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Comparison of consumption of tractor at three different driving wheels on grass surface

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Abstract. The paper deals with possibility of reduction of tractor fuel consumption when working on grass surface, and compares use of two versions of spike devices embedded to the original tyre body. The device was designed at Department Transport and Handling (Slovak University of Agriculture in Nitra). Older as well as newer system proposed in 2017 comprises spikes and it is assembled to common tractor tyre tread pattern with auxiliary grooves cut in. Same device can be set to two positions, allowing to work as 8-spikes and 16-spikes system. The spikes are tilted in grooves when moving on paved road. The spikes are ejected out to reduce wheels slip when operated in field. Remaining eight spikes are tilted in case of 8-spikes system. Measurements were realised on grass surface. Tractor Mini 070 type was loaded with heavier tractor MT8-065 type in tests with 3 different driving wheels, balancing the actual weight in all cases. Drawbar pull and fuel consumption were measured in tests, allowing to compute specific drawbar consumption and fuel consumption per hour for three different loads. The results pointed out a fact the tyre slip loss and energy consumption of tractor movement increase at the soil humidity 19.45%. It follows from results achieved that use of both 8- and 16-spikes wheel device versions reduced fuel consumption when cultivating higher humidity soil, preferable for tillage. Eight spikes system with semi-tilted remaining spikes is the most efficient method.

Key words: tyres, spikes devices, consumption of fuel, agriculture, drawbar pull.

INTRODUCTION

The testing of tractors used in agriculture is continuously increasing because these machines directly influence the results of agricultural production. Agricultural tractors are losing a lot of energy by the slip of driving wheels. The wheels properties can be theoretically researched using the numerical computation methods (Nadikto et al., 2015; Adamcuk et al., 2016) or under laboratory conditions using the special testing device (Kučera et al., 2016) or under real tractor operation conditions (Semetko et al., 2002). To reduce the tyre slip, tractors are loaded with a heavy weight, which increases the drawbar pull but excessively increases soil compaction and tyre wear on a hard surface (Semetko at al., 2004).

Nowadays, diesel oil and petroleum products belong to the most used fuels. Unfortunately, fossil fuels are non-renewable and exhaustible sources of energy

(Müllerová et al., 2012). The increase of tractor drawbar pull influences the fuel consumption and emissions of exhaust gases.

Tractor fuel consumption is influenced considerably by used transmission system and drive type of tractor in transportation and field operation. Fuel consumption is achieved using new concepts of combustion control in engines. Fuel consumption at high engine slip contributes to environment impacts much more than it is at low slip. Significant savings of fuel used by tractor combustion engines can be achieved by tractor wheel slip reduction using crawler adapters (Molari et al., 2012).

The results of a theoretical analysis reveal that, for a four-wheel-drive tractor to achieve the optimum tractive performance under a given operating condition, the thrust (or driving torque) distribution between the front and rear axles should be such that the slips of the front and rear tyres are equal. Field test data confirm the theoretical findings that, when the theoretical speed ratio is equal to 1, the efficiency of slip and tractive efficiency reach their respective peaks, the fuel consumption per unit drawbar power reaches a minimum, and the overall tractive performance is at an optimum (Wong et al., 1998).

Subsoil tillage is a remedy for adverse soil compaction (Malý & Kučera 2014 and Malý et al., 2015) that results in improved conditions for crop growth.

Not least the drawbar properties improvement of the driving wheels influences the soil compression since lower slip and higher operation speed means lower soil compression (Rataj et al., 2009, Hrubý et al., 2013 and Jobbágy et al., 2016).

MATERIALS AND METHODS

Measurement system and conditions

The drawbar pull measurement of the tractor Mini 070 type (Fig. 2) equipped with different wheels was performed by means of a tensometric force sensor marked as EMS 150, as shown in Fig. 1. The force sensor is connected between the loading tractor MT8-065 and the tractor Mini 070 type through a chain. A portable recording unit HMG 3010 (Hydac GmbH, Germany) was used to record electrical signals from the force sensor. A description of measurement devices and sensor are presented in the works published by Tulík et al. (2013) and Tkáč et al. (2017).

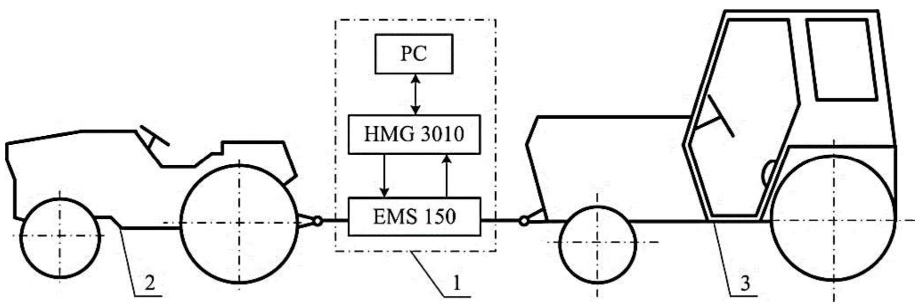

Figure 1. System for measurement of tractor drawbar pulls.
1 – measurement system; 2 – tractor Mini 070 type equipped with different wheel types; 3 – loading tractor type MT8-065; HMG 3010 – digital portable recording device; EMS 150 – force sensor; PC – personal computer.

Technical parameters and specification of tractor Mini 070 type equipped with different wheels types and the loading tractor MT8-065 type used to brake the first one are listed in Table 1.

Table 1. Specifications of the tractors

Tractor type	Tractor part	Parameter	Value
MT8-065	All tractor	Construction weight	970 kg
	Engine	Type and manufacturer	Petrol four-stroke water-cooled (Škoda)
		Number of cylinders	4
		Displacement	1,200 cm^3
		Max. performance	20 kW
Mini 070	All tractor	Construction weight	310 kg
	Engine	Type and manufacturer	Petrol four-stroke air-cooled (Briggs & Stratton)
		Number of cylinders	1
		Displacement	400 cm^3
		Max. performance	8 kW

Drawbar pull measurements procedure is as follows:

– attachment of tractor MT8-065 type (no gear engaged) to the tractor via drawbar pull sensor for the first measurement,
– removal of four spark from engine head of the loading tractor MT8 – 065 type to achieve constant drawbar pull with 1st and 4th gear engaged and stopped engine for the second and third measurements,
– system start in sufficient distance before the sector start,
– start of the stopwatch when the tractor front part passing the staring rods, start the drawbar pull measurement Hydac 3010 and count the drive wheel rotates,
– stop of the stopwatch and tractor when tractor front part passes finish rods,
– repetition of measurements using the tractor Mini 070 type at first and second gear with loading tractor at no, first and fourth gears engaged,
– repetition of measurements with tractor equipped with standard tyres Mitas 6.5/75–14 TS – 02 type (Mitas a. s., Czech Republic), spikes device with all 16 spikes ejected to the angle 90° (16-spikes tyres) and spikes device with 8 spikes ejected to angle 90°and 8 spikes to angle 30° (8-spikes tyres); 8 spikes at angle 90° alternate with 8 spikes at angle 30° around the wheel circumference (Fig. 3).

The measurements of tractor drawbar pull and fuel consumption with three different driving wheels were realised in October 2017 with average volume soil humidity 19.45% and soil volume weight 1.24 g cm^{-3}. The measurement were realised on the grass plane surface at sunny weather in Slovak Agricultural Museum in Nitra. The area for measurement was approximately 0.5 ha. Measuring sector limited by rods had rectangular shape with dimensions 30 x 25 m.

Spikes device

The spike device was designed based on previous research of wheel drawbar pull transfer to surface improvement (Abrahám et al., 2014), where the wheel ploughing sleeves used on two-wheel walking tractors was clearly the best solution.

Fig. 2 shows the spikes device assembled to the tractor tyre body. It consists of eight segments connected together by carrying wire rope 3 and operated by control wire rope 4. Control wire rope 4 provides spikes tipping from tyre body and mutual holding of individual segments in the same position.

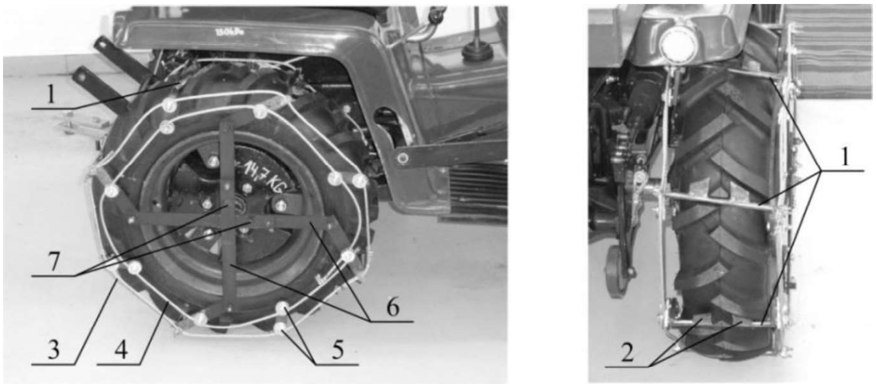

Figure 2. The tractor type Mini 070 equipped with standard tyres and special spikes device: 1 – spike segment; 2 – spikes; 3 – carrying wire rope; 4 – control wire rope; 5 – pivot pins; 6 – lever mechanism; 7 – locking screws.

Spike segments (Fig. 5) are tilting to avoid need for removal when moving on the road and reduce the health risks for operator. The tilting is realised by spikes 2 rotation to tangential position not outreaching the tyre body (tread). Spikes 2 eject automatically due to tractor drive wheel slip, when lever mechanism 6 is locked-off using the locking screws 7. It is necessary to lock tilted position of spikes 2 using lever mechanism 6 and locking screws 7 to prevent spikes recline to transport position when generating drawbar pull back in reverse motion. Locked transport position suitable for movement on paved roads is shown in Fig. 2.

Fig. 3 shows the spikes positioning in the tyre-tread pattern. 8 spikes are ejected to the angle 90° and 8 spikes to 30°. This experiment tests the influence of the spikes position on the drawbar pull of the tractor.

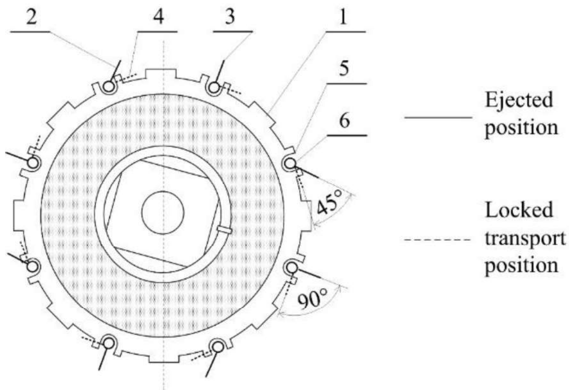

Figure 3. Spikes positioning during drawbar pull measurements: 1 – tractor tyre; 2 – spikes ejected to angle 30°; 3 – spikes ejected to angle 90°; 4 – spikes in locked transport position; 5 – groove in tyre-tread pattern; 6 – spike segment.

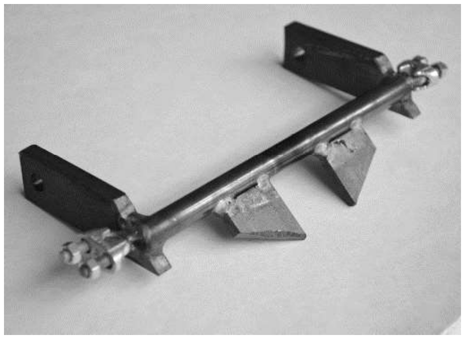

Figure 4. Spikes device on tractor wheel tyres TS – 02 type with 8 active spikes.

Figure 5. Detail of spike segment.

Measurement and calculation of fuel consumption

Fuel consumption of the small tractor Mini 070 type at stable load is measured by weight method using three-way valve (Fig. 7) and particularly adapted measuring tank (Fig. 6) with volume 1dm^3, fixed to main fuel tank. Three-way valve is set to position reachable to driver. It has three positions: first for fuel flow from main fuel tank to tractor fuel system. Second position allows fuel flow from measuring tank to tractor fuel system. Third position blocks fuel flow from and to any direction above mentioned.

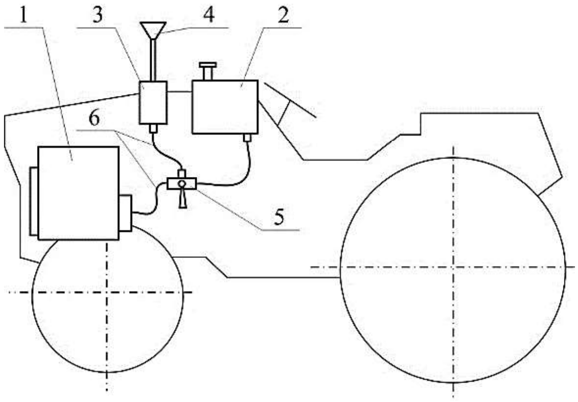

Figure 6. Modified tractor fuel system for fuel consumption measurment: 1 – tractor engine; 2 – main fuel tank; 3 – measuring tank; 4 – funel with gauge line; 5 – three-way valve; 6 – hoses.

Filling hole of measuring tank is funnel with 8 mm pipe internal diameter and gauge line indicating full fuel level to be filled before measurement fuel consumption is determined based on weight of the fuel in doser used for filling.

Filling hole of measuring tank is funnel with 8 mm pipe internal diameter and gauge line indicating full fuel level to be filled before measurement fuel consumption is determined based on weight of the fuel in doser used for filling. Fuel is refilled after each tractor ride to full measuring tank level and remaining fuel in doser is then weighed. Used fuel is the weight difference on digital scale (Fig. 8) of full doser and doser after measuring tank refilling (after tractor ride).

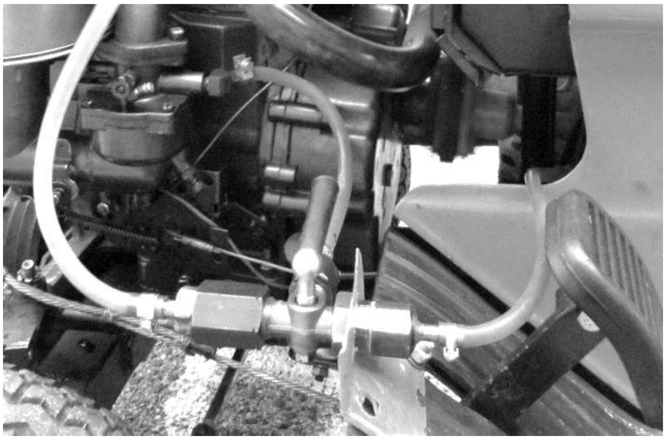

Figure 7. Three-way valve set to flow from the measuring tank.

Figure 8. Doser and digital scale with precision 0.01 g.

Fuel consumption pre hour (M_{ph}) is calculated using this formula:

$$M_{ph} = \frac{m_1 - m_2}{t}, \text{ g h}^{-1} \quad (1)$$

where m_1 – weight of full doser, g; m_2 – weight of doser after filling measuring tank (after tractor ride), g; t – time of ride, h.

Specific drawbar fuel consumption (m_{pe}) as a function of drawbar power at actual load level and speed is calculated using equation:

$$m_{pe} = \frac{M_{ph}}{P_t} = \frac{M_{ph}}{F_t v}, \text{ g kW}^{-1} \text{ h}^{-1} \quad (2)$$

where P_t – drawbar power, kW; F_t – drawbar pull in one ride, kN; v – tractor speed in one ride, m s^{-1}.

The average drawbar power is determined by average drawbar pull and motion speed of tractor. Drawbar characteristics of tractor determine tractor drawbar capacity defined by its drawbar pull F_t at particular motion speed, specifying tractor drawbar power P_t. Tractor drawbar power determines significantly driving wheels slip δ, particularly on unpaved supports. Slip values are therefore accompanying specification of drawbar parameters. Average drawbar power (P_t) can be calculated according to:

$$P_t = F_t v, \text{ W} \quad (3)$$

where F_t – average drawbar pull, N; v – tractor speed, m s^{-1}.

A standard arithmetical average formula and measured values of drawbar pull were used to calculate the average drawbar pull F_t.

Fuel consumption and drawbar pull measurements were realised at the same time. The fuel consumption measurement procedure is as follows:

- staking of the measuring sector of 30 m on grass using two rods at the sector start and finish,
- connection of the tractor fuel tank with the engine using the three-way valve (engine consumes the fuel from the tractor fuel tank and not from the measuring tank),
- passage of the tractor to the sector start,

– refilling measuring tank with fuel up to gauge line (Fig. 9, a),
– connection of measuring tank with engine fuel system using three-way valve, tractor start along with time measurement start using stopwatch,
– tractor stop at the sector finish and block the fuel from measuring tank to the tractor engine using the three-way valve to stop the fuel consumption from the capillary (Fig. 9, b),
– refilling used fuel from the full doser up to gauge line (Fig. 9, c),
– doser weighing (Fig. 8, 9, c),
– calculation of used fuel weight as a weight difference of full doser and doser after measuring tank refilling,
– measurement repetition at no, first and four gear on the loading tractor,
– realization of measurements at full tractor engine power at the full throttle.

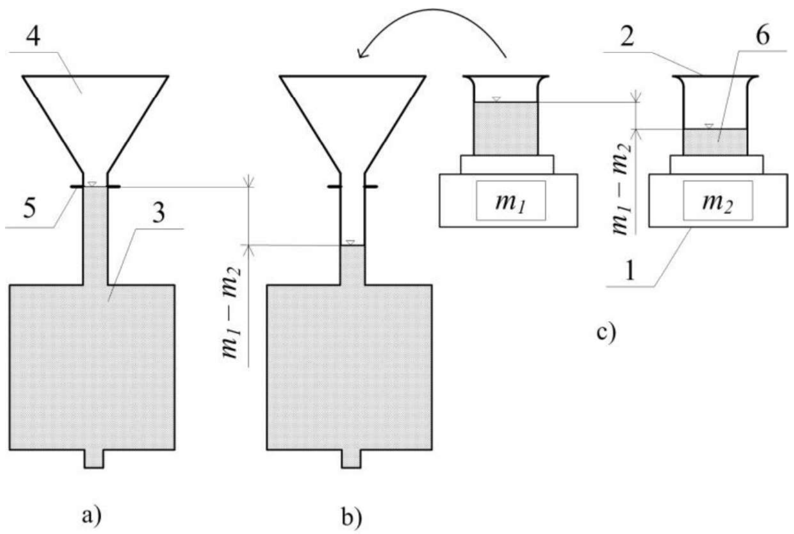

Figure 9. Fuel consumption measurement: 1 – digital scale; 2 – doser; 3 – measuring tank with fuel; 4 – funnel with gauge line; 5 – gauge line; 6 – fuel; a) fuel level corresponds gauge line befor the tractor start; b) fuel level decrease after the tractor ride; c) weighting of consumed fuel.

RESULTS AND DISCUSSION

Tables 2, 3 and 4 show the measured and calculated values describing the fuel consumption of tractor with different driving wheels under three load levels (no, fourth and first gear of loading tractor). The tractor was tested under smallest load at the no gear, medium load at the fourth gear and the highest one at first gear using the loading tractor.

Jenane et al. (1996) achieved minimum specific fuel consumption at values of slip varying between 10% and 30% depending on the soil surface. The author presented that a tractor should be operated at a minimum dynamic traction ratio of 0.4 and at its maximum tractive efficiency to ensure minimum specific fuel consumption. In our case, the spikes device reduces the wheels slip and also the fuel consumption.

Janulevicius & Damanauskas (2015) show that in order to reach the lowest fuel consumption, the following is needed: first, to choose the lowest permissible air pressures in the tyres, and the second to choose the efficient ballast weights. This fact also corresponds with the results of Battiato & Diseren (2013). The spikes device allows reducing the tractor fuel consumption without the need for tyres air pressure change and ballast weight.

Table 2. Measured values of tractor with tyres

Parameter	Unit	Transmission gear of the tractor Mini 070 type					
		1st gear engaged			2nd gear engaged		
Transmission gear of the loading tractor		no gear	4.	1.	no gear	4.	1.
Time of ride t	s	79.28	81.47	118.28	44.33	46.49	79.27
Tractor speed v	m s^{-1}	0.378	0.368	0.254	0.677	0.645	0.378
Weight of full doser m_1	g	163.1	182.2	184.9	150.5	173.8	181.2
Doser weight after filling measuring tank (after ride) m_2	g	142.0	159.2	140.9	133.0	145.4	139.1
Fuel consumption $m_1 - m_2$	g	21.0	23.0	44.1	17.5	28.4	42.1
Fuel consumption per hour M_{ph}	g h^{-1}	955.4	1,017.2	1,340.7	1,417.1	2,195.3	1,913.3
Specific drawbar fuel consumption m_{pe}	g kW^{-1} h^{-1}	2,231.2	1,928.7	2,288.2	1,984.1	2,169.5	1,635.7
Average drawbar pull F_t	N	1,131.6	1,432.3	2,310.1	1,055.4	1,568.1	3,090.9
Average drawbar power P_t	W	428.2	527.4	585.9	714.2	1,011.9	1,169.7

Table 3. Measured values of tractor with 8-spikes tyres

Parameter	Unit	Transmission gear of the tractor Mini 070 type					
		1st gear engaged			2nd gear engaged		
Transmission gear of the loading tractor		no gear	4.	1.	no gear	4.	1.
Time of ride t	s	79.91	82.47	85.87	41.93	37.21	61.87
Tractor speed v	m s^{-1}	0.375	0.364	0.349	0.715	0.806	0.485
Weight of full doser m_1	g	148.0	178.4	174.1	178.9	161.1	169.7
Doser weight after filling measuring tank (after ride) m_2	g	128.8	154.6	144.6	164.9	144.7	145.0
Fuel consumption $m_1 - m_2$	g	19.2	23.8	29.5	14.0	16.4	24.7
Fuel consumption per hour M_{ph}	g h^{-1}	862.7	1,038.1	1,234.7	1,202.9	1,587.6	1,438.4
Specific drawbar fuel consumption m_{pe}	g kW^{-1} h^{-1}	2,348.5	1,698.5	1,325.8	1,348.0	1,309.5	927.3
Average drawbar pull F_t	N	978.5	1,680.1	2,665.6	1,247.1	1,503.8	3,199.1
Average drawbar power P_t	W	367.3	611.2	931.3	892.3	1,212.4	1,551.2

Results achieved (Tables 2, 3 and 4) were divided for evaluation according to gear used on tractor Mini 070 type when testing. Variances were observed in drawbar pull when using common tyres, 8-spikes tyres and 16-spikes tyres. These differences are caused by higher motion speed achieved by tractor with spikes device leading to higher engine speed of tractor MT8-065, resulting in recorded higher drawbar pull and higher mechanical resistance. Similar variances were observed with second gear engaged, with differences even more significant due to higher motion speed.

Table 4. Measured values of tractor with 16-spikes tyres

Parameter	Unit	Transmission gear of the tractor Mini 070 type					
		1st gear engaged			2nd gear engaged		
Transmission gear of the loading tractor		no gear	4.	1.	no gear	4.	1.
Time of ride t	s	75.41	76.59	96.81	42.75	45.3	61.5
Tractor speed v	m s^{-1}	0.398	0.392	0.310	0.702	0.662	0.488
Weight of full doser m_1	g	180.9	151.9	163.1	151.4	178.1	155.0
Doser weight after filling measuring tank (after ride) m_2	g	158.2	131.2	120.4	136.2	157.1	132.7
Fuel consumption $m_1 - m_2$	g	22.7	20.8	42.7	15.2	21.0	22.3
Fuel consumption per hour M_{ph}	g h^{-1}	1,083.7	975.8	1,589.0	1,282.5	1,669.7	1,306.0
Specific drawbar fuel consumption m_{pe}	g kW^{-1} h^{-1}	2,356.5	2,074.1	1,939.0	1,796.0	1,738.2	839.4
Average drawbar pull F_t	N	1,156.0	1,201.1	2,644.4	1,017.6	1,450.4	3,189.4
Average drawbar power P_t	W	459.9	470.5	819.5	714.1	960.6	1,555.8

Figs 12 and 13 are the best representation of the comparison of efficiency of drawbar pull transfer of wheel to surface. An improvement of drawbar pull transfer and reduction of fuel consumption can be observed from the dependency of specific drawbar fuel consumption the on load level in Fig. 12 when 1st gear engaged for both versions of spikes driving wheels with tilting spikes used, starting from medium load at the fourth gear. This improvement can be characterised as a decrease of specific drawbar fuel consumption with load level increase besides the standard tyres. Tyres have the most favourable fuel consumption at medium load. The most favourable fuel consumption dependency was found in case of 8-spikes tyres with partially ejected remaining 8 spikes. It also results from comparison of the both versions of spikes tyres it is more efficient to eject the spikes to the angle less than 90°. Likely due to cable mechanism allowances the spikes ejected to 90° are tilted to more than 100° angle when drawbar pull is generated and the drawbar efficiency is falling.

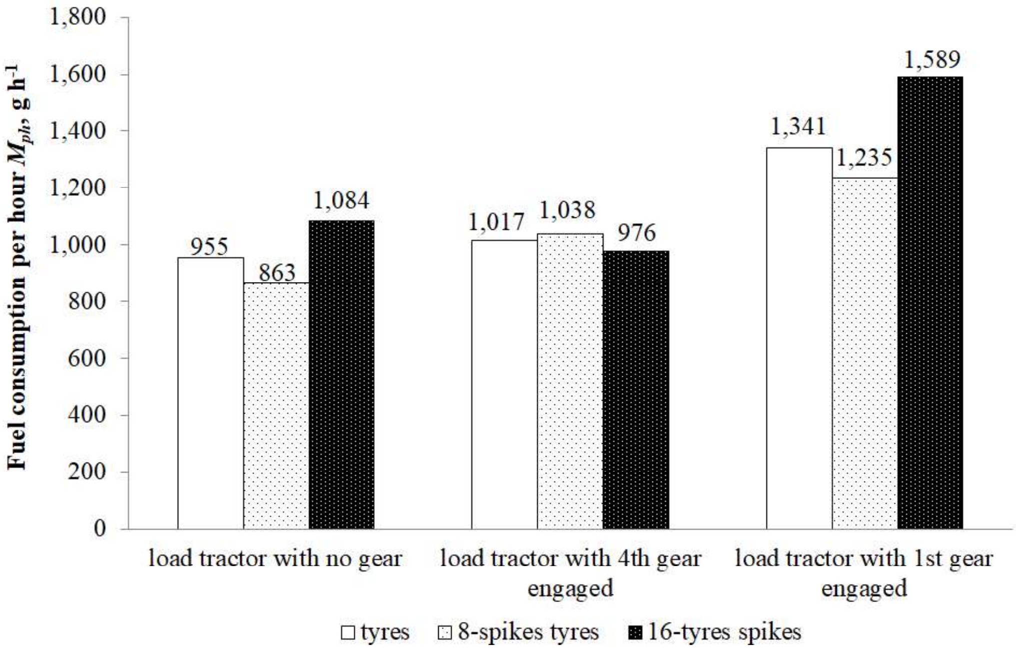

Figure 10. Comparison of fuel consumption per hour, 1st gear engaged.

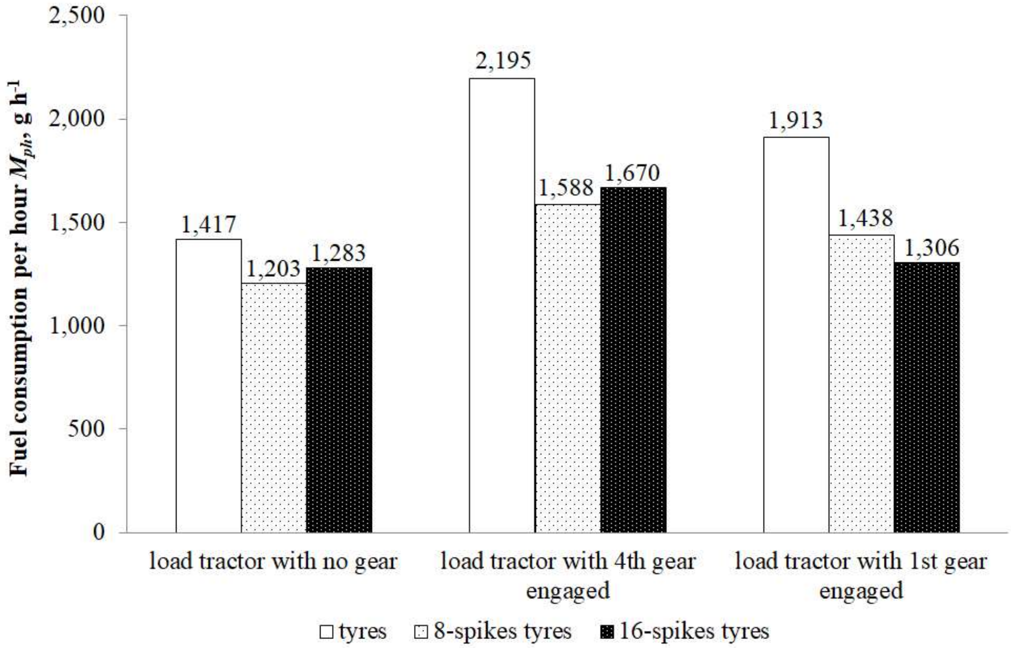

Figure 11. Comparison of fuel consumption per hour, 2nd gear engaged.

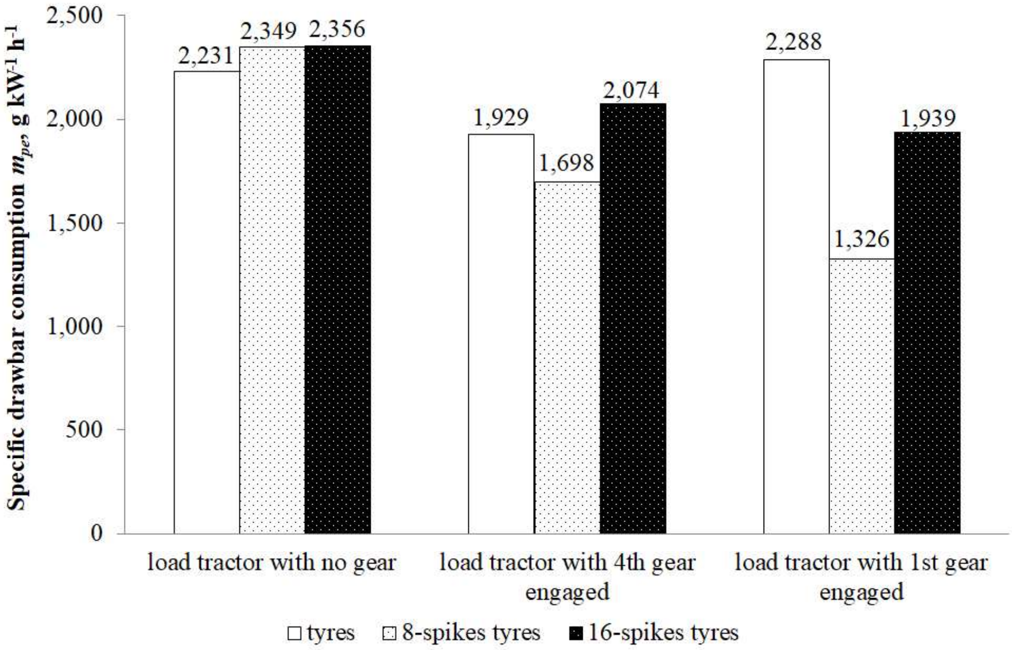

Figure 12. Comparison of specific fuel consumption, 1st gauge engaged.

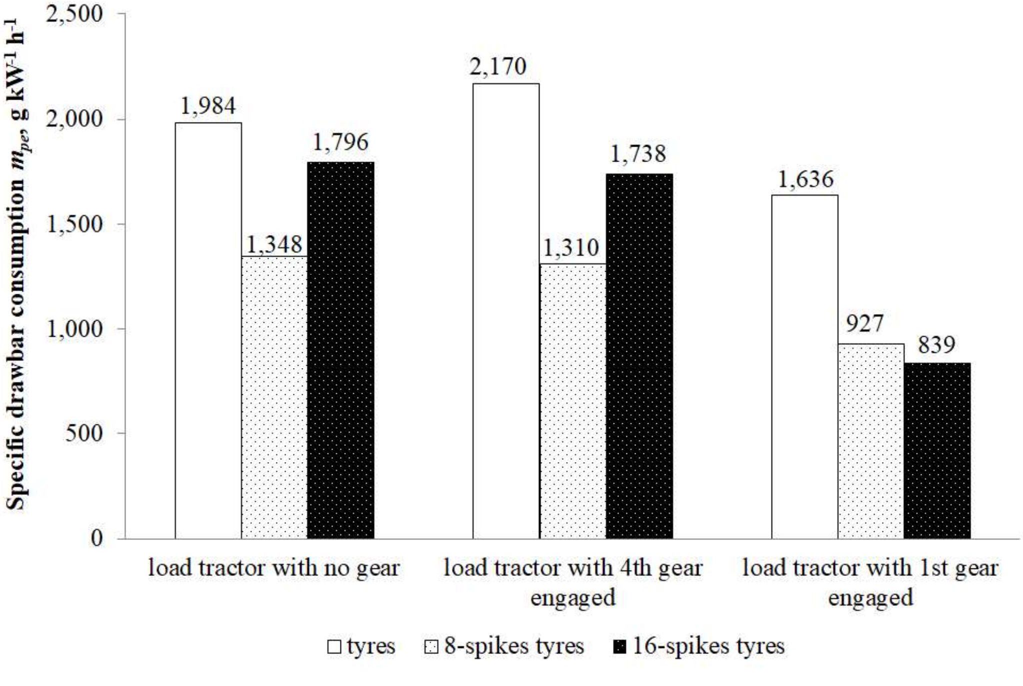

Figure 13. Comparison of specific fuel consumption, 2nd gauge engaged.

The most improvement of the drawbar pull transfer to surface is observed with 1st gear engaged and 8-spikes tyres with partially ejected remaining spikes, based on resulting of dependency of fuel consumption per hour on load level (Fig. 10, 11). This improvement can be characterised as a proportional slip growth up to certain value in case of all three types of driving wheels (Kielbasa & Korenko, 2006). In contrast, with the 2nd gear engaged, 16-spikes tyres and particularly 8-spikes tyres with remaining 8 spikes partially ejected are able to generate higher drawbar power up to medium load as it is evident from Fig. 13. Tyres itself change the dependency from increasing to decreasing at the medium load already and the fuel consumption falls with additional drawbar power due to tyres tread clogging and multiple slip of the driving wheels. It is worth to mention the efficiency improvement of drawbar pull transfer by tyres to surface when 2nd gear engaged (Fig. 11) compared to the 1st (Fig. 10) gear engaged, with the fuel consumption per hour.

CONCLUSIONS

The spikes mechanism was designed to allow comparison of drawbar of different number of spikes engaged in one device. The device was tested intentionally in real soil moisture conditions suitable for soil tillage to let express to the greatest extent differences in drawbar properties of tyres itself and both spikes devices. The next step is to build the spike mechanism into off-road car tyre body and to compare it in long term-test in varied conditions as forest road ride or winter conditions. If needed, the spike device can be easy removed from the tyres in couple minutes similarly as snow chains. The tyres can be used regularly without spikes device after being worn to the tilted spikes diameter, for instance in summer dry conditions. It is first time the devices were compared in this version. The drawbar improvements found will be even more significant in more difficult conditions as dry oil covered by manure, or frozen soil with melted surface layer.

It results from test the spikes device affects the tractor fuel consumption favourably cutting it down and thus improves drawbar pull to elastic surface transfer efficiency at the soil moisture 19.45% compared to common tyres.

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REFERENCES

Abrahám, R., Majdan, R. & Tkáč, Z. 2014. *Research streamlining traction drive wheels of the tractor.* Slovak university of agriculture in Nitra, Nitra, 150 pp. (in Slovak).

Adamchuk, V., Bulgakov, V., Nadykto, V., Ihnatiev, Y. & Olt, J. 2016. Theoretical research into the power and energy performance of agricultural tractors. *Agronomy Research* **14**(5), 1511–1518.

Battiato, A. & Diseren, E. 2013. Influence of Tyre Inflation Pressure and Wheel Load on the Traction Performance of a 65 kW MFWD Tractor on a Cohesive Soil. *Journal of Agricultural Science* **5**(8), 197–215.

Hrubý, D., Bajla, J., Olejár, M., Cviklovič, V. & Tóth, L. 2013. New generation portable vertical penetrometer design. In: *Trends in agricultural engineering 2013*. University of Life Sciences Prague, Prague, pp. 223–227.

Janulevicius, A & Damanauskas, V. 2015. How to select air pressure in the tires of MFWD (mechanical front-wheel drive) tractor to minimize fuel consumption for the case of reasonable wheel slip. *Energy* **90**, 691–700

Jenane, C., Bashford, L.L. & Monroe, G. 1996. Reduction of fuel consumption through improved tractive performance. *Journal of Agricultural Engineering Research* **64**(2), 131–138.

Jobbágy, J., Krištof, K. & Findura, P. 2016. Soil compaction caused by irrigation machinery. *Agronomy Research* **14**(3), 790–800.

Kielbasa, P. & Korenko, M. 2006. Influence of machine working resistance on slippage rate of driving wheels of tractor. *Acta Technologica Agriculturae* **9**(3), 44–47.

Kučera, M., Helexa, M. & Čedík, J. 2016. Link between static radial tire stiffness and the size of its contact surface and contact pressure. *Agronomy Research* **14**(4), 1361–1371.

Malý, V. & Kučera, M. 2014. Determination of mechanical properties of soil under laboratory conditions. *Research in agricultural engineering* **60**(special iss.), 66–69.

Malý, V., Tóth, F., Mareček, J. & Krčálová, E. 2015. Laboratory test of the soil compaction. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **63**(1), 77–85.

Molari, G., Bellentani, L., Guarnieri, A., Walker, M. & Sedoni, E. 2012. Performance of an agricultural tractor fitted with rubber tracks. *Biosystems Engineering* **111**(1), 57–63.

Müllerová, D., Jablonický, J., Hujo, Ľ., Tkáč, Z., Kučera, M. & Kosiba, J. 2012. Measurement of operating parameters and emissions of tractor with diesel oil and biofuel. In: *TEAM.* Josip Juraj Strossmayer University, Osijek-Baranja, pp. 299–302 (in English).

Nadykto, V., Arak, M. & Olt, J. 2015. Theoretical research into the frictional slipping of wheel-type undercarriage taking into account the limitation of their impact on the soil. *Agronomy Research* **13**(1), 48–157.

Rataj, V., Galambošová, J. & Macák, M. 2009. Experiences in GPS application in Slovak Republic (Skúsenosti so zavedením systému CTF na Slovensku). In: *GPS autopilots in agriculture.* Czech University of Life Sciences Prague, Prague, pp. 34–38 (in Slovak).

Semetko, J., Janoško, I. & Pernis, P. 2002. Determination of driving force of tractor and trailer wheels. *Acta technologica agriculturae* **5**(1), 1–4.

Semetko, J., Janoško, I. & Pernis, P. 2004. Determination of power of multidrive vehicles. *Acta technologica agriculturae* **7**(1), 20–23.

STN 72 1010 The statement of soil bulk density. 1989.

Tkáč, Z., Čorňák, Š., Cviklovič, V., Kosiba, J., Glos, J., Jablonický, J. & Bernát, R. 2017. Research of biodegradable fluid impacts on operation of tractor hydraulic system. *Acta technologica agriculturae* **20**(2), 42–45.

Tulík, J., Kosiba, J., Hujo, Ľ., Jablonický, J. & Šinský, V. 2013. The durability of a tractor gear-hydraulic circuit. In: *Trends in agricultural engineering 2013*. Czech University of Life Sciences Prague, Prague, pp. 617–621 (in English).

Wong, J.Y., McLaughlin, N.B., Knezevic, Z. & Burtt, S. 1998. Optimization of the tractive performance of four-wheel-drive tractors. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* **212**(4), 285–297.