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Implementation of simultaneous performance of two technological operations with different machine-and-tractor units

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Abstract. The gap between two technological operations should be minimal in the production environment. For this, special combined (multi-operational) machine-and-tractor units (MTU) are used. Their agricultural machines have sequentially installed working devices for various technological purposes. In the absence of such MTUs, single-operation units are used. Such units more often have different working widths. For their simultaneous operation in the same field, the first unit (for example, a sowing unit) must have a wider width than the second one (for example, a rolling one). In practice, the opposite case occurs more often when the first unit's working width is less than the second unit's working width. As a result, the first machine-and-tractor unit delays the work of the second one. This article aims to develop the algorithm for the simultaneous operation of two machine-and-tractor units of different field performance. The first of them (a sowing unit) has a working width of 3.6 m, and the second (a rolling one) is 6.1 m. As a result, the following has been established using the example of processing a field of 80 hectares: the second unit should start its work (i.e., rolling the crops) when the first one (sowing) has sown a certain area. According to the formula proposed in the article, the size of this area is 44 hectares. Under natural working conditions, the second unit (rolling) started its work after the first (sowing) unit has sown 44 hectares of the field area. As a result, both units have completed the entire area with a half-hour gap, i.e., practically simultaneously and without delay from each other.

Key words: operating speed, sowing, rolling, technological operation, working width.

INTRODUCTION

The execution time of technological operations in the agricultural crop growing has a significant impact on its yield. From factory farming, for example, it is known that the shorter the technological operation time for:

i) soil preparation and sowing;

ii) sowing and rolling crops, etc., the less moisture loss, the more efficient its use.

First of all, use wide-cut, which means high-performance machine-and-tractor units (MTU). They consist of both one and several machines (units) (Ivanovs et al., 2018; Bulgakov et al., 2018; Bulgakov et al., 2021).

Combined MTUs are best suited to shorten the time between adjacent technological operations (e.g., soil preparation and sowing, sowing, and rolling). The most typical of them is the unit considered in work (Bulgakov et al., 2017). It is a series-connected machine for applying mineral fertilizers and a grain seeder. A characteristic feature of this MTU is the same working width of used machines. Its primary disadvantage is its sizeable kinematic length.

A combined unit for harrowing soil and crops and grain crops sowing with the synchronous application of the main, starting fertilizer, and rolling the crops with a spiral-screwed roller (Jebur et al., 2013; Maslov et al., 2019), is more complicated. Combining the listed operations in one pass is based on working bodies such as applicators for the main application of mineral fertilizers, conventional double-disk furrow openers for sowing seeds of grain crops, and a starting fertilizer dose. A spiral-screwed roller is used to roll the sown seeds to a given depth into the soil layer with an optimal density in series with them.

Bertollo et al. (2018) investigated two technological operations that are performed sequentially. The first operation consists of preparing the soil with a chisel plow, and the second involves sowing an agricultural crop. The difference between the combination of these technological operations is that they can be performed asynchronously. This fact means that the operating mode of each unit does not depend on each other.

The appearance of tractors equipped with a front linkage and a front power take-off shaft makes it possible to create combined units according to the ‘push-pull’ scheme (Yaroshenko, 2015; Bulgakov et al., 2016). In this variant, the rear agricultural machine operates in the traction mode and the front one in the pushing mode. The machines are spaced apart in the longitudinal direction at a distance approximately equal to the tractor's overall length. However, the cut width of the front and rear machines in such a unit is equal. And since they are used with the same tractor, they also work in the same way.

Recently, the Controlled Traffic Farming (CTF) system has been increasingly used in many countries (Tullberg et al., 2007; Antille et al., 2015; Chamen, 2015; Galambošová et al., 2017). In this system, machine and tractor units' movement occurs along permanent traffic lines (PTL). The working cut width of the used machine and tractor units is equal to or a multiple of the PTL pitch (Talarczyk et al., 2016; Antille et al., 2019). All technological operations are generally performed sequentially. And if some machine and tractor units work simultaneously, their movement modes depend on each other. This circumstance is predetermined by the system's essence, which provides aggregate movements in strictly defined field zones.

From the above analysis, the following remains unclear: how to organize the operation of machine-and-tractor units in one field under the following conditions:

i) MTU operation should occur with a minimum time gap;

ii) the unit's performance executing the first operation is more significant than the MTU performance performing the second technological operation.

In the absence of such units' work, the first one, i.e., less productive of them, can disrupt the mode of operation of another. In practice, this will manifest itself in the latter's periodic downtime, which is an undesirable result.

To avoid this, the goal of this work is to develop an algorithm for operating two MTUs in one field, in which the performance of the first unit is lower than that of the second one.

THEORETICAL PREMISES

The basis of the developed algorithm for operating two MTUs of different performances is as follows: the first unit, less productive starts working first; the second unit is included in the technological process at a particular time and then works simultaneously with the first unit until the entire work volume is completed.

First, one should answer the question: what area of the field (let us label it by S_o) the first unit should process for the second one to work right after it until the very end without stopping.

According to the condition, the performance of the first MTU W_1 is less than the performance of the second unit W_2. Then:

$$\left.\begin{aligned} &W_1 < W_2; \\ &W_1 = 0.1B_1 \cdot V_1 \cdot \tau_1; \\ &W_2 = 0.1B_2 \cdot V_2 \cdot \tau_2, \end{aligned}\right\} \qquad (1)$$

where $B_1, V_1, \tau_1; B_2, V_2, \tau_2$ = the working width, the travel speed, and the working time's utilization factor for the first and second MTU, respectively.

The duration of the first unit operation is labeled T_1, and the second one is T_2. And since the performance of the latter is higher, then the time of its operation over the entire field of S area will not be less than some ΔT value, that is:

$$T_2 = T_1 - \Delta T.$$

Because of this, we can write that:

$$\left.\begin{aligned} S &= W_1 \cdot T_1; \\ S &= W_2 \cdot T_2 = W_2(T_1 - \Delta T). \end{aligned}\right\} \qquad (2)$$

Equating the right-hand sides of the equations of system (2) and taking into account the second and third equations of system (1), after transformations, we obtain:

$$\Delta T = \frac{S}{0.1B_1 \cdot V_1 \cdot \tau_1} \cdot \left(1 - \frac{B_1 \cdot V_1 \cdot \tau_1}{B_2 \cdot V_2 \cdot \tau_2}\right). \qquad (3)$$

The ΔT value is the time it takes for the first unit to process the field with the S_0 area and after which the second unit starts working, i.e.:

$$S_o = W_1 \cdot \Delta T. \qquad (4)$$

Taking into account the Eq. (3), the expression (4) will take the following final form:

$$S_o = S \cdot \left(1 - \frac{B_1 \cdot V_1 \cdot \tau_1}{B_2 \cdot V_2 \cdot \tau_2}\right). \qquad (5)$$

It should be noted that under the condition of both units' same performance, i.e., when $B_1 \cdot V_1 \cdot \tau_1 = B_2 \cdot V_2 \cdot \tau_2$ from Eqs (3) and (5), we obtain $\Delta T = S_o = 0$, which is quite a logical result.

MATERIALS AND METHODS

For checking the developed theoretical prerequisites, experimental studies of two machine-and-tractor units based on the MTZ-890 (Belarus) tractor have been carried out. The first has sown winter wheat (Fig. 1), and the second unit has carried out rolling crops (Fig. 2). In the south of Ukraine's arid conditions, such a technological method as rolling is essential.

Figure 1. Sowing machine-and-tractor unit.

Figure 2. Rolling machine-and-tractor unit.

Brief technical description of both MTUs is presented in Table 1. Both units have worked in the field with an area is equal to S = 80 ha. This field size is typical for the south of Ukraine. In the process of experimental studies, the speed of movement V and the working width B of each MTU have been determined.

Table 1. Brief technical description of sowing and rolling units

Index	Sowing MTU	Rolling MTU
Tractor	MTZ-890 (Belarus)	MTZ-890 (Belarus)
Tractor weight (kg)	3,900	3,915
and engine power (kW)	65	65
Machine	SZ-3.6	KZK-6
Manufacturer	Elvorti	Vostok
Constructive width (m)	3.6	6.1
Working device	Disk furrow opener	Single packer roller
Number of working devices	24	51
Connection to the tractor	Trailed	Trailed
Minimum turning radius (R_{min}, m)	4.1	4.1
Length of straight movement on the headland (L_o, m)	6.3	7.0
Weight (kg)	1,300	2,400

For this, the field has been divided into sections L_a = 250 m long each. The time t_a of the unit passing the test section in two replicates has been recorded using an FS-8200 electronic stopwatch with a measurement accuracy of 0.1 s.

The speed of movement of the machine-and-tractor unit has been calculated using the formula:

$$V = \frac{L_a}{t_a}.$$

The method for determining the working width of the machine-and-tractor unit has been as follows. The passage of each of them has been determined by the visible edge of the processed field strip. At the given L distance from it, 50 pegs have been set with 1 m steps. Then the machine-and-tractor unit has made a working stroke, the visibility of which has been determined by the new edge of the field's processed strip. After that, the shortest h_i distance from this edge to each installed peg has been measured (Fig. 3).

The working width B of the machine-and-tractor unit has been calculated from the following equation:

$$B = L - h_i.$$

In this case, the L index value has been equal to 5 m for the sowing unit and 8 m for the rolling one.

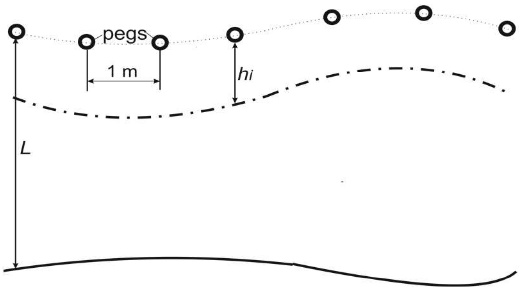

Figure 3. The measuring scheme of the MTU working width:
– edge of the MTU previous pass;
– edge of the MTU last working pass.

To measure the L distance with an accuracy of 1 cm, a Tolsen tape measure with a measurement limit of up to 10 m has been used.

The seeding and rolling machine-and-tractor units' quality of work have been assessed by the statistical parameters of fluctuations in their working width. The latter ones have been taken as:

i) average squared deviations;

ii) coefficients of variation;

iii) normalized correlation functions. As known (Nadykto, 2017), the latter characterizes the degree of interaction (correlation) between the random process values at different points in its course time. That is, they estimate the frequency of the oscillatory process.

RESULTS AND DISCUSSION

Experimental studies have established that, according to its potential capabilities, the seeding machine-and-tractor unit could move at a speed of 2.28 m s^{-1} (8.2 km h^{-1}). The average value of its effective working width has been 3.5 m (Table 2).

Table 2. Research results of sowing and rolling units

MTU	B, m	V, km h^{-1}	τ	W, ha h^{-1}	S_0, ha	ΔT, h
Sowing	3.5	8.2	0.70	2.0	44.0	22.0
Rolling	6.0	8.9	0.85	4.5		

Studies of such units in Ukraine have established that the efficiency factor (τ) averages 0.70. Then, taking into account the second equation of system (1), the calculated performance of the sowing machine-and-tractor unit is $W_1 = 2.0$ ha h^{-1}.

The maximum possible movement speed of the second, i.e., the rolling unit, has been 2.47 m s^{-1} (8.9 km h^{-1}), as follows from experimental studies. Its average effective width has been 6.0 m. The efficiency factor in time for such units, as practice shows, is higher and is, on average, 0.85.

Using the third equation of system (1), it has been established that the estimated performance of such a machine-and-tractor unit should be equal to $W_2 = 4.5$ ha h^{-1}. It is 2.25 times more than the seeding unit performance (Table 2).

The width of the headland has been calculated for both machine-and-tractor units. The latter is known to have two meanings:

i) minimum (E_{min});

ii) valid (E_r).

On the headland, both units have performed a pear-shaped turn. In this maneuver, E_{min} is calculated using the following formula:

$$E_{min} = 2.8 \cdot R_{min} + L_o + 0.5 \cdot B.$$

The actual value of the swath width E_r is known to be either equal or a multiple of the machine working width:

$$E_r = \text{Integer}\left(\frac{2.8 \cdot R_{min} + L_o + 0.5 \cdot B}{B}\right) \cdot B.$$

Numerical values for determining E_{min} and E_r parameters are presented in Table 1 below. The calculations have established the following:

– for sowing MTU: $E_{min} = 19.58$ m; $E_r = 21.6$ m;

– for rolling MTU: $E_{min} = 21.48$ m; $E_r = 24.4\ m$.

As can be seen, the effective width of the headland of the sowing machine-and-tractor unit E_r is equal to 6 values of its working width *B*. For the rolling MTU, the value of the parameter E_r is equal to 4 values of the value *B*.

The calculation according to the formula (5) has shown that for the simultaneous completion of the work of both units in the same field, the first of them (i.e., sowing one) must be the first process (sow) 44 hectares. For this, it will need 22 hours (Table 1).

After that, the second (i.e., rolling) machine-and-tractor unit is connected to work. In the future, both units must operate in the same field until both operations are completed (Fig. 4).

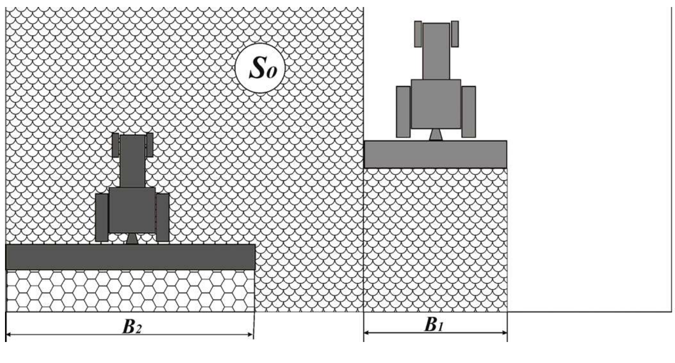

Figure 4. Operating scheme of sowing and rolling machine-and-tractor units.

According to the calculations, the sowing machine-and-tractor unit has worked in the field for 22 hours in the considered machine-and-tractor units' actual operation. Then the second machine-and-tractor unit started to perform its technological process. Later, both units finished processing the entire field with a gap of 0.5 hours. That is, almost simultaneously.

The unit's work quality was satisfactory. It is evidenced by the normalized correlation functions of each working width oscillations (Fig. 5).

An essential characteristic of each function is the point where they cross the zero threshold. In practice, this abscissa means the length of the correlation between adjacent dimensions of the process under study. The greater the location of this point from the vertical coordinate axis, the more low-frequency process is the random oscillatory process.

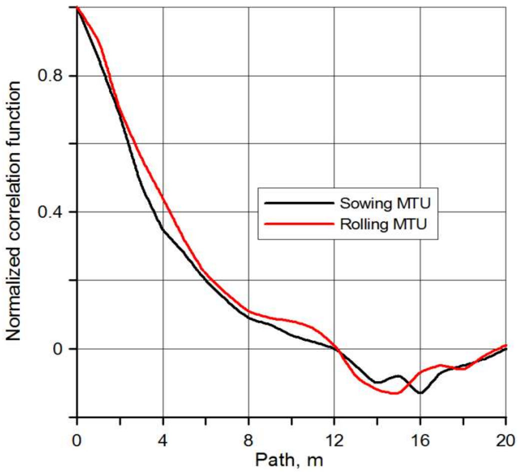

Figure 5. Normalized correlation functions of MTU width oscillations.

In this case, both units' correlation length has turned out to be practically the same and approximately equal to 12 m (Fig. 5).

In principle, this means that for a sowing unit moving at a speed of 2.28 m s^{-1}, the tightness of the connection between two adjacent measurements of the working width has disappeared only after 12 m / 2.28 m s^{-1} = 5.3 s. For the rolling unit, this figure has been 4.9 s.

The root-mean-square deviation of fluctuations in the sowing unit's working width is ± 3.4 cm, and the rolling one is ± 3.6 cm. The variation coefficients of the oscillations of the parameters B_1 and B_2 have not exceeded 1%. Together, this data indicates a fairly rectilinear movement of the studied units, which, in the end, is a positive fact.

CONCLUSIONS

A methodology has been developed to organize two technological operations of sequential execution by machine-and-tractor units. The first performance is less than the performance of the second one. It has been established that the latter must begin its work after the first machine-and-tractor unit completes its technological process in a particular area (S_o). This parameter's value can be determined from Eq. (5), which links the entire field (S) with both units' performance.

The theoretical dependencies' reliability has been proven by the practical work of the seeding and rolling machine-and-tractor units. The performance of the second has been 2.25 times higher than the performance of the second one. Using the proposed methodology for organizing their joint work has allowed both units almost simultaneously and with satisfactory quality to complete the sowing and rolling of winter wheat crops in a field of 80 hectares.

The proposed technique can be successfully applied to organize the conduct of two technological operations of sequential execution by any other machine-and-tractor units, in which the performance of the first is less than the performance of the second one.

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