Substantiating the Parameters of a Two-drum Roller for Tillage

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Abstract. The article reveals the research urgency. A device for an experimental two-drum roller, a flow-chart of its operation, a design model and an analytical relationship for substantiating its main design parameters are described. The dependence of the horizontal component of the roller on its operating width at different diameters of the inner drum is shown. It is proved that to reduce energy costs and meet the agrotechnical requirements for tillage, the diameters of the inner and the outer drums (Dk2 and Dk1) should be 0.25 and 0.5 m, respectively, with the number of straps on the outer and inner drums being ns1 = 16 pcs and ns2 = 30 pcs. The results of experimental studying the two-drum roller made according to the substantiated parameters are given. The experimental studies proved the ability of the two-drum roller to provide the due structural composition of the seed layer, with soil lumps exceeding 50 mm being totally absent, a better evenness of the soil surface as compared to the one obtained with the traditional type of treatment, earlier and friendly sprouting of spring rape and the yield increase by 21.7%.

1. Introduction

Tillage for crop production being the most energy-intensive process, the main task for agricultural engineering is to find ways to reduce costs, with agrotechnical requirements for tillage being met. Most researchers see the solution to this problem in using combined units that can perform a full range of pre-sowing tillage activities in one pass, as well as modifying the working parts [1-5].

Rollers as integral parts of any tillage and sowing unit are used for the main and surface tillage for grinding large lumps, leveling and mulching the soil surface, removing weed roots on the soil surface, creating seedbeds during pre-sowing treatment and creating the contact of seeds with the soil when sown [6-8].

The outer diameter of all types of rollers depends on the size of the lumps occurring on the soil surface after the main or surface tillage. According to researches, the roller diameter is to be determined by pinching the soil lump between the roller working surface and the soil surface without soil shafts being formed in front of it.

Depending on the purpose, type and condition of the soil, the diameters of lumps, as well as the requirements for soil tillage, one- and two-drum rollers with different diameters are used, with rods of various types and sizes at different angles to the direction of movement [9,10,11].

Research urgency. Despite the wide range of existing designs of tillage rollers, there is a need to construct a roller to provide high-quality pre-sowing treatment necessary for crops, especially with small seeds.

Research purpose: the traction resistance determination of a two-drum roller and the substantiation of its design parameters.
2. Methods

The experimental roller consists of two drums: the inner and outer ones. The inner drum is placed in the inner space of the outer drum without any rigid kinematic connection with it. It is connected to the cultivator frame with a hinged-powered device equipped with a spring loader. The operating surfaces of both drums are formed by one-side sharpened straps rigidly fixed in the side discs. The outer drum rotates due to the adhesion of the straps with the soil due to acting traction force, with the rotation of the inner drum being ensured by the friction force occurring at the point of contact [12].

The two-drum roller with the straps of the outer drum compacts the pre-seed layer and destroys large soil lumps. Soil lumps passed between the straps inside the roller are treated with the inner drum straps. The soil treated this way is thrown onto the field surface to form a loosened mulch cover. Thus, the necessary differentiation of the seed layer concerning its density and structural composition happens.

The parameters for the outer roller drum being chosen, its kinematic and design parameters can be substantiated.

When operating, the following forces act on the two-drum roller (Figure 1): $G_1$ is the gravity of the outer drum, kN; $G_2$ is the gravity of the inner drum, kN; $P$ is the resistance force of the roller acting along the lead, kN; $R$ is the soil resistance force occurring when the roller straps enter the soil, kN; $R_x$ is the force of interacting the roller with the soil, kN; $T$ is the interaction force between the rollers, kN; $F$ is the friction force between the rollers, kN; $F_0$ is the compression force of the loader spring, kN.

The horizontal component of the roller traction resistance $P_x$, kN, depends on its design parameters and physical-mechanical properties of the soil

$$P_x = \left( \frac{G_1}{\sin \alpha} - \frac{R_x - \delta \cdot b \cdot l_{outer} \cdot n_{a0} \cdot \cos \alpha_0}{f \cdot \sin \alpha} + \frac{\pi \cdot D_{kinner}^2 \cdot b \cdot c \cdot \rho}{4 \cdot \sin \alpha} \right) \cdot \cos \alpha,$$

(1)

where $\alpha$ is the angle of the lead inclination, degrees, $\delta$ is the soil shear resistance coefficient; $b$ is the operating width, m; $l_{outer}$ is the thickness of the outer drum strap, m; $n_{a0}$ is the number of straps contacting with the soil, pcs.; $f$ is the coefficient of the soil friction with steel; $D_{kinner}$ is the diameter along the inner surface of the outer drum straps, m; $c$ is the roller filling coefficient; $\rho$ is the specific gravity of the soil, kN/m$^3$.

![Figure 1 – The diagram for determining the forces acting on the two-drum roller](image)

The horizontal component of the roller traction resistance is determined according to Formula (1) and its main design parameters are justified. The initial data for the calculations are given in Table 1.
Table 1  The initial data for the calculations

| No. | Parameter                                      | Measurement unit | Designation | Value       |
|-----|-----------------------------------------------|------------------|-------------|-------------|
| 1   | The roller depth                             | m                | a           | 0.10        |
| 2   | The angle of the lead inclination             | degree           | α           | 20.00       |
| 3   | The specific gravity of the soil              | kN/m³            | ρ           | 25.50       |
| 4   | The soil shear resistance coefficient         | kN/m²            | δ           | 10.00−30.00|
| 5   | The roller filling coefficient                | c                |             | 0.10        |
| 6   | The outer drum rolling coefficient on the soil|                  | η₁          | 0.95        |
| 7   | The inner drum slipping coefficient relatively to the outer drum |                  | η₂          | 0.90        |
| 8   | The coefficient of the soil friction with steel |                  | f           | 0.50−0.80   |
| 9   | The thickness of the straps of the outer and inner drums | m          | l₁ outer st., l₂ inner st. | 4·10⁻³ |
| 10  | The outer drum diameter                       | m                | D₁ outer    | 2 D₂        |
| 11  | The inner drum diameter                       | m                | D₂          | 0.20−0.35   |
| 12  | The operating width                           | m                | b           | 1.00−3.00   |

3. Research results and their discussion

The results of the calculations are presented as graphs (Figure 2).

![Graph](image)

Figure 2 – The dependence of the horizontal component of the roller traction resistance $P_x$, kN, on its operating width $b$ with various diameters of the inner drum $D₂$.

The specific resistance of a traditional roller with a non-smooth surface being $k_{sp} = 0.6÷0.9$ kN/m, its critical traction resistance $P_{cr}$, kN, (see Figure 2) can be defined as

$$P_{cr} = k_{sp} \cdot b, \text{ kN},$$

(2)

where $b$ is the operating width, m.

To substantiate the diameter of the experimental two-drum roller, we accept the condition

$$P_x \leq P_{cr}.$$  

(3)
To fulfill this condition, the diameter of the inner drum is recommended to be $D_{k1} = 0.25$ m, with the diameter of the outer drum being $D_{k2 \text{ outer}} = 2D_{k2} = 0.5$ m.

According to the agrotechnical requirements for the quality of pre-sowing treatment, there shouldn’t be any soil lumps exceeding 10 cm in size, with lumps exceeding 2.6 cm being absent after treatment. The distance between the straps of the outer drum is recommended to be $l_{z1} = 10$ cm, $l_{z2} = 2.6$ cm. Then $D_{k2} = 0.25$ m and $D_{k2 \text{ outer}} = 0.5$ m, their number being $n_{k1} = 16$ pcs on the outer drum and $n_{k2} = 30$ pcs on the inner one. The straps on the drums are arranged circumferentially, radially and regularly. The length of the outer drum straps protruding from the side discs is determined by the sowing depth equaling to 2 cm.

At the Institute of Agroecology, a branch of South Ural State Agrarian University, a two-drum roller was made according to the substantiated parameters.

The comparative assessment of tillage quality proved a tillage unit equipped with two-drum rollers to ensure:

- the due structural composition of the seed layer: the content of lumps exceeding 10 mm was 28.4% of the total test piece, and there were no lumps exceeding 50 mm, with the content of lumps 2-5 mm in size being 45.9%;
- a better evenness of the soil surface as compared to the one obtained with the traditional type of treatment: the mean-square deviation of the soil surface irregularities after the two-drum roller cultivator treatment was 1.7 cm, with the soil unevenness being 37% less if compared with the traditional type of treatment;
- earlier and friendly sprouting of cultivated crops and increased yields: the yield of spring rape green mass obtained from the pieces of ground treated with the two-drum roller cultivator is 21.7% higher than the yield obtained from the pieces of ground treated traditionally.

The energy data of the operating unit according to GOST 52777-2007 were determined by the Ural Testing Center for Agricultural Equipment of South Ural State Agrarian University on the experimental field of the Institute of Agroecology. In the course of the experiment, the value of the two-drum roller traction resistance at the speed of 2.8 m/s was obtained. It amounted to 0.72 kN with the operating width $b = 1$ m, the theoretical and experimental data differing within the acceptable limits (10%).

4. Conclusion

The presented design model and analytical dependence made it possible to substantiate the main design parameters of a two-drum roller with energy saving parameters. The experimental studies proved the ability of the two-drum roller to provide the due structural composition of the seed layer, a better evenness of the soil surface as compared to the one obtained with the traditional type of treatment, earlier and friendly sprouting of spring rape and increased yields.

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