The results of studies of specific energy intensity of the basin formation process of the onion harvester

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Abstract. Crop farming is believed to be the most energy intensive sector of the agricultural industry. The sector accounts for 70\% of all the expenses including more than 40\% harvesting-related expenses. Conservation culture cultivation technologies are being actively introduced. These are based on the reduction of the number of production process operations and the replacement of mouldboard soil cultivation with nonmouldboard processes, direct seeding of crops and application of herbicides at all stages of plant farming, harvesting of crops with the use of multi-function harvesters that perform a number of process operations during a single pass: moving of tops, lifting and extraction of the tuber root-bearing layer, separation of commercial products from soil-and-vegetable impurities, and loading onto a vehicle with subsequent transportation for post-harvest processing and storage. A crucial problem implementation of any technology is aimed at solving is the decrease of labor and energy, and resource conservation, as well as increasing of the yield of cultivated crops and thus the reduction of prime cost of products. This aim is impossible to achieve without first determining the energy costs of agricultural product production process operations. Despite the substantial number of scientific studies dedicated to the problem of energy and resource preservation in the cultivation and harvesting of agricultural crops, and the development of engineering tools that ensure high quality of process operations, some issues remain unresolved to this day.

1. Introduction
The reduction of prime costs and simultaneous improvement of quality of commercial products are the essential criteria of an effective farming irrelevant of the form of incorporation of the producer.

It would be impossible to reach the above goals of effective farming without innovative high-performance machines and equipment whose processes are based on cutting-edge scientific research within the field of integration of applied and fundamental studies in the area of advanced technologies of cultivation and harvesting of agricultural crops [1-3].

One of the major aspect of reducing prime cost share withing the production structure of agricultural products at all its stages is the improvement of effectiveness of machine-processing complexes. This can be most clearly seen in the potato and vegetable cultivation sectors [4-7].

It should be noted that when discussing individual processes of vegetable production, the most energy-intensive is the process of harvesting of onion, garlic and root crops with subsoil fructification since
extraction of crops from the soil is highly energy-demanding due to the need to actuate lifting and separating working elements [8-11].

2. Materials and methods
When carrying out on-site studies to determine the quality characteristics of the set onion harvester (figure 1), a supplemental topic of study was selected to be the parameter of specific energy intensity of the basin formation process for setting set onions within a roll [11-15].

Set onion harvester is comprised of frame 1, lifting plowshare 2, traveling wheels 3, screw 4 depth adjustment mechanism, colter disk 5, main 6 and secondary 7 separating elements, top-pulling 8 and support rollers, roller separator 10, tapering chute 11, roll forming device 12, haulm stripper 13 which removes foreign materials, and working element drive gearbox 14.

The harvester is equipped with elliptic agitators 15 located at the main 6 and secondary 7 separating elevators, frame 16 which bears foreign materials ejection trough 17 and basin-forming roller (figure 2), which includes spiral 18 and smooth cylindrical 19 rolls. The active rolls 18 and 19 are driven by gearboxs 20 and 21.

Power intensity assessment of set onion harvester equipped with the basin-forming roller was carried out in accordance with OS AIST 8.7-2013 «Tests of agricultural machinery. Machines for harvesting
vegetables and gourds. Methods for evaluation of functional indicators», and GOST Standard 20915-75. «Agricultural machines. Methods for determining testing conditions».

The value of torque at tractor's PTO was determined using a strain gage fork 1 (figure 3), and the rate of revolution of PTO - with an induction sensor 1.

3. Results and discussion

Based on the results of a multi-factor experiment, an adequate mathematical model with encoded results was developed, which described the dependency of specific energy intensity of the basin formation process \( \nu' = (n_{SR}, f, n_{SV}, V_M) \) of the set onion harvesting machine on the following factors:

\[
Y = 239 - 14,12x_1 - 7,75x_2 + 5,37x_3 - 27,25x_1^2 - 3x_2^2 - 2,24x_3^2 + 0,24x_1x_2 - 10,5x_1x_3 + 0,24x_2x_3. \quad (1)
\]

The hypothesis of the second order model's validity was verified using statistical analysis of regression equation.

The Fisher's ratio test value \( F \) for the 5% significance level for the obtained equation and the degree of freedom of the numerator \( \nu' = N_o - (k_f + 1) = 11 \), and of the denominator \( \nu_2 = N_o(m - 1) = 30 \), was selected to be equal to 2.1. The calculated value of Fisher's ratio test \( F = 1.73 \).

Since \( F_T = 2.1 > F = 1.73 \), the mathematical model is adequate.

By substituting value \( x_1=0 \) into the equation (1), we produced a two-dimension section of the response surface, which characterizes the quality characteristic of the basin-forming roller, i.e., specific energy intensity of the the basin-forming roller on the rate of rotation of the cylindrical roll \( (x_2) \) and the travel speed of the set onion harvester \( (x_3) \):

\[
Y = 239 - 7,75x_2 + 5,37x_3 - 3x_2^2 - 2,24x_3^2 + 0,24x_2x_3. \quad (2)
\]

The coordinates of the response surface were determined by differentiating the equation (2) and solving the following system of equations:

\[
\begin{align*}
\frac{dy}{dx_2} &= -7,75 - 6x_2 + 0,24x_3 = 0, \\
\frac{dy}{dx_3} &= 5,37 - 4,48x_3 + 0,24x_2 = 0.
\end{align*} \quad (3)
\]

By solving the set of equations (3), we produced the coordinates of the center of the response surface function in an encoded format: \( x_2 = -0,83, \ x_3 = 1,15 \) (the decoded value: \( n_{SV} = 29.2 \text{ min}^{-1}, \ v_M = 1.56 \text{ m/s} \)).

By applying values \( x_2 \) and \( x_3 \) to the equation (1), we obtained the value of the response function at the center of the surface:

\[
Y_S = 246,35. \quad (4)
\]
By applying canonical transformation of the equation (1), we obtained the equation in its canonical form:

\[ Y - 246.35 = 2.21x_2^2 + 3.02x_3^2. \]

(5)

Axes turning axle is:

\[ \tan 2\alpha_2 = \frac{0.24}{3.00 - 2.24} = 0.19. \]

(6)

Angle \(\alpha_2 = 2.6^\circ\).

By applying various values of the response function (1), we obtained contour plot (ellipse) equations. Calculation results are shown in figure 4.

Figure 4 demonstrates that specific energy intensity of operation of set onion harvester’s basin-forming roller is 225 kJ/m³ with the optimal values of the analyzed factors: the rate of revolution of the cylindrical roll of \(n_{SV} = 20.0 \text{ to } 38.5 \text{ min}^{-1}\), and the speed of travel of the set onion harvester of \(v_M = 1.42 \text{ to } 1.58 \text{ m/s}\).

The two-dimension section of response surface characterizing the dependency of specific energy intensity of the basin-forming roller on the rate of rotation \((x_1)\) of the spiral roll and the rate of rotation \((x_3)\) of the cylindrical roll is described by equation (1) with \(x_2 = 0\). Following the above:

\[ Y = 239 - 14.12x_1 + 5.37x_3 - 27.25x_1^2 - 2.24x_3^2 - 10.5x_1x_3. \]

(7)

Differentiation of equation (7) produces the following set of equations:

\[ \begin{align*}
\frac{dy}{dx_1} &= -14.12 - 54.5x_1 - 10.5x_3 = 0, \\
\frac{dy}{dx_3} &= 5.37 - 4.48x_3 - 10.5x_1 = 0.
\end{align*} \]

(8)

Solving this set of equations produced coordinates of the center of the response surface: \(x_1 = -0.813, x_3 = 3.24\) (and, respectively, in the decoded form, \(n_{SR} = 44.8 \text{ min}^{-1}, n_{SV} = 34.8 \text{ min}^{-1}\)) (figure 5).
By applying values $x_1$ and $x_3$ to the equation (1), we obtained the value of the response function at the center of the surface:

$$Y_S = 231,05.$$  \(9\)

After the calculation of the regression equation coefficients in its canonic form, the regression equation in the canonic form could be rewritten as follows:

$$Y - 231,05 = 20,45x_1^2 - 12,19x_3^2.$$  \(10\)

Axes turning axle is:

$$\operatorname{tg} 2\alpha_2 = \frac{4,75}{15,01 - 3,18} = 2,43.$$  \(11\)

Angle $\alpha_2 = 1.21^\circ$.

Figure 5 demonstrates that specific energy intensity of set onion harvester equipped with basin-forming roller is 240 kJ/m³ at the optimal values of the analyzed factors: the rate of rotation of spiral roll of the basin-forming roller $n_{SR} = 38 \text{ – } 53 \text{ min}^{-1}$, and the rate of rotation of the cylindrical roll $n_{SV} = 25.0 \text{ – } 40.5 \text{ min}^{-1}$.

The two-dimension section of response surface characterizing the dependency of specific energy intensity of the set onion harvester equipped with basin-forming roller on the rate of rotation ($x_1$) of the spiral roll and the travel speed ($x_2$) of the set onion harvester is described by equation (1) with $x_3 = 0$ (figure 6). Following the above:

$$Y = 239 - 14,12x_1 - 7,75x_2 - 27,25x_1^2 - 3x_2^2 + 0,24x_1x_2.$$  \(12\)

By differentiating the equation (12) and solving the set of equation:

$$\begin{cases}
\frac{dy}{dx_1} = -14,12 - 54,5x_1 + 0,24x_2 = 0, \\
\frac{dy}{dx_2} = -7,75 - 6x_2 + 0,24x_1 = 0,
\end{cases}$$  \(13\)

we obtain the coordinates of the response surface $x_1 = -0,26$, $x_2 = -1,32$ (and in the decoded form, respectively, $n_{SR} = 39 \text{ min}^{-1}$, $v_M = 1.58 \text{ m/s}$).

By applying values $x_1$ and $x_2$ to the equation (12), we obtained the value of the response function at the center of the surface:
After the calculation of the regression equation coefficients in its canonic form, the regression equation in the canonic form could be rewritten as follows:

\[ Y - 245.91 = 0.34x_1^2 - 3.58x_2^2. \]  

(A15)

Axes turning axle is:

\[ \tan 2\alpha_2 = \frac{0.24}{27.25 - 3.00} = -0.009. \]  

(A16)

Angle \( \alpha_2 = -31^\circ \).

The two-dimensional section of the response surface was generated on the basis of obtained data (Figure 6).

An analysis of Figure 6 reveals that the specific energy intensity of set onion harvester equipped with basin-forming roller is 236 kJ/m³ with the optimal values of the studied factors: the rate of revolution of the spiral roll and the travel speed of the set onion harvester within the range of \( n_{SR} = 28.5 - 54.5 \) min\(^{-1} \), \( v_M = 1.18 - 1.58 \) m/s.

Taking into account the significance of the regression coefficients, equation (1) can be represented as follows:

\[ Y = 10.03 + 0.33n_{SR} + 0.24v_M + 168.3n_{SV} - 0.02n^2_{SR} - 25.3v^2_M - 0.00007n^2_{SV} - 0.15n_{SR}v_M - 0.09n_{SR}n_{SV} - 0.7n_{SV}v_M. \]  

(A17)

An analysis of two-dimension sections presented on Figures 4 to 6 reveals that the optimal values of the studied factors lie within the following limits: the rate of rotation of spiral roll \( n_{SR} = 39.5 - 45.0 \) min\(^{-1} \), the travel speed of set onion harvester \( v_M = 1.56 - 1.58 \) m/s, and the rate of rotation of the cylindrical roll \( n_{SV} = 29 - 35 \) min\(^{-1} \).

4. Conclusion

The conducted studies show that at the rate of rotation of the spiral roll of the basin-forming roller at 22 to 55 min\(^{-1} \) the degree of soil opening (v,%) alters from its maximum value of 92.8%, which corresponds the speed of 0.7 m/s, to its minimum value of 70%, at the speed of 1.5 m/s. The variation interval of the degree of soil opening has values from 4 to 23%. It is worth noting, that the difference...
between the maximum and the minimum values of the degree of soil opening within the same speed interval varies from 2 to 8%.

The results of the conducted studies allow to make the conclusion that with the increase of travels speed $v_M$ of set onion harvester, the degree of soil opening declines since the volume delivered to the spiral roll of the basin-forming roller increases as the result of reduced intensity of action of the spiral roll on the formed basin and the increase of specific energy intensity of set onion harvester.

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