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Justification of the operating parameters of the soil mill for the formation of a ridge

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Abstract. This paper presents the development and justification of operating parameters for a soil milling machine designed to form ridges for the pre-sowing preparation of industrial crops. The study focuses on determining the optimal parameters of the working bodies and operating modes of the cutter, emphasizing the importance of reducing undesirable soil fractions to enhance seed germination. Experimental results demonstrate that the use of organomineral complexes significantly improves soil structure, leading to better moisture retention and reduced vibrations during sowing. The machine's design incorporates four sections, each equipped with milling drums, ridge formers, and compaction rollers, allowing for efficient soil preparation in a single pass. Key findings indicate that increasing the number of knives on the milling drum enhances soil crumbling efficiency, with optimal configurations yielding significant improvements in grain weight and overall crop quality. The research highlights the effectiveness of the developed machine in achieving high-quality tillage while conserving resources, thereby contributing to more sustainable agricultural practices.

1. Introduction

The requirements for the aggregate composition of the soil are to reduce to a minimum the content of fractions (lumps) with sizes > 50 mm and < 0.25 mm (dust), since this reduces the evaporation of moisture from the soil necessary for seed germination.

A generalization of the results of determining the aggregate composition of gray soils and meadow soils prepared for sowing cotton showed that practically the content of these undesirable fractions in the soil (> 50 mm and < 0.25 mm) can be reduced to 5-10% (of each fraction). Such results are obtained with a sufficient amount of moisture in the soil and the modern application of the system of basic and pre-sowing soil cultivation in relation to each characteristic subzone of cotton growing. If these conditions are not met, the aggregate composition deteriorates. Which negatively affects not only the preservation of moisture, but also the quality of work of the seeding working parts of the seeder, since this increases the vibrations of the working parts, and consequently, the uniformity of seed placement in depth and width deteriorates.

Experiments have shown the absence of significant differences in the aggregate composition depending on the type and mechanical composition of the soil with the same methods of preparing it for sowing [1-7].

During pre-sowing and inter-row cultivation of potatoes, corn, cotton and other crops, row cutters provide high quality soil crumbling and weed destruction. Pre-sowing and inter-row milling is especially effective in heavy loamy and peaty soils [8-11].

Milling has a positive effect on the physical properties of the soil, water and nutritional regimes of plants. Mixing soil layers increases the biological activity of the entire cultivated horizon and, consequently, the yield of agricultural crops.

In the world, special attention is paid to the technological process of sowing industrial crops, the creation of equipment and technologies that ensure pre-sowing tillage of the soil with rotary working bodies, precise sowing of seeds of industrial crops to a given depth at optimal rates and their uniform distribution over the field surface.

2. Materials and methods

The study was conducted to evaluate the operating parameters of a newly developed soil milling machine designed for the formation of ridges during pre-sowing tillage of industrial crops. The research was carried out at the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, utilizing experimental plots representative of the typical agricultural conditions in Uzbekistan.

The experiments were performed on a field with gray and meadow soils, which were prepared for sowing cotton. The soil was characterized by a moisture content sufficient for optimal tillage. The machine consists of four sections, each equipped with aprons, milling drums, ridge formers, and fillet-shaped compaction rollers. Furrow makers were placed between sections to facilitate soil movement.

The milling drums had a diameter of 30 cm and were fitted with varying numbers of knives (3, 4, and 5) to assess their impact on soil crumbling efficiency. The peripheral speed of the milling drums was maintained at 6-7 m/s, with an adjustable depth of tillage controlled by a screw mechanism. Soil feed to the knives was set at 7-8 cm.

Soil samples were collected from various depths (0-3 cm, 3-6 cm, 6-9 cm, and 9-12 cm) to measure soil density and aggregate composition. The weight of 1000 grains was recorded for each treatment to evaluate the quality of the soil preparation. The chlorophyll content in plant leaves was analyzed to assess the biological activity resulting from different tillage treatments.

Data were analyzed using standard statistical methods to determine significant differences between treatments. Yield increases were calculated by comparing results from treatments with those from control plots.

This comprehensive approach allowed for a thorough evaluation of the machine's performance in optimizing soil conditions for successful crop establishment.

3. Results and discussion

A machine for milling with the formation of a ridge for pre-sowing tillage, which ensures high-quality tillage and resource conservation by ensuring the stability of the operation of sowing devices and sowing seeds based on established standards has been developed. The article provides some results of operating parameters and working bodies.

The developed machine consists of four sections (Figure 1), each section consists of aprons, milling drums, ridge formers and fillet-shaped compaction rollers installed sequentially on a frame. Furrow makers are installed in front between the sections. The machine works as follows: furrow cutters feed the soil into milling drums and crush the lumps lying on the surface of the field. The depth of tillage with the milling drum is adjusted by a screw on the rods to strengthen the apron. Aprons reflect ejected soil particles to form a ridge. The forming part of the apron is a box whose inlet opening is wider than the outlets. The formed ridge is compacted with a fillet-shaped roller. The degree of compaction is regulated by a rod screw for fastening the compactor. Between the former and the seal, devices are installed for laying a targeted irrigation hose. Next, the seeder is connected through the coupling devices.

The milling drums are driven into rotation from the tractor's power take-off shaft through a bevel gear, chain drives, and the seeder's sowing apparatus from its support wheels.

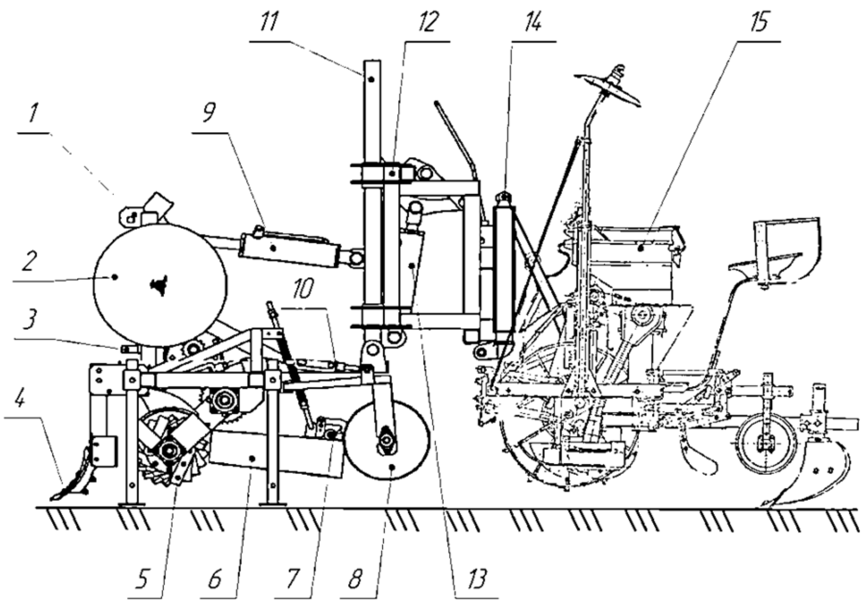

Figure 1. Diagram of a combined machine: 1-hitch for the tractor; 2 - drum for targeted irrigation hose; 3-shaft gearbox; 4-furrow makers; 5-milling drum; 6-apron-former: 7-device for laying a targeted irrigation hose on the ridge; 8-fillet-comb seal; 9 - rod for fastening the seeder mounting device; 10-rods for adjusting the seal; 11-frame device for attaching the seeder; 12-devices for lifting and lowering the hitch of the seeder; 13, 14-hydraulic cylinders; 15-seeder.

On the developed machine, technological processes depend on crumbling the soil on milling drums. Therefore, we will consider the basic process of grinding soil on a milling drum.

Figure 2. Milling drum (front view).

From the analysis of literature [1-5] and the conducted research, the main parameters and operating modes of the cutter were established.

The number of knives of each milling drum. The combination machine has four sections with milling drums, each of which has five discs for mounting knives. On them, on one side, knives are installed with opposite inclination of the knives and in a checkerboard pattern relative to adjacent disks. Based on the information in the scientific literature, the number of knives on each disk is assumed to be 4 pieces, and the number of knives installed on each milling drum is assumed to be 20 pieces.

Knife feed. This parameter is considered one of the main parameters that determine the degree of crushing of lumps by the milling drum and affect the energy intensity. An increase in it leads to a decrease in the degree of crushing of lumps and energy intensity, and a decrease leads to their increase. Based on studies carried out on a prototype cut (figure 2), the feed to the knife is accepted in the range of 7-8 cm.

The radius of the milling drum is determined by the following expression

$$R_b = R_d + \Delta h_f + h_f \quad (1)$$

where $R_d$is the radius of the disk for installing the knives of the milling drum, m ; Δh_f- gap between the field surface and the blade disk, m; h_f- processing depth, m.

To determine the peripheral speed of the milling drum from the condition of crushing lumps that get in the way, we obtained the following expression

$$V_b \geq [\sigma_{ch}] R_b \sqrt{\frac{(J + mR_6^2)}{3EJ\rho(1-k^2)\left(2R_6 h_f - h_f^2\right)}} \quad (2)$$

where $[\sigma_{ch}]$is the limiting value of the stress formed in the lump under the influence of an impact, Pa; J- moment of inertia of the milling drum, kgm^2; m- average mass of the lump, kg; ρ- lump density, kg/m^3; k- lump recovery coefficient; E- modulus of soil elasticity, Pa.

The operating mode of the milling drum was determined by the following equation

$$\lambda = 2\pi R_b / z S_f \quad (3)$$

where $z$is the number of knives in one disk; S_f- feed to knife, m .

The translational speed of the milling drum is determined by the known values of the peripheral speed and operating mode, i.e.

$$V = V_0 / \lambda \quad (4)$$

Installation angle of the milling drum knife wing. This angle is determined based on the condition that during operation the back side of the knife wing does not touch its path of movement

$$\gamma = arccos\left(\frac{1}{\lambda} + \frac{b_f}{2R_b}\right) \quad (5)$$

where $b_f$is the width of the milling drum knife wing, m .

Having accepted $z = 4, \Delta h_f = 0{,}02\ m, h_f = 0{,}08\ m, [\sigma_{ch}] = 3{,}5 \cdot 10^3\ Pa, E = 1{,}9 \cdot 10^6 Pa,$ $\rho = 1200\ kg/m^3,\ m = 1{,}02\ kg,\ k = 0{,}3,\ J = 0{,}11\ kgm^2,\ R_b = 0{,}2\ m,\ b_f = 0{,}04\ m$ according to expressions (1), (2), (3), (4) and (5), it is established that the radius of the milling drum should be 0.3 m, the peripheral speed of the milling drum should be at least 6 m/s, the operating mode of the milling drum should be in the range of 3.9-4.5, the translational speed of the milling drum in the range of 1.5-2.0 m/s and the installation angle of the milling drum knife wing in the range of 72^{O} - 74^{O}.

The experiments were carried out on milling drums with a diameter of 30 cm and the number of knives 3, 4, 5 pieces. According to the results obtained, when the number of milling drum knives was 3 pieces, the soil fractions with a diameter of more than 25 mm, 10-25 mm and less than 10 mm were respectively 12.3%, 13.9%, 73.8%, with 4 pieces - 7.7% , 13.8%, 78.5%, with 5 pieces - 6.9%, 11.5%, 81.6%. This means that with an increase in the number of knives, the soil and knives interact more with each other. That is, the longer the soil and knives interact, the better the crushing of lumps will be. In addition to studying the quality of grinding of the soil layer processed by the milling drum, the soil density in layers 0-3 cm, 3-6 cm, 6-9 cm, and 9-12 cm was measured. With the number of milling drum knives being 3 pieces, the soil density in layers 0- 3 cm, 3-6 cm, 6-9 cm 1.13 g/cm^3, and layers 9-12 cm - 1.16 g/cm^3, with the number of knives 4 and 5 pieces in layers 0-3 cm, 3 -6 cm, 6-9 cm was 1.12 g/cm^3, in the layer 9-12 cm - 1.15% g/cm^3.

4. Conclusion

The analysis conducted in this study has led to the development of a combined machine designed for pre-sowing tillage and seed sowing of industrial crops in a single pass. This innovative machine integrates a furrow cutter, milling drum, roller, and seeders on a sequentially mounted frame. By optimizing the parameters of the milling drums—specifically, the installation of four knives on each disk with a radius of 20 cm and a peripheral speed of 6-7 m/s—the machine effectively prepares the soil for planting. The operational mode, set between 3.9 and 4.5, along with a knife wing angle of 72-74 degrees, ensures high-quality execution of the tillage process.

The results indicate that this combined approach not only streamlines the planting process but also enhances soil preparation quality, which is critical for optimal seed germination and crop establishment. The significant reduction in soil clumps greater than 50 mm and less than 0.25 mm demonstrates the machine's effectiveness in achieving the desired aggregate composition necessary for successful sowing. Furthermore, the study highlights the positive impact of milling on soil physical properties, which contributes to improved water retention and nutrient availability for crops.

In conclusion, this research underscores the importance of integrating advanced machinery in agricultural practices to promote efficiency and sustainability. The developed combined machine represents a significant advancement in agricultural technology, providing farmers with an effective tool for enhancing productivity while conserving resources. Future studies could explore further optimizations and adaptations of this technology to meet diverse agricultural needs across different soil types and crop varieties.

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