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Special tractor driving wheels with two modification of spikes inclination angle

R. Abrahám[1,*], R. Majdan[1] and R. Drlička[2]

[1]Department of handling and transport machinery, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr.A. Hlinku 2, SK949 76 Nitra, Slovak Republic
[2]Department of Quality and Engineering Technologies, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr.A. Hlinku 2, SK949 76 Nitra, Slovak
[*]Correspondence: rudolf.abraham@uniag.sk

Abstract The paper presents a research on an improvement of tractor drawbar properties using special driving wheels. Two modifications of the special driving wheels were designed and tested under field conditions. The results were compared with standard tyres. The special driving wheels consists of the tyres with a modified tyre-tread pattern and equips with the spike segments. The special driving wheels allow to activate or deactivate the spike segments to improve a drawbar pull at worse adhesive conditions of the ground or transport on roads with standard tyres. The first modification activates all 8 spike segments at spike inclination angle 90° and the second one 4 at angle 90°and 4 at 30°. The measurements were realised in October 2017 in an area of the Slovak Agricultural Museum in Nitra. The drawbar properties of the special driving wheels were evaluated based on drawbar pull of the test tractor Mini 070 type connected with a load tractor MT8-065 type. Using the test tractor in 1st and 2nd gear, the measurements were realized at 100% wheels slip and repeated 4 times. The results show the statistically significant differences in the drawbar pull of the test tractor with different driving wheels on a grass plot. The highest increase in drawbar pull reached the value 25.56% (2nd gear) and 19.98% (1st gear) in case of the special driving wheels with 4 spike segments at 90° and 4 at 30°. In case of the special driving wheels with 8 spike segments at 90°, increase in the drawbar pull reached the value 10.09% (1st gear) and 15.21% (2nd gear) in comparation with the standard tyres.

Key words: tyres, drawbar pull, force sensor, wheels slip.

INTRODUCTION

At present, agricultural tractors as manufactured are characterised by high rates of standardisation and feature a range of additional attachments which allow the wider use of each tractor and greatly facilitate its operation (Kosiba et al., 2012). The need for tractors and agricultural machinery to be tested from the point of view of their suitability to agricultural use will grow continuously because these machines directly affect agricultural production (Hujo et al., 2012; Hujo et al., 2017).

Driving wheels are significant part of a tractor construction because they transmit power to a ground. Therefore, tractor wheels affect a total energy efficiency, a fuel consumption (Uhrinová et al., 2012; Uhrinová et al., 2013), and a soil compaction (Rataj et al. 2009; Hrubý et al., 2013; Malý & Kučera 2014; Malý et al., 2015).

Agricultural tractor loses a lot of energy by a driving wheels slip. To reduce the wheels slip, an additional ballast load loads the tractors. This solution improves a drawbar property of the tractors but on the other hand increases the soil compaction and tyres wear on a hard surface (Semetko et al., 2002; Semetko et al., 2004).

The drawbar efficiency affects the fuel consumption and an emission production. The wheels slip reduction improves the fuel consumption, reduces the emission production and so improves an economy and an ecology of a tractor operation.

Many authors (Dickson et al. 1983; Nadykto et al., 2015; Adamchuk et al., 2016; Kučera et al., 2016) researched an impact of driving wheels on the tractor drawbar properties and an environment. This paper is aimed at a research on a new type of the special driving wheels to improve the tractor drawbar pull without a need for the addition ballast load.

MATERIALS AND METHODS

Special driving wheels with spike segments

The special driving wheels (Fig. 1) consists of the spike segments (1) which are placed in special grows (2) in the tire-tread pattern. The tyre-tread pattern of a standard tractor tyre was cut to make eight special grows around the wheel circumference.

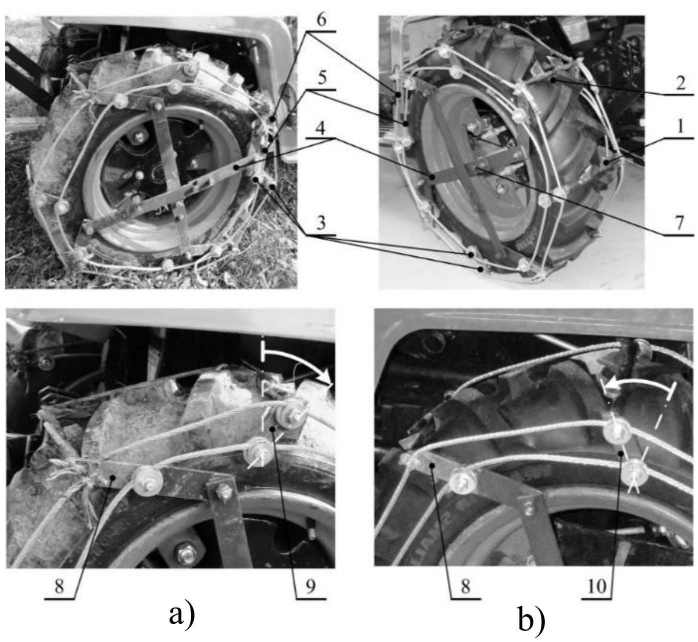

Figure 1. The special driving wheels: a) 8 spike segments at 90° inclination angle under test operation, b) 4 spike segments at 90° inclination angle and 4 at 30° inclination angle: 1 – spike segments; 2 – grow in tyre-tread pattern; 3 – pins; 4 – control levers; 5 – control steel rope; 6 – supporting steel rope; 7 – safety screw; 8 – spike segments at 90°; 9 – position of the lever of spike segments at 90°; 10 – position of the lever of spike segments at 30°.

The grows are parallel with rear wheels axle. Every spike segment consists of two spikes. Therefore, the special driving wheels can use 16 spikes to improve the tractor drawbar properties. The shape and dimensions of the spikes are adopted to the tyre-tread pattern to allow active or inactive position. The spike segments can turn to the active position when the spikes overhang the wheels diameter and help to generate the drawbar pull. To transport of tractor on the roads, the spike segments turn to the inactive position when the spikes do not contact the ground. Abrahám et al. (2018) and Majdan et al. (2018) detailly describe the construction of the special driving wheels with the spike segments. This article presents the modification of the special driving wheels to compare the system with different inclination angles of spikes. The first one with all 8 spike segments at 90° inclination angle (Fig. 2, a) and second one with 4 spike segments at 90° and 4 at 30° inclination angle (Fig. 2, b). In both cases, the spike segments (8) connected with control levers (4) can be activated only at 90° while others spike segments can be activated at 90° (9) or 30° (10) depending on two possible lever position. White arrow sign (Fig. 1) shows the difference position of the lever allowing the 90° or 30° inclination angle of spikes.

Two experiments were realized. The first one (Fig. 2, a) uses the special driving wheels with all 8 spike segments at 90° inclination angle (3). The second one (Fig. 2, b) with 4 spike segments at 30° inclination angle (2) and 4 at 90° inclination angle (3). Construction of the special driving wheels uses the tractor tyre (1) and allows to modify the angle of every other spike segments which are not connected with lever mechanism (Fig. 1, position 6).

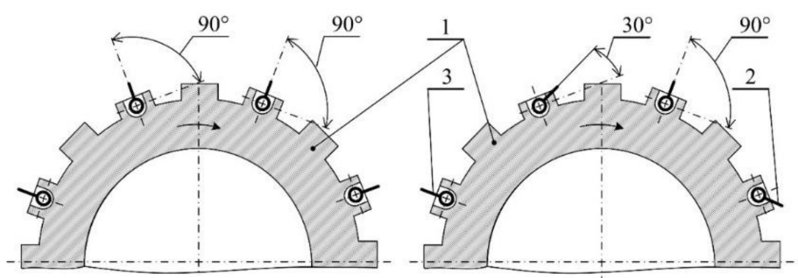

Figure 2. Position of spike segments: a) all 8 spike segments at 90°; b) 4 spike segments at 90° and 4 at 30°.

Measurement system

The properties of the special driving wheels with the spike segments were tested according to drawbar pull of the test tractor Mini 070 type (Agrozet, Czech Republic) which was equipped with different driving wheels. The force sensor 150 EMS type (Emsyst spol. s. r. o., Slovak Republic) measured the drawbar pull of the test tractor at 100% of driving wheels slip. Parameters of the force sensor EMS 150 type are listed in the Table 3.

Table 3. Specification of force sensor EMS 150 type

Parameter		Unit	Value
Accuracy class			0.5
Rated Capacities		N	10,000
Rated Output	Voltage	V	0–10
	Current	mA	4–20
Non-linearity Hysteresis		%	0.1 of full scale
Temperature range	Compensated	°C	0–50
	Operating		-20–50

A portable record device HMG 3010 (Hydac GmbH, Germany) recorded the measured data at sampling frequency 50 Hz. Tulík et al. (2013) and Tkáč et al. (2014) detailly describe the technical specification of device HMG 3010 type. The steel chain connected the test tractor with load tractor MT8-065 type (Agrozet, Czech Republic) to stop the first one and reach the 100% of driving wheels slip (Fig. 3). Novák et al. (2014) Procházka et al. (2015) and Porteš et al. (2013) also used the connection of the test and load tractor under field conditions.

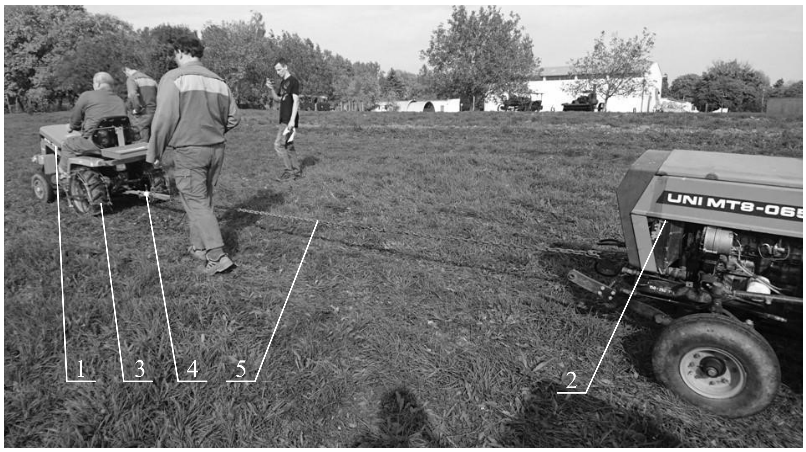

Figure 3. Measurement of drawbar pull of the tractor with special driving wheels: 1 – test tractor Mini 070 type; 2 – load tractor MT8-0652 type; 3 – special driving wheels; 4 – force sensor EMS 150 type; 5 – steel chain.

The weight of the load tractor MT8-065 type (970 kg) is approximately three times higher than the test tractor Mini 070 type (310 kg) to generate adequate braking force to stop the test tractor. The relatively low tractor weight together with a power (8 kW at 3,600 rpm) of a gasoline engine of the test tractor continually generates the drawbar pull at 100% of driving wheels slip.

Experiment conditions

The paper presents results of two experiments. The first one evaluates the drawbar pull of the test tractor with the special driving wheels with all 8 spike elements at 90° (Fig. 1a and Fig. 2a) and the second one with 4 spike segments at 90° and 4 at 30°. Two versions of the special driving wheels were compared with the standard tractor tyres TS-02 6.5/75-14 4PR TT type, (Mitas, a. s., Czech Republic).

The measurements of the test tractor drawbar pulls were four times repeated to eliminate the measurements errors. The results were verified by two measurements of the drawbar pull of the test tractor in 1st and 2nd gear.

All experiments were realized on the grass plot (Chernozem soil type) of the Slovak Agricultural Museum in Nitra (Slovak Republic). We used plain grass plot area in October 2017.

Statement of soil moisture and bulk weight

The bulk weight of soil was stated according to standard STN 72 1010 using Kopecky rollers as follows:

$$\rho_w = \frac{m_1 - m_2}{V_s}, \text{ g cm}^{-3} \quad (1)$$

where m_1 – weight of soil volume and Kopecky roller, g; m_2 – weight of empty Kopecky roller, g; V_s – volume of Kopecky roller, cm^3.

The soil moisture was stated according to standard STN 72 1012 after drying at temperature 105 °C as follows:

$$w = \frac{m_1 - m_3}{m_3 - m_2} \cdot 100, \% \quad (2)$$

Where m_3 – weight of soil volume after drying and Kopecky roller, g.

Average value of drawbar pull

The drawbar pull measurements of the test tractor with different driving wheels were repeated four times to eliminate the measurements errors. To compare the different driving wheels types, average values of the drawbar pulls (F_{DP}) were calculated.

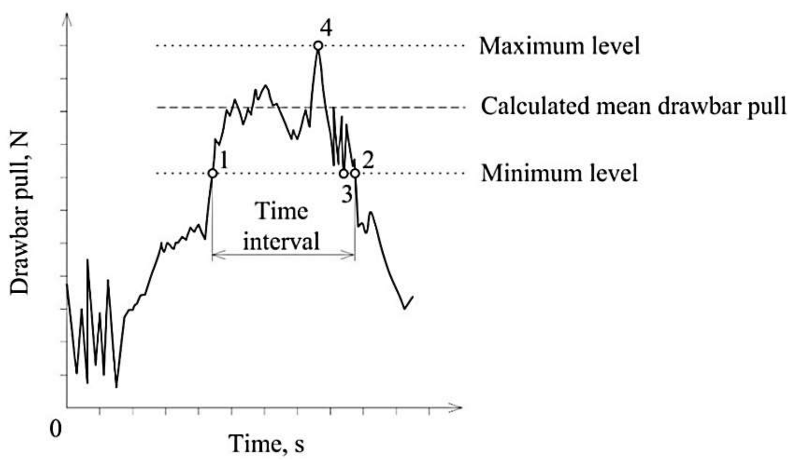

Figure 4. Example of one measurement of the drawbar pull and statement of the average value.

During the drawbar pull measurement the values (y_i) oscillate around the average value (x) mainly due to the shape of the tire-tread pattern and the spikes of the special driving wheels. Therefore, the drawbar pull of the test tractor is not constant. Fig. 4 shows an example of one measurement of the drawbar pull to state mean values x_1, x_2, x_3 and x_4. A begin (point 1) and an end (point 2) of a time interval must be stated to identify a data set for average value calculation. These points are cross-sections of dotted line (minimum level) with solid line (measured course of the drawbar pull). The position of the dotted line (minimum level) is determined by the lowest value (point 3) of the data set. Therefore, the data set contains the values from minimum (point 3) to maximum (point 4) level.

RESULTS AND DISCUSSION

Fig. 5 shows the test tractor equipped with the special driving wheels during the drawbar pull measurement under field measurement conditions. The measurements were realised on a grass plot in October 2017. The soil moisture 19.45% was calculated according Eq. 2 and bulk weight of soil 1.24 g cm^{-3} according to Eq. (1).

Tables 4 and 5 show the results of four measurement repetitions of drawbar pull of the test tractor with two versions of the special driving wheels in comparison with standard tyres. Using the Microsoft Excel, the drawbar pulls F_{DP} and a confidence interval (95%) were calculated to state if the differences between the various driving wheels are statistically significant. Švenková et al. (2010) and Kozelková et al. (2018) present, that the 95% confidence interval is adequate for experiments in agricultural praxis.

Figure 5. The test tractor Mini 070 type equipped with the special driving wheels.

Table 4. The measured values of the drawbar pull of the test tractor in 1st gear

Parameter	Type of driving wheels: 8 spike segments at 90°	4 spike segments at 90° and 4 at 45°	Standard tyres
	Drawbar pull, N		
x_1	3,530.1	4,074.4	3,123.1
x_2	3,570.8	3,917.5	3,268.0
x_3	3,620.2	4,006.3	3,187.6
x_4	3,488.2	3,968.5	3,196.6
F_{DP}	3,552.3	3,991.7	3,193.8
Confidence	3,462.5	3,886.5	3,099.5
interval (95%)	3,642.1	4,096.8	3,288.2

Table 5. The measured values of the drawbar pull of the test tractor in 2nd gear

Parameter	Type of driving wheels: 8 spike segments at 90°	4 spike segments at 90° and 4 at 45°	Standard tyres
	Drawbar pull, N		
x_1	3,654.2	4,207.3	3,061.0
x_2	3,612.0	4,258.4	2,994.7
x_3	3,635.6	4,217.0	3,204.6
x_4	3,814.3	4,100.4	3,217.3
F_{DP}	3,679.0	4,195.8	3,119.4
Confidence	3,532.9	4088.6	2,945.6
interval (95%)	3,825.2	4,302.9	3,293.2

Fig. 6 and 8 show the comparison of various driving wheels based on the drawbar pull F_{DP} with the confidence interval (95%). The measured and statistically processed results show the statistically significant differences between all driving wheels versions in case of 1st and 2nd gear. The special driving wheels with 4 spikes segments at 90° and 4 at 30° shows the best improvement of the drawbar properties of the test tractor in comparison with the second one and the standard tyres. Higher differences were reached in case of 2nd gear because the test tractor can generate a higher power.

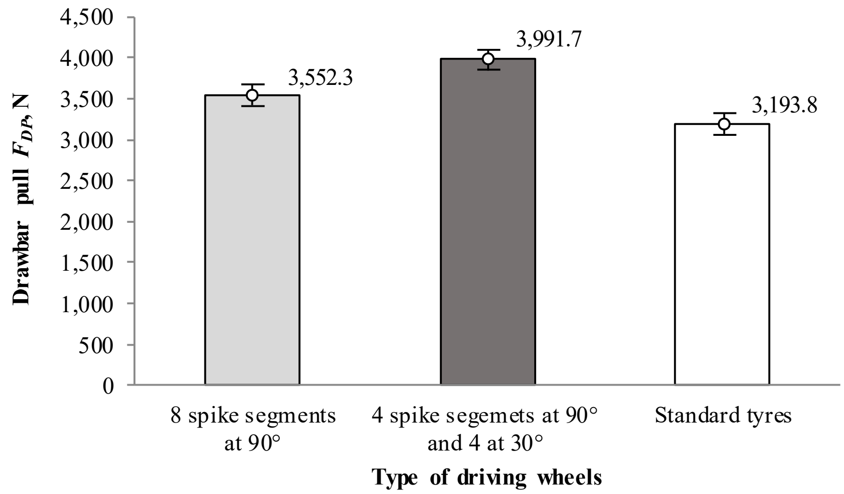

Figure 6. Comparison of the drawbar pulls of the test tractor in 1st gear.

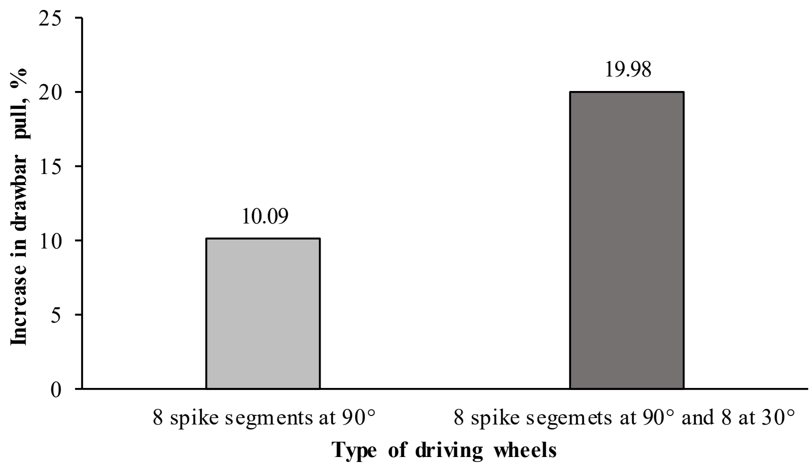

Figure 7. Percentage increase in drawbar pulls compared with the standard tyre (1st gear).

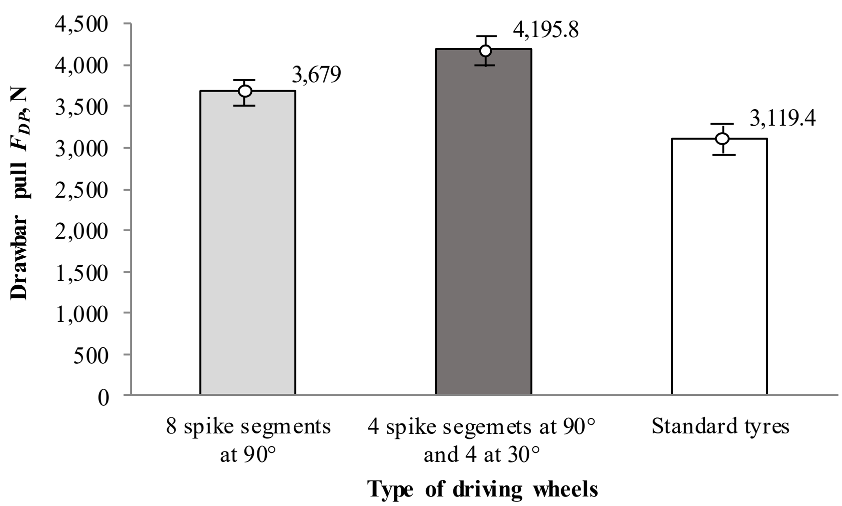

Figure 8. Comparison of the drawbar pulls of the test tractor in 2nd gear.

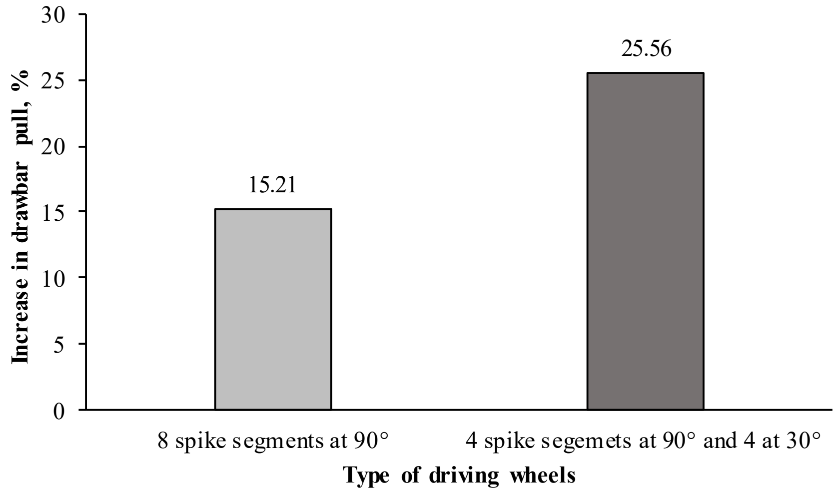

Figure 9. Percentage increase in drawbar pulls compared with the standard tyre (2nd gear).

Hermawan et al. (1996) and Hermawan et al. (1997) realised experiments with single movable lug to state the influence of the lug inclination angle on the pull force. The flat movable lug with 45° lug inclination angle generated a slightly higher peak of pull force than those with 30° and 60° lug inclination angles. Therefore, the authors demonstrated the significant differences between pull forces resulting in lug inclination angle. Fajardo et al., (2014) reached the higher performance index and tractive efficiency in case of wheel with 13° lug inclination angle in comparison of 0°. Statistical analyses of this results showed that draft, axle power, drawbar power, performance index and tractive efficiency were significantly affected by the lug angle, number of pass, shaft speed, and the combination of lug angle and shaft speed. Yang et al., (2014) researched force interaction between the lug and soil at various inclination angles. They measured normal and tangential forces acting on a single lug as functions of inclination angle, moving direction angle, sinkage length, horizontal displacement, and traveling speed. The authors experimentally confirmed the effect of lug inclination angle on lug-soil forces. The special driving wheels allow to change the inclination angle of the spikes. The experiment with 4 spike segments at 90° and 4 at 30° showed the better drawbar properties of the test tractor than with all 8 spike segments at 90°. In the first case, the increase in the drawbar pull of the test tractor in 1st gear reached the value19.98% (Fig. 7) and in 2nd gear 25.56% (Fig. 9). In the second case the increase in the drawbar pull reached lower values, namely 10.09% (Fig. 7) when the test tractor was in 1st gear and 15.21% (Fig. 9) in 2nd gear. Therefore, we experimentally confirmed the fact that the spike inclination angle affect the drawbar pull of the tractor with the special driving wheels.

CONCLUSIONS

The design of the special driving wheels allows to use two versions of the inclination angles of the spike segments. The first one uses all 8 spike segments at 90° and the second one 4 spike segments at 90° and 4 at 30°. It allows to compare the drawbar pull of the test tractor with two versions of the special driving wheels and standard tyres. The drawbar properties of the test tractor were improved by both versions of the special driving wheels. The drawbar pull of the test tractor were measured at 100% driving wheels slip when the tractor was stopped. The standard tyres started to slip at the lowest drawbar pull. The special driving wheels with all 8 spike segments at 90° reached 10.09% increase in the drawbar pull (1st gear) and 15.21% (2nd gear). The highest increase in the drawbar pull 19.98% (1st gear) and 25.56% (2nd gear) reached the test tractor with the special driving wheels with 4 spike segments at 90° and 4 at 30°. We can conclude that the spike inclination angle of the special driving wheels affects the tractor drawbar pull. In the future research, the special driving wheels will be modified to reach the best improvement of the drawbar properties at optimum inclination angle of the spikes.

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