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Article

Results of Determining The Number of Machine-Tractor Aggregates Used in Preparing Soil Plowed in Autumn by The Traditional Method for Sowing

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Abstract: This article examines the issues of determining the number of machine-tractor units used in preparing autumn plowed soil for sowing and evaluating their efficiency. The study compared traditional and combined processing methods and determined the optimal composition of the units. As a result of calculations, it was established that the use of combined units allows for the efficient use of tractor power and reduces labor and fuel consumption. It is also substantiated that reducing the number of field passes reduces soil compaction. The number of technical means required to prepare 1,000 hectares of land for sowing within the established agrotechnical timeframe has been calculated. The research results showed that the use of combined machines is more economically and operationally efficient. The article serves to improve the effective use of agricultural machinery and soil cultivation technologies.

Keywords: productivity, tractor, unit, roller, working time, harrowing, coverage width, combined unit, land area.

Introduction

The optimization of machine-tractor aggregates is essential for improving operational efficiency and preserving soil health in modern sustainable agriculture. During seedbed preparation for crops sown in autumn, traditional multi-pass tillage systems—which rely on sequential, separate operations like chiseling, harrowing, and leveling—frequently underutilize tractor power. This operational mismatch significantly inflates labor costs, fuel consumption, and overall production expenditures [1], [2]. Mechanization theory establishes that agricultural productivity depends heavily on maximizing the tractive efficiency of the tractor while minimizing field passes to mitigate structural degradation. However, a notable knowledge gap persists regarding the exact mathematical optimization of equipment width and composition when transitioning from traditional configurations to integrated, combined machinery setups under specific regional agrotechnical timelines.

Previous studies have extensively documented the general benefits of combined tillage implements, yet few provide comparative quantitative modeling that maps tractor power utilization directly against multi-stage operational field demands [3], [4]. This study addresses this gap by analyzing three distinct machine-tractor configurations for preparing autumn-plowed soil over a standard 1,000-hectare area. Utilizing empirical traction formulas, we determine the optimal coverage width for an integrated unit and mathematically model its performance against traditional and fully combined single-pass configurations. It is expected that consolidating operations will mathematically maximize tractor power utilization while lowering operational days. The findings demonstrate that combined configurations dramatically cut field passes, resource expenditure, and compaction. Ultimately, these results provide actionable insights for resource-saving agricultural management and machinery optimization [5], [6].

Materials and Methods

The methodology evaluates the technical and operational efficiency of preparing 1,000 hectares of autumn-plowed soil for sowing within a strict 15-day agrotechnical timeframe. Working parameters are established around a two-shift daily schedule totaling 16 hours, utilizing a CLAAS ARION 630C tractor with an estimated traction power of 85 kW and a shift utilization coefficient of 0.8. The mathematical framework calculates three-hour performance, daily productivity, and total workload capacity across three operational options to determine the required number of physical units [7]. Option one models a traditional separate sequence of chisel cultivation, toothed zigzag harrowing, and mole harrowing. Option two optimizes the tractor's power utilization by calculating an mathematically optimal coverage width (Bopt) for a combined chisel and toothed harrow aggregate. This optimal width is derived from the tractor's traction power and the specific soil resistance of the implements, which averages 7 kN/m for the chisel and 1.5 kN/m for the harrow. This option then pairs the optimized aggregate with a secondary mole harrowing unit [8], [9]. Option three introduces a fully combined machine that integrates a chisel-cultivator, leveler, and roller into a single-pass system operating at 8.5 km/h. Finally, a comparative matrix analysis is applied to all three options to quantify total tractor requirements, machine operator labor hours, and total fuel consumption per 1,000 hectares, establishing a clear statistical basis for technological and resource-saving efficiency.

Results and Discussion

Option one. Preliminary data: cultivated area F = 1000 ha, duration of work D = 15 days, duration of one shift T = 8 hours, due to the urgency of the work, work is carried out in two shifts, shift time utilization coefficient τ = 0.8, tractor: CLAAS ARION 630C, technological operations: chisel cultivation + toothed zigzag harrowing + harrowing (MV - 6.0).

We calculate by technological operations.

1. Parameters of the chisel cultivator: coverage width: B = 4 m; operating speed: V = 7 km/h; τ = 0.8.

Let's find the three-hour performance:

$$W_h = 0{,}1 \cdot B \cdot \upsilon \cdot \tau = 0{,}1 \cdot 4 \cdot 7 \cdot 0{,}8 = 2{,}24 \frac{\text{hectare}}{watch}, \qquad (1)$$

Let's determine the daily productivity:

$$W_k = W_h \cdot T_k = 2.24 \cdot 16 = 35.84 \frac{\text{hectare}}{\text{day}}, \qquad (2)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 35.84 \cdot 15 = 537{,}6 \text{ hectare}, \quad (3)$$

Determine the required number of units.

$$N = \frac{F}{F_1} = \frac{1000}{537{,}6} = 1{,}86, \quad (4)$$

Based on this result, we take the number of units required to cultivate 1000 hectares as 2.

With these two units, it is possible to chisel 1,000 hectares of land in 14 working days [10].

2. Parameters of the "Zig-zag" toothed harrow: coverage width: B = 10 m; operating speed: V = 10 km/h; τ = 0.8.

Let's find the three-hour performance:

$$W_h = 0{,}1 \cdot B \cdot \upsilon \cdot \tau = 0{,}1 \cdot 10 \cdot 10 \cdot 0{,}8 = 8{,}0 \frac{\text{hectare}}{\text{watch}}, \qquad (5)$$

Let's determine the daily productivity:

$$W_k = W_h \cdot T_k = 8.0 \cdot 16 = 128.0 \frac{\text{hectare}}{\text{day}}, \qquad (6)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 128.0 \cdot 15 = 1920{,}0 \text{ hectare}, \qquad (7)$$

Determine the required number of units.

$$N = \frac{F}{F_1} = \frac{1000}{1920{,}0} = 0{,}52, \qquad (8)$$

Based on this result, we assume the number of units required to cultivate 1000 hectares is 1.

With this unit, it is possible to harrow 1,000 hectares of land in 13 hours over 7 days [11], [12].

3. Harrowing. Parameters of the MV-6,0 mole: range: B = 6.0 m; operating speed: V = 8 km/h; τ = 0.8.

Let's find the three-hour performance:

$$W_h = 0{,}1 \cdot B \cdot \upsilon \cdot \tau = 0{,}1 \cdot 6 \cdot 8 \cdot 0{,}8 = 3{,}84 \frac{\text{hectare}}{\text{watch}}, \qquad (9)$$

Let's determine the daily productivity:

$$W_k = W_h \cdot T_k = 3{,}84 \cdot 16 = 61.44 \frac{\text{hechtare}}{\text{day}}, \qquad (10)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 61.44 \cdot 15 = 921{,}6 \text{ hectare}, \qquad (11)$$

Determine the required number of units.

$$N = \frac{F}{F_1} = \frac{1000}{921{,}6} = 1{,}08 \quad (12)$$

Based on this result, we assume the number of units required for harrowing an area of 1000 hectares is 1 ARION 630C tractor and 2 MV-6.0 harrows.

With this unit, it is possible to harrow 1,000 hectares of land in 16.5 working days. In this case, to reduce the harrowing time, a second harrow can be used with a tractor released from harrowing.

Based on this result, we take the number of units required to cultivate 1000 hectares as 2. However, considering that the second units can process 1,000 hectares of land in 7 days and 13 hours, we will take the number of tractors for the third unit as 1 and the number of harrows as 2 [13] ,[14].

It follows that to prepare 1,000 hectares of land for sowing in 15 days, 4 ARION 630C tractors, 2 chisel cultivators, 2 harrows, and 10 zigzag harrows with a coverage width of 1 meter are sufficient.

Second option. From the above data, it can be seen that machines attached to the ARION 630C tractor to prepare lands plowed in autumn for sowing using the existing traditional method do not ensure the efficient use of the tractor's power. Therefore, let us consider the possibility of ensuring the efficient use of the tractor's power.

In this case, the problem is posed as follows: For a combined unit consisting of a chisel cultivator and a toothed harrow, it is necessary to determine the coverage width such that the tractor's traction power is sufficient, the unit's productivity is maximum, and fuel consumption is minimal.

First unit composition: Traktor + chisel cultivator + toothed harrow. Such an aggregate is a combined soil tillage unit and performs the following operations in one go: loosening the soil, crushing clods, and leveling the soil to a certain extent. As a result, the field approaches the state of being ready for sowing, and the number of operations decreases.

Composition of the second unit: Traktor+mole (MV-6,0). Such an aggregate prepares the soil for final sowing.

Determine the technical and operational parameters of the first unit.

Now let's determine the optimal coverage width of the first unit [15].

DETERMINATION OF THE TRACTIVE RESISTANCE OF THE CHISEL + TOOTHED HARROW UNIT.

The total tractive resistance of the unit is determined by the formula:

$$R = B \cdot (k_1 + k_{2)} \quad (13)$$

where: R is the tractive resistance of the unit (kN); B – aggregate coverage width (m); k – specific soil resistance (kN/m).

In our conditions: for the chisel cultivator, k = 6-8 kN/m; for the toothed harrow, k = 1-2 kN/m.

Let us take the average value of these indicators: Resistance of the chisel cultivator: 7 kN/m; Resistance of the gear harrow; 1.5 kN/m;

The traction power of a tractor must satisfy the following condition:

$$P_t \geq R \cdot v \quad (14)$$

where P_t is the tractor traction power (kW)

The traction power for the ARION 630C tractor is approximately:

$$P_t \approx 85kW$$

Determine the optimal coverage width.

Combining the above equations 4 and 5:

$P_t = B_{opt} \cdot (k_1 + k_2) \cdot v$ Let's take the expression.

From this, the optimal coverage width will be:

$$\mathbf{B_{opt}} = \frac{\mathbf{P_t}}{(\mathbf{k_1}+\mathbf{k_2})\cdot \boldsymbol{\upsilon}}, \quad \mathbf{(15)}$$

Determine the velocity: υ = 7 km/h = 1.94 m/s.

$$B_{opt} = \frac{P_t}{(k_1 + k_2) \cdot \upsilon} = \frac{85}{(7 + 1{,}5) \cdot 1{,}94} = 5{,}15 \text{ m}, \qquad (16)$$

Calculation results showed that the optimal coverage width of the unit is *Bopt =5.15* meters. In practice, units are manufactured with standard widths; therefore, we assume that the unit's coverage width is *B = 5 m. </7>*

It was established that the optimal parameters of the unit are:

$$R_t = 5 \cdot (7 + 1{,}5) = 42{,}5\ kW \text{Traction resistance:;}$$

$$W_h = 0{,}1 \cdot B \cdot v \cdot \tau = 0{,}1 \cdot 5 \cdot 7 \cdot 0{,}8 = 2{,}8\ hectare/watch \text{ Performance:}$$

Calculations showed that due to the optimization of the unit's coverage width, the tractor's power utilization increased from 33% to 50%, and the unit's productivity increased by 20-25%.

Based on these parameters, we determine the number of units required to prepare an area of 1000 hectares for sowing within 15 working days [16].

Let's determine the daily productivity:

$$W_k = W_h \cdot T_k = 2.8 \cdot 16 = 44.8 \frac{hectare}{day}, \quad (17)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 44.8 \cdot 15 = 672 \text{ hectare}, \qquad (18)$$

Determine the required number of units:

$$N = \frac{F}{F_1} = \frac{1000}{672} = 1{,}49, \quad (19)$$

Based on this result, we take the number of units required to cultivate 1000 hectares as 2.

With these two units, it is possible to chisel 1,000 hectares in 10 days and 1 hour.

Determine the technical and operational parameters of the second unit.

Based on the coverage width and operating speed, we determine the unit's productivity.

Let's determine the hourly productivity:

$$W_h = 0{,}1 \cdot B \cdot \upsilon \cdot \tau = 0{,}1 \cdot 6 \cdot 8 \cdot 0{,}8 = 3.84 \frac{hectare}{\text{vatch}}, \qquad (20)$$

Daily productivity:

$$W_k = 3.84 \cdot 16 = 61.44 \frac{\text{hectare}}{\text{day}}, \quad (21)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 61.44 \cdot 15 = 922 \text{ hectare}, \qquad (22)$$

Determine the required number of units.

$$N = \frac{F}{F_1} = \frac{1000}{922} = 1{,}08 \quad (23)$$

Based on this result, we take the number of units required to cultivate 1000 hectares as 2. However, taking into account that the first units can process 1,000 hectares of land in 10 working days, we take the number of tractors for the second unit as 1 and the number of harrows as 2.

It follows that to prepare 1,000 hectares of land for sowing in 15 days, 3 ARION 630C tractors, 2 chisel-cultivators, 2 harrows, and a 10-toothed "zigzag" harrow with a coverage width of 1 meter are sufficient.

Option three. From the above data, it can be seen that due to the large number of machine and tractor units and the number of field passes intended for preparing lands plowed in autumn for sowing using the existing traditional method, the costs are high, the soil is excessively compacted, and high fuel and labor costs lead to an increase in the processing cost [17]. Therefore, let us consider the use of a combined machine consisting of a chisel-cultivator + a leveler + a roller, which allows for a reduction in the number of tractor passes through the field and costs.

$V = 8{,}5$ km/soat**Parameters of the combined machine**: coverage width: B = 4 m; operating speed:; τ = 0.8.

Let's find the three-hour performance:

$$W_h = 0{,}1 \cdot B \cdot \upsilon \cdot \tau = 0{,}1 \cdot 4 \cdot 8{,}5 \cdot 0{,}8 = 2{,}72 \frac{\text{hectare}}{\text{watch}}, \qquad (24)$$

Let's determine the daily productivity:

$$W_k = W_h \cdot T_k = 2.72 \cdot 16 = 43.52 \frac{hectare}{\text{day}}, \qquad (25)$$

Determine the 15-day workload:

$$F_1 = W_k \cdot T_{um} = 43.52 \cdot 15 = 652{,}8 \text{ hectare}, \qquad (26)$$

Determine the required number of units:

$$N = \frac{F}{F_1} = \frac{1000}{652{,}8} = 1{,}53 \qquad (27)$$

Based on this result, the number of units required for cultivating 1000 hectares is assumed to be 2.

With these two units, it fully prepares 1,000 hectares of land for sowing in 11.5 working days.

Table 1

Number of machine and tractor units used to prepare 1000 hectares of land plowed in autumn for sowing.

No	Indicators	Chisel cultivation + toothed zigzag harrowing + harrowing	Chisel-cultivator-toothed zigzag harrow + harrowing	Combined machine processing
1.	Number of tractors	4.	3.	2.
2.	Number of chisel cultivators	2.	2.	2.
3.	Number of toothed zigzag harrows	10	10	-
4.	Number of moles (MB-6.0)	2.	2.	-
5.	Leveler	-	-	2.
6.	Roller	-	-	2.

Table 2.
Comparative indicators of machine-tractor units used to prepare for sowing 1000 hectares of land plowed in autumn.

No	Indicators	Chisel-cultivator	Toothed harrow	Hammer	Chisel-cultivator-toothed zigzag harrow	Hammer	Combined machine
1.	Coverage width, m	4.0	10.0	6.0	5.	6.	4.0
2.	Operating speed, km/h	7.0	10.0	8.0	7.	8.	8.5
3.	Time utilization ratio	0.8	0.8	0.8	0.8	0.8	0.8
4.	Hourly productivity, ha/hour	2.24	8.0	3.84	2.8	3.84	2.72
5.	Fuel consumption, l/ha	14.0	3.9	8.2	11.2	8.2	15.1
6.	1000 ha cultivation time, hours	447	125	261	357	261	368
7.	Fuel consumption per 1000 ha	14000	3900	8200	11200	8200	15100

Analysis of the data presented in the table 1 showed that in the first variant, the specified volume of work was completed in 15 working days, with labor costs amounting to 833 hours and fuel consumption G=26100 liters. In the second variant, the specified volume of work was completed in 13 working days, with labor costs amounting to 618 hours and fuel consumption G=19400 liters (table 2). In the third variant, the specified volume of work was completed in 12 working days; labor costs amounted to 368 hours, and fuel consumption was G=15100 liters. Labor costs decreased by 35%, 126%, and 68%, respectively, while fuel consumption decreased by 35%, 73%, and 28%, respectively. At the same time, the number of passes of the machine-tractor unit through the field was 3.2.1 times, and the number of tractors required to perform the technological process was 4.3.2 units [18]. The number of involved machine operators is 8, 6, and 4 respectively, as the work is organized in two shifts. At the same time, the established agrotechnical period was 15, 13, and 12 working days, respectively.

Conclusion

As a result of the conducted research, the technological and economic efficiency of various machine-tractor units used in preparing autumn plowed soil for sowing was evaluated. Calculations have shown that technological operations performed using traditional methods require a large amount of machinery, fuel, and labor. The use of combined units reduces the number of technological operations and allows for the efficient use of tractor power. As a result, the number of field passes is reduced, excessive soil compaction is prevented, and the possibility of adhering to agrotechnical deadlines increases.

According to the research results, it was determined that the use of combined machines significantly reduces labor and fuel costs. At the same time, the number of tractors and units required to prepare 1,000 hectares for sowing has also decreased. This serves to reduce production costs and increase economic efficiency. Thus, the use of combined machines in soil cultivation is a resource-saving and efficient technology in agricultural production.

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