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Comparison of tyres for self-propelled sprayers

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Abstract. This article deals with comparison of two types of tyres (MITAS VF and MITAS AC 85) for self-propelled sprayers in terms of their grip properties and effect on soil. The MITAS VF tyre has a new construction allowing it to work with lower inflation pressure and in higher speed than standard tyre. In order to compare the grip properties there was measured dependence of slippage on tractive force. In order to compare the effect on soil there will be measured footprint area of tyre, specific pressure on base (material), compaction of topsoil by means of wire profilograph and penetration resistance of soil by means of penetrometer. The measurement has been taken place on medium-heavy soil, on stubble after wheat cultivation. The MITAS AC tyres showed lesser tread pattern than the MITAS VF tyres. The VF tyres showed also better grip properties and lesser effect on the topsoil. The soil cone index showed statistically not significant difference in comparison with non-compacted soil and it was approximately the same in case of both variants.

Key words: tyres, sprayer, tractive force, slippage, soil compaction.

INTRODUCTION

In agricultural practice there are increasingly implemented tyres with higher requirements for operation. To the important properties belong higher load at lower inflation pressure and higher maximum permitted speed. In case of standard tyres (MITAS AC 85) there are required inflation pressure of 400 kPa and max. operating speed of 20 km h^{-1} for a given load on sprayer, new so-called VF (Very High Flexion) tyres requires the inflation pressure of 320 kPa and max. speed is increased up to 65 km h^{-1} while carrying the same load. The advantages of use of these tyres are clear. By means of comparative tests we wanted to determine the effect of VF tyres on energy intensity and on soil in comparison with standard tyres.

The grip properties of tyres, especially dependence of tractive force or contact ratio coefficient on slippage of wheels, have an influence on traction efficiency and fuel consumption. The higher wheel slippage, the higher fuel consumption. The grip properties depend on load and soil conditions, it means moisture, type of soil or hardness of base material (Abrahám et al., 2014; Ahokas & Jokiniemi, 2014). Furthermore, the grip properties depend, of course, on parameters of tyres (Schreiber and Kutzbach, 2008), and especially on inflation pressure (Noréus & Trigell, 2008).

The soil compaction represents a negative consequence of interaction between a tyre and base material (soil). It reduces water infiltration, retention capacity of soil, accelerates erosion and increases soil cone index. It consists above all in changes in volume weight of soil, porosity and air and water capacity (Hůla et al., 2011; Chyba et al., 2013; Syrový et al., 2013; Głąb, 2014; Chyba et al., 2014;). High degree of compaction has an adverse effect on crop yields depending on kind of crop (Braunack et al., 2006; Kuth et al., 2012; Arvidsson & Håkansson, 2014). For the determination of soil compaction it can be used its dry bulk density. It should move approximately in the range of 1.2–1.5 g cm^{-3} (Syrový et al., 2013). The density can be also determined by means of measured vertical soil stress (Eguchi & Muro, 2009). The soil compaction depends on many factors. To the main factors belong contact pressure between tyre and base material. This pressure increases with decreasing size of contact area between tyre and soil, with increasing pressure in a tyre with increasing stiffness of a tyre and higher normal static and dynamic load. The soil compaction increases also with decreasing travel speed and with higher number of passages. Furthermore, soil compaction depends on type of soil, moisture and density (Défossez et al., 2003; Lamandé & Schjønning, 2011a,b,c; Nugis & Kuth, 2012; Rodríguez et al., 2012; Głąb, 2014; Keller et al., 2014; Kviz et al., 2014; Taghavifar & Mardani, 2014; Varga et al., 2014). In order to determine contact area of tyre with soil it is possible to use, apart from measurement, also mathematical models based on commonly detectable parameters such as diameter and width of tyre, inflation pressure and various empirically determined coefficients (Prikner & Aleš, 2010; Palancar et al., 2001; McKyes, 1985). Max. pressure acting on soil can be more than twice greater, than specific pressure calculated from footprint area and a load of a tyre (Lamandé & Schjønning, 2011a,b,c). Lozano et al. (2013) says, that during the harvest of sugar cane with dry bulk density below 1.4 g cm^{-3} and moisture over 16% there is a high risk of soil compaction. Braunack (2004) states, that better results can be achieved at use of one wide tyre (445/65R22.5) than when using double axle and narrow tyres (11R22.5).

The objective of measurement was to compare 2 MITAS tyres (MITAS VF and MITAS AC 85) for self-propelled sprayers in terms of grip properties and effect on soil. The VF tyre has new construction, which allow it to work in higher speeds with lower inflation pressure while carrying the same load, as mentioned above. For this purpose it was carried out measurement of dependance of tractor tractive force on slippage of wheels, measurement of topsoil compaction by means of profilograph and measurement of soil cone index by means of penetrometer.

MATERIALS AND METHODS

Self-propelled sprayer Challenger RoGator (see Fig. 1) has the working width 30.2 m, two controlable axles, performance 167 kW and weight 17,420 kg. For the sprayer there were used tyres MITAS AC 85 with dimension 380/90 R 46, 159 A8, E8 and inflation pressure 400 kPa and tyres MITAS VF with dimension 380/90 R 46, 173 D, E8 with inflation pressure 320 kPa.

In order to determinate tyre loading the sprayer was weighed at first by means of portable weighing machine Haenni (precision ±20 kg). During the measurement the sprayer was filled by water. Then the tyre footprint area was measured and specific pressures on base calculated. This measurement was carried out on right rear wheel due to impossibility to lift the front axle at full sprayer.

Measurement of tyre grip properties was carried out at first without load of tractive force and then with unbraked tractor FENDT 415 VARIO with curb weight 5,740 kg.

Tractor wasn´t braked, because the sprayer isn´t destined for loading by tractive force and sole manner of load by longitudinal forces is the uphill driving. Another reason is hydrostatic drive of sprayer, which don´t permit high slippage of the wheels. For measurement of wheel revolutions there were used sensing elements SICK DKS 40 (360 pulses/revolution) and for measurement of revolutions of fifth wheel the speed indicator ZME ORS 120 (120 pulses/revolution). For measurement of tractive force there was used tensometer sensing element HBM U10M (rated load 125 kN). For the measurements there were determined 4 routes with length roughly 170 m. During the measurement there was recorded average speed about 13.5 km h^{-1}. In order to obtain the points for tensile characteristics there were used the average values from sections with stable parameters.

Figure 1. Self-propelled sprayer Challenger RoGator with tractor FENDT 415 VARIO during measurement.

For the measurement of effect on upper layer of soil there was used wire profilograph with wire pitch 25 mm. For every tyre there was determined unevenness of soil surface by means of profilograph in the direction perpendicular to the direction of driving. After cover of testing distance by right front and rear tyre of sprayer the measurements of unevenness of soil surface have been repeated in beforehand determined transversal directions. In this way there was measured the permanent deformation of upper layer of soil after driving by a given tyre. In order to measure of effect on soil there was used digital penetrometer. Measurement by means of penetrometer was carried out always both in track and out of track (as reference). For each measurement 6 repetitions were carried out. Results of measurement by means of penetrometer were evaluated using the analysis of variance (ANOVA). The penetrometer meets the standard of ASAE S313.3. The penetrometer has a cone angle of 30°, area of 130 mm^2, cone base diameter of 12.83 mm, driving shaft diameter of 9.53 mm. The penetrating speed was according to the standard approx. 30 mm s^{-1}.

During the measurements the data has been recorded on computer hard disc HP mini 5103 by means of analog digital converter LabJack U6 and I/O module for impulse sensor Papouch Quido 10/1 with frequency approximately 1 Hz. These data was processed by means of the MS Excel programme.

Measurements were carried out on field of AGROSS Klíčany company, near to Prague, on stubble after wheat with some places with emerged cereal shedding (latitude 50.1985325°N, longitude 14.4342406°E). For measurement conditions there was determined soil moisture depending on depth. At depth 0–50 mm the moisture was 22.27%, at the depth 50–100 mm the moisture was 18.31%, at the depth 100–150 mm the moisture was 18.79% and at the depth 150–200 mm it was 18.08%. Samples for determination of the soil moisture were taken at the time when measurement was carried out, and they were taken at eight places along the test route in approximate distance of 20 m between each other.

Furthermore, there were determined soil texture, soil type and average dry bulk density according to standard ČSN 46 5302 (Characterization of soils cultivated by implements). In soil there was prevailed the content of dust particles (average 0.002–0.05 mm) in range of 53.53 up to 73.39% over the share of sandy grains (average 0.05–2 mm) and clay. According to analysis of grains it is medium-heavy soil. It is fine loam with dusty texture. The average dry bulk density was determined to 1.57 g cm^{-3}.

RESULTS AND DISCUSSION

In the Table 1 there are mentioned the loads falling on particular wheels. The sprayer was weighed in several combinations relating to setting of frame height and spraying arms for determination of maximum load. The maximum load was in transport position on left front wheel and makes 5,650 kg (55.4 kN) (Table 3). The MITAS AC 85 tyres was inflated to the pressure recommended by producer 400 kPa and MITAS VF tyres to 320 kPa. The total weight of full sprayer made roughly 18.3 t.

Table 1. Load on the individual wheels at transport position

	Load (kg)	
	Left	Right
Front	5,650	4,510
Rear	3,920	4,210
Side total	9,570	8,720
Total	18,290	

In the Fig. 2 and in the Table 2 we can see dependence of slippage of the left front and rear wheel on tractive force. It can be seen, that the MITAS VF tyres had with zero tractive force in average by 30.5% lower slippage, than MITAS AC 85. At tractive force around 11–13 kN (unbraked tractor) the MITAS VF tyres had in average by 35% lower slippage, than MITAS AC 85 tyres. This can be caused by lower inflation pressure which the VF tyres allow for the given load. Monteiro et al. (2013) also found that lower inflation pressure improves the fuel consumption and lowers the tyre slippage and thereby improves energetic efficiency of tractor tyres. Another reason may be the bigger fulness of tyre profile (Table 3, Fig. 3). From the Fig. 2 it is further obvious, that, the front wheel had always bigger slippage, than rear wheel. With regard to higher load of front wheel (see Table 1) this difference can be awaited.

Table 2. Measurement summary of results of dependence of slippage on tractive force

Tyre	Average speed (km h^{-1})	Section length (m)	Average tractive force (kN)	Average tyre slippage of left rear wheel (%)	Average tyre slippage of left front wheel (%)
MITAS	13.67	106.94	0	5.771	4.183
AC 85	11.77	96.07	12.63	7.456	5.711
MITAS	15.18	123.67	0	4.396	2.622
VF	13.52	110.73	10.85	5.156	3.475

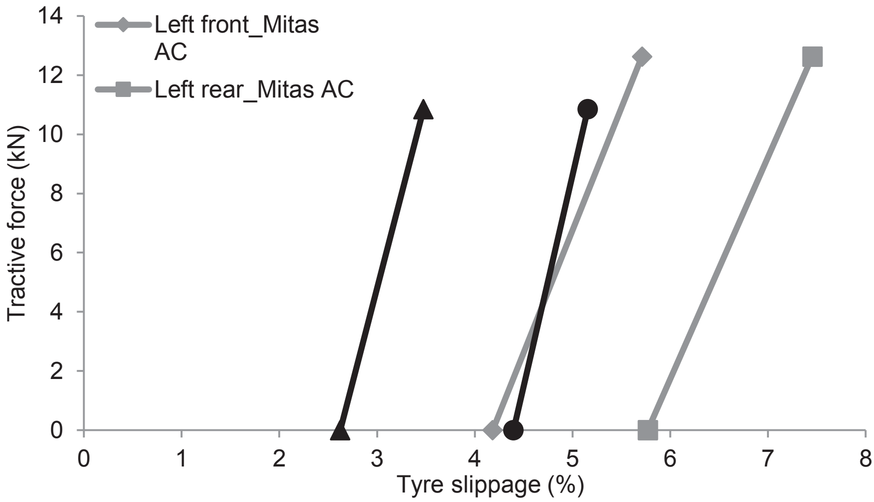

Figure 2. Dependence of tractive force on tyre slippage for both tested tyres.

In the Table 3 there are mentioned footprint areas of right front wheel (load 41.3 kN) and specific pressures acting on base material. Footprint area for MITAS AC 85 tyre was approx. by 13.7% bigger, than for MITAS VF tyre. However, from the depth of footprint measured by profilograph in Fig. 4 it is obvious, that the tyre moved along the field only on tyre profile area, which was in case of MITAS VF tyre by 21.5% bigger, it means by 45% bigger fulness of tyre profile and also corresponding lower pressure in tyre profile area. In these soil and moisture conditions it is more sound for soil use of VF tyres in comparison with standard ones.

Table 3. Footprint and mean pressure on the surface for both tested tyres

Tyre	Load on right rear wheel		Tyre footprint	Contact area of tyre profile	Fulness of footprint of tyre profile	Pressure in contact area of tyre	Pressure in footprint area of tyre
	M	F_r	S_o	S_d	γ	p_s	p_o
	(kg)	(kN)	(cm^2)	(cm^2)	(%)	(kPa)	(kPa)
MITAS AC 85	4,210	41.29	1,787	474	26.52	871.01	231.04
MITAS VF	4,210	41.29	1,572	604	38.42	683.54	262.63

In the Fig. 4 there is shown permanent compaction of topsoil measured by means of profilograph for the MITAS AC 85 and MITAS VF tyres. It can be seen, that the MITAS AC 85 tyre has in average by 9 mm deeper track and also by 50 mm wider. The cause is above all smaller area of footprint of tyre profile, which is smaller than in case of VF tyre. The footprint of the VF tyres is longer, therefore effect on soil is smaller. At the use of MITAS AC 85 tyres, the bigger area of topsoil is influenced into deeper layer of soil (almost 60 mm). Hamza et al. (2011) found that the ratio between the weight of the external load and the contact area between the load and the surface affects primarily the top layers of the soil, which was confirmed by our results (Fig. 4). The comparison of tyre footprints on hard base material is shown in the Fig. 3.

Figure 3. Tyre footprints – left MITAS AC 85, right – MITAS VF (load 4.29 kN).

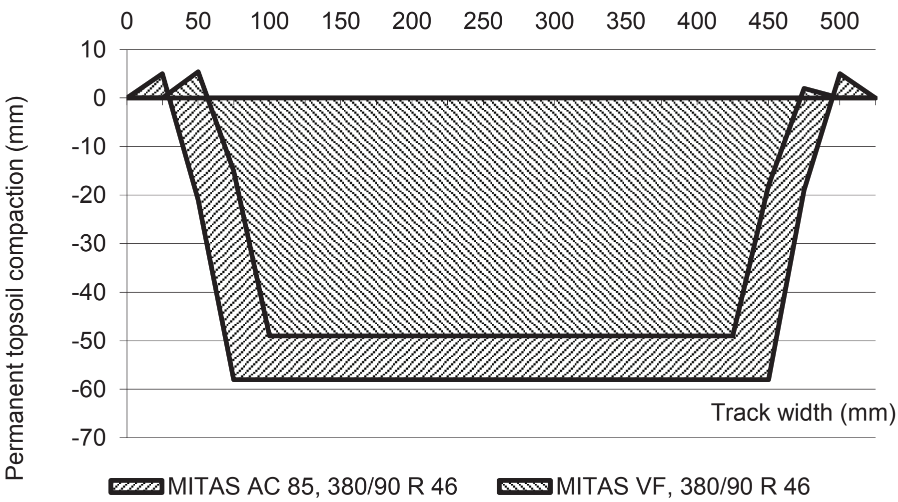

Figure 4. Profile of track in a perpendicular direction to the direction of travel for both tested tyres.

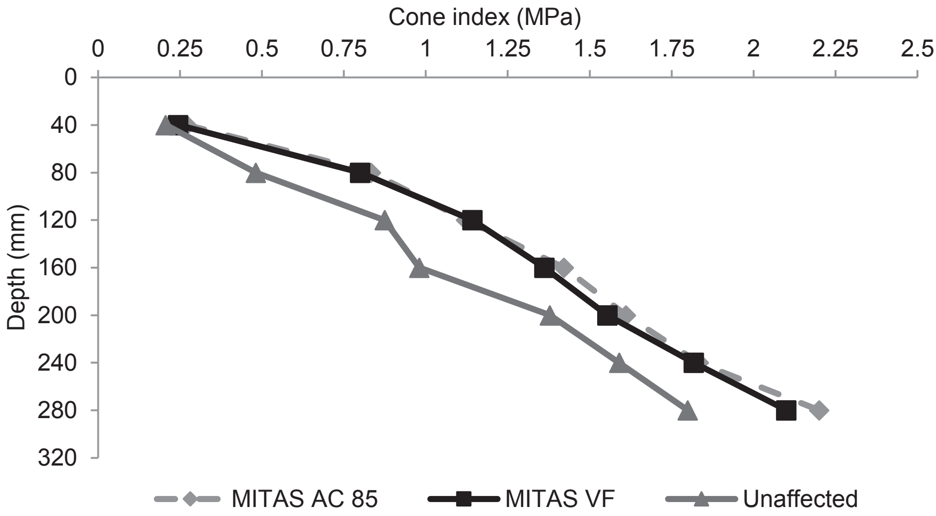

Figure 5. Soil cone index in dependence on depth for both tested tyres and unaffected soil as reference.

Table 4. Analysis of variance (ANOVA) for results of measurement using penetrometer ($F_{0,05(2,15)} = 3.68$)

Depth (mm)	Variability	Sum of Squares	Degree of Freedom	Mean Square	F-ratio	p-value
40	Between groups	0.012	2	0.006	0.357	0.706
	Within groups	0.261	15	0.017		
	Total	0.274	17			
80	Between groups	0.454	2	0.227	2.865	0.088
	Within groups	1.187	15	0.079		
	Total	1.641	17			
120	Between groups	0.268	2	0.134	0.417	0.667
	Within groups	4.829	15	0.322		
	Total	5.097	17			
160	Between groups	0.688	2	0.344	1.386	0.28
	Within groups	3.723	15	0.248		
	Total	4.411	17			
200	Between groups	0.175	2	0.088	0.286	0.756
	Within groups	4.607	15	0.307		
	Total	4.782	17			
240	Between groups	0.223	2	0.111	0.465	0.637
	Within groups	3.585	15	0.239		
	Total	3.808	17			
280	Between groups	0.523	2	0.261	0.666	0.528
	Within groups	5.884	15	0.392		
	Total	6.407	17			

In the Fig. 5 there are illustrated the average values of soil cone index in dependency on depth for MITAS VF and MITAS AC 85 tyres and for non-influenced soil. From the results it is evident, that there were no statistically significant differences between the soil cone index after passage with both of tyres and unaffected soil at any depth (Table 4) mainly because of large scattering of the measured values. However, from the graph it can be seen, that in comparison with non-compacted soil, in case of both tyres occurred slight increase of soil cone index in all depths apart from 0–40 mm. Between the tyres there are only small differences in favour of MITAS VF tyre, especially in the depths 120–160, 160–200 and 240–280 mm. Antille et al. (2013) found that decrease of inflation pressure by 30 and 60 kPa (at our case it was 80 kPa) results in statistically significant decrease in soil cone index which was not confirmed at this case.

CONCLUSIONS

From the results it is obvious, that MITAS VF tyres have better grip properties than MITAS AC 85 tyres, because have lower slippage at the same load. Better traction contributes to lower fuel consumption and more economic operation. It can be caused by lower inflation pressure and bigger area of profile on MITAS VF tyres, which in combination with smaller footprint area create considerably higher fulness of tyre profile.

In relation to the effect on soil the MITAS VF tyre shows smaller permanent compaction of topsoil, than MITAS AC 85 tyre, because it has recognizable narrower and shallower track. In relation to soil penetration resistance we can say, that both tyres cause a slight but statistically not significant increase of soil cone index in comparison with non-compacted soil and this cone index is almost the same for both variants of tyres. It can be caused by the fact, that the MITAS AC 85 tyres have bigger area of tyre footprint, while the MITAS VF tyres have bigger area of tyre profile, which can produce different distribution of contact pressure on base material.

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