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ENERGY CONSUMPTION STUDIES OF SOIL-PROTECTING MACHINE-TRACTOR AGGREGATE FOR SOIL LOOSENING

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Over the years, soil loosening, as a primary form of soil tillage, has been performed with machines of various construction characteristics that usually work at a depth of 0.40 m or sometimes even greater depths. These machines include cultivators for soil loosening, machines for deep soil loosening, and subsoilers. In Bulgaria, the Maschio-Gaspardo subsoiler, model Artiglio 300/7, has been successfully used for three years to perform this technological operation. This machine is aggregated with tractors with a nominal towing capacity of 50 kN, such as John Deere 8R280 tractors. The efficient use of this machine-tractor aggregate required a thorough energy-consumption study using the tensiometer method. The paper presents the study findings, which show that the tractor chosen for this newly formed aggregate is suitable due to its towing and power capacity. Its maximum towing resistance when performing soil loosening reaches 36.40 kN, while the normal indicator for this tractor is 50.00 kN. The maximum power consumption can reach up to 208.78 kW, with an engine load factor of 92.01% and a permissible wheelspin of a maximum of 14.9%. This machine-tractor aggregate is properly sized in terms of power consumption and ensures optimum towing and speed operation when carrying out the soil conservation method of soil loosening as main tillage on agricultural land with calcic chernozem soil.

Keywords: energy performance assessment; energy-consumption indicators; soil-loosening machine; subsoiler; machine-tractor aggregate for soil loosening; soil calcic chernozem

Experiments to replace main tillage (ploughing) with loosening have been carried out for many years worldwide. According to these studies, some advantages of soil loosening include higher productivity, better quality of the tilled soil, the possibility of increasing the depth of ploughing, energy savings, etc. (Alkhafaji et al.,2018; Babu et al., 2020, 2024; Beloev and Dimitrov, 2019; Jakasania et al., 2018; Petrov et al.,2020; Ranjbarian et al., 2017; Rodias et al., 2017; Sarkar et al., 2021). Compared to ploughs, subsoilers break up the hardpan layer and loosen the soil to a greater extent, making it possible to reduce the number of subsequent cultivating operations to prepare the soil for sowing (Beloev and Dimitrov, 2019). Breaking up and loosening soil requires the completion of different tasks. Therefore, machines and tools with different designs are used, namely cultivators for soil loosening, machines for deep soil loosening, and subsoilers (Beloev and Sigalov, 2021; Stoynev, 2004; Jakasania et al., 2018). Soil loosening machines with working units reaching a working depth of 0.35–0.40 m must be used on soils of light and medium mechanical composition (Beloev and Dimitrov, 2019). As noted above, they replace basic tillage with a plough by breaking up the compacted hardpan layer formed beneath the surface. This helps plants develop a deeper root system and subsequently improves their access to both water and nutrients during vegetation (Beloev and Dimitrov, 2019; Beloev and Sigalov, 2021). Furthermore, soil loosening, as a basic cultivation operation, is also successfully applied in the Republic of Bulgaria as a highly effective soil conservation method for limiting the degradation processes of water erosion and soil compaction, which are a major and persistent problem when using sloping agricultural land (Beloev and Dimitrov, 2019).

Each method of tillage has its own advantages and disadvantages (Tarasenko et al., 2025). Traditional methods of reducing the energy consumption of tillage are no longer effective (Tarasenko et al., 2023). Numerous methods for reducing the tillage force of subsoiling tools have been proposed, such as biomimetic, oscillatory, lubrication, experimental, line element design, and others, which were largely found to be effective (Wang et al., 2023). Although these methods are excellent in some soil conditions and working parameters, they have various limitations that hinder their development to further improve tool performance (e.g., high cost and more energy consumption due to additional mechanisms) (Gürsoy et al., 2017; Sadek et al., 2021).

Over the years, in Bulgaria, this method has been applied using different types of soil breaking and loosening machines such as KRN cultivators for soil loosening

(KRN-1.75; KRN-2.4; KRN-3.0), SR chisel-cultivators (SR-9), and RN subsoilers for soil loosening (RN-3.8R) (Beloev and Dimitrov, 2019; Beloev and Sigalov, 2021). Last year, the Maschio Gaspardo subsoiler, model Artiglio 300/7, was imported from the Italian manufacturer Maschio-Gaspardo. As recommended by the manufacturer, this machine is aggregated with tractors with a nominal towing capacity of 50 kN. Unfortunately, the aggregation of machines in this machine-tractor aggregate cannot rely on scientifically based energy studies because there is no research involving the energy sources available in Bulgaria. The aggregation relies solely on the recommendations of the agricultural machine manufacturer and the technical characteristics of the energy sources used in the country. To determine the technical service life and reliability, laboratory or operating tests are used (Kosiba et al., 2022, 2024), while also considering ecology (Tulík et al., 2024). The future widespread use of this newly composed machine-tractor aggregate in Bulgarian agricultural practice and its efficient utilisation necessitated energy studies in field conditions by the "Angel Kanchev" University of Ruse. This research was conducted to determine the appropriate combination of machines in the aggregate and to ensure optimum towing and speed results. With reference to this, the purpose of this paper is to review the procedure for conducting an energy-consumption evaluation of this machine-tractor aggregate for soil loosening, as well as to analyse the findings concerning the main energy performance indicators of the aggregate.

Material and Methods

The energy consumption studies were carried out in 2023 on the agricultural lands of Kubrat town, Ruse region, on a stubble field with carbonate black soil (calcic chernozem) with an average slope of 5° (8.7%). The research was done under conditions of soil moisture of 17.90% in the 0–1.50 m layer and soil hardness of 14.78 kg·cm^{-2} in the 0–0.40 m layer, according to the specific agrotechnical requirements for performing the technological operation of soil loosening.

Fig. 1 Machine-tractor aggregate consisting of tractor John Deere 8R280 and subsoiler for soil loosening Maschio-Gaspardo, model Artiglio 300/7
Source: Agronika, 2025

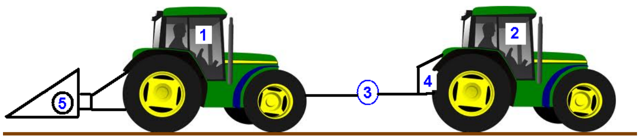

Fig. 2 Scheme of the experiments determining the energy indicators
1 – main tractor; 2 – second (towing) tractor; 3 – tensiometer unit for towing effort; 4 – sensor (converter) for the rotation frequency of the PTO; 5 – attached machine
Source: Dimitrov and Beloev, 2016

The main energy indicators were determined for a machine-tractor aggregate consisting of a John Deere 8R280 tractor as an energy source and a Maschio-Gaspardo subsoiler, model Artiglio 300/7, for soil loosening (Fig. 1).

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. 2, and the measurements of the required indicators were carried out using a mobile tensiometer laboratory (PTL-1) with a set of multipurpose tensiometer units. Part of the experiment results were recorded with the help of a 4-channel Oscillograph H700 (towing resistance), while the remaining ones (speed, wheelspin, time, frequency of rotation) were obtained digitally by the ASIT-1 microprocessor system. Based on the obtained results, a total energy-consumption balance of the studied machine-tractor aggregate for soil loosening was compiled. The data was processed using a software application of PCs, which is a component of the ASIT-1 system, in accordance with the standard of the Republic of Bulgaria BDS 12949-75:2016 (Dimitrov and Beloev, 2016).

The total towing effort of the machine-tractor aggregate is measured with the help of a second (towing) tractor and the wheelspin of the main tractor. The wheelspin of the main tractor is also determined by the formula specified in BDS 12949-75:1976 (Dimitrov and Beloev, 2016):

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

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 soil loosening, three forward speeds were used for the 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 Dimitrov and Beloev (2016) by applying the following formula:

$$P_e = P_T + P_{COB} + P_M + P_C + P_b + P_x \pm P_i \quad (2)$$

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} – the power for the PTO shaft (kW); P_M – the power to overcome the mechanical losses in the transmission, PTO, and hydraulic drive mechanism (kW); $P_b = \delta \cdot P_B \cdot 10^{-2}$ – the power consumed by the wheelspin of the wheel drive mechanism (kW); b – the 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, because there is no hydraulic drive mechanism and a longitudinal gradient, P_x and P_i are equal to zero.

In addition, the specific resistance per meter of working width in kN·m^{-1} and the engine load factor of the used tractor were also calculated according to Dimitrov and Beloev (2016) by using the following formula:

$$K_E = \frac{P_E}{P_n} \cdot 100 \quad (3)$$

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

In this case, the John Deere 8R280 tractor, which is included in the machine tractor aggregate for soil loosening, has a nominal engine power value of P_H = 226.9 kW. A specialised computer application was developed and used to calculate and register the processed data of the general energy balance.

Results and Discussion

The results of the energy-consumption studies of the machine-tractor aggregate for soil loosening, which consists of a John Deere 8R280 tractor and a Maschio-Gaspardo subsoiler, model Artiglio 300/7, are presented in Table 1.

The analysis of the results from Table 1 shows that this aggregate can operate on a stubble field with a speed ranging from 6.12 to 10.08 km·h^{-1} (1.7 to 2.8 m·s^{-1}). Based on the built-in gearshift range of the John Deere 8R280 tractor, the technological operation of soil loosening can be carried out with the studied aggregate in terms of the speed capabilities of this tractor. With reference to towing and power capacity, the John Deere 8R280 tractor is also suitable for being used in the aggregate since its maximum towing resistance when loosening soil on a stubble field at a depth of 0.49 m reaches 36.40 kN. In comparison, the nominal towing resistance of this tractor is 50 kN. The energy balance shows that the nominal power of the tractor (P_n = 226.9 kW) is sufficient to perform this soil-protecting operation. On a stubble field, the maximum power consumption can reach up to 208.78 kW, with an engine load factor of 92.01%. The wheelspin of the tractor reaches a maximum of 14.9% and is within the permissible range of 17–18% for wheeled tractors (Dimitrov and Beloev, 2016).

In contrast to the tensiometer method applied in this study, some authors use and research an interesting method for determining the specific fuel consumption of a tractor by building an artificial neural network model

Table 1 Energy-consumption indicators of a machine-tractor aggregate consisting of a tractor John Deere 8R280 and a subsoiler Maschio-Gaspardo, model Artiglio 300/7

No	Indicators	Measurement units	Indicator values		
1	gear shift	–	1	2	3
2	forward speed	m·s^{-1}	1.7	2.3	2.8
3	towing resistance	kN	34.80	35.20	36.40
4	towing capacity	kW	59.16	80.96	101.92
5	wheelspin	%	14.20	14.50	14.90
6	wheelspin power	kW	8.41	11.74	15.19
7	resistance of the aggregate in an independent movement mode	kN	13.80	13.90	14.10
8	power of the aggregate in an independent movement mode	kW	23.46	31.97	39.48
9	power for mechanical losses in the transmission	kW	30.34	41.56	52.19
10	effective power	kW	121.37	166.23	208.78
11	engine load factor	%	53.0	73.0	92.0
12	working width	m	3.0	3.0	3.0
13	depth of tillage	m	0.52	0.51	0.49
14	specific resistance: – per 1 m working width – per unit of the layer cross section	 k·Nm^{-1} k·Nm^{-2}	 11.60 22.31	 11.73 23.00	 12.13 24.76

during the technological operation of deep tillage (Al-Sager et al., 2024). This method considers important parameters such as tractor power, soil texture index, soil moisture, soil bulk density, etc. (Al-Sager et al., 2024). However, it does not study and provide information about the energy consumption balance in machine-tractor aggregates for soil loosening.

Only the tensiometer method applied by us, which has been developed in Bulgaria, gives a comprehensive, objective energy-consumption assessment of the studied machine-tractor aggregates in experimental studies, in specific soil and field conditions.

Other researchers from around the world use methods similar to the energy-consumption studies used by us (Adamchuk et al., 2016; Bulgakov et al., 2019; Kim et al., 2021; Moinfar and Shahgholi, 2018; Oskin and Tarasenko, 2017; Petrov et al., 2020; Tihanov and Ivanov, 2021).

The above-mentioned data, obtained from the tensiometer method used in our study, can also be utilised when it is necessary to come up with the optimal combination of machines for putting together machine-tractor aggregates for soil loosening as one of the main soil treatments in agriculture. With the proper selection of a power unit and a subsoiler, optimum towing and speed range, low engine load factor of the tractor, and acceptable wheelspin can be achieved.

Conclusion

Based on the conducted energy consumption studies and the obtained results, the following conclusions can be drawn:

- The tensiometer method, developed in Bulgaria and used in this experimental study, is a feasible and reliable tool for optimal selection of an energy source and a working machine for the implementation of the soil conservation method of soil loosening as the main tillage on agricultural lands.
- The chosen energy source in the newly assembled machine-tractor aggregate, consisting of a John Deere 8R280 tractor and a Maschio-Gaspardo subsoiler, model Artiglio 300/7, is suitable due to its towing capacity and power capabilities. Its maximum towing resistance when loosening the soil of a stubble field reaches up to 36.40 kN, with a nominal value of 50 kN for this tractor. In addition, its maximum power consumption reaches up to 208.78 kW, with an engine load factor of 92.01%, when the acceptable wheelspin is up to 14.9% in the speed range from 1.7 to 2.8 $m \cdot s^{-1}$.
- The John Deere 8R280 tractor and the Maschio-Gaspardo subsoiler, model Artiglio 300/7, are properly combined in a machine-tractor aggregate in terms of energy consumption, and this aggregate ensures optimum towing and speed of operation when carrying out the technological operation of soil loosening on the agricultural lands of the Republic of Bulgaria, namely carbonate black soil (calcic chernozem).

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