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Increase in tractor drawbar pull using special wheels

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Abstract. The paper is aimed at the possibility of increasing in maximal drawbar pull of tractor working on the soil. The increasing in drawbar pull occurred due to a special wheels mounted on drive axle. The special wheels were equipped with auto-extensible blades and designed in Slovak university of agriculture in Nitra. The main advantage of the special wheels is the automatic extension of steel blades to increase the drawbar pull during a wheel slip and automatic return to the base position to allow the transport of tractor by the route. The testing operation points at the increase in drawbar pull resulting in decrease of wheel slip. A drawbar pull of tractor equipped with standard tires and special wheels was compared on the different soil moisture condition. The higher increasing in drawbar pull was measured during the tractor operation on the soil with higher moisture in comparison the soil with lower moisture level. In case of soil moisture 14% the increase in drawbar pull of tractor equipped with special wheels reached the value 17.2% in compare with standard tires. Using the special wheels on the same field with higher level of soil moisture 22% the increase in drawbar pull reached the value 36.1% in compare with standard tires.

Key words: tractor wheels, soil moisture, drawbar pull, wheel slip.

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. 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 et 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.

The drawbar pull, travel reduction (slip), and rolling resistance are the main criteria to describe the traction behaviour of off road vehicles. Besides the engine performance, the drawbar pull is influenced by the traction conditions such as soil and the tire parameters (Schreiber & Kutzbach, 2008).

The drawbar pull of tractor is influenced by various factors. Very significant parameter influencing the drawbar pull is a tire pressure. Noréus & Trigell (2008) realized the measurement of drawbar pull at various tire pressure. The test showed that the drawbar pull is vastly improved at lower tire pressure.

Dabrowsky et al. (2006) realized the tests of terrain vehicle equipped with different tire types. All-season tyres installed in a military truck provide slightly better traction for both terrain surfaces, at all three loading levels, or the differences between traction measures are not significant. Soil stress analysis showed that the difference between the two tread patterns is not significant. Generally, on soft surfaces all-season tyres performed no worse than snow tyres, while they are pronouncedly better for highway use.

Söhne (1968) & Sonnen (1969) compered two and four wheel drive for agricultural tractors. It was found that the tractor with four-wheel drive achieves better drawbar performance in compare tractor with rear wheel drive. It is concluded that as tractor power increases and as soil becomes weaker and less frictional, then the balance of advantage changes from two wheel to four wheel drive. The type of tires is the next important factor to increase the drawbar pull and influence tractive performance, as well as soil stresses under a vehicle. Soil compaction caused by agricultural machinery is important factor which affects soil infiltration rate (Krištof et al., 2010), carbon dioxide (Šima & Dubeňová, 2013) and nitrous oxide (Šima et al., 2013) flux from soils and therefore has significant environmental effect.

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).

Force interaction between tractor drive wheels and ground (soil, grass plot, route etc.) limits a maximum drawbar pull of wheels tractors. Mainly an atmospheric exposure such as rainfall or snow increases the ground moisture resulting in wheel slip and decrease of drawbar pull. In the past, various measures to increase the drawbar pull of wheel tractor have been implemented and published. Some measures are used in practice but many concepts were not successful. This paper presents a new method to increase the drawbar pull of wheel tractors. It is a device that is mounted on the drive wheels of the tractor. The device reduces wheel slip especially in poor traction conditions and thus increases the drawbar pull and also eliminates the undesirable effects of the wheels on the soil. The device could be also suitable for terrain, army or forest vehicles under poor traction conditions. The research presented in this paper is aimed at the increase of drawbar pull using the special wheels designed on Slovak agriculture university in Nitra

MATERIAL AND METHODS

To compare standard tires and special wheels the measurements of drawbar pull were realized on the same field at different soil moisture on October 2010 and 2012. In these years cucumbers were grown on the field. Remains of cucumber plants were taken away so the next to nothing covered the soil. There were a negligible amount of very small stones. The field was ready for autumn tillage. The difference soil moisture results in different rainfall in year 2010 and 2012. Tractor type Mini 070 was used to compare the standard tires and special wheel equipped with auto-extension steel blades. Tractor was braked by the second tractor during the measurement of drawbar pull. The maximum drawbar pull was reached at the 100% wheel slip.

Design of special wheels equipped with auto-extensible blades

Wheels equipped with auto-extensible blades have been developed at the Department of Transport and Handling for the rear driving wheels of a tractor MINI 070. Wheels equipped with auto-extensible blades were designed according to the work published by Sloboda et al. (2008). A big advantage is that they do not have to be removed from the tractor when passing on the road and also that they are automatically extended when the tractor driving wheels are slipping. Re-folding of driving blades occurs with the reverse movement of the tractor. The tractor needs not be equipped with additional load weights because they are replaced by wheels equipped with auto-extensible blades. Wheels equipped with auto-extensible blades are mounted to the wheel disc, and according to Fig. 1, they consist of the following parts.

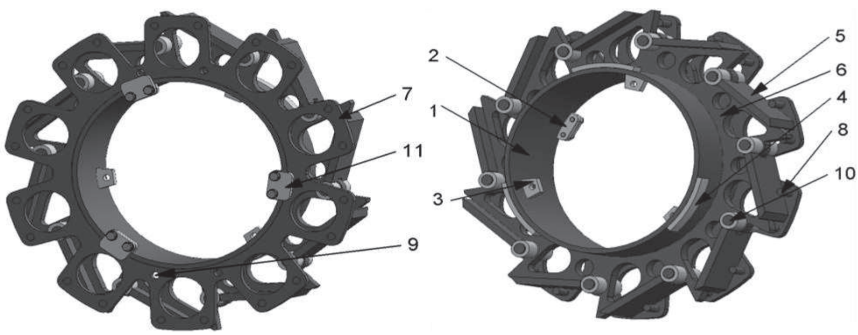

Figure 1. Wheels equipped with auto-extensible blades: 1 – support tube, 2 – locking tab, 3 – bracket fastening the mechanism to the wheel disc, 4 – spacer plates, 5 – blade, 6 – driving disc, 7 – blade control disc, 8 – guide pin, 9 – locking hole, 10 – blade pin, 11 – buffer plate.

A support tube (1) is a basic part of the whole mechanism. It enables the remaining parts of the whole mechanism to be attached to each other. On the support tube, there are welded three locking tabs (2), three brackets (3) by which the whole mechanism is connected to the tractor wheel, and a driving disc (6) containing blades (5) mounted by means of ten pins. On the support tube, there are also welded spacer plates (4) through which the mechanism position is centred with respect to the tractor wheel disc. After the driving disc (6), the support tube contains a freely rotating disc for the control of blades (7). The blade control disc contains on its circumference twenty pressed guide pins by means of which blades move into the extended and retracted positions. On the other side of the blade control disc, there are four locking holes (9) to fix the position of blades in the retracted position. Three buffer plates (11), attached by six screws to the locking tabs (2), fix the blade control disc on the support tube.

The measurement of drawbar pull

The drawbar pull measurement of the tractor type Mini 070 (Fig. 3) equipped with different wheels was performed by means of a tensometric force sensor marked as 150 EMS, as shown in Fig. 2. The force sensor is connected between the loading tractor T4K10 and the tractor type Mini 070 through a chain. A portable recording unit HMG 2020 (Hydac GmbH, Germany) was used to record electrical signals from the force sensor. A description of HMG 2020 is presented in the work published by Drabant et al. (2003). The tractor type Mini was set on the first gear (I gear) during the measurement.

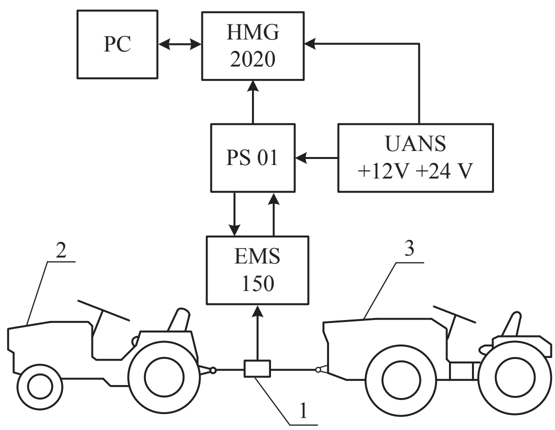

Figure 2. System for measurement of tractor drawbar pulls: 1 – force sensor EMS 150, 2 – tractor type Mini 070 equipped with different wheel types, 3 – loading tractor type T4K10, HMG 2020 – digital portable recording device, UANS – universal battery source, PC – personal computer, PS 01 – junction box.

Figure 3. The tractor type Mini 070 equiped with standard tires and special wheels.

Technical parameters and apecification of tractor type Mini 070 equiped with different wheels types and the tractor type T4K10 used to brake the first one are listed in Table 1 and 2.

The rear drive wheels of tractor type Mini 070 were equipped with tyres type TS 790 – 6.15/155 – 14 – 4PR, 2 pliesnylon + 1 plynylon and chemlon made by company Barum (Barum a. s. Czech republic).

Table 1. Specifications of the tractor type Mini 070

Year of manufacture	1989	
Construction weight	310 kg	
Driving speed at rated engine speed 3,600 rpm	1st gear 2nd gear 3rd gear 4th gear	1.53 km h^{-1} 2.72 km h^{-1} 4.96 km h^{-1} 14.40 km h^{-1}
Clutch	Dry, single plate, with direct mechanical shutoff	
Engine	Petrol, four-stroke, air-cooled Briggs & Stratton Number of cylinders Displacement Max. performance / rotation speed	 1 400 cm^3 8 kW / 3,600 rpm

Table 2. Specifications of the tractor type T4K10

Year of manufacture	1966	
Construction weight	820 kg	
Engine	Two-stroke, air-cooled diesel Number of cylinders Displacement Max. performance	 1 900 cm^3 10 kW

Statistical proceeding of measured values

The measurements of drawbar pull were realized during the time 2.8 second. The sampling frequency 20 Hz was set on portable recording device to obtain the high precision results. Therefore the measured data-set consists of 56 values. The final mean value of drawbar pull was calculated from data file by using the 50 values. The first 6 values represent the increase in drawbar pull and therefore they didn't use to calculate mean value. The measurements of drawbar pull were replicated several times. Tractor was braked along the field length 100 m. In this paper the results from 3 measurements of drawbar pull are presented. During the drawbar pull measurement the data-set were obtained and statistical processed by use the mean value.

The mean value A of drawbar pull was calculated by using the arithmetic mean:

$$A = \frac{1}{n}\sum_{i=1}^{n} a_i \qquad (1)$$

where: n – data-set extent; a_i – variable at the i index of a data-set, N.

The coefficient of variation Cv was used to express a measure of the dispersion of data points in a data series around the mean:

$$Cv = \frac{\sigma}{A}100 \qquad (2)$$

where: σ – standard deviation, N; A – mean, N.

Bulk weight ρ_w of soil was determined by using gravimetric method according to standard STN 72 1010:

$$\rho_w = \frac{m_1}{V} \qquad (3)$$

where: m_1 – weight of soil volume, g; V – volume of soil, cm^3.

The soil moisture was calculated according to standard STN 46 5321 after drying at 105 °C:

$$w = \frac{m_1}{m_2} 100 \qquad (4)$$

where m_2 – weight of soil after drying, g.

RESULTS AND DISCUSION

The measurement of drawbar pull was realized on the field with area approximately 2,000 m^2. The measurements were carried out on soil type chernozem. There were soil moisture $w = 22\%$ and average soil bulk density $\rho_w = 1.33$ g cm^{-3} in the year 2010. In the year 2012 the measurement were realized at soil moisture $w = 14\%$ and average soil bulk density $\rho_w = 1.51$ g cm^{-3}. The penetrometrical resistance was measured by mechanical penetrometer and shown in Fig. 4.

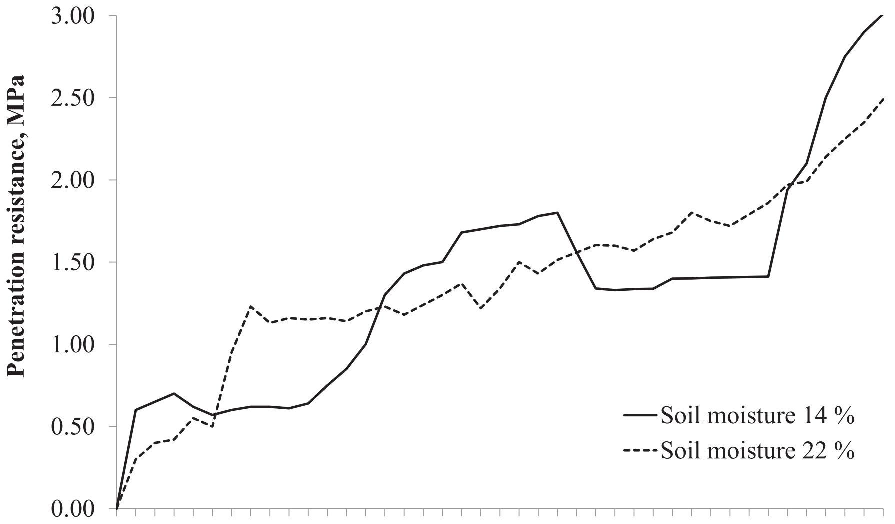

Figure 4. Penetrometrical resistance in the same field at diferent soil moisture.

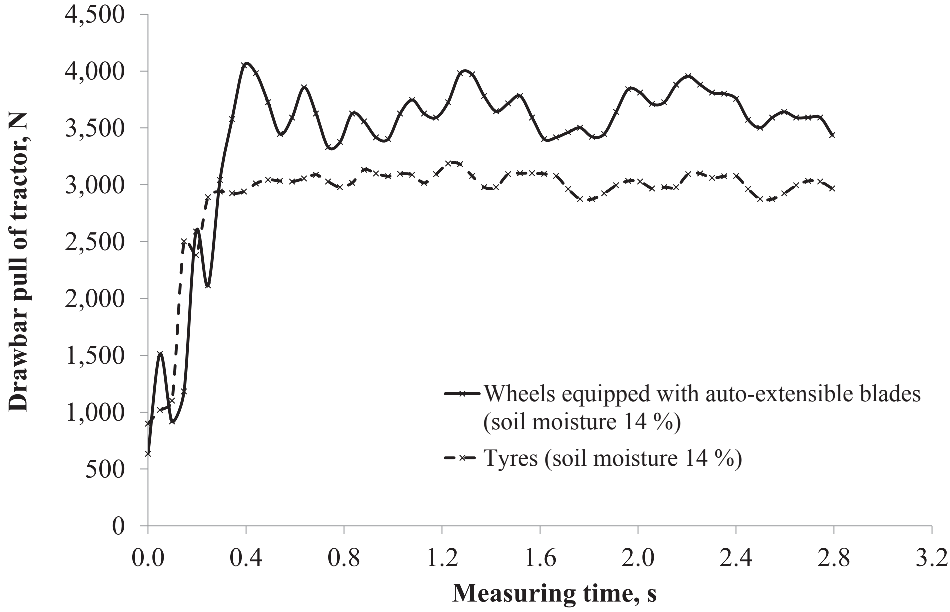

Figure 5. The comparison of special wheels and standard tyres on the basis of drawbar pull measured at soil moisture *w* = 14%.

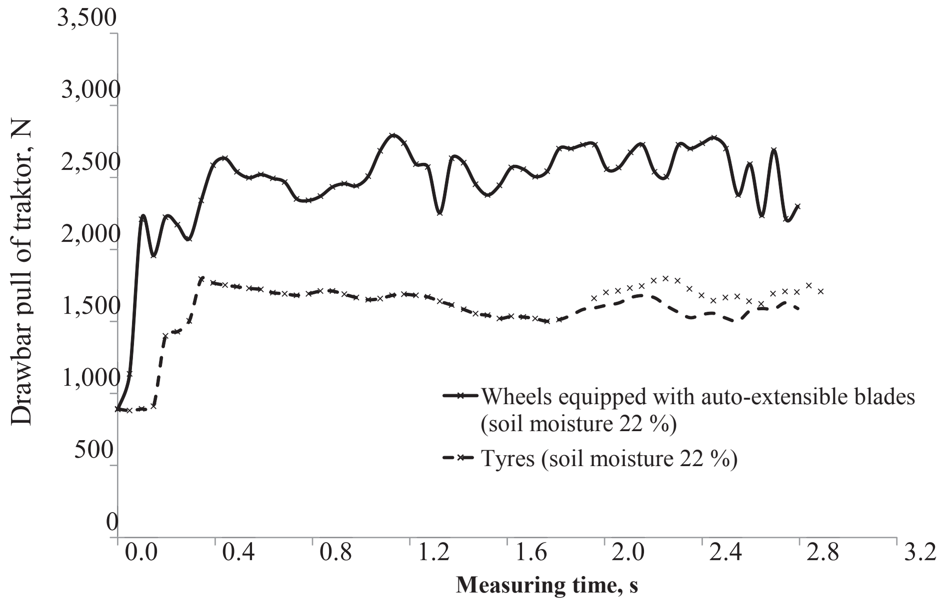

Figure 6. The comparison of special wheels and standard tyres on the basis of drawbar pull measured at soil moisture *w* = 22%.

The measurements of drawbar pull at soil moisture *w* = 14% and *w* = 22% shows the increase in drawbar pull due to the use of special wheels equipped with auto-extensible steel blades.

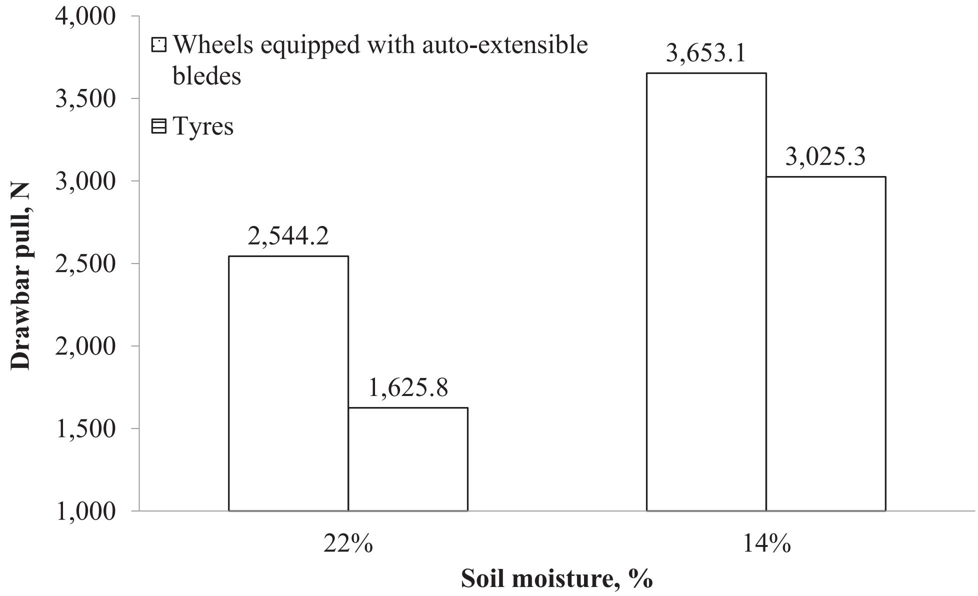

Figure 7. The final comparison of special wheels and tyres installed in tractor.

The measurements were realized on October in year 2010 and 2012 because the soil is prepared to autumn tillage in this time. Tillage is the one of the operation requiring the high drawbar pull of tractor. Fig. 5 and 6 shows the course of drawbar pull at different soil moistures. The measured data and mean of drawbar pull are listed in table 3. The final comparison of special wheels and tires is shown in Fig. 7. The results show that the increase of drawbar pull reached value 17.2% at the soil moisture *w* = 14% and 36.1% at soil moisture *w* = 22%. Therefore, at higher soil moisture the special wheels show the better properties in compare with standard tyres. The special wheels can be used to increase drawbar pull or eliminate the wheels slip and therefor reduce the fuel consumption and soil damage.

Table 3. The measured values and mean of drawbar pull

	Special wheels				Standard tyres			
Soil moisture	14%		22%		14%		22%	
The measured values of drawbar pull, N	3042.4	3591.0	2073.8	2445.0	2940.1	3100.9	1503.8	1520.0
	3576.0	3401.5	2340.0	2568.8	2923.7	3095.3	1793.8	1535.0
	4049.9	3416.4	2583.8	2557.5	2940.1	3077.0	1767.5	1531.3
	3980.0	3461.3	2632.5	2505.0	3011.3	2962.0	1752.5	1520.0
	3725.7	3501.2	2538.8	2542.5	3044.1	2874.4	1741.3	1501.3
	3446.4	3421.4	2497.5	2700.0	3033.2	2874.4	1730.0	1512.5
	3591.0	3446.4	2520.0	2700.0	3027.7	2923.7	1722.5	1542.5
	3855.3	3640.9	2493.8	2726.3	3055.1	2994.8	1700.0	1583.8
	3625.9	3840.4	2467.5	2726.3	3087.9	3033.2	1692.5	1595.0
	3331.7	3810.5	2351.3	2557.5	3027.7	3027.7	1681.3	1613.8
	3376.5	3710.7	2340.0	2568.8	2978.4	2967.5	1692.5	1628.8
	3625.9	3725.7	2370.0	2673.8	3016.7	2978.4	1711.3	1666.3
	3556.1	3880.3	2433.8	2726.3	3131.7	2978.4	1711.3	1680.0
	3416.4	3955.1	2456.3	2538.8	3098.5	3093.4	1688.8	1665.0
	3401.5	3880.3	2441.3	2505.0	3075.2	3098.2	1666.3	1608.8
	3625.9	3810.5	2508.8	2726.3	3095.8	3060.1	1651.3	1563.8
	3745.6	3800.5	2685.0	2700.0	3087.9	3075.3	1658.8	1526.3
	3625.9	3755.6	2790.0	2737.5	3016.7	3077.0	1681.3	1548.8
	3591.0	3571.1	2737.5	2775.0	3093.4	2962.0	1688.8	1556.3
	3725.7	3501.2	2591.3	2700.0	3186.5	2874.4	1681.3	1522.5
	3980.0	3591.0	2572.5	2377.5	3181.0	2874.4	1670.0	1503.8
	3970.1	3640.9	2253.8	2591.3	3077.0	2923.7	1640.0	1575.0
	3780.5	3591.0	2632.5	2235.0	2978.4	2994.8	1613.8	1590.0
	3645.9	3591.0	2602.5	2688.8	2978.4	3033.2	1583.8	1586.3
	3715.7	3591.0	2452.5	2212.5	3093.4	3027.7	1553.8	1631.3
Mean, N	3653.10		2544.19		3025.29		1625.76	
Cv, %	4.94		5.89		2.51		4.80	

CONCLUSION

The comparison of special wheels equipped with auto-extensible steel blades and standard tire was realized on the basis of drawbar pull measurement. The measurements were carried out in October in the year 2010 and 2012 on chernozem soil type in the same area of botanical gardens SPU The year 2010 was extremely dry while the year 2012 was an average year. The drawbar pull of small tractor type Mini 070 equipped with standard tyres and special wheels was measured at slip due to braking by using the second tractor type T4-K10. The special wheels can be used on larger tractors too. The main advantage of the special wheels is the easy using in case of tractor wheel slip. Backward driving after the field operation returns the special wheels to the base position for transportation on the route. In case of soil moisture 14% the increase in drawbar pull of tractor equipped with special wheels reached the value 17.2% in compare with standard tires. Using the special wheels on the same field with higher level of soil moisture 22% the increase in drawbar pull reached the value 36.1% in compare with standard tires.

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