COMPARISON OF THREE SETS OF DRIVE TRACTOR TYRES WITH RESPECT TO TRACTION PROPERTIES

R. Pražan[1], J. Čedík[1], I. Gerndtová [1], J. Neřold[1], M. Pexa[2]

[1]*Research institute of Agriculture Engineering, Drnovská 507, 161 01, Prague 6, Czech Republic;*
[2]*Czech University of Life Sciences, Faculty of Engineering, Department for Quality and Dependability of Machines, Czech Republic*

Abstract
The paper deals with comparison of three types of tractor tyres with same proportions 600/65 R38 from the producer Mitas (IF and VF tyres and PneuTrac prototypes). The tyres are made from different blends and have different structure which allows operation at lower inflation pressure. The comparison is based on tyre footprints, specific pressure and traction properties of the tyres. The inflation pressure was determined according to values recommended by the producer for a given load (3650 kg). The inflation pressure was 160 kPa for IF tyres, 100 kPa for VF tyres and 60 kPa for prototype tyres PneuTrac. The dependence of the slip on the tractive force was measured in order to compare the traction properties. Results show that the prototype tyres PneuTrac with the inflation pressure 60 kPa made the largest footprints and had the most favourable traction properties.

Key words: tyres, traction properties, Very High Flexion tyre, tyre footprint.

INTRODUCTION

Tyres with higher demands on operation are used increasingly in agriculture. Main features of the tyres include higher load at lower inflation pressure which reduces negative impact on soil and positively affects the traction properties.

The traction properties of tyres, especially dependence of the tractive force or the traction coefficient on wheel slip, influence the tractive efficiency and the fuel consumption. Increasing slipping of the wheel causes increase of the fuel consumption and decrease of the traction efficiency. The traction properties depend on the load and soil conditions such as humidity, type of soil or hardness of the surface (ABRAHÁM ET AL., 2014; AHOKAS & JOKINIEMI, 2014). The traction properties also depend on parameters of the tyres (SCHREIBER & KUTZBACH, 2008; DABROWSKI ET AL., 2006) especially on the inflation pressure (NORÉUS & TRIGELL, 2008). In case of frictional soil the traction force primarily depends on normal load while in case of cohesive soil the traction force primarily depends on the overall size of the contact area (WONG & HUANG, 2006). Šmerda & Čupera (2010) claim that reduction of the inflation pressure from 180 to 65 kPa causes increase of the traction coefficient from 0.66 to 0.74.

The main negative impact of tyres moving on the agricultural land is its compaction. The compaction causes changes in bulk density, porosity, air and water capacity. Therefore it limits water infiltration, reduces retention capacity of the soil, accelerates its erosion and increases soil resistance (GŁĄB, 2014; CHYBA ET AL., 2014; CHYBA ET AL., 2013; SYROVÝ ET AL., 2013; HŮLA ET AL., 2011). High degree of soil compaction negatively affects crop yields depending on the type of crop (ARVIDSSON & HÅKANSSON, 2014; KUTH ET AL., 2012; BRAUNACK ET. AL., 2006).

The structure of tyres for agriculture focuses mainly on reducing inflation pressure and increasing the contact area of the tyre and the surface while maintaining the load and maximum speed limit (ČEDÍK & PRAŽAN, 2015).

The inflation pressure is one of the main parameters affecting work of the tyres, especially the traction properties (LYASKO, 2010). The increasing inflation pressure causes that the area of footprint reduces and the pressure on soil increases especially in the centre of the tyre (MOHSENIMANESH & WARD, 2010). On the contrary, the decreasing pressure under 80 kPa causes that the pressure at the tyre edges increases and it is concentrated in a smaller area (SYROVÝ ET AL., 2013). Maximum pressure applied on the soil may be more than two times greater than the specific pressure calculated from the footprint area and the load (LAMANDÉ AND SCHJØNNING, 2011A, B, C). Therefore it is desirable to achieve evenly distributed pressure at low inflation of the tyres. The contact pressure in the area of contact of the tyre and the surface affects mainly topsoil and upper subsoil layers (0.3 m), stress at deeper layers reflects the tyre overall load (LAMANDÉ & SCHJØNNING, 2011B).

The contact area of the tyre and the surface may be calculated by means of mathematical models based on commonly observable parameters such as the diameter and the width of tyres, the inflation pressure etc. and also by means of different empirically determined coefficients (PALANCAR ET AL., 2001; MCKYES, 1985).

The aim of the paper is to compare the traction properties and the footprint areas of three sets of tyres made by the manufacturer Mitas, with proportions 600/65 R38, which differ in used material blend and structural design of the tyre. The manufacturer determined significantly different inflation pressure at the same load for each set of tyres.

MATERIALS AND METHODS

Three types of tyres with proportions 600/65 R38 were selected for the measurement. The tyres differ in structure and used material blend. The following types of tyres were selected: IF – Improved Flexion, these tyres were used as reference tyres; VF – Very High Flexion, these tyres have more flexible structure mainly due to used material blend and different structure; PneuTrac – tyre prototypes. Regarding current tyres and mainly the VF tyres, the most exposed part during the operation is the sidewall which bends considerably due to currently used low inflation pressures in the area of contact of the tyre and the surface. This entails higher demands on the structure, manufacturing accuracy and used materials. At the same time it can be said that this structure of the sidewall and materials is limiting because the current trend in the agriculture continues to use tyres with lower inflation pressure. Change of the sidewall structure may enable reduction of pressure and achievement of larger tyre footprints.

This footprint is extended mainly in the length, in the track direction. The above mentioned change of the sidewall structure is applied to the measured prototype tyres PneuTrac and its shape is depicted in Fig. 1. Sidewalls of this tyre have a V shape in the cross-section of the tyre. This special structure of the sidewalls is deformed inwards and enables operation of tyres at even lower inflation pressure in comparison with currently best commercial tyres, i.e. VF tyres. It can be said that the tread of the tyre partially behaves like a belt.

Measurement of the tyre footprints was carried out in laboratory conditions at a constant load of 3650 kg and at the pressure which was recommended by the manufacturer for each tyre. The inflation pressure for the IF tyres was 160 kPa, 100 kPa for the VF tyres and 60 kPa for the prototype tyres PneuTrac.

Measurement of traction properties of the tyres was carried out on the property of the agricultural cooperative Rosovice ((latitude 49.7410817°N, longitude 14.1392356°E) with the average altitude 411 m.a.s.l., the land slope was within 2°. The surface consisted of a barley stubble field ploughed by a disc harrow to a depth of 120 mm. The measurement was carried out by means of a tractor John Deere 6150 R with the rated power 125 kW, with IPM 97/68EC, with the front axle ballasted with a weight 900 kg and with a weight 1800 kg placed at the rear three-point hitch. The overall weight of the braked tractor was 8910 kg.

Fig. 1. – Prototype tyres PneuTrac mounted on tractor John Deere 6150 R

New Holland 8770 tractor with the rated power 141.7 kW and with IPM 97/68EC was used as the braking tractor; its front axle was loaded with a weight 880 kg. The overall weight of the braking tractor was 8930 kg. Portable scales Haenni WL 103 (accuracy ±20 kg) were used for weighing the tractors. The wheel slip was measured by the incremental rotary encoder SICK DKS 40 with 360 pulse/rev and the radar RDS K/TGSS/MK (accuracy - < ± 3% for 0.5-3 km.hr^{-1} < ± 1% for 3-70 km.hr^{-1}. The traction force was measured by HBM U10M force transducer with a nominal load 120 kN and the position of the set was determined by the GPS receiver Qstarz BT-Q1000X. All data were stored on the hard disk of the measuring computer HP mini 5103 with a frequency of 5 Hz by means of the analog-to-digital converter LabJack U6 and the I/O module for pulse sensors Papouch Quido 10/1. Rolling circumference of each set of tyres was measured by means of the measuring tape. Before the actual measurement was carried out, the real driving speed of both tractors was measured at each individual gear and at the rated engine speed.

The ground speed of 10 km/h was set for the measurement. Such speed corresponds to the common work operations in the field. Measuring of each set of tyres was carried out for seven different traction forces made by the braking tractor. The wheel slip of the tractor was measured during driving on the stubble. Altogether 8 sections were set for the test drives, each section was 25 m long with a gap of 10 m between the sections. One section provided data necessary for calculation of one measurement point at a given setting of the braking tractor. This setting was identical for all variants of measured tyres. Between the individual sections, in so called “gap”, there was a change of the traction force and stabilization of conditions (breaking force) for the next measured section. The traction force was changed due to downshift of the braked tractor. The rear axle drive with a differential lock turned on was used during the measurement.

Samples were taken in order to determine the measurement conditions, i.e. the type of soil and soil moisture. The evaluation of granularity of the soil samples proved presence of particles with diameter smaller than 0.01 mm in the range from 23.31% to 28.58%. According to the granular analysis (ČSN 46 5302) there was medium, sandy loam soil (according to the Novak granular scale), in lower layers 150 – 300 mm there was sandy loam soil to loamy soil. Content of sandy fractions prevailed over fine dust particles to the depth of 150 mm. The soil was loose, well friable, with coherent clods. The soil moisture was determined by the actual content of water in the soil. The soil moisture depending on the depth of taken sample is presented in the Fig. 2. The soil is marked as parched on the surface (0-50 mm) and as dry in other layers. The soil moisture was determined by means of gravimetric analysis.

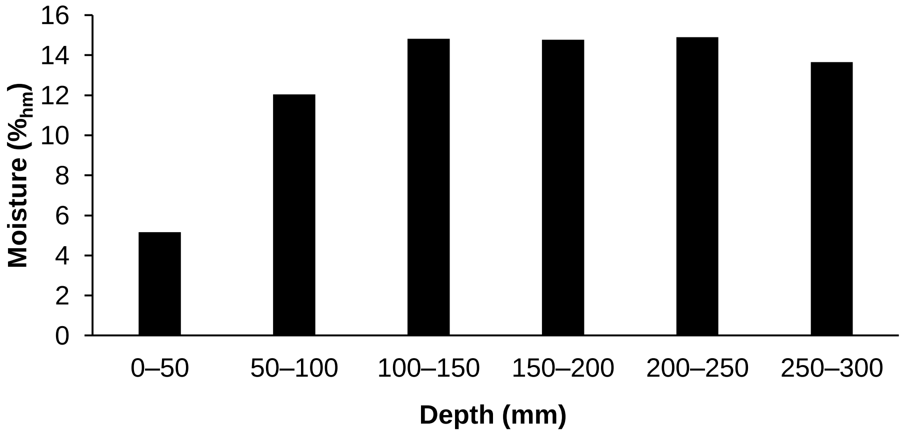

Fig. 2. – Soil moisture

RESULTS AND DISCUSSION

Fig. 3 depicts areas of tyre footprints at load 3650 kg and at manufacturer´s recommended inflation pressure for this load. It can be seen that the tyre Mitas VF600/65 R38 has a 28 % larger footprint area and the tyre Mitas 600/65 R38 PneuTrac has a 49 % larger footprint area than the referential tyre Mitas IF 600/65 R38.

Tab. 1 shows results of the tyre footprints measurement. It is evident that the specific pressure is 32.3% lower in case of Mitas VF tyre and 37.33% lower in case of Mitas PneuTrac tyre than in case of the standard tyre Mitas 600/65 R38. Deflection is higher for Mitas VF and Mitas PneuTrac than for standard Mitas 600/65 R38 which proves usage of more flexible blend. Lateral stiffness is significantly higher in case of Mitas PneuTrac tyre than in case of standard Mitas 600/65 R38 and Mitas VF.

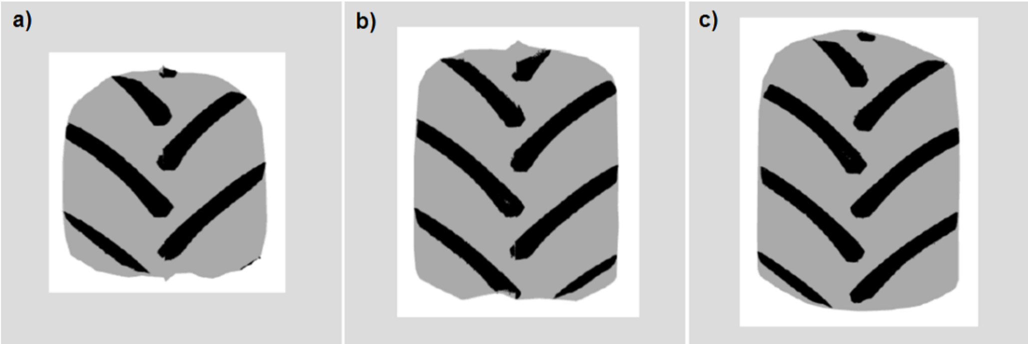

Fig. 3. – Tyre footprints (a – Standard Mitas IF tyre 600/65 R38, b – Mitas VF tyre 600/65 R38, c – Mitas PneuTrac tyre 600/65 R38)

Tab. 1. – Results of the tyre footprints

		Mitas IF 600/65 R38	Mitas VF600/65 R38	Mitas 600/65 R38 PneuTrac
Inflation pressure	kPa	160	100	60
	(%)	100	62.50	37.50
Deflection	(mm)	102	140	152
	(%)	100	137.25	149.02
Footprint	(cm^2)	2584	3299	3557
	(%)	100	127.67	137.65
Ground pressure	(kPa)	139	108	101
	(%)	100	77.70	72.66
Lateral stiffness	(daN/mm)	19	31	65
	(%)	100	163.16	342.11

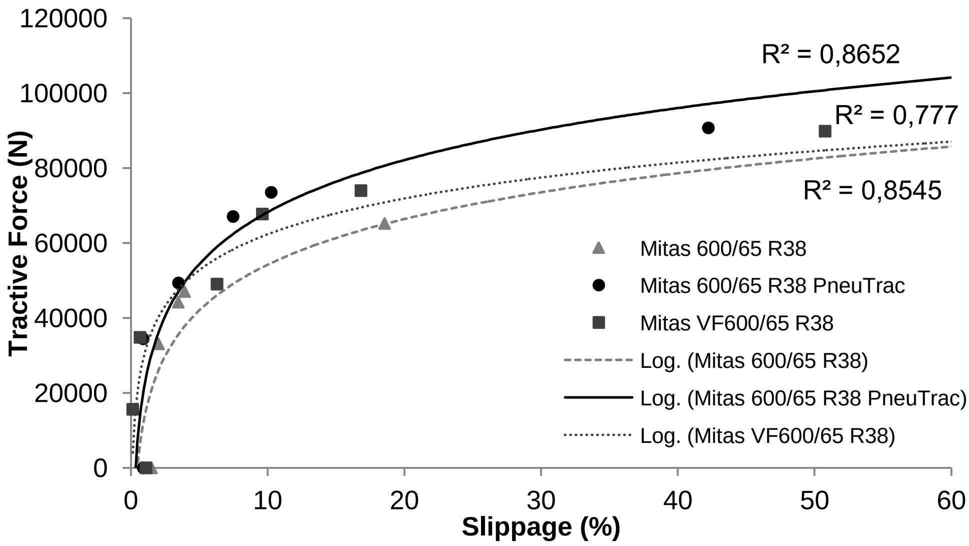

Fig. 4. – Dependence of tractive force on rear tyre slip

Fig. 4 shows dependency of the tractive force on the rare tyre slip. It can be seen that lower slip at lower tractive force was reached by tyres Mitas VF (approximately up to 40-50 kN), and the lowest slip at higher tractive force was reached by tyres Mitas PneuTrac that managed to maintain the highest tractive force 90.7 kN within the measurement. This is most likely due to larger area of the footprint and more favourable distribution of pressure in the footprint since the tread is not deformed to such extent as in case of common tyres at a given inflation pressure. This is caused by the structure of sidewalls because common underinflated tyres tend to push the edges of the tread inward the footprint and thus adversely affect distribution of the pressure. The structure of PneuTrac tyres pushes the edges of the tread away from the longitudinal axis of the footprint at all circumstances and thus ensures contact of the whole tyre footprint with the surface.

CONCLUSIONS

Results make it evident that Mitas PneuTrac tyres proved most flexible blend and structure in radial direction while maintaining lateral stiffness which helped to maintain the maneuverability of the tractor. It is also possible to significantly reduce the inflation pressure by up to 62.5 % compared to standard tyres of the same size and the same load. These tyres reduce negative impact on soil and plants because of lower pressure and larger area of tyre footprint.

From the point of view of traction properties Mitas VF tyres reached the lowest slip at lower tractive force. With increasing tractive force the slip of Mitas VF tyres significantly increased when compared to Mitas PneuTrac tyres. When compared to standard Mitas tyres, Mitas VF tyres maintained c. 12% higher tractive force and Mitas PneuTrac tyres maintained ' c. 26% higher tractive force at the slip of15 %. Mitas PneuTrac tyres maintained the highest tractive force from all compared tyres and thus increased tractive efficiency of the tractor. Better traction properties also contribute to lower fuel consumption and more economic operation.

ACKNOWLEDGEMENT

The paper was created with institutional support for long-term conceptual development VÚZT, v.v.i. RO0614 and with the grant support CLUS – 2016: 31190/1312/3116 "Effect of cutting tool shape on air flow in working area of mulcher with vertical axis of rotation."

REFERENCES

1. ABRAHÁM, R., MAJDAN, R., ŠIMA, T., CHRASTINA, J. & TULÍK, J. 2014: Increase in tractor drawbar pull using special wheels. *Agronomy Research* 12(1), pp. 7–16
2. AHOKAS, J. & JOKINIEMI, T. 2014: Light tractor simulator. *Agronomy Research* **12**(1), pp. 17–24
3. ARVIDSSON, J. & HÅKANSSON, I. 2014: Response of different crops to soil compaction—Short-term effects in Swedish field experiments. *Soil and Tillage Research* 138, pp. 56–63.
4. BRAUNACK, M.V., ARVIDSSON, J. & HÅKANSSON, I. 2006: Effect of harvest traffic position on soil conditions and sugarcane (Saccharum officinarum) response to environmental conditions in Queensland, Australia. *Soil and Tillage Research* 89(1), pp. 103–121
5. ČEDÍK, J. & PRAŽAN, R. 2015: Comparison of tyres for self-propelled sprayers. *Agronomy Research*, 13(1), pp. 53–62
6. DABROWSKI, J., PYTKA, J., TARKOWSKI, P. & ZAJAC, M. 2006: Advantages of all-season versus snow tyres for off-road traction and soil stresses. *Journal of Terramechanics* 43(2), pp. 163–175.
7. GŁĄB, T. 2014: Effect of soil compaction and N fertilization on soil pore characteristics and physical quality of sandy loam soil under red clover/grass sward. *Soil and Tillage Research* 144, pp. 8–19
8. HŮLA, J., GUTU, D., KOVAŘÍČEK, P., STANĚK, L. & KROULÍK, M. 2011: Odolnost půdy vůči zhutňování při řízených přejezdech strojů. (Soil Resistance Against Compaction During the Machines Controlled Traffic). *Agritech Science* 5(1), [online] http://www.agritech.cz/clanky/2011-1-3.pdf. Accessed 11.1.2016 (in Czech)
9. CHYBA, J., KROULÍK, M., KRIŠTOF, K., MISIEWICZ, P.A., CHANEY, K. 2014: Influence of soil compaction by farm machinery and livestock on water infiltration rate on grassland. *Agronomy Research* 12(1), pp. 59-64
10. CHYBA, J., KROULÍK, M., LEV, J., KUMHÁLA, F. 2013: Influence of soil cultivation and farm machinery passes on water preferential flow using brilliant blue dye tracer. *Agronomy Research* 11(1), pp. 25-30
11. KUHT, J., REINTAM, E., EDESI, L. & NUGIS, E. 2012: Influence of subsoil compaction on soil physical properties and on growing conditions of barley. *Agronomy Research* 10(1-2), pp. 329–334
12. LAMANDÉ, M. & SCHJØNNING, P. 2011A: Transmission of vertical stress in a real soil profile. Part I: Site description, evaluation of the Söhne model, and the effect of topsoil tillage. *Soil and Tillage Research* 114(2), pp. 57–70
13. LAMANDÉ, M. & SCHJØNNING, P. 2011B: Transmission of vertical stress in a real soil profile. Part II: Effect of tyre size, inflation pressure and wheel load. *Soil and Tillage* Research 114(2), pp. 71–77
14. LAMANDÉ, M. & SCHJØNNING, P. 2011C: Transmission of vertical stress in a real soil profile. Part III: Effect of soil water content. *Soil and Tillage Research* 114(2), pp. 78–85
15. LYASKO, M. 2010: Slip sinkage effect in soil–vehicle mechanics. *Journal of Terramechanics*, 47(1), pp. 21–31
16. MCKYES E. 1985: *Soil cutting and tillage*. Elsevier Science Publishers, Amsterdam. 217 pp.
17. MOHSENIMANESH, A., & WARD, S. M. 2010: Estimation of a three-dimensional tyre footprint using dynamic soil–tyre contact pressures. *Journal of Terramechanics*, 47(6), pp. 415–421

18. NORÉUS, O. & TRIGELL, A. 2008: Measurement of terrain values and drawbar pull for six wheeled vehicle on sand. In: *16th International Conference of the International Society for Terrain Vehicle Systems*. ISTVS, Turin, pp. 250–257 (in Italy)
19. PALANCAR, T.C., & TERMINIELLO, A.M., 2001: *Jorajuría D. Determinación Expeditiva del Área de Contacto Rueda-Suelo en Máquinas Agrícolas*. Universidad Nacional de La Plata
20. SCHREIBER, M. & KUTZBACH, H. 2008: Influence of soil and tire parameters on traction. *Research in Agricultural Engineering* 54(2), pp. 43-49
21. SYROVÝ, O., SVĚTLÍK, M., PRAŽAN, R., PASTOREK, Z., KUBÍN, K. & GERNDTOVÁ I. 2013: *Mobilní energetické prostředky a orientační hodnoty jednotkových spotřeb paliv a energií (Mobile energy devices and the approximate values of unit fuel and energy consumption)*. Research Institute of Agricultural Engineering, p.r.i., Prague, pp. 56 (in Czech)
22. ŠMERDA, T., & ČUPERA, J. 2010: Tire inflation and its influence on drawbar characteristics and performance – Energetic indicators of a tractor set. *Journal of Terramechanics*, 47(6), 395–400
23. WONG, J. Y., & HUANG, W. 2006: “Wheels vs. tracks” – A fundamental evaluation from the traction perspective. *Journal of Terramechanics*, 43(1), 27–42.

Corresponding author:
Ing. Radek Pražan, Ph.D., Research institute of Agriculture Engineering, Drnovská 507, 161 01, Prague 6, Czech Republic, phone: +420 233 022 536, e-mail: prazan@vuzt.cz