RESEARCH OF THE BURROWING SHARE OF A MACHINE FOR HARVESTING VEGETABLES AND ONIONS UNDER LABORATORY CONDITIONS
/
ИССЛЕДОВАНИЯ ПОДКАПЫВАЮЩЕГО ЛЕМЕХА МАШИНЫ ДЛЯ УБОРКИ ОВОЩНЫХ КУЛЬТУР И ЛУКА В ЛАБОРАТОРНЫХ УСЛОВИЯХ

Dorokhov A.S., Sibirev A.V.*), Aksenov A.G., Sazonov N.V. [1]
FSBSI "Federal Scientific Agronomic and Engineering Centre VIM"/ Moscow, Russia
Telephone: 89645843518; E-mail: sibirev2011@yandex.ru
DOI: https://doi.org/10.35633/inmateh-64-23

Keywords: *onions, digging share, soil admixtures, experimental studies*

ABSTRACT
It was found that the extraction of a tuberous heap, namely potatoes, with a digging working body with a movable frame, has the most significant drawback, which is that when the depth of the burrowing share tip is changed, the angle of its inclination changes, which negatively affects the chipping of the soil layer and leads to the deterioration of the transportation of the excavated soil layer to the separating working bodies, for which it is necessary to determine and clarify the main technological and design parameters of the developed intake plough share for digging / picking up root crops and bulbs due to the fact that potato tubers and onion bulbs have different size and mass and physical and mechanical properties. A method has been developed for determining the amount of supply of a heap of onion sets from the surface of the digging share to the separating working bodies, the required soil moisture necessary for research. The methodology and results of experimental studies to determine the decrease in the content of soil impurities in the gathering heap of onions are presented, the main statistical characteristics of the experiment are reflected. Based on the results of the screening experiment, significant factors have been established that have a decisive effect on the selected optimization criterion: spring preload, determined by the spring length and the forward speed of the digging share. It was found that the minimum possible amount of soil impurities when extracting onions from the soil is 24.8%. It depends on the values of the investigated factors, values that should be set in the interval: the length of the spring L_{PPR} =0.02-0.04 m and the speed of the moving share v_L =1.2-1.4 m/s.

РЕЗЮМЕ
Установлено, что извлечение клубненосного вороха, а именно – картофеля подкапывающим рабочим органом с подвижной рамкой, имеет наиболее значимый недостаток, заключающийся в том, что при изменении величины заглубления носка подкапывающего лемеха происходит изменение угла его наклона, что отрицательно сказывается на скалывании почвенного слоя и приводит к ухудшению транспортирования подкопанного почвенного пласта на сепарирующие рабочие органы, для чего необходимо определить и уточнить основные технологические и конструктивные параметры разработанного приемного лемеха для подкапывания/ подбора корнеплодов и луковиц в связи с тем, что клубни картофеля и луковицы лука-севка обладают различными размерно-массовыми и физико-механическими свойствами. Разработаны методика по определению величины подачи вороха лука-севка с поверхности подкапывающего лемеха на сепарирующие рабочие органы, требуемой влажности почвы, необходимой для проведения исследований. Представлены методика и результаты экспериментальных исследований по определению снижения содержания почвенных примесей в сходовом ворохе лука, отражены основные статистические характеристики эксперимента. По результатам отсеивающего эксперимента установлены значимые факторы, оказывающие определяющее влияние на выбранный критерий оптимизации: поджатие пружины, определяемое длиной пружины и поступательная скорость движения подкапывающего лемеха. Установлено, что минимально возможное количество почвенных примесей при извлечении лука из почвы составляет 24,8%. Это зависит от значений исследуемых факторов, значения которых должны устанавливаться в интервале: длина пружины L_{PPR}=0.02 - 0.04 м и скорость движения подкапывающего лемеха $v_L = 1.2$-1.4 м/с.

[1] *Dorokhov A.S., Prof. PhD. Eng.Sc.; Sibirev A.V., PhD. Eng.Sc.; Aksenov A.G., PhD. Eng.Sc.; Sazonov N.V., Eng.Sc.*

INTRODUCTION

When a swath of onion set at the surface of a field is formed by an onion harvester, onions interact with each other and with the surface of the soil *(Lobachevsky Ya.P. et al, 2016; Laryushin A.M., 2010; Protasov A.A., 2011; Reingart E.S., 1995; Sorokin A.A., 2006).* In the process of onions extraction from the soil, onion harvester advances progressively. This prevents a swath of onion set from having a large height and thus increases the share of damaged bulbs (since the increase of the swath leads to a decrease of bulb falling height and the degree of mechanical impact on lower bulbs being hit, whereas the number of onion set bulbs within the swath layer increases). Limiting rollers formed by the packing roller of the onion harvester prevent excessive growth of the width of onion set swath and thus prevent bulbs from scattering (*Protasov A.A., 2011*).

The analysis of the designs of existing machines for harvesting root crops and onions, as well as patent and technical literature, presented below, revealed shortcomings in the design of the digging parts of machines for harvesting root crops and bulbs, which do not allow ensuring a high-quality performance of the technological process separation of commercial products, and also lead to an increase in energy costs for harvesting, due to the increased rise of the soil layer together with commercial products (*Farhadi R. et al, 2012*).

Known machine for harvesting potatoes consist of basic elements, namely: an undercutting share, a separating bar elevator and support rods (*Tauseef A.M., et al, 2014*).

The main distinguishing feature of the harvester presented above is the design of the undercutting implement 1 (Fig. 1).

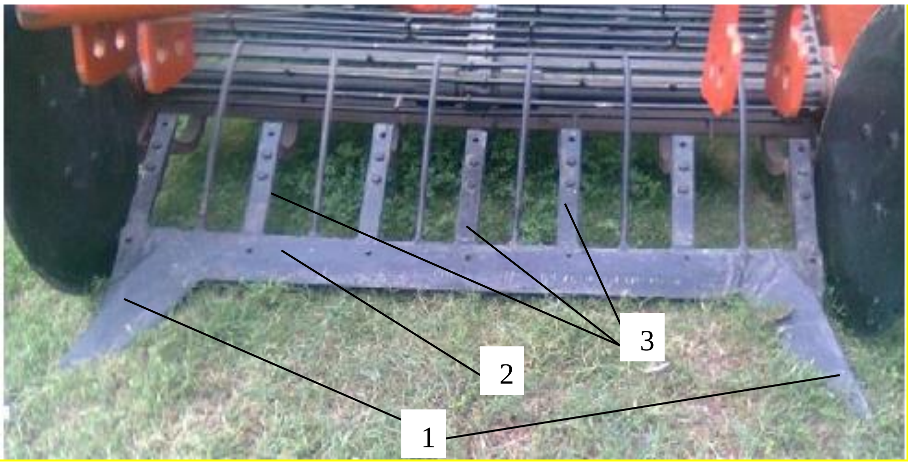

Fig. 1 - General view of the sub-digging body

1 – ripping element; 2 – digging element; 3 –pre-separation slotted holes

The underfloor working body is a combination of loosening *1* and undercutting *2,* elements with pre-separation slotted holes *3,* formed by the working surface of the undercutting element 2.

The loosening element *1* of the digging working body carries out preliminary loosening of the soil layer being dug in order to reduce the supply of soil clods to the separating working bodies, and therefore, intensifying the process of cleaning root crops from commensurate soil clods, as well as reducing the amount of damage to marketable products from collisions with soil clods on the rods cleaning machine. The digging element *2* carries out the extraction of root crops from the soil in the preliminary separation through the slotted holes *3*.

The disadvantages of this digging part include increased losses of root crops through the slotted holes *3* of the digging element *2*; in addition, this design of the digging working body does not reduce the amount of damage to the separated products on the bar elevator due to insufficient loosening of the soil layer of root crops location.

There is a known design of an undercutting working body, in which the front part of the bar elevator web on the part of the undercutting share vibrates in the vertical plane, when the underburned share mounting bracket acts on the supporting roller, which provides an additional force effect on the soil layer, and thereby intensifies the process of soil and plant impurities separation (*Natenadze N., 2016*).

The disadvantages of the known design of the digging working body include increased damage to root crops during the transition from one cascade to another, as well as the impossibility of dispersing a heap of root crops over the entire width of the conveyor.

Analysis of the technical means of mechanized harvesting of root crops allows us to conclude that the functioning elements of the harvesting machine with various types of separation intensifiers do not provide quality indicators for harvesting root crops in terms of such indicators as completeness of separation and damage to root crops.

The aim of the research is experimental research of the power effect of the digging share during mechanized onion harvesting. This need is due to the desire to reduce the traction and specific traction resistance of agricultural implements, which requires a constant search for more advanced, in terms of energy intensity, working bodies and technologies for field work. So, the use of working bodies of one type or another determines the predominance of a certain type of deformation of the soil layer. And since the soil resists differently to different types of influences, this leads to a decrease or increase in its resistivity (*Dorokhov A.S. et al, 2020*).

MATERIALS AND METHODS

The laboratory study program involved a study of the intake plough share used to lift and pick up roots. This was carried out in order to determine optimal values of its structural and process parameters that would ensure maximum thoroughness of harvest of root crops and onions with minimum pickup of soil impurities by separating working tools *(Devsh K., Ashok T., 2017; Koga N. et al 2013; Lü J.Q. et al, 2016).*

To study the volume of a root crop and onion heap transported from the surface of the intake plough share for subsequent lifting and pickup of root crops by the separating working tools of the harvester, research activities were carried out in the Penza Region in 2018 and 2019.

Stuttgarter Riesen onion seeds were planted according to the row/strip cropping system (six 45+25 cm rows), which calls for guess row and tractor wheel spacings of 50 cm and other spacings equal to 40 cm (*Hevko R.B., 2016*).

The quality of lifting of root crops and onions by the intake plough share used to lift/pickup root crops depends on a number of factors *(Dorokhov A.S. et al, 2020)*. In view of this, laboratory studies were carried out using the multifactorial experiment method, at the setup installed at a mobile soil channel (Fig. 2).

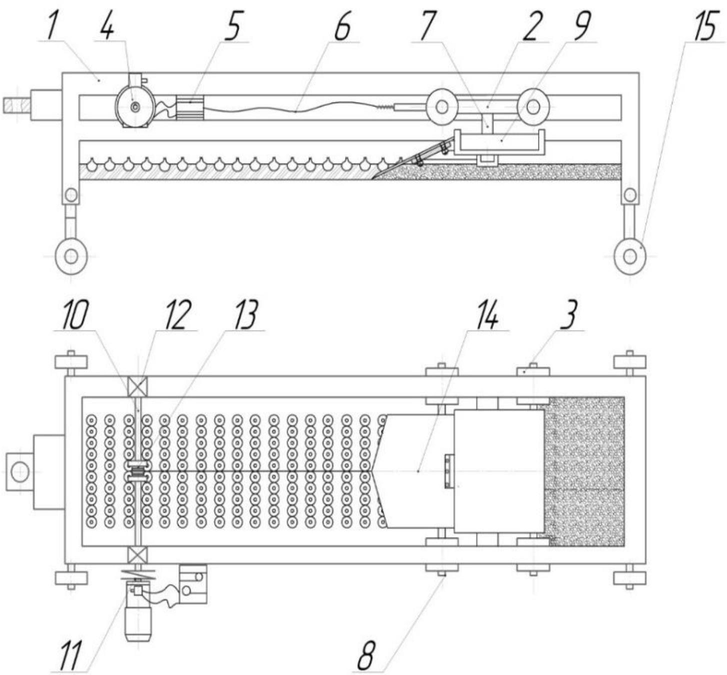

Fig. 2 – Diagram of the laboratory setup for determining the supply speed of onion heap to the digging plough share

1 – guide; 2 – driven trolley; 3 – steel roller; 4 – electric motor; 5 – frequency converter; 6 – rope connection; 7 – mounting rack; 8 – trolley axis; 9 – heap collection tray; 10 – trolley drive shaft; 11 – safety clutch; 12 – bearing; 13 – coil with restrictive flanges; 14 – digging plough share; 15 – supporting wheels

To determine the speed Q_{Bp} (the flow of a heap of onion sets and soil impurities from the surface of the digging share to the separating workers) of onion heap feed to the digging plough share of the root crop and onion harvester, a laboratory setup in the form of a mobile soil channel was used.

This made it possible to study qualitative indicators of digging working tools' operation on soils having varying physical and mechanical composition.

The setup used was a welded structure consisting of guides *1* with the driven carriage *2* moving along them. The carriage was mounted on four wheels *3* and driven by the electric motor *4* equipped with the frequency converter *5*, via the flexible rope connection *6*. The digging plough share *14* and the heap collection tray *9* were attached to the mounting rack *7* which was installed on the driven trolley *2*.

The driven trolley *2* moved along the guides *1* on the steel rollers *3* with the diameter of 0.15 m by means of an electric drive comprising the asynchronous electric motor *4* and the frequency converter *5*. This made it possible to control both the rotation frequency of the electric motor shaft and the direction of shaft rotation.

The method for determining Q_{Bp} the value of onion set heap feed speed from the surface of the digging plough share to the separating working tools is as follows. To account for soil moisture during the studies, it was measured using the method described below.

To ensure the soil moisture level required for the studies, the soil was moistened using surface irrigation, then kept for several hours until the required moisture level was achieved within the soil layer corresponding to the bulb lifting depth.

In accordance with the experiment plan, experiments were carried out with the soil moisture level corresponding to the required value.

A mobile soil channel was mounted on the experimental onion-planting plot (Fig. 3). The digging plough share *7* (standard grasp width 1.2 m) was mounted on the driven trolley *2* at the mobile soil channel to achieve the digging h_L depth within the range of 0.02 m to 0.05 m, and the variation interval of 0.01 m by moving the mounting rack *7* along the driven trolley *2*.

Fig. 3 – General View of the Laboratory Setup for Determining the Feed Speed of Onion Set Heap onto the Digging Plough Share

1 – guide; 2 – driven trolley; 3 – steel roller; 4 – electric motor; 5 – frequency converter; 6 – rope connection; 7 – mounting rack; 8 – trolley axis; 9 – heap collection tray; 10 – trolley drive shaft; 11 – safety clutch; 12 – bearing; 13 – coil with restrictive flanges; 14 – digging plough share; 15 – power supply

Seed onion heap collection tray *9* was rigidly attached to the digging plough share.
After that, the driven trolley *2* was set in motion, its travel speed was changed in increments of 0.2 m/s from the minimum value of 0.4 m/s to the limit value of 1.8 m/s.

After the driven trolley *2* passed the experimental plot, the onion-soil heap was removed from the tray *9* and weighed on an electronic scale (model MK - 15.2 - A21) (the weight of bulbs and soil impurities was determined separately).

When studying the intake plough share used for lifting/pickup of root crops and onions to determine qualitative characteristics of its operation, the content of soil impurities in the resulting heap M_P was assumed as the optimization criteria, characteristics of bulb damage W_L and loss P_L were assumed as limiting parameters (*Dorokhov A.S. et al, 2020*).

The value of the optimization criterion M_{Π} was determined using the following dependency:

$$M_P = \frac{M_{BL} - M_L}{M_{BL}} \cdot 100\%, \tag{1}$$

where M_{BL} – is the mass of onions, mass of soil impurities, mass of vegetable impurities [kg];

M_L – is the mass of onion set [kg].

According to the results obtained during studies of reduction of over consolidated soil delivery to the separating working tools of a potato harvester carried out by F. N. Gallyamov, the highest level of cleanliness of the resulting heap with the acceptable share of tuber loss of up to 3% was achieved at the travel speed of $v_L = 1.2$ m/s, spring stiffness F_{PR} =of 25 kN/m (P – spring, R – rate) and spring load of 0.05 m (*Gallyamov F.N., 2004)*.

The results obtained by *F.N. Gallyamov* applied to tuberiferous heap of potatoes picked up by a digging working tool with a movable frame. This type of working tool has the following drawback - changing the depth of the digging plough share's toe results in variation of its inclination angle, which impacts the quality of the soil layer shearing and transportation of the extracted soil slice to working tools adversely. This led to the necessity to determine and clarify main process and design parameters of the developed intake plough share for lifting/pickup of root crops and onions since potato tubers and onion set bulbs have different sizes and weights, as well as physical and mechanical properties.

Thus, in our case, in order to ensure that the plough share's toe is buried to the maximum depth of 6 cm, down to the minimum depth of onion set bulb location within soil of 3 cm, it is necessary to set spring stiffness to F_{PR} =20 kN/m.

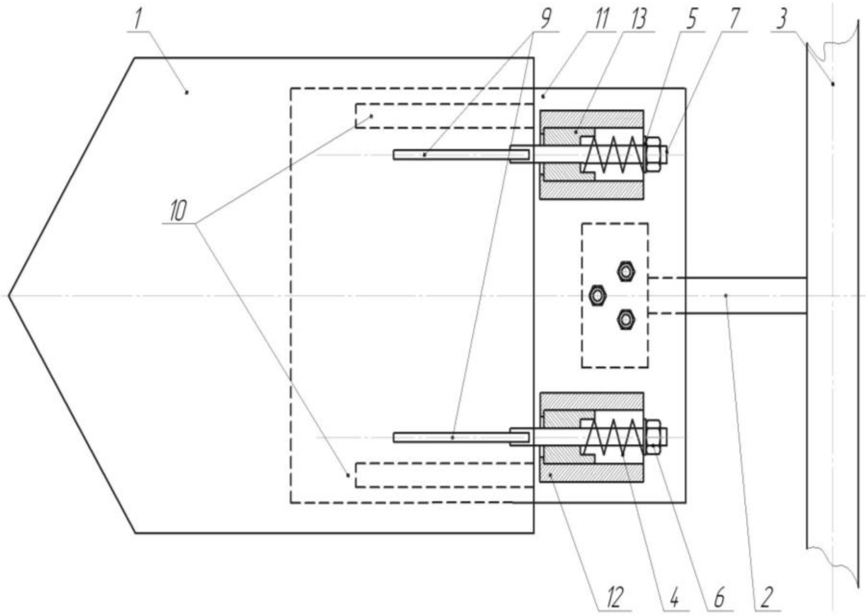

Fig. 4 – Structural and Process Diagram of Intake Plough Share for Lifting/Pickup of Root Crops and Onions

1 – plough share; 2 – bracket; 3 – frame; 4 – elastic support element; 5 – gasket; 6 – nut; 7 – rod; 8, 9 – plungers; 10 – guides; 11 – base plate; 12 – bushing

Based on the results of the screening experiment performed to reveal the most important factors affecting the selected optimization criteria, we distinguished the following two criteria:

- spring load L_{PPR}, [m];
- travel speed of the digging plough share v_L, [m/s].

The working travel speed of the trolley was determined based on the length of the registration plot (4 m) and the time required to complete a passage:

$$v_L = \frac{S_T}{t_T}, \tag{2}$$

where:

S_T – is the distance covered by the trolley, [m];

t_T – is the distance passage time, [s].

The spring L_{PPR} was loaded by relocating the nut *6* along the rod *7*.

Three levels were selected for each factor: lower, upper and base – zero level. After that, factor variation interval was determined (Table 1) and the multifactorial experiment was conducted according to the experiment plan 2^3 (Table 1).

Table 1

Factor Variation Levels when Determining Qualitative Characteristics of Root Crop and Onion Lifting/Pickup Intake Plough Share Operation

Level of variation	Variable Factors		Optimization Criteria
	Spring load L_{PPR}, m	Progressive speed of the digging plough share v_L, m/s	Content of soil impurities in the resulting heap M_P, %
	Variability interval, Δx_i		
	0.02	0.2	
upper (+1)	0.06	1.6	Y
lower (-1)	0.02	1.2	
base (0)	0.04	1.4	
Designations	X_1	X_2	

The studies were carried out with the aim of determining the effect of process parameters (L_{PPR} and v_L) of the root crop and onion lifting/pickup intake plow share on the amount of soil impurities in the resulting heap M_P in a laboratory environment.

Table 2

Two-Factor Experiment Planning Matrix

Designation	Factors	
	Spring load L_{PPR}, m	Progressive speed of the digging plough share v_L, m/s
	X_1	X_2
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	1	0
6	-1	0
7	0	1
8	0	-1
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0

After the results of the multifactorial experiment were processed by STATISTICA 6.0 software, response function values were obtained.

RESULTS

The content of soil impurities in the resulting heap M_P depending on the varied factors, and an adequate encoded mathematical model describing the dependency M_P=f(L_{PPR}, v_L) of onion and soil heap input on the selected factors was developed.

$$Y = 25.23 + 0.12x_1 + 1.63x_2 - 0.001x_1^2 - 0.015x_2^2 - 0.03x_1x_2 \quad (3)$$

The adequacy of the presented model was verified using statistical analysis of the regression equation. The results of statistical characteristic calculations are shown in Table 3.

The coordinates of the yield surface were determined by differentiating the equation (3) and solving the following system of equations:

$$\begin{cases} \frac{dy}{dx_1} = 0.12 - 0.002x_1 - 0.03x_2 = 0, \\ \frac{dy}{dx_2} = 1.63 - 0.03x_2 - 0.03x_1 = 0. \end{cases} \quad (4)$$

By solving the system of equations (8), we determined the coordinates of the encoded response function's surface center: $x_1 = -86.25,\ x_2 = 9.75$ (decoded results are: L_{PPR}=0.032 м, v_L =1.4 m/s).

Table 3

Statistical Characteristics of Experimental Error

No.	Y_1	Y_2	Y_3	$\overline{Y_u}$	$\widehat{Y_u}$	S_y^2	S_{LF}^2	$(Y_u - \widehat{Y_u})^2$
1	23.9	24.2	24.2	24.2	23.43	0.7	0.381	1.413
2	23.1	22.7	22.9	22.9	23.73	1.06	0.581	2.131
3	23.8	23.9	23.7	23.8	26.75	1.08	0.589	2.162
4	22.3	22.5	22.1	22.3	26.93	0.04	0.021	0.081
5	24.2	24.2	23.9	24.1	25.34	0.03	0.016	0.063
6	25.3	24.8	25.2	25.1	25.11	0.06	0.033	0.124
7	25.3	25.4	25.2	25.3	26.84	1.48	0.807	2.961
8	22.8	22.6	22.7	22.7	23.61	1.24	0.675	2.475
9	25.4	25.6	25.2	25.4	25.23	0.08	0.045	0.166
10	25.3	25.0	25.3	25.2	25.23	0.03	0.017	0.062
11	25.4	25.2	25.3	25.3	25.23	0.01	0.009	0.034
12	25.1	25.1	25.4	25.2	25.23	0.03	0.017	0.062
13	25.2	25.2	25.5	25.3	25.23	0.03	0.021	0.074
Σ	-	-	-	316.8	-	5.871	3.212	11.81

By applying values x_1 and x_2 to the equation (7), we obtained the value of the response function at the center of the surface.

$$Y_S = 24.86 \quad (5)$$

By applying canonical transformation of the equation (7), we obtained the equation in its canonical form:

$$Y - 24.86 = 0.0015x_1^2 - 0.471x_2^2 \quad (6)$$

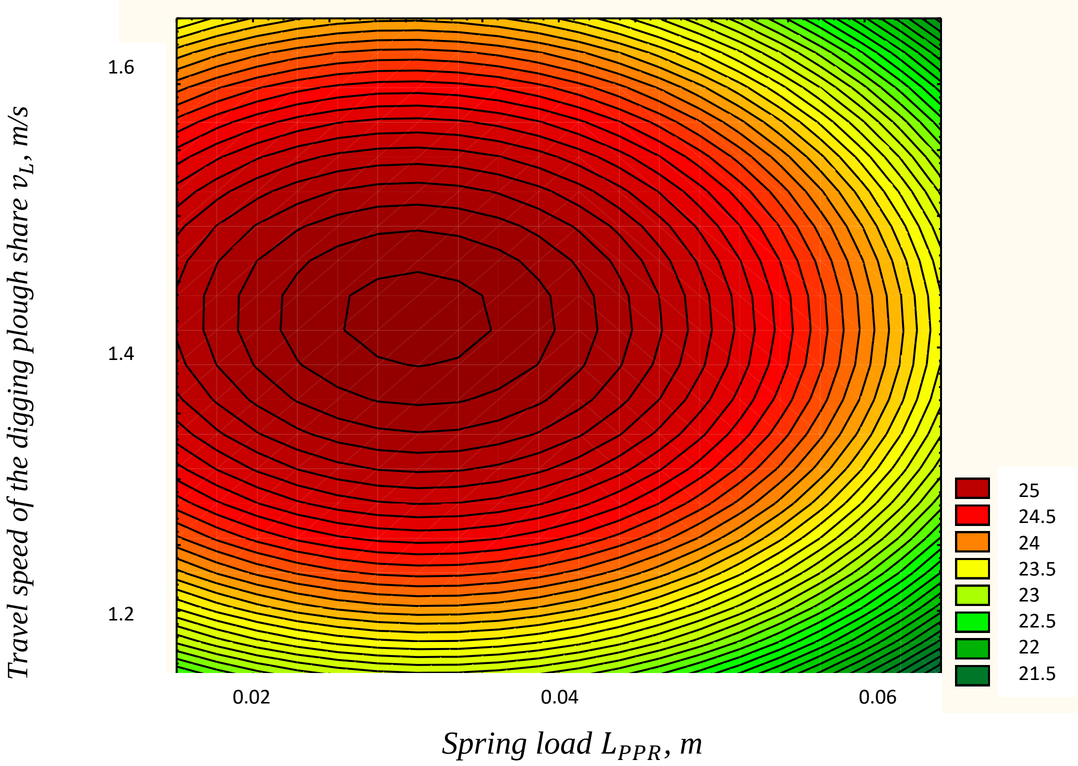

Fig. 5 - Two-Dimensional Section of the Response Surface Characterizing the Dependency of Content of Soil Impurities in the Resulting Heap (in %) from the Spring Load and Travel Speed of the Digging Plough Share

Axis turning axle is:

$$\mathrm{tg}\,2\alpha_2 = \frac{0.005}{0.11 - 0.005} = 0.047 \quad (7)$$

Angle α_2= - 1.26 °.

By applying various values of the response function (3), we obtained contour plot (ellipse) equations. Calculation results are shown in Fig. 5.

CONCLUSIONS

The results of the screening experiment made it possible to determine the significant factors that have a decisive influence on the selected optimization criterion: spring preload, determined by the spring length and the forward speed of the digging share.

It was found that the minimum possible amount of soil impurities when extracting onions from the soil is 24.8%. It depends on the values of the investigated factors, the values of which should be set in the interval: spring length L_{PPR}=0.02 - 0.04 m and the speed of movement of the undercutting share v_L = 1.2-1.4 m/s.

ACKNOWLEDGEMENT

«The reported study was funded by RFBR, project number 19-316-90068».

REFERENCES

[1] Devsh K., Ashok T. (2017), Performance evaluation of tractor drawn potato digger cum-elevator, *International Journal of Agricultural Science and Research*, Issue number 7(2), pp. 433 – 448, Tehran / Iran;

[2] Dorokhov A.S., Sibirev A.V., Aksenov A.G. (2020), Investigation of the performance indicators of the receiving ploughshare for digging / picking up root crops and bulbs in laboratory conditions (Исследование показателей качества работы приемного лемеха для подкапывания/подбора корнеплодов и луковиц в лабораторных условиях), *Agricultural scientific journal*, Issue number 7: pp.70 – 74. Saratov / Russia;

[3] Farhadi R., Sakenian N., Azizi P. (2012), Design and construction of rotary potato grader, *Bulgarian Journal of Agricultural Science*, Issue number 2, pp. 304 – 314, Sofia / Bulgaria*;*

[4] Gallyamov F.N. (2004), *Development and optimization of the parameters of the device for controlling the depth of travel of the undercutting working bodies of potato harvesters (Разработка и оптимизация параметров устройства регулирования глубины хода подкапывающих рабочих органов картофелеуборочных машин)*, dissertation Candidate of Engineering, Orenburg / Russia;

[5] Hevko R.B., Tkachenko I.G., Synii S.V., (2016), Development of design and investigation of operation processes of small-scale root crop and potato harvesters, *INMATEH-Agricultural Engineering*. Vol. 49 (2), pp. 53-60, Bucharest / Romania;

[6] Koga N., Kajiyama T., Senda K., Iketani S, Tamiya S, Tsuda, S., (2013), Energy efficiency of potato production practices for bioethanol feedstock in northern Japan, *European Journal of Agronomy*, Issue number 44(1), pp. 1–8, Amsterdam / Netherlands;

[7] Lü J.Q., Shang Q.Q., Yang Y., Li Z.H., Li J.C., Liu Z.Y. (2016), Design optimization and experiment on potato haulm cutter, *Transactions of the CSAM*, Issue number 47(5), pp.106–114, London / United Kingdom*;*

[8] Lobachevsky Ya.P., Emelyanov P.A., Aksenov A.G., Sibirev A.V., (2016), Onion production machine technology (Машинная технология производства лука), *Monograph, FSBSI "Federal Scientific Agronomic and Engineering Centre VIM".* 168 p. Moscow / Russia;)

[9] Laryushin A.M. (2010), *Energy-saving technologies and technical means for onion harvesting (Энергосберегающие технологии и технические средства для уборки лука), dissertation Doctor of Engineering,* Penza / Russia*;*

[10] Nappe Mordi N. Al-Dosary (2016), Potato harvester performance on tubers damage at the eastern of Saudi Arabia, *Agricultural engineering international: CIGR Journal*, Issue number 18(2), pp. 32–42, Beijing / China*;*

[11] Natenadze N. (2016), The design and theoretical justification of a vibratory digger shovel, *Scientific technical union of mechanical engineering Bulgarian association of mechanization in agriculture*, Issue number 5, pp. 9–12, Sofia / Bulgaria*;*

[12] Protasov A.A., (2011), A functional approach to the development of an onion harvester (Функциональный подход к созданию лукооуборочной машины), *Herald of the Federal State Higher Vocational Education Institution Moscow State Agricultural Engineering University named after V. P. Goryachkin*, Issue number 2 (47), pp. 37-43, Moscow / Russia;

[13] Reingart E.S., Sorokin A.A., Ponomarev A.G., (2006), The new generation of standardized potato harvesters (Унифицированные картофелеуборочные машины нового поколения), *Tractors and agricultural machinery*, Issue number 10, pp. 3-5, Moscow / Russia;

[14] Sorokin A.A., (2006), Theory and calculation of potato harvesters (Теория и расчет картофелеуборочных машин), *Monograph, FSBSI "Federal Scientific Agronomic and Engineering Centre VIM".* 159 p. Moscow / Russia;

[15] Sun D.X., Zhang A.M., Gong J.X. (2016), Design and experiment on 1SZL-250A type subsoiling rotary tillage fertilizer combined soil working machine, *Journal of Chinese Agricultural Mechanization*, Issue number 37(4): pp. 1–6. Beijing / China*.*

[16] Tauseef A. M., Ghafoor A., Munir A., Iqbal M., Ahmad M. (2014), Design modification and field testing of groundnut digger, *Asian Journal of Science and Technology*. Issue number 5: pp. 389–394. Tamil Nadu / India.