Analysis of the influence on the structural composition of the soil of the main design and regime parameters of the vibratory roller

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Abstract. The article presents the results of experimental studies of a soil-cultivating vibratory roller, as a result of which adequate mathematical models have been obtained that characterize the rolling process from the standpoint of compliance with the reference values of the structural composition of the soil. From the condition of ensuring the best quality of work, the optimal mass of the vibratory roller and the rotational speed of unbalancers are determined. According to the results of the research, it was revealed that the quality of rolling by the developed vibratory roller, estimated by the coefficient of compliance with the standard, is 29.9% better than that of the KKZ-6 roller commercially produced by the industry.

1 Introduction

The structural composition of the soil is the percentage of soil clods of various sizes formed during mechanical action on the soil. According to agrotechnical requirements, soil clods cannot be less than 0.025 mm (dust) and more than 50 mm (soil lumps). With a large amount of dust, the supply of moisture and useful minerals to plants is reduced, and large soil blocks make it difficult for plants to germinate [1–4].

During field studies of a soil-cultivating vibrating roller (vibratory roller), one of the mandatory elements of the experiments is taking soil samples to determine its structural composition after each pass of the roller in three repetitions. For this, soil samples were placed in an oven to dry them. The main indicator after drying the soil is the same residual moisture in all samples, which was checked without fail.

Then the dried soil samples were separated into different fractions using a set of sieves equipped with a vibrator (Figure 1) with hole diameters from 50 mm to 0.025 mm. After pouring the sample onto the upper sieve, the device was turned on for a minute. During this time, the sample was divided into fractions. Then, each soil fraction was weighed separately [5–8].

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Fig. 1. Set of sieves with vibration drive.

To more accurately fulfill the agrotechnical requirements, we have developed a new soil-cultivating vibratory roller (Figure 2), the main feature of which is the vibrational effect on the soil, provided by the rotation of the unbalancers 1. The unbalancers 1 are installed on the axis 2 of the vibratory roller and are driven from a smooth cylinder 3 located between the bars 4 and axis 2 in the inner space of the vibratory roller (Figure 3).

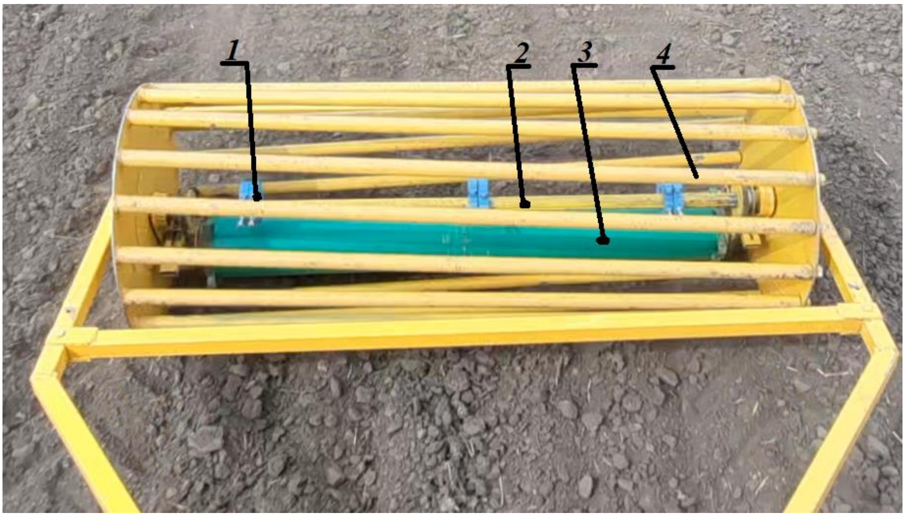

Fig. 2. Soil-cultivating vibratory roller.

In the course of the theoretical substantiation of the vibratory roller, the main design and operating parameters were identified that have the greatest impact on the quality of the roller, in particular, on the quality of the destruction of soil clods.

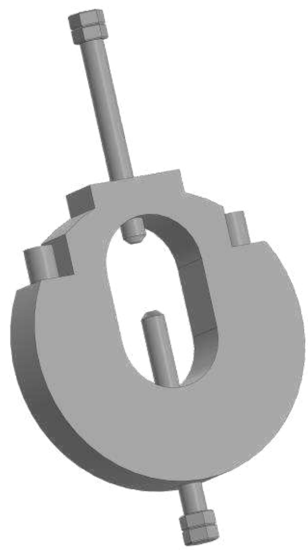

Fig. 3. Vibratory roller unbalancer.

2 Materials and methods

To confirm the correctness of the performed theoretical calculations, it is required to conduct field studies on a prepared field and determine the convergence of theoretical and experimental data.

The studies were carried out on the experimental field of the Ulyanovsk State Agrarian University, the preliminary preparation of which consisted of autumn plowing and spring cultivation (one day before rolling).

The main indicator that directly affects the quality of tillage with all agricultural implements is soil moisture. Therefore, before carrying out the experiments, we determined the soil moisture with the TDR 100 device in three repetitions along the diagonal of the site. Soil moisture averaged 24%. This slightly exceeds the permissible limits (from 18% to 22%), but the main feature of this experiment was the maximum approximation of the conditions to real production conditions, since sowing work was already underway in neighboring fields [9, 10].

To increase the yield, it is necessary to achieve a certain structural composition of the soil both before and after sowing. GOST 20915-2011 "Testing of agricultural machinery. Methods for determining test conditions" makes it possible to determine the structural composition of the soil according to the generally accepted methodology. During the experiments, we changed the design and operating parameters of the vibratory roller (Table 1).

Table 1. Variation of design and operating parameters.

Parameter name	**Parameters in natural values of factors**		
Pulley diameter on the axis of the hollow cylinder *d*, mm	80	60	40
Unit movement speed v, km/h	7	11	15
Ballast weight m, kg	0	50	100

Since the rotation frequency of the unbalancers varies depending on the speed of the unit movement v and the diameter of the pulleys d on the axis of the hollow cylinder, it is advisable to choose only one control measured parameter. The relationship of the above parameters can be traced according to the data given in Table 2.

Table 2. Changing the rotational speed of unbalancers.

	Pulley diameter on the axis of the hollow cylinder *d*, mm		
	80	**60**	**40**
Unit movement speed v, km/h	Rotation frequency of unbalancers n, min^{-1}		
7	468	624	936
11	736	918	1471
15	1003	1338	2006

3 Results

Using the STATISTICA program (Figure 4), we obtained adequate mathematical models of the process of soil compaction with a vibratory roller in 3D format in natural values of factors (Figure 5) and in 2D format in coded factor values (Figure 6). These models represent the dependences of the coefficient of conformity of the standard on the structural composition of the soil kstr on the ballast mass *m* (coded value - x) and the rotational speed of unbalancers *n* (coded value - y).

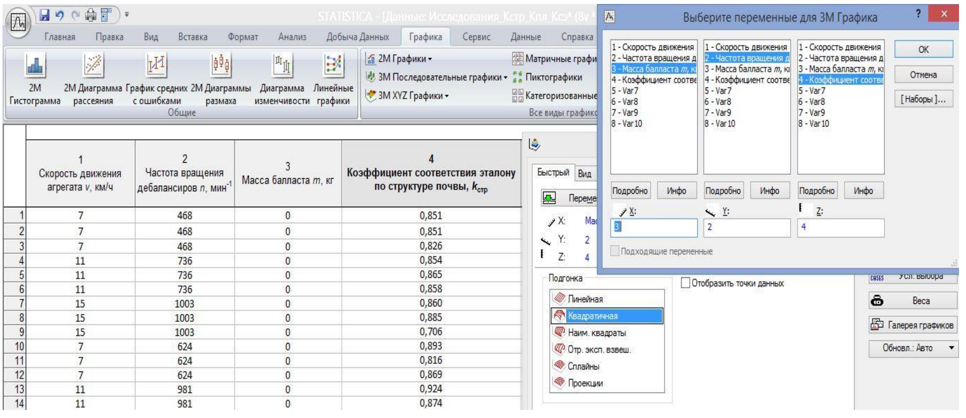

Fig. 4. Processing of experimental data in the program STATISTICA 10.

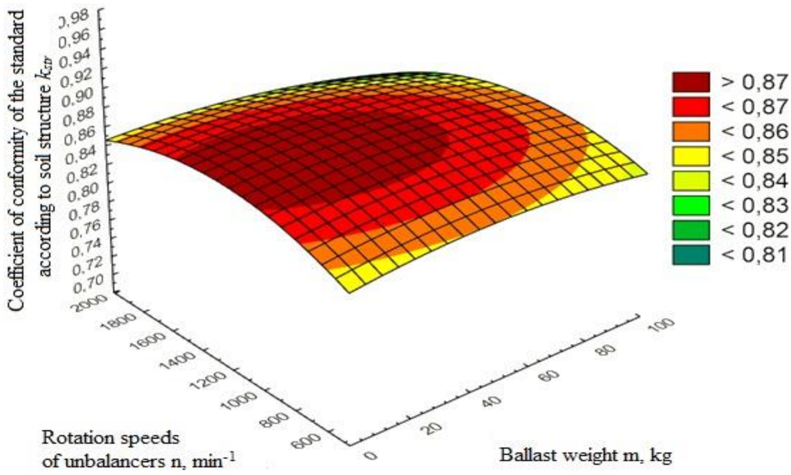

Fig. 5. 3D-mathematical model of the process of soil compaction with a vibratory roller.

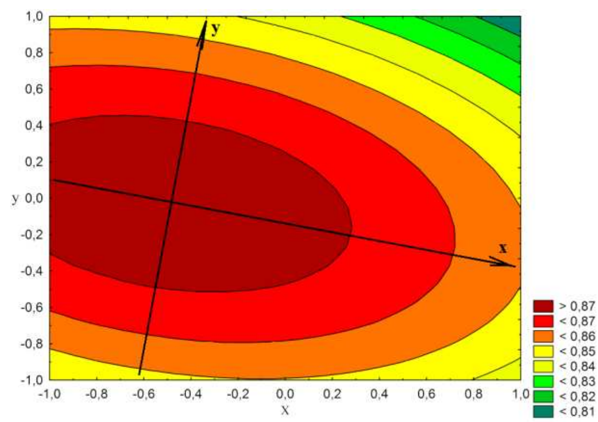

Fig. 6. 2D mathematical model with coded factor values.

We also present a mathematical model of the process in natural (1) and coded (2) factor values:

$$k_{str} = 0.7891 + 0.0006m + 0.0001n - 4.8738 \cdot 10^{-6}m^2 - 2.5605 \cdot 10^{-7}mn - 5.2273 \cdot 10^{-7}n^2 \quad (1)$$

$$K = 0.8738 - 0.0124x - 0.0068y - 0.0122x^2 - 0.0099xy - 0.031y^2 \quad (2)$$

After analyzing the obtained graphs, it is possible to identify the dependence of the coefficient of compliance with the standard on the structural composition of the soil on the frequency of rotation of unbalancers and on the mass of ballast in the vibratory roller. The ballast mass has a greater influence on the quality of the vibratory roller than the rotational speed of the unbalancers. Since the rotational speed of the unbalancers, in turn, depends on other parameters of the vibratory roller, then, taking into account the technically achievable speed of the unit under a specific soil condition and the pulley diameter determined by the technical conditions, it is possible to choose the parameters at which the maximum quality of work is achieved.

To achieve the maximum quality of the vibratory roller, which provides the best structural composition of the soil after rolling (extremum point in Figure 4), it is necessary to increase its mass *m* by 27 kg and ensure the rotational speed of unbalancers n = 1190 min^{-1}. In this case, the coefficient of compliance with the standard k_{str} = 0.87 is achieved.

Also, for a comparative assessment of the quality of work of the developed vibratory roller in the control area, similarly prepared for sowing, rolling was carried out with a serial roller KKZ-6, followed by soil sampling. After processing the data for this case, we obtained the coefficient k_{str} KKZ equal to 0.67.

4 Discussion

In the course of the experiment, we obtained results confirming the best quality of soil compaction by the developed vibratory roller from the standpoint of the compliance of the structural composition of the soil with agrotechnical requirements.

The resulting mathematical models are adequate and tested according to the Fisher and Cochran criteria. Checking models by Student's criterion confirms the significance of the coefficients of equations (1) and (2).

5 Conclusion

Based on the results of experimental studies, the following conclusions can be drawn:

- The mathematical models obtained after processing the results of the study made it possible to identify the optimal values of independent factors (ballast mass m = 27 kg, unbalancer rotation frequency n = 1190 min^{-1}), at which the best quality of soil cultivation is achieved, characterized by k_{str} = 0.87.
- The developed design of the vibratory roller provides an increase in the degree of compliance of the quality of the rolled field with the agrotechnical requirements for soil structure by 29.9% compared to the serial roller KKZ-6, which provides k_{str} KKZ, not exceeding 0.67.

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