

# Field studies of the wave roller

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**Abstract.** The article presents a description of a fundamentally new design of a soil-cultivating wave roller and presents the results of its research. Adequate mathematical models of the soil rolling process are presented from the standpoint of compliance with the reference values of its density and aggregate composition. Thanks to the research, it was found that the quality of rolling by the developed wave roller is 20.9% better than that of the KKZ-6 roller commercially produced by the industry. To obtain the most high-quality rolling result, the developed wave roller determined its main design and operating parameters optimized for the process of surface tillage, namely: the speed of movement and the distance from the edge of the hollow cylinder to the inner surface of the compactor.

## 1 Introduction

One of the most important technical operations in the system of basic and pre-sowing soil preparation is rolling, which is carried out by tillage rollers. Rolling before sowing crops is of great importance in tillage systems, since it ensures the destruction of substandard soil clods and creates the required microrelief of the field surface, as well as provides optimal soil density [1-4].

When conducting field studies of the wave roller, we determined the following soil indicators: moisture content, aggregate composition, and density.

These soil indicators have a direct impact on the growth and development of cultivated plants. In particular, with optimal soil density, high-quality contact of seeds with soil is ensured, which contributes to their faster germination. At the same time, the aggregate composition of the soil corresponding to agrotechnical requirements reduces the time of emergence of seedlings, since there are no large soil clods on the path of germinating plants that seedlings need to go around or overcome [5-8].

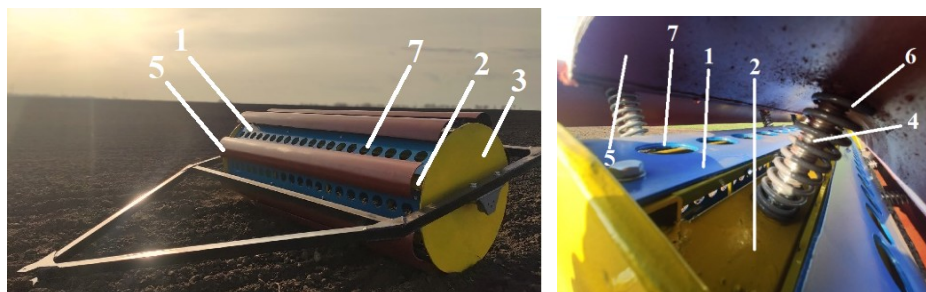
Having carried out theoretical studies of the wave roller, we have identified the main design and operating parameters of this tool, which have a direct impact on the quality of soil compaction: the speed of the unit and the distance from the edge of the hollow cylinder to the inner surface of the compactor.

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## 2 Materials and methods

We have proposed a completely new design of the wave roller (Figure 1), the main structural difference is the presence of elastic elements installed in parallel under the sealing elements. Due to the total stiffness of the springs installed on one compactor, which is 38.33 kN/m, the shock load in the contact zone of the compactor with the soil is reduced, as a result of which the soil surface is compacted to the required agrotechnical interval, with the formation of a wave relief on it.



**Fig. 1.** Soil-cultivating wave roller: 1 - generatrix of a hollow cylinder; 2 - rib; 3 - vertical disk; 4 - hairpin; 5 - sealing element; 6 - elastic element; 7 - hole.

Field preparation for the experiment consisted of autumn plowing, as well as cultivation a day before the start of field experiments.

Soil density is the most important indicator of the quality of tillage, as it directly affects the yield of crops. Overcompacted soil is a significant obstacle to the germination of roots in its lower layers, and undercompaction leads to a violation of the normal water regime of the soil, a decrease in the field germination of seeds and the occurrence of water and wind erosion of the soil. To meet the agrotechnical requirements for soil density, it is necessary to ensure its values vary from 800 kg/m<sup>3</sup> to 1200 kg/m<sup>3</sup>.

To determine the soil density in the experimental and control plots, a density meter was used (RF patent for utility model No. 149064), which measured the soil density in the depressions and in the crest of the wave relief formed by the developed roller. At the same time, soil samples were taken to determine its aggregate composition, which shows the relative content in the soil of its structural elements of various shapes and sizes.

The quality of tillage with a soil-cultivating wave roller was studied on the experimental fields of the Federal State Budgetary Educational Institution of Higher Education of the Ulyanovsk State Agrarian University and the fields of LLC "Ulyanovskaya NIVA". Soil samples were taken under different operating conditions of the rink. Part of the experiment plan for determining the operating parameters of the wave roller is presented in Table 1.

**Table 1.** Indicators of soil density and aggregate composition after rolling with the proposed roller.

Factor value		Fraction weight									Soil sample weight for density, g		
		Content, kg											
v, km/h	l, mm	50..10 mm	10..7 mm	7..5 mm	5..3 mm	3..1 mm	1..0.5 mm	0.5..0.25 mm	less than 0.25mm	Σ	0..3 cm	3..6 cm	6..9 cm
7	90	238.2	88.5	74.7	111	253.7	180.1	101.6	85	1132.8	111.3	137.8	166.9
7	90	271.2	192.3	134.6	190.5	332.3	219	141.2	85.2	1566.3	53.0	167.7	181.3
7	90	257.6	134.2	106	144.7	214.4	158.8	108.6	59.6	1183.9	76.1	126.7	187.4
11	90	140.5	60.2	49.7	100	180	120.5	95.6	50.6	797.1	86.3	142.4	156.7
11	90	139	58.3	54.7	104.5	209.1	179.8	120.9	31.6	897.9	75.0	116.9	161.4
11	90	59.7	37	63.5	100.6	184.8	146.3	134.2	14.3	740.4	19.5	182.7	140.8

### 3 Results

As a result of the work carried out, we obtained the results of experimental studies. After their processing using the STATISTICA 10 program, adequate mathematical models of the process of soil compaction by a wave roller were obtained in natural values of factors (Figure 2) and in coded values of factors (Figure 3). These models represent the dependence of the coefficient of conformity of the standard  $k_{se}$  ( $K$ ) [9, 10] on the speed of the wave roller  $v$  ( $x$ ) and the distance from the rib of the hollow cylinder to the inner surface of the seal  $l$  ( $y$ ). The maximum  $k_{se}$  value corresponds to the best rolling quality.

In studies, the translational speed of the wave roller  $v$  varied in the range from 7 km/h to 15 km/h, and the distance from the rib of the hollow cylinder to the inner surface of the seal  $l$  varied in the range from 40 mm to 90 mm. The coded values of the above factors  $x$  and  $y$ , respectively, ranged from  $-1$  to  $1$ .

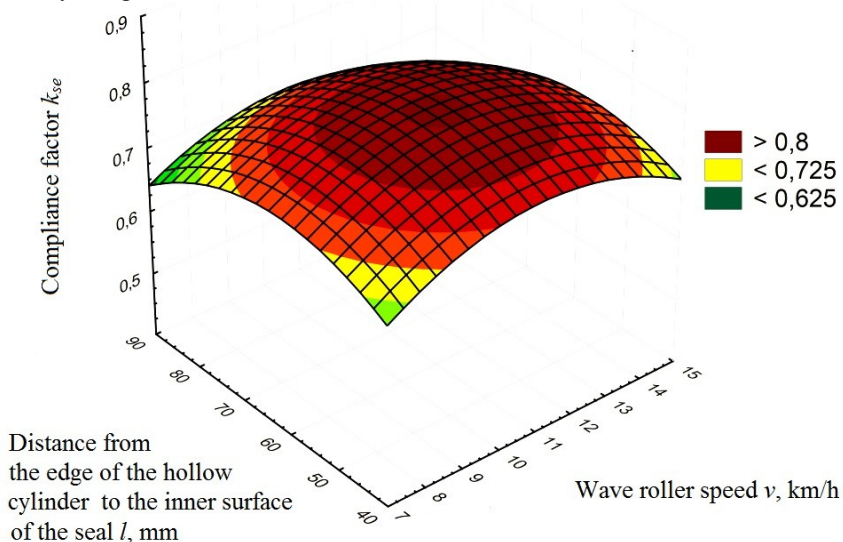


Fig. 2. Mathematical 3D model of the rolling process in natural values of factors.

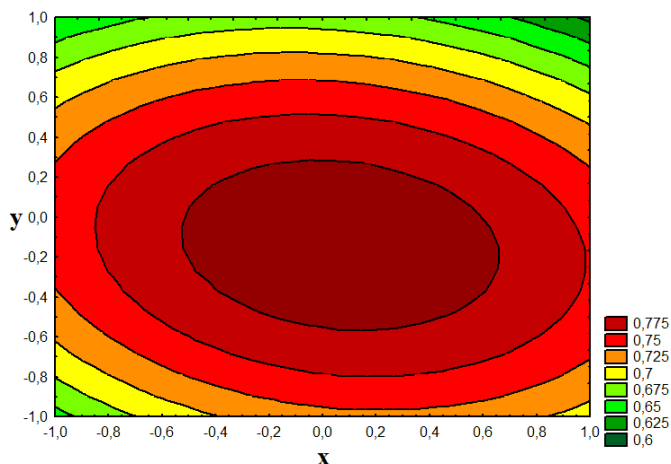


Fig. 3. Mathematical 2D model of the rolling process in coded values of factors.

We also present mathematical models in a formalized form in natural (1) and coded (2) factor values:

$$k_{se} = -0.1894 + 0.1024v + 0.0143l - 0.0045v^2 - 7.7189 \cdot 10^{-5}vl - 0.0001l^2 \quad (1)$$

$$K = 0.7913 + 0.0041x - 0.0274y - 0.0521x^2 - 0.0196xy - 0.1017y^2 \quad (2)$$

As a result of the work done by us, it was found that the maximum coefficient of compliance with the standard  $k_{se} = 0.81$  at the speed of the unit  $v = 11$  km/h and the distance from the rib of the hollow cylinder to the inner surface of the seal  $l = 67$  mm.

At the same time, it should be noted that the optimum area is 20–25% of the entire response surface, which indicates a sufficient quality of tillage with a wave roller in a wide range of design and regime parameters. This confirms the versatility of the developed wave roller when used on various types of soil.

To compare the data obtained during the study of the proposed wave roller, at the experimental site, the soil was simultaneously rolled with a KKZ-6 serial roller with soil sampling according to a similar method. After processing the experimental data, it was revealed that the coefficient of compliance with the standard  $k_{se} = 0.67$  in the area of the field rolled by the KKZ-6 skating rink. Consequently, rolling the soil with a wave roller improves the quality of surface tillage by 20.9% compared to the KKZ-6 roller.

## 4 Discussion

In the course of the experiment, we obtained results confirming the improvement in the quality of soil compaction by the developed wave roller from the standpoint of matching the density and structure of the soil to 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 each coefficient of equations (1) and (2).

## 5 Conclusion

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

- The total stiffness of the springs installed on one compactor and amounting to 38.33 kN/m makes it possible to reduce the shock load in the zone of contact of the compactor with the soil, as a result of which the soil is compacted to the required agrotechnical interval, with the formation of a wave relief on it, which is necessary for high-quality overwintering of winter crops crops in the zone of risky farming.
- Mathematical models obtained after processing the results of the study made it possible to reveal that the best quality of tillage ( $k_{se} = 0.81$ ) is achieved at the speed of the unit  $v = 11$  km/h and the distance from the edge of the hollow cylinder to the inner surface of the compactor  $l = 67$  mm .
- The developed design of the wave roller provides, in comparison with the serial roller KKZ-6, an improvement in the quality of soil compaction, expressed through the coefficient of compliance with the standard  $k_{se}$  by 20.9%, from  $k_{se\ KKZ} = 0.67$  to  $k_{se\ vc} = 0.81$ .

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