OPTIMIZATION OF THE STACKER PARAMETERS OF THE POMEGRANATE BURYING MACHINE USING THE METHOD OF MATHEMATICAL PLANNING OF EXPERIMENTS

Abdunazarov Elbek Elmurodovich
Doctoral Student (PhD), Scientific Research Institute of Agricultural Mechanization (QXMITI), Uzbekistan
*Email: abdunazarovelbek@gmail.com

Abstract
The article presents the results of optimizing the parameters of the soil stacker of a machine designed for covering pomegranate bushes with soil, based on the method of mathematical planning of experiments. The optimization was conducted using a multi-factor experimental design, which allowed the determination of the most effective working parameters that ensure high-quality performance and minimal energy consumption.

Keywords: machine for covering pomegranate bushes, soil compaction device, degree of bush damage, soil ridge density, ridge height, ridge width, covering thickness, stacker. are reduced to a level that is ineffective for their induction, and therefore they can degrade even low concentrations of pollutants.

Introduction

In the climatic conditions of Uzbekistan, to prevent pomegranate bushes from being damaged by frost, they are covered with soil in late autumn and uncovered in spring. However, due to the absence of specialized machinery, the operations of burying and uncovering the bushes have not yet been mechanized and are still performed manually. Consequently, this increases labor costs, reduces productivity, and negatively affects the cultivation of pomegranates, yield potential, and the establishment of large-scale plantations [1; 2; 3; 4; 5].

It should also be noted that since the covering operation is usually carried out in late autumn, early winters prevent full manual coverage of all plantation areas, resulting in the loss of bushes due to frost. Considering these factors, a research project has been initiated at our institute to develop a machine for covering pomegranate bushes with soil and to justify its design and working parameters [6; 7; 8].

To study the combined effect of the main design and operational parameters of the stacker (soil placing mechanism) on the machine's performance indicators, multi-factor experiments were carried out using the method of mathematical planning of experiments. This approach enables the determination of optimal parameter combinations with minimal experimental effort while maintaining statistical validity [9; 10].

Research Methods and Results

To study the mutual influence of the parameters of the stacker of the pomegranate burying machine—previously analyzed theoretically and in single-factor experiments—and to determine their optimal values, multi-factor experiments were conducted using the method of mathematical planning of experiments [11; 12].

In these studies, it was assumed that the effect of the factors on the response functions could be expressed by a second-order polynomial equation, and the experiments were organized according to the B_4 design matrix [13].

The following parameters were identified as the most influential factors affecting the quality and energy indicators of the machine: Y_p – stiffness of the stacker's pressure spring (N/m), Y_r – diameter of the stacker rollers (mm), n_{rs} – number of stacker rollers (pcs), V – movement speed of the aggregate (km/h). These factors were conditionally denoted as follows: X_1 – stiffness of the pressure spring (N/m), X_2 – diameter of the rollers (mm), X_3 – number of rollers, X_4 – movement speed (km/h).

Based on theoretical research and single-factor experiments, the variation ranges and levels of the factors were determined (Table 1) [14]. In the multi-factor experiments, the following were selected as response criteria: Y_1 – degree of mechanical damage to the pomegranate bush trunk (%), Y_2 – burial thickness of pomegranate bushes (%), Y_3 – proportion of unburied bushes (%). To minimize the influence of uncontrollable factors, the sequence of experiments was determined using a random number table [15; 16]. Experimental data were processed using the PLANEXP software, developed in the SRIAM laboratory for experiment design. The following statistical criteria were used in data analysis: Cochran's test – to assess homogeneity of variance, Student's t-test – to evaluate regression coefficients, Fisher's test – to assess model adequacy [17].

Table 1. Factors, their coded designations, variation intervals, and levels

Name of the factor	Factor				
	Symbol	Variation interval	Symbol		
			– 1	0	+1
1. Stiffness of the pressure spring, N/m	X_1	50	300	350	400
2. Diameter of the rollers, mm	X_2	20	50	70	90
3. Number of rollers, pcs	X_3	1	2	3	4
4. Movement speed, km/h	X_4	1	5	6	7

Experimental data processing yielded the following regression equations that adequately describe the relationships between the influencing factors and the response functions [18]:

For the degree of cutting and crushing of the bush stem (%):

$$Y_1=3{,}007+0{,}400X_1-0{,}928X_2-0{,}667X_3+0{,}563X_4+0{,}727X_1X_1+0{,}000X_1X_2+0{,}037X_1X_3+ +0{,}000X_1X_4+1{,}125X_2X_2-0{,}401X_2X_3+0{,}404X_2X_4+0{,}450X_3X_3+0{,}417X_3X_4+0{,}263X_4X_4; \quad (1)$$

For the degree of stem fracture (%):

$$Y_2=1{,}172+0{,}265X_1-0{,}652X_2-0{,}232X_3+0{,}282X_4+0{,}471X_1X_1+0{,}064X_1X_2+0{,}039X_1X_3- -0{,}011X_1X_4+0{,}671X_2X_2-0{,}168X_2X_3+0{,}095X_2X_4+0{,}000X_3X_3+0{,}090X_3X_4+0{,}127X_4X_4 \quad (2)$$

For the degree of stem detachment (%):

$$Y_3=0{,}642+0{,}266X_1-0{,}465X_2-0{,}173X_3+0{,}217X_4+0{,}343X_1X_1-0{,}015X_1X_2-0{,}017X_1X_3+ +0{,}008X_1X_4+0{,}400X_2X_2+0{,}042X_2X_3-0{,}043X_2X_4+0{,}035X_3X_3+0{,}048X_3X_4+0{,}088X_4X_4 \quad (3)$$

For the degree of branch damage (%):

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Y_4=3,998+1,201X_1-2,107X_2-0,773X_3+0,883X_4+1,199X_1X_1+0,528X_1X_2-0,064X_1X_3+ +0,000X_1X_4+1,309X_2X_2-0,693X_2X_3+0,613X_2X_4-0,264X_3X_3+1,204X_3X_4-0,221X_4X_4 (4)

Analysis of the obtained expressions (1–4) and corresponding graphical dependences showed that the working quality with minimal energy consumption could be ensured by determining the optimal parameter values through simultaneous solution of the regression equations in Microsoft Excel using the "Goal Seek" tool [19].

The optimization conditions were as follows: Y_1 (bush stem damage) – minimum possible value; Y_2 (burial thickness) – within 10–15 cm; Y_3 (unburied share) – ≤ 3%. Under these constraints, the optimal parameter ranges were determined for working speeds of 5– km/h as: Stiffness of the pressure spring: 260.3–267.5 N/m, roller diameter: 82.55–86.54 mm, number of rollers: 6.3–6.6 pcs.

Table 2 Optimal values of stacker parameters

X_4	X_1	X_2	X_3
7	267,5	89,22	6,0
6	267,9	88,16	6,0
5	268,4	87,35	6,0

Since the number of rollers must be an integer, it was set to 6 rollers. Accordingly, the system was optimized for working speeds of 5.0–7.0 km/h, yielding the results summarized in Table 2.

Conclusion

The conducted analysis showed that, at an operating speed of 5–7 km/h, with the optimized parameter values, the pomegranate burying machine ensures high-quality performance with minimal mechanical damage to the plants. The degree of cutting and crushing of the bush trunk ranged from 2.86% to 1.76%, the degree of stem fracture from 0.41% to 1.11%, the degree of stem detachment from 0.34% to 0.42%, and the degree of branch damage from 1.37% to 3.85% [20].

Thus, under these operating conditions, the machine's stacker provides effective burial of pomegranate bushes while maintaining the integrity of the plants, reducing labor intensity, and improving overall mechanization efficiency. The experimental results confirm that the mathematical planning of experiments is an effective tool for optimizing the working parameters of agricultural machinery, particularly in developing specialized equipment for pomegranate cultivation in Uzbekistan's climatic conditions.

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