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DOI: 10.2478/ata-2025-0024

Acta Technologica Agriculturae 3
Nitra, Slovaca Universitas Agriculturae Nitriae, 2025, pp. 191–196

ENERGY CONSUMPTION STUDIES OF MACHINE-TRACTOR AGGREGATE FOR STAGGERED SOWING OF HOEING CROPS ON CALCIC CHERNOZEM

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In the Republic of Bulgaria, in the last few years, a DeltaRow technology of staggered sowing of the seeds of hoeing crops such as maize for grain and sunflower has been successfully applied in some agricultural regions. An Azurit 10.8 seed drill is used to implement the staggered sowing technology. This precision seeder is aggregated with tractors with a nominal towing resistance of 30 kN (New Holland T6.165). The efficient use of this machine-tractor aggregate required a comprehensive study of its energy consumption by applying the tensiometer method. This paper discusses the scheme of the main procedures of the experiment conducted, the order and method of determining the relevant energy indicators, and the results of this study. The findings demonstrate that the chosen energy source in the newly assembled machine-tractor unit is appropriately chosen due to its towing and power capabilities because the maximum towing resistance, when sowing a field after pre-sowing treatment, reaches up to 12.1 kN, while the nominal one of this tractor is 30 kN. In addition, its maximum power consumption reaches up to 56.98 kW, with an engine load factor of 53.25% and acceptable wheelspin of up to 6.3% in the operating speed range of 2.3–3.4 m·s^{-1}. In addition, the researched machine-tractor aggregate in terms of energy consumption ensures an optimum towing and speed of operation when carrying out the technological operation of staggered sowing with paired sown rows of hoeing crops on the agricultural lands of the Republic of Bulgaria with calcic chernozem.

Keywords: energy performance assessment; energy consumption indicators; seeder for staggered seed placement; DeltaRow technology of staggered sowing of seeds

The amount of energy consumed during technological operations performed by machine-tractor aggregates is essential for the cost of agricultural production. Therefore, it is necessary to optimise the performance and annual workload of these aggregates so that they work efficiently. In addition, it is important to choose an appropriate power source machine and working machine that constitute the aggregate to guarantee an optimal fuel consumption (Maslov et al., 2016). With reference to this, an interesting method has been proposed to determine the energy consumption by optimising the parameters and operating modes of a multipurpose aggregate for sowing row crops (Maslov et al., 2016; Tsybulevsky et al., 2021). Some studies have considered the selection of the main parameters of tractors used for direct sowing of cereals according to different optimisation criteria, such as minimum CO_2 emissions, minimum fuel consumption per ha, maximum productivity, and maximum towing efficiency of the energy vehicle (Khafizov et al., 2022). Other publications provide a rationale for an energy mathematical model based on system analysis and numerical experiments of high energy process operations, determining the optimal number of tractors to perform a job by the total energy cost (Khafizov et al., 2021a). A mathematical model, based on system analysis and numerical experiments, considering a combination of low and high energy consuming technological operations grouped by energy consumption is also proposed (Khafizov et al., 2021b).

Another important condition to be considered when assembling machine-tractor aggregates with reference to the optimal use of the towing capacity of power units (tractors) is the selection of a suitable working machine which corresponds to tractor's towing capacity. Very often machines are aggregated without necessary scientific justification, which results in high-cost technological operations, low productivity, high fuel consumption, etc. Such errors can occur when old generation power sources (tractors) are combined with new machines due to a lack of sufficient compatibility research. Some authors propose an interesting methodology for assembling machine-tractor aggregates based on the potential characteristics of the tractor using a graph-analytical method (Yudina et al., 2021). Other authors have shown that tractor towing capacity on soft ground is largely influenced by tire contact length rather than tire contact width (Chandrakar and Raheman, 2024). In addition to determination of tractors' towing capacity, fuel consumption is another important factor of efficient operation when determining the energy consumption related to performing technological operations with machine-tractor aggregates. The effect of selecting different transmission gears on tractor performance and fuel consumption during deep tillage has also been studied (Kichler et al., 2011). One of the most important technological operations in agriculture is sowing. Its correct performance in accordance with the technical parameters of sowing machines, the technological requirements of the sown crop, and agro-meteorological conditions during sowing is a prerequisite for the simultaneous germination of all seeds and meeting the requirements for number of seedlings per ha. Some researchers consider the tractor–tire–tool system and make interesting comparisons between the agronomic and energy consumption features during the sowing of spring barley (*Hordeum vulgare*) (Mohieddinne et al., 2023). Other authors prove the effectiveness of crawler tractors for scarifying and sowing cereals (Hafizov et al., 2022). Depending on the distribution of seeds over the area, there are different types of sowing: broadcast, narrow-row, wide-row, strip (slot), dotted (precision), nested, and direct seeding (Vasilev et al., 1986). The precise distribution of plants in rows is of great importance because this guarantees an even distribution of nutrients needed for the germination of hoeing crops and subsequently obtaining high yields from them (Hörbe et al., 2016). Pneumatic vacuum seeders are widely used in agriculture for row crops. It has been found that their precision of sowing is in the range between 0.5% and 2.5% (Vučajnk et al., 2017). In recent years, due to climate changes, new non-traditional sowing technologies, such as the DeltaRow technology, have been introduced in Bulgaria in search for efficient technologies to increase maize and sunflower yields in the conditions of persistent drought. With this technology, 6 or 8 paired rows of sowing are carried out at a distance of 0.125 m from each other, and their inter-row distance is 0.70 m (Fig. 1). Compared to conventional sowing, this method, which is new to Bulgaria, provides up to 70% more space per plant. This means that plants have greater access to water, light, and nutrients. The technology also guarantees better resistance of soil to erosion (Donev et al., 2021). The technology is widely studied and tested in many European countries, particularly in Croatia where the obtained results are mainly about its influence on yields from sown crops (Banaj et al., 2017; Ogrizović, 2015). For the implementation of the DeltaRow technology for staggered seed sowing of some hoeing crops (Fig. 1), specialised Lemken seed drills of the Azurit 10.8K series are used in Bulgaria, performing both sowing and fertilising (Donev et al., 2021).

Fig. 2 Machine-tractor aggregate for staggered sowing of hoeing crops
Source: Agronika, 2024

Fig. 1 DeltaRow seeding method with paired rows
Source: Agronika, 2024

It is combined with tractors with nominal power from 120 kW to 140 kW. As a power source in this aggregate, New Holland T6.165 tractors are used in Bulgaria. Unfortunately, when imported Lemken seed drills were paired in machine-tractor aggregates, there was no scientifically based energy consumption research concerning available tractors and seed drills for applying the DeltaRow technology. Initially, the design of the aggregate relied both on the recommendations of the manufacturer and the technical characteristics of available power sources (tractors) and imported Lemken seed drills. The machine-tractor aggregate for sowing is shown in Fig. 2. The efficient use of this machine-tractor aggregate required conducting energy consumption studies by a team of researchers from the "Angel Kanchev" University of Ruse to properly combine the elements of the aggregate and to ensure its optimum towing and speed performance.

Conducting such energy consumption assessments of all agricultural aggregates used in Bulgarian agriculture is a tradition and a very important requirement in choosing and providing the most appropriate technical equipment for agricultural production.

With reference to this, the purpose of this paper is to outline the sequence of steps and procedures of conducting the energy consumption evaluation of the machine-tractor aggregate for staggered sowing of hoeing crops and to analyse the obtained results concerning its main energy indicators. After a detailed study, it is reported that no such energy studies have been done on this method and device, which is a novelty in these experimental studies.

Material and methods

The energy consumption research was done in 2023 on the agricultural land of the town of Kubrat, Ruse Region, on a field with calcic chernozem, after pre-sowing soil tillage. The studies were carried out at a soil moisture of 11.30% in the 0–1.50 m layer and a hardness of 17.28 kg·cm^{-2} in the 0–0·40 m layer, according to the specific agrotechnical requirements for performing the technological operation of staggered sowing with paired sown rows, as well as according to established research methodology (Dimitrov and Beloev, 2016., Dimitrov et al., 2020).

The main energy indicators have been determined for the machine-tractor aggregate with a New Holland T6.165 tractor as an energy source and an Azurit 10.8 precision seeder for staggered sowing (Fig. 2).

The tensiometer method was used to determine the energy indicators of the above-mentioned aggregate. The speed of movement of the aggregate was determined on experimental plots with a length of 100 m. The scheme according to which the energy studies were conducted is shown in Fig. 3. The measurements of required indicators were carried out by using a mobile tensiometer laboratory (PTL-1) with a set of multipurpose tensiometer units. To reveal the traction and speed capabilities of the used tractor, the energy studies were performed at three forward speeds. From the obtained results, a general energy balance of the considered machine-tractor unit for sowing was compiled, and a program product for a computer element of the measuring system was used to process the data (Dimitrov and Beloev, 2016).

The total towing effort of the machine-tractor aggregate is measured with the help of the second (towing) tractor and the wheelspin of the main tractor. The wheelspin of the main tractor is also determined by the formula specified in standard (BDS)-12949-75 (1976), namely:

$$\delta = \frac{B_{PTO1} - B_{PTO2}}{B_{PTO1}} \cdot 100 \qquad (1)$$

where: δ – the wheelspin of the main tractor (%); B_{PTO1} – the number of pulses from the sensor attached to the PTO when the aggregate goes along the experimental plot with a working machine attached to it; B_{PTO2} – the number of pulses from the sensor attached to the PTO when the aggregate goes along the experimental plot when the aggregate is in an idle time mode

According to the technological requirements for the aggregate for staggered seed planting, three forward speeds were used for calculations. A general energy consumption balance was drawn up where the consumed effective power of the tractor used during the work process was calculated according to standard (BDS)-12949-75 (1976) by applying the following formula:

$$P_e = P_T + P_{COB} + P_M + P_C + P_\delta + P_x + P_i \qquad (2)$$

where: P_e – the effective power of the tractor engine (kW); $P_T = F_T \cdot V$ – the towing capacity of the tractor (kW); F_T – the towing resistance of the attached machine (kN); V – the average forward speed of the aggregate (m·s^{-1}); P_{COB} – power for the PTO shaft (kW); P_M – the power to overcome the mechanical losses in the transmission, PTO, and hydraulic drive mechanism (kW); $P_\delta = \delta \cdot P_B \cdot 10^{-2}$ – the power consumed by the wheelspin of the wheel drive mechanism (kW); δ – wheelspin (%); P_C – the power of the aggregate in an independent movement mode (kW); P_x – the power taken from the hydraulic drive mechanism (kW); P_i – the power needed to overcome a slope (kW)

In our particular cases, since there is not a hydraulic drive mechanism and a longitudinal gradient, P_x and P_i are equal to zero.

In addition, the specific resistance per metre of working width in kN·m^{-1} and the engine load factor of the used tractor were also calculated according to standard (BDS)-12949-75 (1976) by using the following formula:

$$K_E = \frac{P_e}{P_n} \cdot 100 \qquad (3)$$

where: K_E – the engine load factor of the used tractor (%); P_e – the effective engine power (kW); P_H – nominal engine power (kW)

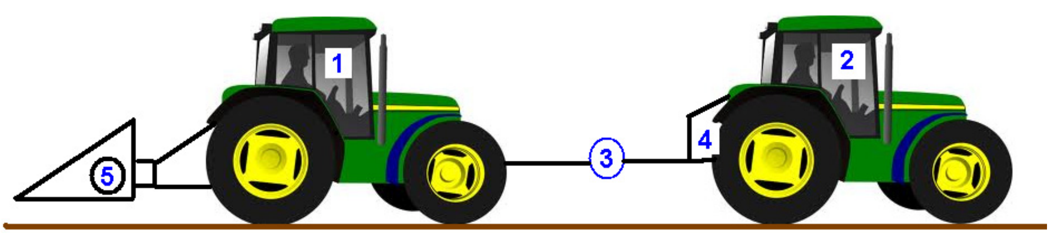

Fig. 3 Scheme of the experiments determining the energy indicators
1 – main tractor; 2 – second (towing) tractor; 3 – tensiometer unit for towing effort; 4 – sensor (converter) for the rotation frequency of the PTO; 5 – attached machine

In this case, the New Holland T6.165 tractor, which is included in the machine-tractor aggregate for staggered seed placement, has a nominal engine power value P_H = 107 kW. A specialised computer program was developed and used to calculate and enter the processed data of the general energy balance (Dimitrov and Beloev, 2016).

Five measurements were made for each gear shift. The mean value was calculated from these measurements according to the following formula:

$$\overline{x} = \frac{1}{N_s} \cdot \sum_{i=1}^{N_s} x_i \tag{4}$$

where: N_s – the range of the statistical file; x_i – the value of variable

Results and discussion

The results of the energy consumption studies for the machine-tractor aggregate for staggered sowing, consisting of the New Holland T6.165 tractor and the Azurit 10.8 seeder, are presented in Table 1.

After the analysis of the results from Table 1, it can be seen that this aggregate can operate in the field after pre-sowing tillage in a speed range from 8.28 to 12.24 km·h^{-1} (2.3–3.4 m·s^{-1}). Based on the built-in gearshift range of the New Holland T6.165 tractor, the technological operation of staggered sowing with paired rows can be carried out with the studied aggregate in terms of the speed capabilities of this tractor. In terms of towing and power capacity, the New Holland T6.165 tractor is also suitable for sizing the aggregate since its maximum towing resistance when sowing a field after pre-sowing cultivation at a depth of 0.10 m reaches 12.1 kN. In comparison, the nominal towing resistance of this tractor is 30 kN. The energy balance shows that the nominal power of the tractor (P_n = 107 kW) is sufficient to perform staggered sowing. In a field after pre-sowing tillage, the maximum power consumption reaches 56.98 kW, with an engine load factor of 53.25%. The wheelspin of the tractor reaches a maximum of 6.3% and is within the permissible range (Simeonov et al., 1986) of 17–18% for wheeled tractors.

Unlike the tensiometer method used in this study, some authors optimise the parameters and modes of operation in the row sowing of maize by simultaneous application of mineral fertiliser. This is done by using a mathematical model and an algorithm including some variables such as the towing effort applied by tractors, their towing capacity, the speed of movement, working width, specific fuel consumption, the length of movement along the cultivated plot, and the capacity of the seed and fertiliser hopper (Tsybulevsky et al., 2021). Soil compaction is an important physical limiting factor for root growth and plant emergence and is one of the major causes for reduced crop yields worldwide, thus determining the type and degree of tillage that suit the soil conditions (Mojžiš et al., 2024, Vacho et al., 2022). A similar graphical-analytical method has been proposed by other authors (Yudina et al., 2021). These two

Table 1 Energy consumption indicators of seeding aggregate consisting of the New Holland T6.165 tractor and the Azurit 10.8 precision seeder for applying the DeltaRow method (the mean value)

No.	Indicators	Measurement units	Indicator values		
1	gear shift	–	1	2	3
2	forward speed	m·s^{-1}	2.3	2.8	3.4
3	towing resistance	kN	6.4	8.2	12.1
4	towing capacity	kW	14.72	22.96	41.14
5	PTO torque	kN·m	40.0	42.0	43.0
6	PTO rotational speed	min^{-1}	540	540	540
7	PTO power	kW	2.3	2.4	3.0
8	wheelspin	%	5.2	5.8	6.3
9	wheelspin power	kW	0.76	1.33	2.59
10	resistance of the aggregate in an independent movement mode	kN	2.8	3.2	3.8
11	power of the aggregate in an independent movement mode	kW	6.44	8.96	12.92
12	power for mechanical losses in the transmission	kW	0.26	0.27	0.33
13	effective power	kW	22.18	33.91	56.98
14	engine load factor	%	20.72	31.69	53.25
15	working width	m	5.6	5.6	5.6
16	tillage depth	m	0.10	0.10	0.10
17	specific resistance: – per 1 m working width – per unit of the layer cross section	kN·m^{-1}	1.14 11.43	1.46 14.64	2.16 21.61

proposed methods, however, provide only preliminary theoretical background data regarding the optimal choice of a tractor and working machine in the composition of machine-tractor aggregates for particular technological operations. There is a lack of experimental studies conducted on soils with different mechanical composition, moisture, and plant residues; therefore, there is no comprehensive objective energy consumption assessment for tested aggregates.

The conditions of operation of a combustion engine under actual conditions are characterised by a wide range of engine speeds and torques (Jablonický et al., 2023). This has a direct impact on vehicle fuel consumption and exhaust emissions that may be expressed with a variety of characteristics (Merkisz and Rymaniak, 2017). The most important parameter of an engine is its power (Tulík et al., 2024).

The above-mentioned data, obtained through the tensiometer method in our study, can be used in combining appropriate machines in machine-tractor aggregates for staggered sowing. The proper selection of a power unit and a seeder can allow farmers to reach the optimum speed range of the aggregate, as well as to achieve low tractor engine load factor and tolerable wheelspin.

Conclusion

Based on the conducted energy consumption studies and the obtained results, the following conclusion can be drawn.

The innovative tensiometric method used in the study, which was developed and applied in Bulgaria, is a proven and reliable tool in the optimal selection of an energy source and working machine for the implementation of the Deta Row sowing of hoeing crops.

The energy source in the newly assembled machine-tractor unit, i.e. the New Holland T6.165 tractor and the Azurit 10.8 staggered drill, is appropriately chosen due to its towing and power capabilities. Its maximum towing resistance, when sowing a field after pre-sowing treatment, reaches up to 12.1 kN, while the nominal one of this tractor is 30 kN. In addition, its maximum power consumption reaches up to 56.98 kW, with an engine load factor of 53.25% and acceptable wheelspin of up to 6.3% in the operating speed range of 2.3–3.4 $m \cdot s^{-1}$.

The New Holland T6.165 tractor and the Azurit 10.8 precision seeder for staggered sowing are properly combined in the machine-tractor aggregate in terms of energy consumption. It ensures an optimum towing and speed of operation when carrying out the technological operation of staggered sowing with paired sown rows of hoeing crops on the agricultural lands of the Republic of Bulgaria on calcic chernozem.

Acknowledgment

This study was funded by the European Union – NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project no. BG-RRP-2.013-0001.

Results and discussion

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