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Effects of Harrow Tooth Length and Mass Per Tooth on The Performance of a Harrow-Roller Implement

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Abstract: This study presents experimental results on the effects of harrow tooth length and mass per tooth on the agrotechnical and energy performance of a harrow-roller. The evaluated indicators included tillage depth and its standard deviation, degree of soil crumbling, standard deviation of field-surface irregularity heights, and specific draft resistance. The results showed that, under the tested field conditions and travel speeds, a harrow tooth length of 140–160 mm and a mass per tooth of 2.10–2.25 kg provided the required performance.

Keywords: Soil harrowing, harrow-roller, tooth harrow, plank roller, leveler, experimental study, tooth length, mass per tooth, tillage depth, degree of soil crumbling, field-surface roughness, specific draft resistance.

Introduction:

Under the conditions of Uzbekistan, one of the first and most important operations in preparing soil for spring sowing is surface harrowing. Timely and high-quality harrowing forms a loose surface layer, suppresses weeds, and creates favorable conditions for the rapid germination of cotton and other crop seeds. It also helps preserve moisture accumulated in the soil during the autumn–winter period. In contrast, delayed or omitted harrowing results in moisture loss, increased cloddiness, hardening of the arable layer, and weed infestation. Consequently, seedbed preparation becomes more difficult and the conditions required for timely, high-quality sowing deteriorate. Therefore, in spring, as soon as the upper 8–10 cm soil layer reaches a condition suitable for tillage, fields intended for spring crops should be harrowed within a short period.

In Uzbekistan, to ensure the required work quality, harrowing is commonly performed using BZSS-1.0, BZTS-1.0, and BZTX-1.0 tooth harrows arranged sequentially in two rows [1]. However, such two-row harrowing units have several significant disadvantages:

- the unit must be stopped to remove weeds and crop residues entangled in the harrows, and the cleaning is performed manually. For this purpose, two to four additional workers are assigned to each unit. According to data from the Center for Certification and Testing of Agricultural Machinery and Technologies (UzAgroTest), the time spent removing weeds and crop residues from the harrows accounts for approximately 30% of the total shift time [2,3];

- when moving from one field to another, the unit must be disassembled, transported using an additional vehicle, and then reassembled. According to UzAgroTest data, these operations require 5.4 person-hours [2,3];

- two-row harrowing units have low maneuverability, are inconvenient to operate, and have large overall dimensions.

All these shortcomings reduce the productivity and work quality of harrowing units while increasing fuel consumption, labor requirements, and other operating costs.

METHODS

To eliminate the aforementioned shortcomings, improve the quality and productivity of soil harrowing, reduce energy and material requirements, and decrease the overall dimensions of harrowing units, a harrow-roller was developed [4]. Its schematic diagram is shown in Figure 1.

The harrow-roller consists of a frame 2 equipped with a hitching device 1, tooth harrows 3 connected to the frame by chains, levelers 4 installed in front of the harrows, and plank rollers 5 installed behind them.

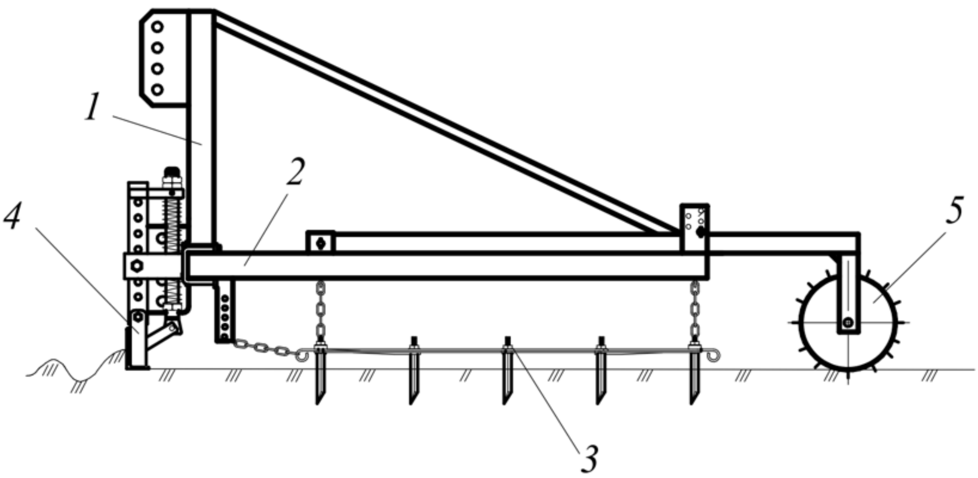

Figure 1. Schematic diagram of the harrow-roller: 1 – hitching device; 2 – frame; 3 – tooth harrows; 4 – levelers; 5 – plank roller.

During operation, the levelers installed at the front of the frame level the irregularities on the field surface. The tooth harrows crush surface clods, loosen the soil to a depth of 4–6 cm, break the soil crust, and eliminate weeds. The plank roller then levels the tracks formed by the harrow teeth and further crumbles the loosened soil and remaining clods. As a result, a loose 4–6 cm surface layer is formed, which promotes soil-moisture retention and creates favorable conditions for high-quality sowing and seed germination in accordance with agrotechnical requirements.

This article presents the results of experimental studies on the effects of harrow tooth length and mass per tooth on the agrotechnical and energy performance indicators of the developed harrow-roller.

In the experiments, harrow tooth length was varied from 100 to 160 mm in 20 mm increments, while mass per tooth was varied from 1.80 to 2.40 kg in 0.15 kg increments. The travel speeds were 6 and 9 km h^{-1}.

For the experiments, harrow teeth with lengths of 100, 120, 140, and 160 mm were prepared (Fig. 2), and the mass per tooth was varied by adding supplementary weights to the harrow.

a) b) c) d)

Figure 2. Harrow teeth with lengths of 100 (a), 120 (b), 140 (c), and 160 (d) mm.

In the experimental studies, the performance criteria were tillage depth, degree of soil crumbling (the proportion of soil fractions smaller than 25 mm in the tilled layer), standard deviation of field-surface irregularity heights, and specific draft resistance of the harrow-roller per unit working width. The agrotechnical performance indicators were determined in accordance with O‘z DSt 3412:2019, “Testing of agricultural machinery. Machinery and equipment for surface soil cultivation. Testing program and methods,” while draft resistance was measured in accordance with O‘z DSt 3193:2017, “Testing of agricultural machinery. Methods for the energy assessment of machines,” using strain-gauge pins [5,6].

RESULTS AND DISCUSSION

The experiments were conducted in the fields of the Institute’s experimental farm during the early-spring harrowing period. The average soil moisture contents in the 0–10 and 10–20 cm layers were 15.3% and 18.4%, soil hardness values were 0.61 and 0.84 MPa, and soil bulk densities were 1.16 and 1.21 g cm^{-3}, respectively.

The results obtained in the experiments are presented in Tables 1 and 2.

Table 1. Effect of harrow tooth length on the performance indicators of the harrow-roller

Tooth length, mm	Tillage depth, cm		Degree of soil crumbling, %	Standard deviation of field-surface irregularity heights, cm	Specific draft resistance, kN m^{-1}
	Mean	SD			
Travel speed: 6 km h^{-1}					
100	4.3	0.88	82.6	1.38	1.65

120	4.6	0.91	81.9	1.33	1.82
140	5.2	0.98	81.7	1.36	2.12
160	6.1	1.04	78.6	1.48	2.23
Travel speed: 9 km h⁻¹					
100	4.0	0.90	83.4	1.32	2.05
120	4.2	0.94	82.8	1.28	2.28
140	4.9	1.02	82.5	1.34	2.50
160	5.8	1.06	80.0	1.42	2.75

As shown in Table 1, increasing harrow tooth length at both travel speeds increased the mean tillage depth and its standard deviation. This trend was associated with greater penetration of the harrow teeth into the soil as tooth length increased.

When harrow tooth length increased from 100 to 160 mm, the mean tillage depth increased from 4.3 to 6.1 cm and its standard deviation increased from 0.88 to 1.04 cm at 6 km h^{-1}. At 9 km h^{-1}, the corresponding values increased from 4.0 to 5.8 cm and from 0.90 to 1.06 cm, respectively.

As harrow tooth length increased, the degree of soil crumbling, expressed as the proportion of fractions smaller than 25 mm, decreased from 82.6% to 78.6% at 6 km h^{-1} and from 83.4% to 80.0% at 9 km h^{-1}. With shorter teeth, the harrow frame was positioned closer to the field surface, promoting additional fragmentation of larger clods and thereby increasing the degree of soil crumbling.

Increasing harrow tooth length also increased the standard deviation of field-surface irregularity heights and the specific draft resistance of the harrow-roller. These changes were likewise associated with the greater penetration depth of the harrow teeth.

Increasing travel speed from 6 to 9 km h^{-1} reduced tillage depth, increased the degree of soil crumbling, reduced the standard deviation of field-surface irregularity heights, and increased specific draft resistance.

To satisfy the adopted performance requirements—a tillage depth of 4–6 cm, a degree of soil crumbling of at least 80%, and minimum values of field-surface roughness and specific draft resistance—the results in Table 1 indicate a suitable harrow tooth length of 140–160 mm.

Table 2. Effect of mass per harrow tooth on the performance indicators of the harrow-roller

Mass per harrow tooth, kg	Tillage depth, cm	Degree of soil crumbling, %	Standard deviation of field-surface irregularity heights, cm	Specific draft resistance, kN m^{-1}

	Mean	SD			
		Travel speed: 6 km h⁻¹			
1.80	4.6	0.98	85.6	1.12	1.78
1.95	4.9	0.92	85.1	1.19	1.89
2.10	5.0	0.86	84.5	1.28	1.96
2.25	5.2	0.82	83.9	1.36	2.12
2.40	5.6	0.78	84.1	1.42	2.25
		Travel speed: 9 km h⁻¹			
1.80	4.3	1.03	86.4	1.10	2.22
1.95	4.6	0.94	85.9	1.13	2.36
2.10	4.9	0.88	85.2	1.21	2.48
2.25	5.1	0.86	84.6	1.32	2.66
2.40	5.4	0.83	84.3	1.38	2.82

According to Table 2, increasing the mass per harrow tooth at both travel speeds increased tillage depth while reducing the standard deviation of tillage depth. The greater load acting on the teeth promoted deeper soil penetration and improved the stability of the harrow with respect to tillage depth.

When the mass per harrow tooth increased from 1.80 to 2.40 kg, tillage depth increased by 1.0 and 1.1 cm at travel speeds of 6 and 9 km h^{-1}, respectively, while the standard deviation of tillage depth decreased by 0.20 cm at both speeds. Over the same mass range, the degree of soil crumbling decreased by 1.5 and 2.1 percentage points at 6 and 9 km h^{-1}, respectively. This decrease can be attributed to the greater tillage depth, which increased the proportion of larger soil fractions in the tilled layer. At the same time, the standard deviation of field-surface irregularity heights increased by 0.30 and 0.28 cm, and the specific draft resistance increased by 0.47 and 0.60 kN m^{-1} at 6 and 9 km h^{-1}, respectively.

Based on the data in Table 2, a mass per harrow tooth of 2.10–2.25 kg is required for the harrow-roller to achieve the specified performance requirements.

CONCLUSIONS

The experimental results showed that, under the tested field conditions and travel speeds, the developed harrow-roller can reliably perform the specified technological process at the required agrotechnical level when the harrow tooth length is 140–160 mm and the mass per harrow tooth is 2.10–2.25 kg.

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