Analysis of the structural composition of the soil during field studies of a soil-cultivating 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 were obtained from the standpoint of compliance with the reference values of the structural composition of the soil. According to the results of the research, it was revealed that the quality of rolling by the developed vibratory roller is 23.9% better than that of the serially produced roller KKZ-6. The optimal speed of movement of the unit and the frequency of rotation of unbalancers are also determined.

1. Introduction
Surface tillage is no less important task than the main one. Surface tillage includes such operations as cultivation, peeling, harrowing, rolling, etc. [1-3] Now there are a fairly large number of types and means of mechanization of tillage, but let's focus on rolling, since soil rolling ensures the fulfillment of agrotechnical requirements for the most important indicators, namely, soil density and structure [5-8].

The structural composition of the soil is soil aggregates of various sizes, they can be the size of dust (less than 0.025 mm), as well as in the form of soil blocks (the size of soil fractions is more than 50 mm). The structural composition of the soil has a direct impact on the growth and development of plants, since a large number of small soil particles (dust) reduces the number of pores (air and water) in the soil, and also increases wind erosion, while soil fractions of more than 50 mm do not allow growth and development plants.

When conducting field studies of the vibratory roller, we determined the soil moisture, and also took soil samples for structural composition.

Having carried out theoretical studies of the vibratory roller, we have identified the main design and operating parameters of this tool, which have a direct impact on the quality of rolling: the speed of the roller, the specific linear pressure (the change is carried out by adding ballast) and the rotational speed of unbalancers.

2. Materials and methods
We have developed a fundamentally new design of the vibratory roller (figure 1), the main design difference of which is the presence of a passive drive of unbalancers. The rotation is transmitted to the axis of the vibratory roller by means of a belt mounted on the pulleys on the sides of the smooth cylinder and on the axis of the hollow cylinder.
To conduct field experiments, the preparation of the field was carried out, which consisted of autumn plowing and cultivation a day before the start of the experiment.

Before the beginning of the field experiments, the moisture content in the soil was measured using a TDR 100 moisture meter in the seed location area (from 3 cm to 6 cm) in five repetitions, along the diagonal of the selected area for the experiment, while the distance between measurements was chosen the same, as a result soil moisture content varied from 24% to 28%, which exceeds the allowable soil moisture content for tillage and sowing, but the main goal of the experiment was to determine the optimal parameters in the field during the sowing campaign [9-10].

One of the most important indicators of the quality of tillage before and after sowing is the structural composition of the soil. This indicator directly affects both the sowing company and the quality of growth and development of the plant. To meet the agrotechnical requirements for soil structure, it is necessary to ensure that the size of soil aggregates varies from 50 mm to 0.025 mm, which corresponds to agro-requirements, soil aggregates larger than 50 mm (soil blocks) and less than 0.025 mm (soil dust) are not allowed at all.

The structural composition of the soil in the selected areas was determined by the generally accepted method in accordance with GOST 20915-75.

When studying the soil-cultivating roller on the experimental fields of the Federal State Budgetary Educational Institution of Higher Education of the Ulyanovsk State Agrarian University, we assessed the quality of soil cultivation by structural composition, taking soil samples at different operating modes of the rink (according to the experimental plan). Consider the variation of the operating parameters, which are presented in table 1 and table 2.

For a qualitative analysis of the results of the study, we use a factor coding system that allowed us to perform a qualitative analysis of the obtained regression equations and determine the significance of each parameter.

| Indicators | Parameters in natural values / coded values of factors |
|------------|------------------------------------------------------|
| Unit movement speed, km/h | 7 / -1 | 12 / 0 | 15 / -1 |

One of the main operational parameters of the vibratory roller is the rotational speed of unbalancers, which directly depends on the following parameters:

- Unit movement speed, \( v \).
The diameter of the pulley installed on the axis of the hollow cylinder (variation during the experiment $d_1 = 80$ mm; $d_2 = 60$ mm; $d_3 = 40$ mm).

**Table 2.** Variation of unbalancer rotation frequency (min$^{-1}$) in natural and coded values of factors.

| Pulley diameter on the axis of the hollow cylinder $d$, mm | 80   | 60   | 40   |
|----------------------------------------------------------|------|------|------|
| Unit movement speed, km/h                                | 7    | 11   | 15   |
| Parameters in natural factor values / coded factor values| 468 / -1 | 624 / -0.7906 | 936 / -0.3924 |
|                                                          | 736 / -0.6515 | 918 / -0.3329 | 1471 / 0.304 |
|                                                          | 1003 / -0.3043 | 1338 / 0.1313 | 2006 / 1     |

3. Results

As a result, we obtained experimental data, and after processing them in the STATISTIKA program, we obtained adequate mathematical models in 3D format in natural values of factors (figure 2) and 2D in coded values of factors (figure 3) values of the coefficient of conformity of the standard according to the structural composition of the soil $k_{str}$ depending on the speed of the unit movement $v$ (coded value $x$) and the frequency of rotation of unbalancers $n$ (coded value $y$).

![Mathematical 3D model](image1)

**Figure 2.** Mathematical 3D model.

![Mathematical 2D model with coded factor values](image2)

**Figure 3.** Mathematical 2D model with coded factor values.
We also present the formulas of the mathematical model in natural (1) and coded (2) factor values:

\[
 k_{str} = 0.7297 + 0.0188v + 6.0224 \times 10^{-5}n - 0.0016v^2 + 1.7368 \times 10^{-5}vn - 1.1562 \times 10^{-7}n^2
 \]

\[
 K = 0.8751 + 0.0191x - 0.0267y - 0.0258x^2 + 0.0534xy - 0.0684y^2
 \]  

(1)

The resulting mathematical model describes the quality of soil rolling from the standpoint of the compliance of the structural composition of the soil with the reference values of the specified agrotechnical requirements, which are expressed in the coefficient of compliance with the standard \(k_{str} = 0.88\), at the speed of the unit \(v = 12.5\) km/h and the frequency of rotation of unbalancers \(n = 1160\) min\(^{-1}\).

But it should also be noted that in figures 2 and 3 the surface is not significantly convex, which indicates a sufficient quality of soil cultivation with a vibratory roller in the entire range of studies. As a result, we can conclude about its versatility and high quality tillage.

Also, in order to assess the quality of the work of the developed vibratory roller, for comparison, in the experimental area, we performed rolling with a serial roller KKZ-6 and also took samples in this area. After processing the data, we obtained a coefficient \(k_{str}\) in this area equal to 0.67.

4. Discussion

In the course of the experiment, we obtained results confirming the 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 criteria of Student, Fisher and Cochran. Also, the obtained mathematical model in the coded values of the factors fully confirms the significance of each mode parameter.

5. Conclusion

Based on the data obtained, the following conclusions can be drawn:

- When processing the results of the study, we obtained mathematical models that allowed us to reveal that the improvement in the quality of tillage \((k_{str} = 0.88)\) is achieved with the speed of the unit \(v = 12.5\) km/h and the frequency of rotation of unbalancers \(n = 1160\) min\(^{-1}\).
- The developed design of the vibratory roller ensures the fulfillment of agrotechnical requirements for soil structure by 23.9%, since the coefficient \(k_{str}\) for the serial roller KKZ-6 was 0.67.

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