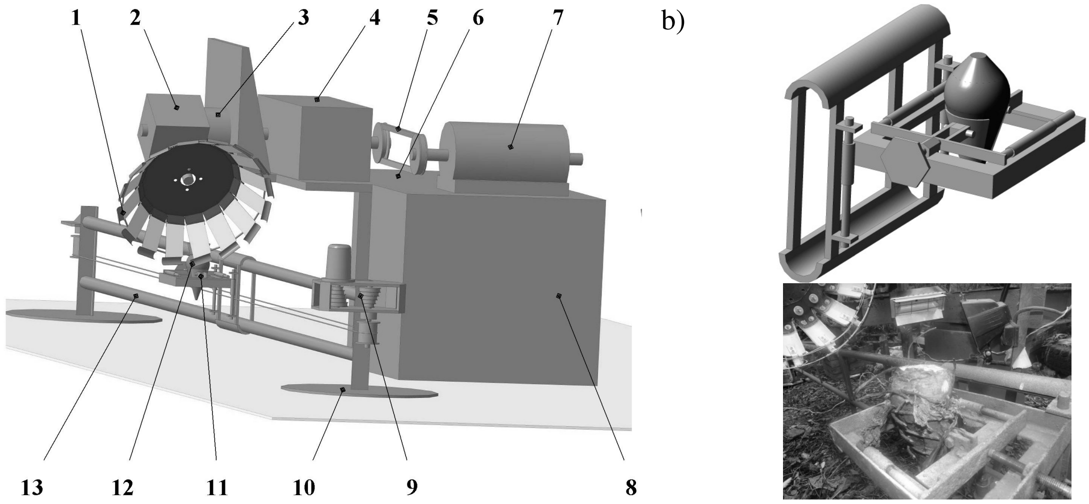

Fig. 2. S**cheme of the laboratory equipment for investigation of the top removal process:** a – general view; b – frame for fixing the root crop (the photo and 3D model)

The mass of the root crop with its top was determined by the electronic balance SOEHNLE ULTRA 2.0 with a precision to 0.1 g. Investigations by means of the laboratory equipment were conducted in the following way. A root crop was selected by the required projection height above the level of the soil, fixed by clamps at the necessary height in the mobile frame which was in the initial position on the frame 12. Deviations of the root crop from the axial line of the row were determined, as well as the value of the vertical gap, the frequency of revolutions and the speed of the forward movement of the root crop. The part of the head of the root crop cut off by the operating element was caught by special traps and afterwards its careful weighing was carried out. The remnants of the leaves on the head of the root crop which were not cut off by the operating element were removed by means of the blunt side of a knife and were weighed, too.

Results and discussion

The developed equipment provides a possibility to study the following cinematic and design parameters of the technological process and the new operating element: the frequency of rotation of the rotor ω, the speed of the forward movement of the root crop V, the inclination angle of the rotor to the horizon β, the angle of incidence of the rotor α, distance between root crops in the row S, deviation of the root crop from the conditional axial line of the row δ, the projection height of the root crop head above the conditional surface of the soil h and others. The control circuit of the motor 3 provides for a reversing mode of the movement. In the present experimental investigation are studied: the speed of the forward movement V, the projection height of the root crop head h, deviation of the operating element from the conditional axial line of the row δ.

On the whole, the results of the experiments do not contradict the previously conducted theoretical research, which is a prerequisite for statistical processing and analysis of the research results. The losses of the sugar-bearing mass and remnants of the tops on the root crops confirmed the results of theoretical simulation published in the article [12].

A sufficient precondition for the analysis of the experimental data is homogeneity of dispersion of the conducted experiments, which makes it possible to reproduce the research results. Correspondence to this condition was checked by means of the Kohren criterion and a methodology expounded in [13-14]. The calculated values of the criteria mentioned above were less than the allowed ones. The statistical processing of the experimental data was carried out using a regression analysis. Depending on the character of the previously obtained theoretical dependencies of the quality indicators of the root crop topping process, approximating quadratic dependency was selected from the controlled factors.

On the basis of the results of laboratory investigations regression dependencies were obtained (Fig. 3) of the quality indicators of the process from the forward speed V, the projection height of the root crop heads h, deviation of the operating element from the conditional axis of the row δ.

When examining the surface of response and its two-dimensional section, we see that the basic quality indicators change in the following way: deviation of the shear plane from the horizontal line is from 3 to 8 %, the remnants of the leaves on the heads of the root crops is from 5 to 25 %, the losses of the sugar-bearing mass are from 1.5 to 3.5 %. The prevailing factor leaving the most essential impact on the position of the shear plane (H, G, B) is the projection height of the root crops h (deviation of the shear plane from the horizontal line is from 2 to 9º, the remnants of the leaves on the root crops are from 0 to 25 %, and the losses of the sugar-bearing mass constitute from 1 to 4 %). The speed of the forward movement of the top removal machine affects the height of the cut-off part of the root crop head, and its optimal value lies within the limits from 1.5 to 2.2 $m \cdot s^{-1}$.

This can be explained by different duration and intensity of the interaction of the root crop heads of different projection heights with the operating elements of the top remover. This is confirmed by the revealed deviation of the actual cutting heights of the root crop heads from the designed gap of the cutting part a (10…40 mm). For instance, the cutting height for low root crops is less than the vertical gap of the cutting part but for the tall ones it exceeds considerably the vertical gap. The short time of the interaction with the feeler controlled part does not allow the operating element to remove a layer of leaves on the heads of low root crops, and therefore a lesser layer of the head is cut off. When tall root crops interact with a great number of elements of the feeler controlled part, the entire layer of the leaves is removed with the upper part of the head. It is evident that this effect should be taken into account when choosing rational parameters of the top removal with a feeler and the combined way of the top removal.

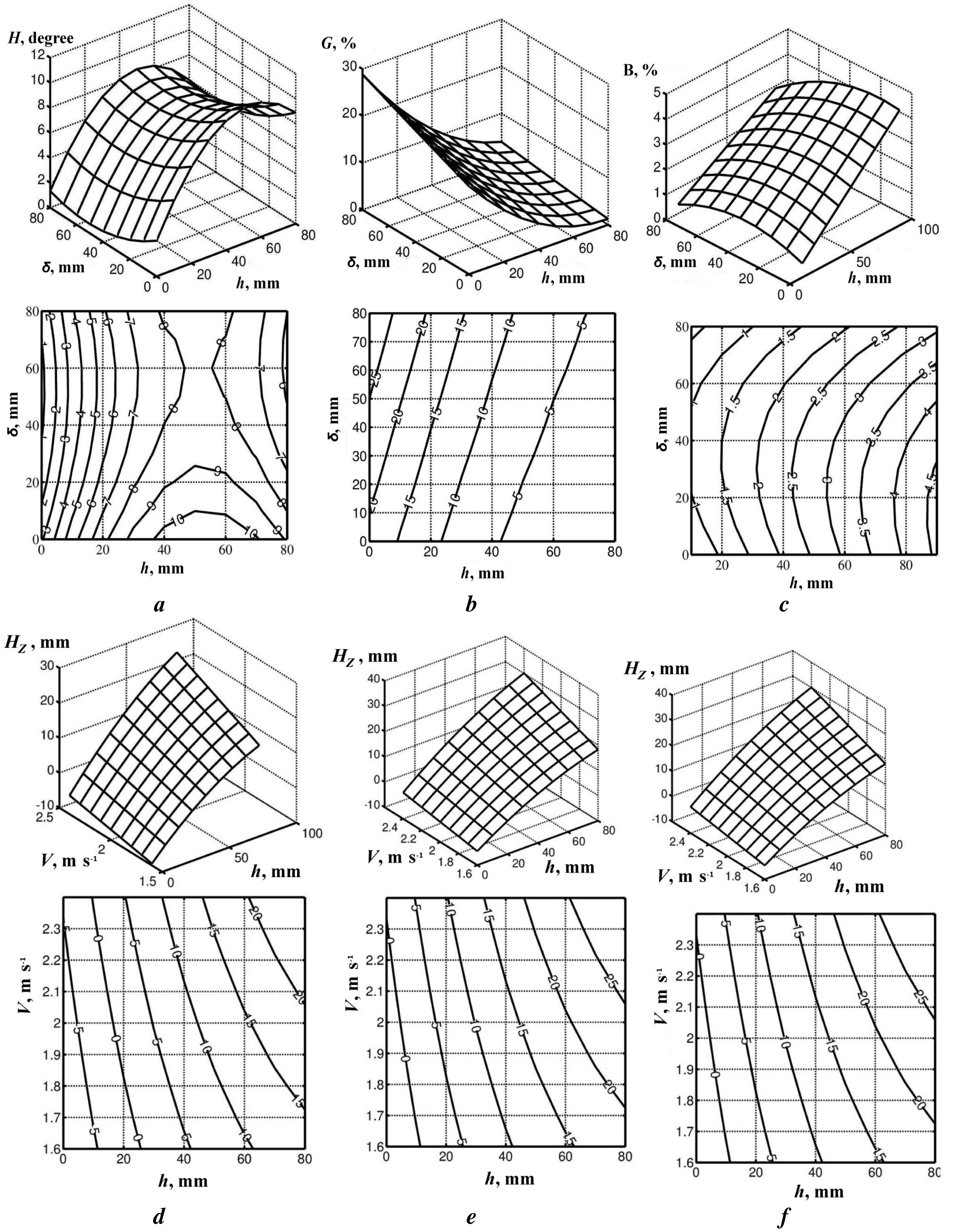

Fig. 3. **Dependencies of the quality indicators of the topping process:** *a*, *b*, *c* – deviation of the shear plane from the horizontal *H*, remnants of leaves on the root crops *G* and losses of the sugar-bearing mass *B,* respectively, from the parameters δ and *h* at a = 25 mm; *d*, *e*, *f* – deviation of the corresponding topping height of the root crop heads H_z from the parameters *V* and *h* at a = 10, 25, 40 mm and δ = 40 mm.

There are minimal deviations of the shear plane within the limits $\delta = 50...60$ mm when the forward speed of the operating element is about $2\ \mathrm{m \cdot s^{-1}}$. Allowed deviations of the shear plane (not more than 10º) will be at the value $\delta < 30$ mm, which is regulated by agrotechnical requirements for the root crop harvesting. Apparently, further increase in the deviation of the operating element from the axis of the row may lead to an increased amount of the top remnants on the low heads of the root crops (Fig.3*b*). The losses of the sugar-bearing mass at $\delta = 20...50$ mm increase, and this indicates increased pressure of the operating elements upon the head of the root crop, and, consequently, a more intense removal of the tops and parts of the root crop head with the sugar-bearing mass. Topping beyond the limits of this range reduces the losses of the sugar-bearing mass. Therefore, considering what was stated above, as a rational range of deviation of the rotor axis from the conditional axis of the row may be regarded $\delta = 30...50$ mm.

The vertical gap of the cutting part of the operating element a affects inconsiderably the section thickness of the root crop heads H_z (for instance, when it changes from 10 to 40 mm, the section thickness changes only by 5 mm). To study this effect, we conducted an additional investigation of the interaction of the feeler controlled and the cutting parts of the operating element with the top (leaves) and the head of the root crop. For this purpose, during the experimental investigation of the top removal process from the root crop heads by means of the new operating element, the removed structural parts of the tops and parts of the root crop head were fixed using special screens. After that from the collected structural parts of the tops and heads the initial structure of the sugar beet head with its top was restored artificially. This gave a possibility to evaluate the surface of the root crop head obtained as a result of interaction with the feeler controlled part of the operating element. Figure 4 presents an instance of interaction of the operating element with the root crop head, the average range of the projection height distribution, exactly with the feeler controlled part of the operating element. As a result of this study the following character of the topping process was established: When the feeler controlled part interacts with the root crop head, in reality the main mass of the top is removed from the heads of highly projecting root crops and the root crops of a medium range of projections. The remnants of tops on the heads which are characteristic for the low projecting root crops remain starting from the height 10...20 mm. This is due to different duration and intensity of interaction of the root crop heads from different height projection groups with the operating elements of the top remover. It is confirmed by the revealed deviation of the actual cutting heights of the root crop heads from the preset vertical gap. For instance, for the low projecting root crops the cutting height is less than the vertical gap of the cutting part but for the highly projecting root crops it considerably exceeds the vertical gap. In fact, when the highly projecting root crops interact with a great number of the blades, the feeler controlled part cuts off the entire layer of the leaves and the upper part of the head. Each operating element, in turn, moving along the surface of the root crop head, removes a portion of the leaves, forming a surface of the head as shown in Figure 4. The obtained empirical dependencies of the cutting height of the head from the design and technological parameters and working modes of the operating element may be used for the calculation of the quality indicators of the top removal process using a feeler or in a combined way, and for technological regulations of the top removal.

Fig. 4. **View of a root crop head after its interaction with the feeler controlled part of the operating element (the head is restored after its interaction with the operating element)**

It should be remarked that it is impossible in experimental laboratory investigations to reproduce the real conditions how the root crops are fixed in the soil, the random character of the arrangement of root crops in relation to the conditional axis of the row and the position of the root crop heads in relation to the surface of the soil. Therefore, in order to determine rational parameters of the process under field conditions, additional research is needed concerning the impact of the vertical gap and the forward speed on the quality indicators of the process.

Conclusions

1. The developed new laboratory equipment allows imitation with sufficient precision of the top removal process from the sugar beet heads by means of an experimental operating tool and investigation of the impact of its individual design and technological parameters upon the quality of the work.
2. The basic indicators of the quality of the work of the experimental operating tool change in the following way: the remnants of the tops (leaves) on the root crop heads – from 5 to 25 %, the losses of the sugar-bearing mass – from 1.5 to 3.5 %, deviation of the section area from the horizontal position – from 3 to 8 %.
3. The optimal value of the displacement of the rotor axis from the conditional axial line of the row is within the limits 30...50 mm.
4. The speed of the forward movement of the top removal machine affects the height of the cut-off part of the root crop head, and its optimal value lies within the limits from 1.5 to 2.2 m s^{-1}.
5. Under the conditions of investigations on laboratory equipment the vertical gap of the cutting part of the operating element did not have any essential impact on the height of the cut-off part of the root crop heads. However, in order to achieve more precise determination of this dependence, separate experimental investigations are necessary under the field conditions taking into account additional impact of the soil irregularities.
6. The most essential factor affecting the position of the section area of the tops is the projection height of the root crops above the soil level. It was established that the experimental operating tool removes the tops practically completely from the sugar beet crops which project to a great or medium height from the soil level; however, the average height of the top remnants of the low-projecting root crops is 10...20 mm.

References

1. Zuckerrüben: Erntetechnik und Bodenschutz / FAT-Berichte Nr. 567. Eidgenssische Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), CH-8356 Tänikon TG – 2001 S. 1-19. (In German).
2. Roller O. Entblatten statt Köpfen / Dr. Olaf Roller // Zuckerrüben Journal № 2 / Rheinischer Landwirtschafts-Verlag GmbH. – 2010, S. 14-15. (In German).
3. Merkes R. 50 Jahre Prodaktionstechnik im Zuckerrübenbau in Deutchland / R. Merkes / Zuckerrübe. – 2001, № 4. – S. 214-217. (In German)
4. Es geht um den Kopf/ Zuckerrüben Journal №3 / Rheinischer Landwirtschafts-Verlag GmbH, – 2010, S. 7 - 8. (In German).
5. Погорелый Л.В., Татьянко Н.В. Свеклоуборочные машины: История, конструкция, прогноз. (Sugar beet harvesters: History, design, prognosis.)– К.: Феникс, 2004. – 232 с. (In Ukrainian).
6. Булгаков В.М. Теория свеклоуборочных машин. (Theory of sugar beet harvesters) – К.: Издательский центр НАУ, 2005. – 245 с. (In Ukrainian).
7. Зуев Н.М. и др. Бескопирный срез головок корнеплодов (Cutting the root crop heads without a feeler)/ Сахарная свекла. – 1988. – № 6. – С. 42-45. (In Russian).
8. Роик Н.В. и др. Научно-методические рекомендации к уборке сахарной свеклы (Scientific and methodological recommendations for sugar beet harvesting) / К.: Аграрная наука, 2002. – 40 с. (In Ukrainian).
9. Механико-технологические свойства сельскохозяйственных материалов (Mechanical and technological properties of agricultural materials) / Царенко А.М., Яцун С.С. и др.; под ред. С.С. Яцуна. – К.: Аграрное образование, 2000. – 93 с. (In Ukrainian).

10. Булгаков В., Борис А., Ивановс С. и др. Очисник головок коренеплодив (Cleaner heads of root crops) /Патент Украины № UA 103816 C2, 2013. (In Ukrainian).
11. V.Bulgakov, N.Boris, S. Ivanovs. (2013) Mathematical model of interaction of operating element of top remover with head of root crop. / 12th International Scientific Conference Engineering for Rural Development. Proceedings, Volume 12, May 23-24, 2013. pp.115-120.
12. Борис А.Н. Обоснование рационального диапазона копирного среза ботвы сахарной свеклы (Substantiation of a rational range of beet top removal with a feeler) / Сборник научных трудов Луцкого национально-технического университета, №21(1). – Луцк, 2011, с. 26-30. (In Ukrainian).
13. Василенко П.М. Основы научных исследований (Foundations of scientific research) / Механизация сельскохозяйственного производства. П.М. Василенко, Л.В. Погорелый. – К.: Высшая школа, 1984. – 266 с. (In Russian).
14. Адлер Ю.П.и др. Планирование эксперимента при поиске оптимальных условий (Planning of an experiment in search of optimal conditions) / М.: Наука, 1971. – 283 с. (In Russian).