

Optimization of Parameters and Operating Modes of Vibration roller



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Abstract: The optimal parameters and operating modes of vibratory roller for soil compaction after sowing winter wheat were substantiated. For objective function - the optimum coefficient of variation of density of soil during operation of vibratory roller for compacting winter wheat regression equation was obtained in the planning according to the B_k plan of the experiment. The adequacy of model according to Fisher criterion, the significance and reliability of coefficients of regression equation was established. The response surface obtained by the shape of hyperboloid rotation was studied, two-dimensional sections of three factors were constructed on optimization criterion. With its minimum value, the optimal parameters of vibratory roller were established: the mass of roller is 293 kg, the spring stiffness is 11.95 kN/m, the working speed of roller is 9.6 km/h. The minimum value of optimization criterion is 10.43%.

Keywords: experiment planning, regression equation, optimization criteria, response function, canonical equation, vibratory roller.

I. INTRODUCTION

A further increase efficiency of agricultural production is impossible without improving machine technologies, as well as optimizing parameters, rational operation modes of machines and their use. The competitiveness of manufactured products is determined by their cost, productivity of machines and quality of their

work. Optimization of parameters and operating modes of machines in this area is an urgent task, because production efficiency depends on technology. Scientific approaches [1, 2, 3] to the substantiation parameters of technology determine results of research. The purpose of article submission - based methods of planning 3 factorial experiment by the B_k plan optimal parameters and operation of vibrating roller for optimal compaction in winter wheat.

II. RESEARCH MATERIALS

The influence of following three factors established as a result of previously conducted one-factor experiments, as well as their fixed values at optimal levels by the uniformity of soil density in treated area, was studied: operating speed, km/h; roller mass, kg; spring stiffness, kN/m. Other parameters of developed vibratory roller are impractical to use as controlled factors, since they are not decisive for reducing the unevenness of soil density in the packed area.

The symmetric compositional plan of the B_k type was chosen to build plan for 3-factor experiment, whose star points are equal ± 1 . Factors, intervals of variation and their levels for the experiment are shown in table 1.

Table 1 - Factors, intervals and their levels of variation

Factors	Coded representation	Variation interval	Factor variation levels		
			-1	0	+1
Operating speed (v), km/h	x_1	4	4	8	12
Roller mass (G), kg	x_2	100	150	250	350
Spring stiffness (N), kN/m	x_3	6	6	12	18

The operating speed v of movement was set by shifting gears in the gearbox and supplying fuel. The stopwatch measured time of movement of the unit on a certain section of path in field marked by pegs. The mass of the roller was weighed on platform scales. The stiffness of the springs was selected depending on diameter of wire, cross-sectional area of spring and material of the spring.

The three-factor experiment planning matrix is shown in table 2.

In the experiment, a second-order polynomial with three variables was used as a response function. After processing the obtained data, was obtained a regression equation with imaginary coefficients.

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Table 2 - Experiment planning matrix.

Coded value variables			Natural value variables			Coefficient of soil density variation ν , %
x_1	x_2	x_3	Operating speed (ν), km/h	Roller mass (G), kg	Spring stiffness (H), kN/m	
+1	+1	+1	12	350	18	21,1
-1	+1	+1	4	350	18	16,2
+1	-1	+1	12	150	18	29,3
-1	-1	+1	4	150	18	28,9
+1	+1	-1	12	350	6	21,2
-1	+1	-1	4	350	6	19,9
+1	-1	-1	12	150	6	22,8
-1	-1	-1	4	150	6	26,1
+1	0	0	12	250	12	10,3
-1	0	0	4	250	12	8,9
0	+1	0	8	350	12	10,8
0	-1	0	48	350	12	18,1
0	0	+1	8	250	18	20,9
0	0	-1	8	250	6	21,2

Criteria for optimizing problem (response) is the coefficient of variation ν of soil density series in corresponding series of experimental plan. The minimum value of the coefficient ν is corresponds to the best result of uniformity of compaction and determines the optimal design and regime parameters of the vibratory roller: its mass G , spring stiffness H and operating speed ν of the unit.

The regression equation (1) of the response function has the form:

$$Y = 11,108 + 0,469x_1 - 3,551x_2 + 0,523x_3 + 1,377x_1x_2 + 0,912x_1x_3 - 1,638x_2x_3 - 1,357x_1^2 + 3,46x_2^2 + 10,094x_3^2 \quad (1)$$

where Y – coefficient of soil density variation;
 x_1 – coded value of the unit speed;
 x_2 – coded value of the roller mass;
 x_3 – coded value of stiffness of the spring.

Below is the equation for translating coded values of factors into valid ones:

$$X_1 = 8x_1 + 4; X_2 = 250x_2 + 100; X_3 = 12x_3 + 6 \quad (2)$$

where X_1 – valid value of unit speed, km/h;
 X_2 – valid value of roller mass, kg;
 X_3 – valid value of spring stiffness, kN/m.

The coefficients of regression equation (1) obtained as a result of calculation were checked for significance by tentative calculating the confidence interval using Student's criterion. As a result, all coefficients of obtained equation turned out to be significant.

$$db_0 = 0,41; db_i = 0,073; db_{ij} = 0,066; db_{ii} = 0,412; \text{ at } t = 2,57.$$

To verify adequacy of the model according to the Fisher criterion, used the obtained experiments in the center of the plan to find variance of experience.

The natural values of variables of the plan in center of the plan are presented in table 3.

Table 3 - Natural values of variables in center of the plan

Coded value variables			Natural value variables			Coefficient of soil density variation ν , %
x_1	x_2	x_3	Operating speed (ν), km/h	Roller mass (G), kg	Spring stiffness (H), kN/m	
0	0	0	8	250	12	10,29
0	0	0	8	250	12	10,88
0	0	0	8	250	12	10,51
0	0	0	8	250	12	10,56
0	0	0	8	250	12	10,32

As a result of calculations variance of experience is obtained
 $S_y^2 = 0,255; F_{\text{tabular}} = 4,74; F_{\text{calculated}} = 0,78$

Equation is adequate $F_{\text{tabular}} \geq F_{\text{calculated}}$.
 System of linear equations is obtained by differentiating equation for each variable and equating it to zero:

$$\begin{cases} dy/dx_1 = 0,469 - 2,714x_1 + 1,376x_2 + 0,912x_3 \\ dy/dx_2 = -3,55 + 1,376x_1 + 6,92x_2 - 1,638x_3 \\ dy/dx_3 = 0,523 + 0,912x_1 + 1,638x_2 + 20,188x_3 \end{cases} \quad (3)$$

The coordinates center of response surface are can be found by solving system of linear equations: $x_1 = 0,39; x_2 = 0,433; x_3 = -0,0083$.

Substituting into original regression equation (1) values of x_1, x_2, x_3 , it can be received value of optimization parameter ν in center of response surface. This is the response value at new origin (free term of the canonical equation) $Y_s = 10,428$.

Perform to canonical conversion. For this, equation (1) was transferred to a new coordinate system and the coordinate axes were rotated. In this case, equation (1) is simplified to the form:

$$Y - Y_s = B_{ii} \cdot x_i^2 + B_{jj} \cdot x_j^2 + B_{kk} \cdot x_k^2 \quad (4)$$

where B_{ii}, B_{jj}, B_{kk} – canonical equation coefficients.

The angle α rotation of original coordinate axes of response surface is determined unto align with main axes of figure $\alpha = 6,93$ deg.

After transformations, equation (1) in canonical form has following form:

$$Y - 10,428 = -1,357X_1^2 + 3,36X_2^2 + 10,194X_3^2 \quad (5)$$

To further study response surface (4) it's two-dimensional cross-sections were constructed. Initially, the cross-section of response surface with X_1SX_2 plane is considered. To do this, substitute $x_3 = -0,083$ in equation (1) and get:

$$Y_{12} = 11,105 + 0,461x_1 - 3,537x_2 + 1,376x_1x_2 - 1,357x_1^2 + 3,468x_2^2 \quad (6)$$

where Y_{12} – coefficient of variation in the density (6) of the soil in the interaction of 1 and 2 factors, when the 3rd factor is in plan center of experimental design.

Performing canonical transformation and solving system of linear equations is found response surface central coordinates $Y_s = 10,428$ when $x_3 = -0,0083$.

III. RESULTS AND DISCUSSION

The angle α rotation of coordinate axes is determined. It is equal $- 7,97$ deg., And coefficients at unknowns in canonical form are equal: at $B_{11} = -1,453$; at $B_{22} = 3,556$. The response surface equation in canonical form is obtained:

$$Y_{12} - 10,428 = -1,453X_1^2 + 3,556X_2^2 \quad (7)$$

The resulting response surface (fig. 1) is hyperboloid rotation, which is indicated by the coefficients of regression equation (7) in canonical form, since they have different signs. The optimal value of response function is at point with coordinates: $X_1 = 0,39, X_2 = 0,433$.

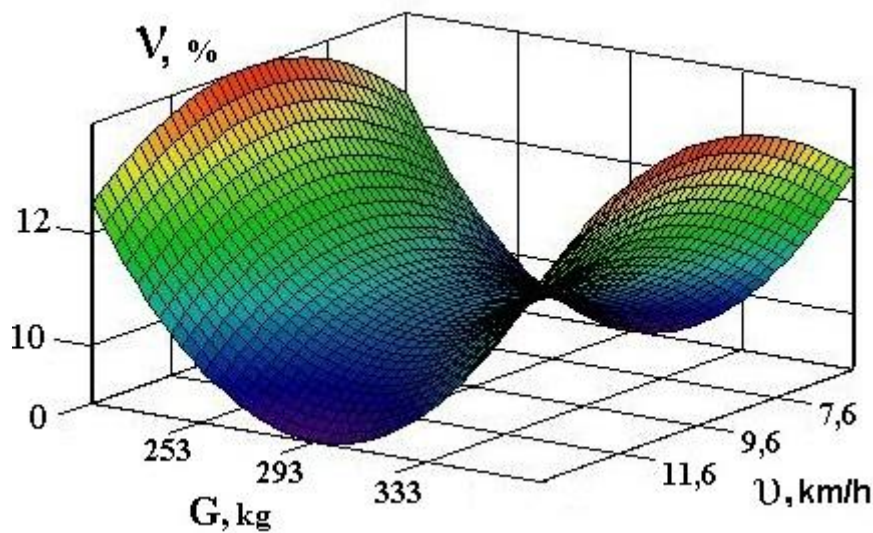


Figure 1. Response surface for depending on unit speed v and roller mass G
 Given values of variables and substituting them in equation (7), a family of conjugate isolines is obtained (fig. 2).

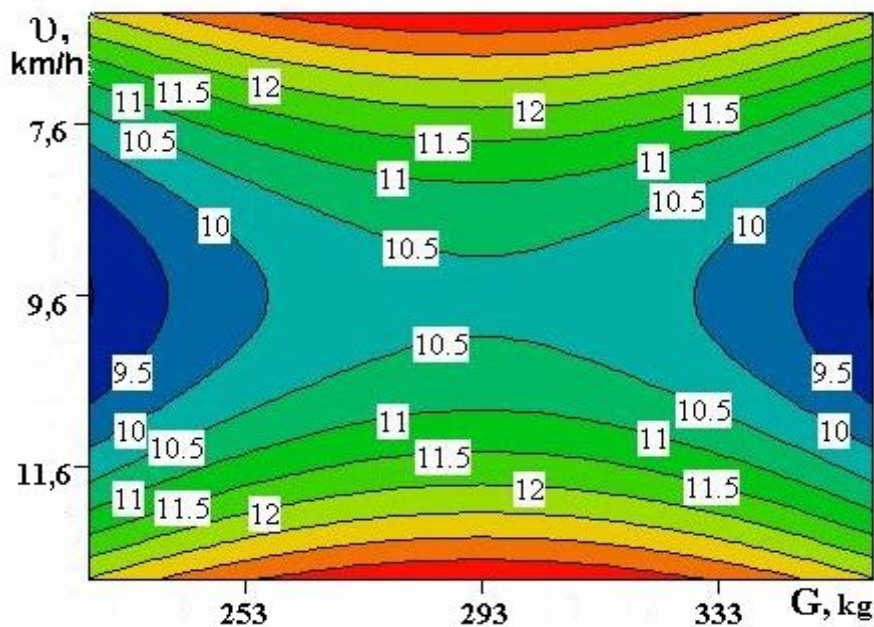


Figure 2 - Two-dimensional cross-section of response surface depending on machine speed v and roller mass G

The contours obtained as a result of cross section of response surface are elongated along axis of corresponding operating speed of unit. Therefore, this factor 7.3 times less affects uniformity of soil density during compaction with vibratory roller than roller mass.

When $x_3 = -0,0083$ in coded form, i.e. when coefficient of soil density variation in the center of the experiment plan and equal to 10.428%, the working speed is $v = 9,6\text{km/h}$, and roller mass G is 293 kg.

Consider the cross section of response surface with density X_1X_3 . For this, $x_2 = 0,434$ in the regression equation (1) is substituted. The regression equation took form:

$$Y_{13} = 10,22 + 1,065x_1 - 0,188x_3 + 0,913x_1x_3 - 1,354x_1^2 + 10,094x_3^2 \quad (8)$$

Having performing canonical transformation and solving system of linear equations, was founding

coordinates of center response surface: $x_1 = 0,39$, $x_3 = -0,0083$.

Substituting found value of x_1 and x_3 into equation (1) was determining value of parameter of optimization in center of response surface at $x_2 = 0,433$. The value of parameter of optimization – coefficient of soil density variation $Y_{13} = 10,428$. The rotation angle of coordinate axes α is $-2,28$ degrees, and regression coefficients in canonical form are equal: at X_1 $B_{11} = -1,375$, at X_3 $B_{33} = 10,113$. Now response surface equation in canonical form takes the form:

$$Y_{13} = 10,428 - 1,375X_1^2 + 10,113X_3^2 \quad (9)$$

The response surface has form of hyperboloid rotation (fig. 3), because coefficients of regression equation are B_{11} and B_{33} with different signs.

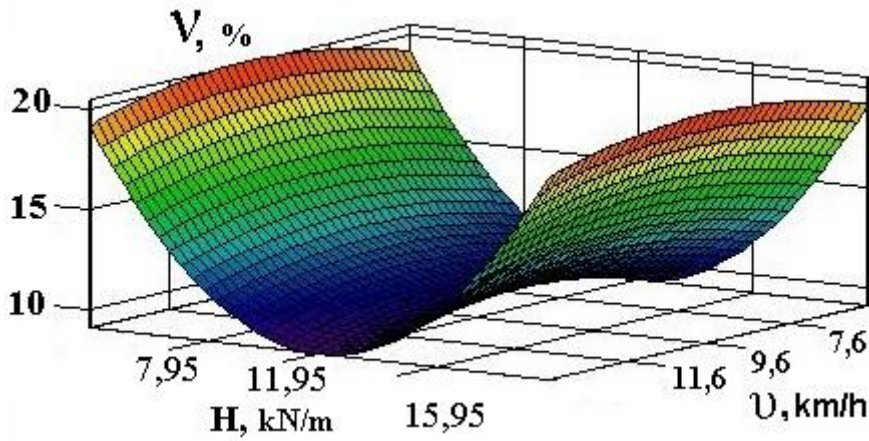


Figure 3 - Response surface depending on operating speed of unit and spring stiffness

The optimal value of response function is at the point with coordinates $x_1 = 9,6\text{km}/\text{u}$, $x_3 = 11,95\text{KH}/\text{M}$.

Consider two-dimensional cross section of response surface of X_1SX_3 plane (fig. 4), when $x_2 = 0,434$, i.e. at its optimum value. The cross section of response surface in experiment area gives isolines (fig. 4), from which it follows that change in operating speed of unit affects less than spring stiffness, because the elongation of isolines by unit speed is higher than along x_3 axis, and coefficient of regression equation is $|B_{11}| < |B_{33}|$.

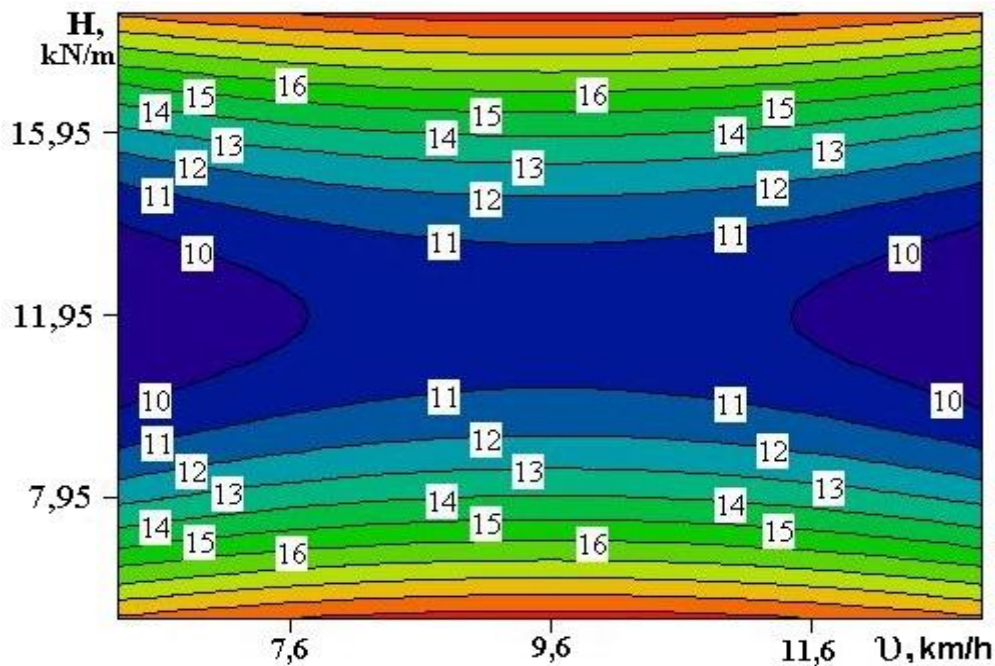


Figure 4 - Two-dimensional cross-section of response surface depending on operating speed of unit and spring stiffness

Consider cross section of response surface by X_2SX_3 . plane. To do this, substitute value $x_1 = 0,39$ in equation (1) and obtain following expression

$$Y_{23} = 11,085 - 3,14x_2 + 0,878x_3 - 1,638x_2x_3 + 3,468x_2^2 + 10,094x_3^2 \quad (10)$$

Having performing canonical transformation and solving system of linear equations, were founding coefficients of center response surface: $x_2 = 0,434$ and $x_3 = -0,0083$. Substituting found value in equation (1), was determined the value of parameter of optimization in center of response surface at optimal value $x_1 = 0,39$.

Equation (10) has pair interaction (x_2x_3) , and rotation angle of coordinate axes α is 2.28 degrees. The motion of regression coefficients in canonical form are equal: at X_2 $B_{22} = 3,36$, at X_3 $B_{33} = 10,194$.

The regression equation of response surface in canonical form is:

$$Y_{23} - 10,128 = 3,36X_2^2 + 10,194X_3^2 \quad (11)$$

The response surface (fig 5) is paraboloid of rotation, and optimum value of response function is at point with coordinates: $x_2 = 0,434$ and $x_3 = -0,0083$ with positive values. The isolines of two-dimensional sections (Fig. 6) were obtained in form of an ellipse, and its long axis indicates a lesser effect on uniformity of soil density by roller mass compared to spring stiffness: $|B_{22}| < |B_{33}|$ at $B_{22} = 3,36$ and $B_{33} = 10,194$.

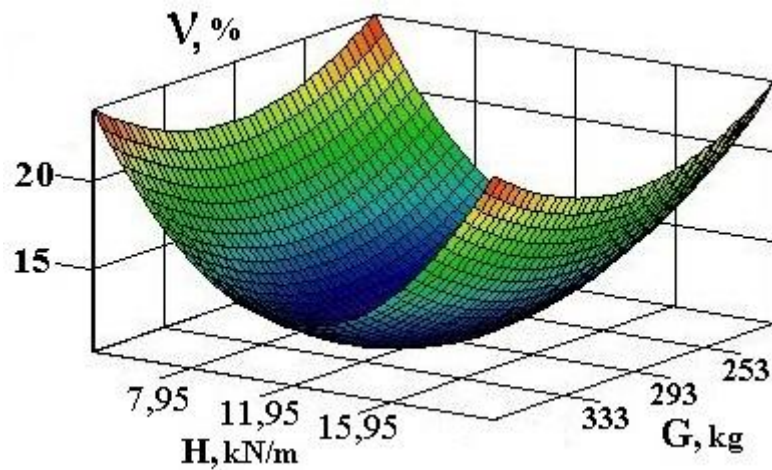


Figure 5 - Response surface depending on roller mass and spring stiffness

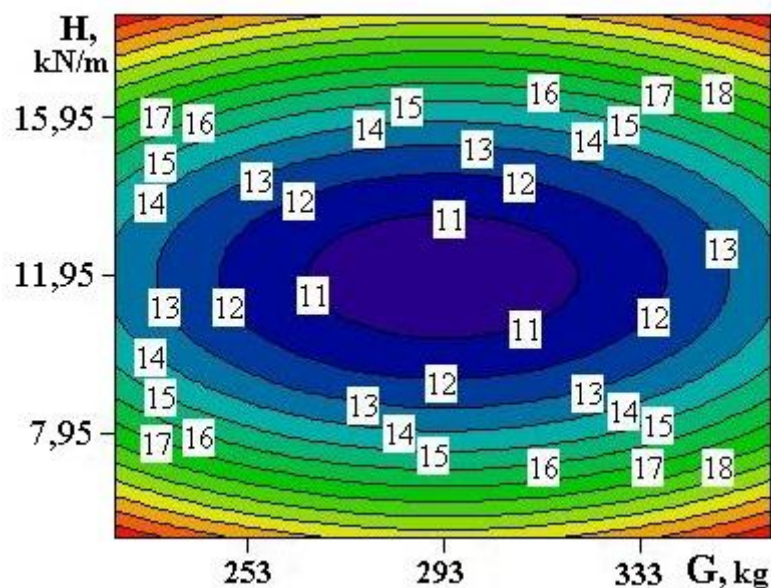


Figure 6 - Two-dimensional cross-section of response surface depending on roller mass and spring stiffness

Thus, in proposed vibratory roller the largest influence on quality of soil compaction is affected by spring stiffness, which creates vibration of the compacting drum of roller.

IV. CONCLUSION

The optimal parameters of vibration roller and its operating modes were established by planning the experiment according to plan B_k using a 3-factor experiment, taking into account the fulfillment of agricultural requirements for the uniformity of soil compaction by rollers.

According to obtained regression equation, according to criterion of minimum value of coefficient of soil density variation after the passage of vibratory roller, the optimal operating speed of the unit is $v = 9,6$ km/h, the roller mass $G = 293$ kg, the spring stiffness is $H = 11.95$ kN/m. At a minimum value of optimization criterion $v = 10,43$ %.

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