Research results for eccentric tillage rollers

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Abstract. An innovative double-drum eccentric roller has been developed. The proposed roller allows you to effectively destroy soil lumps and evenly compact the soil surface. Its main advantage is the varying effect on the same areas of soil with its working surfaces, due to which the maximum result of crushing of soil lumps is achieved. The roller is tested in the field with the quality control of its tillage in accordance with agro-technical requirements. As an optimization criterion, we adopted the coefficient of conformity to the standard $k_s$. It characterizes the quality of soil cultivation by the proposed roller from the position of conformity of the structural composition of the soil to agrotechnical requirements. A comparison of the processing quality of the proposed roller and ring-spur roller was made. When the structural composition of the soil fully complies with the agrotechnical requirements $k_s = 1$. Experimental studies of the eccentric roller made it possible to determine its optimal parameters for which the coefficient of compliance with the standard $k_s = 0.72$, which is 20% better than the ring-spur roller KKSh-6G-02 ($k_s = 0.52$). The achieved quality of soil cultivation by the eccentric roller made it possible to increase the yield of spring wheat by 320 kg/ha in comparison with a ring-spur roller, which provides a profit of 3593 rubles per 1 ha.

1. Introduction
The analysis of scientific works [1–3] indicates that rolling is an important technological process, which results in the uniformity of the distribution of seeds over the field area and their germination are significantly improving, which increases the yield of cultivated crops.

However, the design of modern tools for rolling soil does not provide the proper quality of work. The main disadvantage of the rollers is their heterogeneous compaction of the soil surface and an insufficient quality of the destruction of soil lumps. Also, many rollers have a high metal consumption, and therefore have a high cost. Thus, the development of a tillage skating rink, through which it is possible to carry out high-quality tillage and thereby increase crop yields, is an important and urgent task.

2. Materials and methods
Considering the disadvantages of modern rollers and other tools for the soil rolling, an innovative double-drum eccentric roller was created. The proposed roller allows you to effectively destroy soil lumps and evenly compact the surface layer of soil to the optimum density value specified by agricultural requirements. The main advantage of the new roller is the varying effect on the same sections of soil with its working surfaces, due to which the maximum result of crushing of soil lumps is achieved.
The eccentric roller contains frame 1 (Figure 1) with two hollow cylinders 2 and 3 set on it with the possibility of rotation in the same direction on axles 4 on cylinders 2 and 3. On one side there are sprockets 5 which are connected by chain 6. The cylinder axes are mounted eccentrically and shifted in opposite directions vertically at equal distances. The eccentric roller also has a trailing device 7, pivotally mounted on frame 1 [4].

*Figure 1. Eccentric tillage roller:* 1 – frame; 2, 3 – hollow cylinders; 4 – axis of hollow cylinders; 5 – asterisks; 6 – roller chain; 7 – tension asterisk; 8 – trailing device; 9 – hinge

The principle of operation of the eccentric roller is as follows. First, the eccentricity value necessary for a given soil is selected. Having displaced the axis of cylinders 2 and 3 vertically in different directions concerning the plane of frame 1 by the required value, they are fixed in a predetermined position. In this position, sprockets 5 are connected by chain 6. Then, with the help of trailing device 7, the eccentric roller is hooked up with the tillage unit or directly to the tractor [1].

When the unit moves, hollow cylinders 2 and 3 begin to rotate, rolling the soil. In this case, the part of cylinder 2, which has a large mass, is eccentrically installed relative to axis 4, rolls over one section of the field surface, and the part of cylinder 2, which has a lower mass, rolls over the next section of the field surface. Then the eccentrically installed relative to axis 4 part of cylinder 3, having a lower mass, rolls over a portion of the surface of the field, which was previously sealed by the part of cylinder 2, which has a larger mass. Conversely, an eccentrically mounted relative to axis 4 part of cylinder 3 having a larger mass rolls over a portion of the field surface that has been sealed by the part of cylinder 2 having a lower mass. In this case, more intensive crumbling of the soil lumps is achieved with the parts of cylinders 2 and 3 eccentrically set relative to their horizontal axes of symmetry.

The displacement of axis 4 of cylinder 2 from its horizontal axis of symmetry to the side opposite to the direction of the displacement of axis 4 of cylinder 3 from its horizontal axis of symmetry allows us to maintain a constant soil density after the passage of hollow cylinders 2 and 3 of the roller and to ensure high quality soil rolling and lumps crumbling. Moreover, the crumbling intensity of soil lumps with increased hardness can be further increased by increasing the speed of the aggregate and the value of the eccentricity [4].

An important criterion for assessing the quality of tillage by rolling is the granulometric composition of soil. A valuable soil structure according to agricultural requirements is a substance with soil aggregate sizes of 0.25 ... 10 mm, which when sown in black soil should be 45 ... 60 % of the total mass of the surface soil layer. The soil structure deteriorates with an increase in the amount of dust (that is, particles which size is less than 0.25 mm) to 30 ... 40 %. Thus, agricultural requirements for sowing necessitate the presence of a loosened surface layer that contains soil aggregates with a size of less than 25 mm in an amount of 80 % or more. Lumps of 50 mm or more in size are not allowed on the surface of soil [5, 6].
The structural composition of the soil was investigated using the so-called sieve method. The samples taken after soil cultivation were sieved through a set of sieves. In this case, a device which consists of a vibrodrive and a set of sieves with different diameters was used. (Figure 2).

To determine the structure of the soil, a generally accepted technique was used according to GOST. In the field, after soil treatment, the proposed roller took soil samples. Soil samples were taken diagonally of the cultivated area using a square frame with a side of 50 cm. The frame was laid on the soil surface, after which soil samples were taken from the inside of the frame to the depth of compaction of the soil layer. Soil sampling was carried out for each of the experiments at least three times in order to improve the quality of the results of the structural study.

![Figure 2. Device for soil structure analysis: 1 – vibrodrive panel; 2 – display; 3 – control buttons](image-url)

Soil samples were placed in an oven for six hours. Then the samples were sieved using a special device with a vibratory drive, which allows sifting dry samples, preventing them from shaking. Then, the mass of each of the fractions was determined using weights with high measurement accuracy. Using the obtained measurement results, we calculated the mass fraction of each fraction and expressed the result as a percentage [7, 8].

3. Results and Discussion

The proposed eccentric tillage roller has been field tested. Relevant factors were chosen for the study: 

\[ v \] – speed of processing with an eccentric roller, km/h; 

\[ m_y \] – the mass of weighting agents, kg; 

\[ e \] – vertical displacement of the axis of the hollow cylinder from the initial position, mm

The criterion for assessing the quality of soil rolling was the coefficient of conformity to the standard \( k_s \), which characterizes the quality of rolling from the point of view of compliance of the structural composition of the soil with agrotechnical norms [9, 10]. The coefficient \( k_s \) was determined by the formula:

\[
K_s = \frac{C}{100},
\]

where \( C \) is the content of valuable soil aggregates as a proportion of the total mass of the sample, %

After processing all the results of the study, we obtained the regression equations in natural and coded values of the factors. The regression equations characterize the influence of the speed of the roller \( v \), the mass of weighting agents \( m_y \) and the displacement of the axis of the roller relative to its center \( e \) on the coefficient of compliance with the standard \( k_s \).

The regression equation in natural factors is as follows:

\[
K_s = 0.2204 + 0.0845v + 0.0002e - 0.0041v^2 + 0.0001ve - 7.7872E^{-6}e^2.
\]

In coded values:

\[
K_s = 0.7113+0.0036x+0.0286y-0.0655x^2+0.0259xy-0.028y^2.
\]
The graphic image of the response surface and its two-dimensional cross-section are as follows (Figure 3).

![Figure 3. The response surface (a) and its two-dimensional cross section (b) from the interaction of speed \( v \) and eccentricity \( e \) and their combined influence on the coefficient of conformity to the standard \( k_s \).](image)

As a result of processing the experimental data, it was determined that after processing by the eccentric roller proposed by us, the coefficient of conformity to the standard is \( k_s = 0.72 \). The obtained value fully meets the agrotechnical requirements. This value of \( k_s \) is achieved when the speed of the unit is \( v = 11.5 \) km/h, the mass of the ballast is \( m_b = 130 \) kg and the axes are displaced relative to the center of the roller \( e = 61 \) mm.

A comparative assessment of the packing quality of the proposed innovative roller and the KKSh-6G-02 roller, the most common in Russian agricultural enterprises, showed not only an improvement in the quality of the rolling by the proposed roller, but also a higher yield of spring wheat cultivar Simbirtsit, which amounted to 3050 kg/ha against 2730 kg/ha after rolling in the crops with a ring-spur roller. Thus, the yield increase was 320 kg/ha, which in 2020 prices will give a profit of 3593 rubles per 1 ha.

4. Conclusion
Studies have shown that the coefficient of conformity to the standard after tillage with a ring-spur roller \( k_s = 0.52 \), and after the eccentric roller \( k_s = 0.72 \), which is 20 % better. The achieved quality of soil cultivation by an eccentric roller made it possible to increase the yield of spring wheat by 320 kg/ha or 11 % compared to the ring-spur roller. The profit from the increase in yield when using the proposed eccentric roller is 3593 rubles per 1 ha.

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