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THE EFFECT OF THE TRACTOR TIRES LOAD ON THE GROUND LOADING PRESSURE

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Abstract

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The contribution, based on the experimental measurement, analyses the issue of a specific pad loading pressure in relation to radial wheel load and tire inflation. Tile inflation in terms of allowed radial load, which we wish to be high as far as possible in terms of the power transmission from the wheels to the ground is important for the field tensile works, on the other hand, the pressure in the tire is closely related to the contact area and ground loading pressure. The obtained results show the following: Michelin Multibib 650/65 R38 tire, inflated to a pressure of 80 kPa has a sufficient reserve in radial load. As the measurement results show, ground loading pressure at the highest load of 36.55 kN, which was used during the measurement, is under the value of 100 kPa, which would mean on loamy soil at a humidity of 17% that the limit of the ground pressure on the ground has not been exceeded.

Keywords: stress transmission, tire inflation pressure, area of imprint, pressure in area of imprint

INTRODUCTION

Increasing demands on the tractor performance result in an increase of their weight. It may be accompanied by negative impacts on undesirable soil compaction which is caused by the movement of heavy machinery on land under unsuitable conditions. The soil is classified as an elastic-plastic medium which behaves as an elastic medium under a certain pressure degree and as a plastic medium over this degree (Lamandé and Schjønning). Pedo-compaction occurs under the effect of various factors exerting a pressure on the soil which exceeds the tolerable soil limit. Under this pressure, the particular soil particles are compressed together. Considerably compacted soils exhibit a layer with difficult permeability in a certain soil horizon which results in structural changes in the soil. Changes are in particular of physical, biological and chemical nature and cause deterioration of the properties of a particular soil and its limited functions (DeJong-Hudges *et al.*, 2001). As a result, there is erosion, increased resistance when working soil, deterioration of water management and reduced yield due to the formation of an impermeable layer. According to the estimates published in *Situation and Outlook Report Soil* (Novák *et al.*, 1999), 45% of the agricultural land fund was threatened with compaction. The 2012 yearbook (Budňáková and Jacko) even confirms this increase up to 49%. Of which, 30% of soils are threatened by so called genetic compaction which is given by natural properties of soil and is typical especially for soils with a higher content of clay. Around 70% of soils are, however, compacted by so called technogenic compaction which is caused by the movement of agricultural machinery or by inappropriate agrotechnical interventions. In order to maintain soil fertility and homogeneity, it is necessary to take steps which will ensure that the soil structure is maintained and the compacted layers are eliminated. For these purposes, one can use e.g. the design of a tractor with creeper undercarriage, a double-tire assembly or reduce the pressure in tires. The purpose of these solutions is to increase the contact areas and thereby a better weight distribution of the tractor. This will be manifested by a reduced resulting pressure on the ground and advancement of the tractor traction properties. These are largely influenced also by the accurate weight distribution and, as the case may be, with the possibility to afterload the rear axle of the tractor through the connected machine. If the tractor is aggregated with a plow which is equipped with so called traction servo, it is possible to transmit a part of the plow weight to the rear wheels of the tractors. This results in targeted afterloading of the rear axle which leads to a partial deformation of tires, more accurately to an increase of their contact area. Increasing the contact area leads to reduction of the slip of the assembly, thereby increasing performance and reducing fuel consumption (Bauer *et al.*, 2013). The tractors are equipped with electric-hydraulic control of the three-point hitch (Hereinafter referred to as TPH). The aim of the electric-hydraulic systems of tractors is to transmit the adhesion load from the mounted or semi-mounted tools to the tractor.

The adhesion load of the tractor wheels in terms of power transmission should be as high as possible, however, the limit soil loading which should not exceed the limited ground loading pressure should be respected. For these reasons, attention should be paid to tires, their measurements and proper inflation. The article analyses the issue of tires load and their inflation in relation to ground loading pressure.

MATERIALS AND METHODS

The measurements took place at the laboratories of the Institute of Technology and Road Transport at the Mendel University in Brno. Claas Arion 640 Hexashift tractor, whose selected parameters are listed in Tab. I, was to be tested.

The tractor was equipped with Michelin Multibib tires that can be inflated to pressures from 40 kPa to 200 kPa. The inflating of wheels depends on the load to which the tire is exposed in operation. Three inflation pressures 80, 120 and 160 kPa were chosen for the experimental measurement.

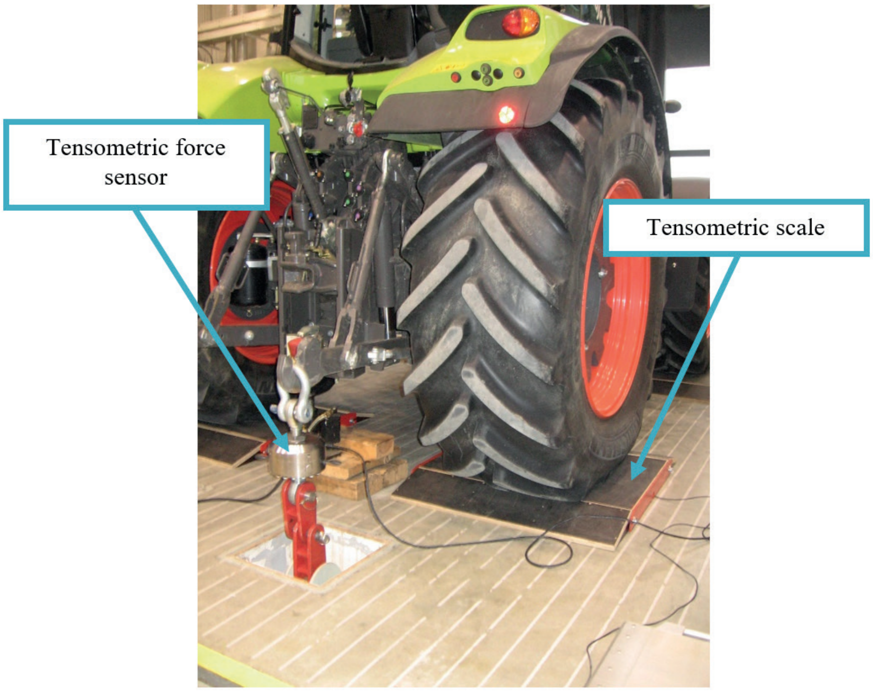
The tractor has been equipped with an electronic-regulation system which helps to control the slip so that low values at work with mounted or semi-mounted tools can be achieved. In addition, it was equipped with Michelin Multibib tires which enable reducing pressure up to 40 kPa and thereby ensuring an increase of the contact area due to tire deformation.

For the purposes of the measurement, the tractor was in horizontal position and a tensometric scale was put under the right wheel in order to determine the load on the given wheel. The end of the right arm of TPH was clamped to the floor to create load under the tractor wheel. As the tractor with mounted or semi-mounted tools works, a certain power operates at the end of the shoulder which is subsequently transmitted to the rear axle of the tractor. If we manage to determine the magnitude of this power and to possibly influence it using electric-hydraulic system by which each tractor is equipped, we can increase the effectiveness of the work performed. Hottinger HBM U 10M strain-gauge sensor was placed between the lower rod of the TPC and floor in order to verify the forces acting at the end of the three point hitch. The measuring set is stated in Fig. 1.

In the first part of the measurement, there was verified the radial load dependence on the measured tire in relation to the force which was generated by the hydraulic cylinder of the three-point hitch of the tractor. The size of the load was captured by a tensometric force sensor (the tensometric force sensor was Hottinger HBM U 10M) placed at the end of the three-point hitch arm. The tire was being loaded at zero force range, i.e. only a part of the tractor weight was on the tire, up to the maximum force, when a value just a little bit lower than the maximum tire loading given by the manufacturer was achieved. According to the manufacturer's data, for the tested tire it amounted to a value of 38.85 kN at an inflation

I: *Selected parameters of measured tractor (manufacturer's data)*

Engine	
Cylinder capacity [cm^3]	6788
Performance homologation value (97/68 EG)[1] [kW/k]	128/174
Transmission	
Type	Hexashift – manual transmission
	Gears changed under load
Tires measurement	
Rear axle	Michelin Multibib 650/65 R38
Front axle	Michelin Multibib 540/65 R28
Measurements and weights	
The wheelbase [mm]	2860
The tractor weight [kg]	9040
Front axle load [kg]	4895
Rear axle load [kg]	4145



1: *Tractor Claas with strain-gauge sensor in arm of three-point hitch and strain gauge scale*

pressure of 80 kPa (it applies for a speed up to 10 km.h^{-1}).

In the second part of the measurement, as we knew the radial forces pertaining to the given heel, depending of the force in the lower rod of the three-point hitch, tire imprints were made. The measurements were made in order to verify the change of the tire imprint area, depending on the degree of its deformation, which is a result of the increasing force. Tread lugs of the tire tread ("arrows") were painted with a colour and subsequently dropped to the pad in order to record the imprint. The imprint was made always at the same force in the lower rod of the three-point hitch of the tractor. After the first imprint was made, the tractor wheel was lifted up, the specimen was re-painted and an imprint with a slightly rotated wheel was made. Thus, at the given pressure and load, other imprints were made in order to get the entire grip area of the tire. The imprints were measured at different inflation pressures and different tire loads, in the next set of measurements, the tire pressure was changed and the measurement was made in the same way in order to get an overall overview of the influence of lad on the contact surface of the tire. The inflation pressures which were used for measurement and individual tire loads are listed in Tab. II.

Fig. 2 shows an example of an imprint at an inflation pressure of 80 kPa and a load of 36.55 kN.

After all measurements were made, the obtained imprints were evaluated using a special method of image capture with a special camera and subsequently evaluated by a software designated for that purpose. The imprints were evaluated by the method of different colour potentials, when there was evaluated the entire area of the imprint which was determined by the boundary of the imprinted and not imprinted area, in addition a white parts area inside this entire imprint and the area of the imprint S_0, which was red. The area of the parts which were not recognized by the software was a negligible part of the imprint.

Subsequently, pressure p_0, acting in the area of the imprint, was calculated. The pressure was calculated equation (1):

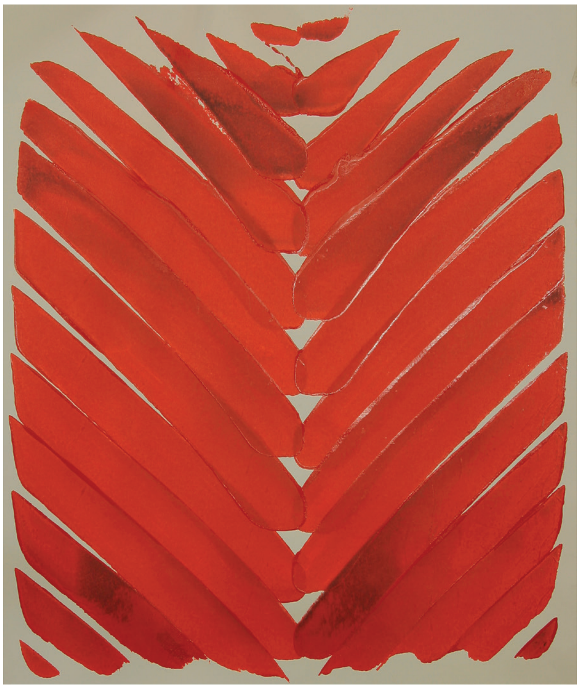
$$p_0 = \frac{F}{S_0} \cdot 10^4 \text{ [kPa]} \tag{1}$$

where:
F .... tire load [kN]
S_0... the area of the imprint [cm^2]

All evaluations of the measures values was done using statistical software Statistica 12 CZ.

II: *Parameters of tyre inflation pressure and wheel load of measured tractor*

Tire inflation pressure [kPa]	Tire load [kN]
80; 120; 160	21.50
80; 120; 160	26.90
80; 120; 160	36.55



2: *Tire imprint at an inflation pressure of 80 kPa and load of 36.55 kN*

RESULTS AND DISCUSSION

The measurements obtained were tested whether they show a normal distribution. Normality was tested using the Kolmogor-Smirnovov test. Based on this test, it was proven that the data come from normal distribution.

In addition, box plots were made. The first box plot (Fig. 3) was made for the variable "*The area of the imprint*", the second plot (Fig. 4) was for the variable "*Pressure in the area of the imprint*". The group variable in both plots was inflation pressure *p*. One box at the given inflation pressure includes all three variants loads (21.50 kN; 26.90 kN and 36.55 kN).

The legend of the box plot Fig. 3 shows average values, standard deviation and 1.96 times the standard deviation. This range was selected from the reason that for the data stemming from the normal division, 95% of all values are in the range ±1.96 multiple of the standard deviation from the average (Meloun and Militký, 2012). As obvious from the plot, the area of the imprint gets reduced as the pressure increases. However, this change is not linear. A second order polynomial transformation was chosen to accurately describe this change. The largest changes occur between the pressure of 80 and 120 kPa. The change of the area of the imprint between these two inflations was 485.4 cm^2. The change of the area of the imprint between 120 kPa and 160 kPa was almost three times lower or only 171.1 cm^2. A large dispersion of measured values at the given inflation pressure is caused by the fact that the values contain a measured area at a different tire load.

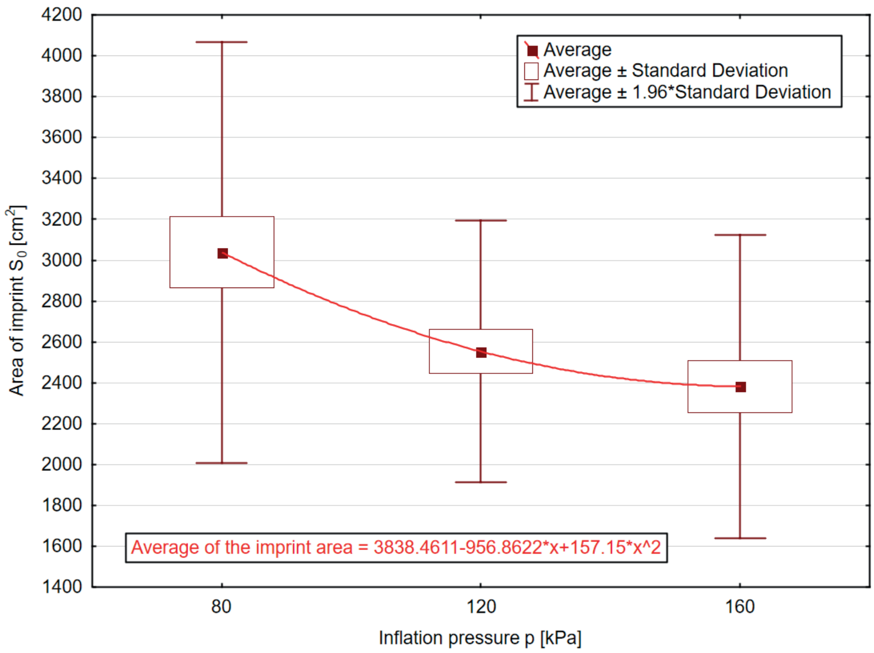
The change of the area of the imprint is related to the change of pressure in the area of the imprint calculated according to relation 1. The average pressure values in the area of the imprint at the given inflation pressure are stated in the box plat in Fig. 4.

The box plot (Fig. 4) also consists of an average, a standard deviation and 1.96 multiple of the standard deviation. As obvious from the plot, with the rising pressure also the pressure in the area of the imprint increases. Likewise in the previous case, this change is not linear. The biggest changes occur again between the pressure 80 and 120 kPa. The pressure in the area of the imprint between these two inflations changes by 17.03 kPa. The change of the pressure in the area of the imprint between 120 kPa and 160 kPa was only 7.83 kPa. The values at the given inflation pressure include also, as in the previous case, the pressure values in the area of the imprint at a different tire load.

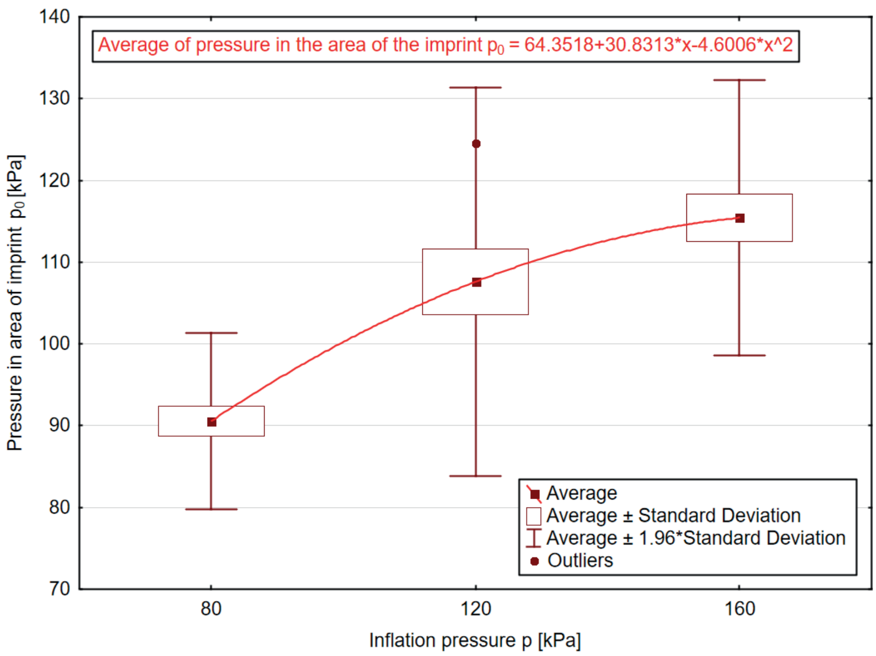
ANOVA was used for statistical evaluation. In the first test, zero hypotheses were verified whether the pressure inflation and tire load affects statistically significantly the area of the tire imprint and the pressure in the area of the imprint. Tukey's test was used for a multiple comparison.

Figs. 5–7 show graphical representation of the ANOVA method results for the area of the imprint. Vertical columns designate 95% average confidence intervals.

It can be seen from Fig. 5, that the tire reaches the biggest changes at a inflation pressure of 80 kPa and at a change of load from 26.9 kN to 36.55 kN. There is an increase of the area approximately by 800 cm^2, which is by 28% higher value, in comparison towards the valued measured at



3: *Box plot for the variable "The area of the imprint"*

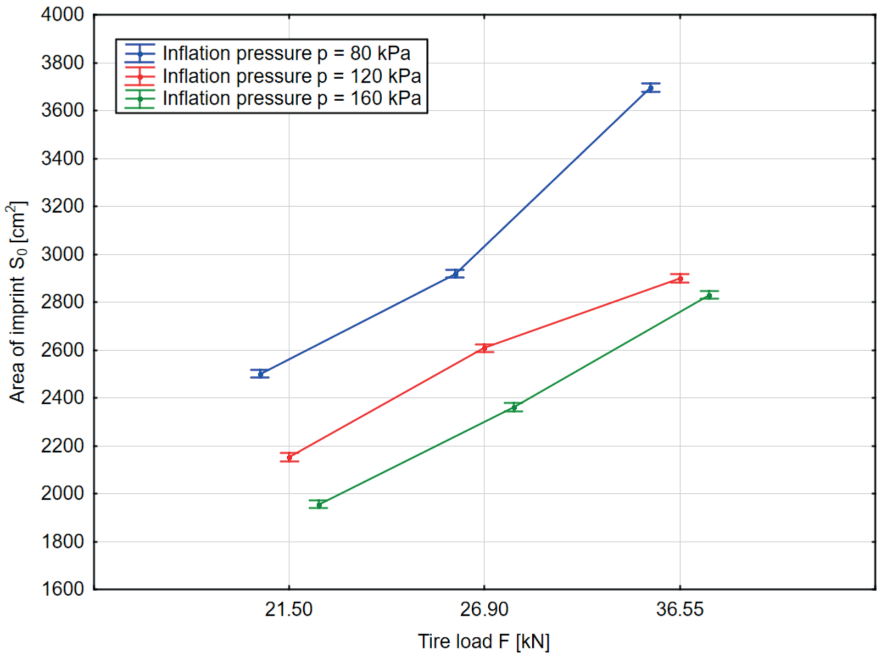


4: *Box variable for the variable "Pressure in the area of the imprint"*

26.9 kN. On the contrary, the smallest change (the smallest increase of the area of the imprint) occurs at the same change of load from 26.90 kN to 36.55 kN at a tire with the inflation pressure 120 kPa. In this change of load, there was an increase of the area of the imprint only by 12%. The area of the imprint at an inflation pressure of 120 kPa and at a load of 36.55 kN is very close to the area of the imprint measured at a inflation pressure of 160 kPa and a same load, i.e. 36.55 kN.

By multiple comparison it was found that in all measurement groups, except for inflation pressure at 80 kPa at a load of 26.90 kN and inflation pressure of 120 kPa at a load of 36.55 kN, there was found a statistically significant difference. Therefore, it can be stated that a tire at an inflation pressure of 80 kPa and a load of 26.90 kN and a tire at an inflation pressure of 120 kPa and a load of 36.55 kN has the same area of the imprint.

We come to similar results also when evaluating the pressure in the area of the imprint, see Fig. 6.



5: *Graphical representation of the area of the imprint depending on the load and pressure*

At an inflation pressure of 80 kPa, the increase of the pressure under the tire area is linear. At an inflation pressure of 120 and 160 kPa, when the load is changed from 21.50 kN to 26.90 kN, the increase of this parameter is significantly lower (3.57 kPa) than at a high load when there is a "sharp" increase of pressure under the tire area (an increase in comparison with a load of 26.90 kN in average by18.69 kPa).

The pressure values are also very close to each other (as the entire areas of the imprint at a inflation pressure of 120 and 160 kPa).

Multiple comparisons have shown that only the pressure under the imprinting area at an inflation pressure of 80 kPa and a load of 36.55 kN does not significantly differ (on a significance level of 95 %) from the pressure under the imprinting area of 120 kPa which was achieved at a lowest load of 21.50 kN.

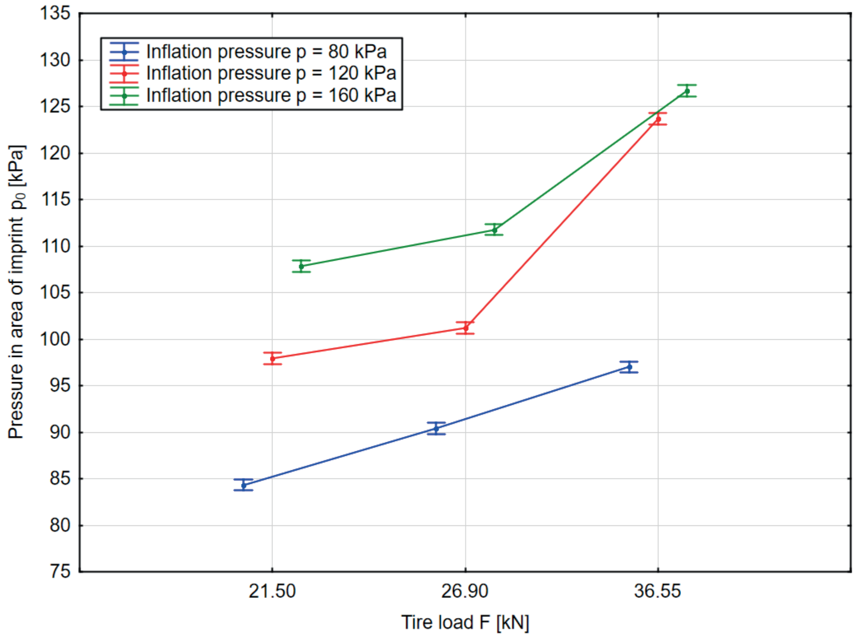
For better clarity, there were created charts of monitored parameters at different inflation pressure for different loads (see Fig. 7). Fig. 7 indicates that for the loads of 21.50 and 26.90 kN, the changes of monitored parameters in all inflation pressures are almost linear. However, it is not the case at a higher load of 36.55 kN. The values of monitored variables (at an inflation pressure of 80 kPa) differ significantly from the values measured for inflation pressures of 120 and 160 kPa.

High demands are put on the tires in terms of the pressure exerted on the ground which should not exceed the limit when the undesirable compaction occurs. For this reason, it is justified, especially in agro-technical operations where we need to achieve the highest possible tensile force, to reduce the pressure in the tire to an acceptable value but not to a value when damage would occur.

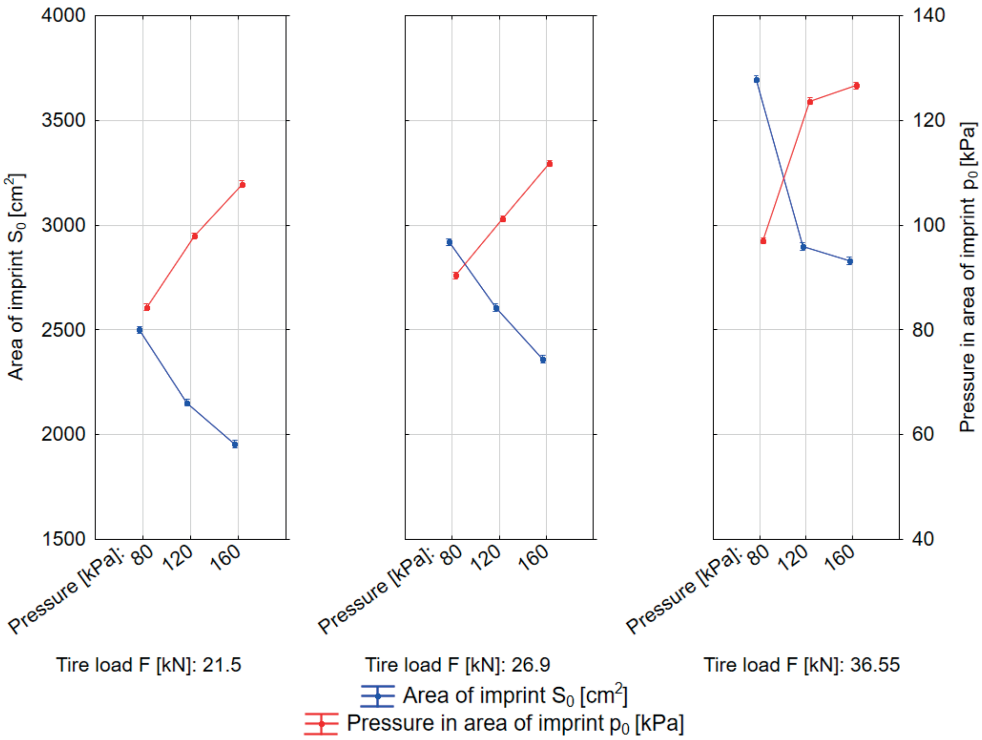
Based on the measurements made and the analysis conducted we can state that a higher tire radial load does not have to have a negative influence on the undesirable soil compaction. Contemporary tire design enables to decrease the inflation pressures and thereby to increase the contact area of the tires.

Fig. 6 and 7 indicate that a lower pressure in the tires has a positive influence on the area of the imprint which is manifested by a lower ground loading pressure. The published article by Keller and Arvidsson from 2004 shows what influence has the pressure under the contact area of the tires on undesirable soil compaction. The authors of the article found by experimental measurement that the inflation pressure influences significantly soil tension, especially in lower depths (up to 30 cm). Undesirable compaction occurring in the subsoil (depths over 30 cm) is than a result of high wheels load (Arvidsson and Keller, 2007) and in the long run of insufficient depth of soil treatment.

Increasing the contact area can also result into more favourable output parameters of the tractor sets. There was an article exploring the influence of the inflation pressure on the output parameters of the tractor published by Sedlák *et al.* in 2007. In the article they came to the conclusion that decreasing the pressure in tires results in an increase of tensile force, tensile performance and in reducing the wheel slip and decline of the tensile consumption.



6: *Graphical representation of the pressure under the area of the imprint depending on the load and pressure*



7: *Graphical representation of monitored parameters depending on the inflation pressure at individual loads*

CONCLUSION

Tractor tires are of great importance for effective use of engine power and its transformation to tensile power. The importance of tires and their inflation is more and more significant in particular for the tractors of higher performance classes used in traction. High demands are placed on tires also in terms of ground loading pressure which should not exceed the limit when the undesired compaction occurs. As the inflation pressure drops, the area of the imprint increases and the contact pressure between the tractor and the pad affecting the undesirable soil compaction decreases. On the basis of the realized experimental measurements and obtains results it can be stated that for field tensile works seems to be the best to choose for the particular tire Michelin Multibib 650/65 R38 pressure of 80 kPa. The inflated tire shows a sufficient reserve in radial load. As the measurement results show, ground loading pressure at the highest load of 36.55 kN which was used during the measurement, is under the value of 100 kPa which would mean in loamy soil at a humidity of 17% that the limit of contact pressure on the soil has not been exceeded.

The above mentioned published articles dealing with a similar issue show that an increase of the contact area of tire and the subsequent drop in pressure affecting the soil has a positive influence not only when applying soil protection technologies but also on increase of tensile force and tractor's wheels slip in energy intensive operations. Changing the air pressure in tires (depending on the operational conditions) is already implemented today, e.g. through the central inflation systems. After loading the drive wheels can be done by adding weight or in a more effective manner, by using regulation systems of the three-point hitch of the tractor when working with mounted or semi-mounted tools.

Acknowledgements

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REFERENCES

ARVIDSSON, J. and KELLER, T. 2007. Soil stress as affected by wheel load and tyre inflation pressure. *Soil and Tillage Research*, 96(1–2): 284–291.

BAUER, F., SEDLÁK, P., ČUPERA, J., POLCAR, A., FAJMAN, M., ŠMERDA, T. and KATRENČÍK, J. 2013. *Traktory a jejich využití*. Praha: ProfiPress s.r.o.

BUDŇÁKOVÁ, M. and JACKO, K., 2012: *Situační a výhledová zpráva Půda*. Praha: Ministerstvo zemědělství.

DEJONG-HUGHES, J., MONCRIEF, J. F., VOORHEES, W. B. and SWAN, J. B. 2001. *Soil compaction: causes, effects and control*. [Online]. Available at: http://www.extension.umn.edu/agriculture/tillage/soil-compaction/ [Accessed: 2017, July 15].

KELLER, T. and ARVIDSSON, J. 2004. Technical solutions to reduce the risk of subsoil compaction: effects of dual wheels, tandem wheels and tyre inflation pressure on stress propagation in soil. *Soil and Tillage Research*, 79(2): 191–205.

LAMANDÉ, M. and SCHJØNNING, P. 2011. 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): 71–77.

MELOUN, M. and MILITKÝ, J. 2012. *Kompendium statistického zpracování dat*. Praha: Univerzita Karlova v Praze – Nakladatelství Karolinum.

NOVÁK, P., LAGOVÁ, J., NĚMEC, J., VOLTR, V., VIGNER, J. and MAREK, V. 1999. *Situační a výhledová zpráva Půda*. Praha: Ministerstvo zemědělství.

SEDLÁK, P., BAUER, F., ČUPERA, F. and ŠMERDA, T. 2007. Vliv huštění pneumatik na tahové vlastnosti traktoru. In: *Sborník mezinárodní konference Technika zemědělství a potravinářství ve třetím tisíciletí*. Brno: MZLU v Brně, pp. 359–364.

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