FIELD TESTING OF COMPACTION CHARACTERISTICS FOR FARM TRACTOR UNIVERSAL 445 / *TESTAREA ÎN CÂMP A CARACTERISTICILOR DE COMPACTARE PENTRU TRACTORUL AGRICOL UNIVERSAL 445*

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ABSTRACT

In the past few decades, size and weight of agricultural machinery have increased significantly, and as a consequence, the severity and depth to which the stress is transmitted into agricultural soil have increased. The objective of experimental determinations was to study the influence of some factors characteristic to compaction: tire inflation pressure, wheel load and contact pressure on the contact area between tire and soil, as well as 2D and 3D mapping of pressure distribution in the footprint. The front tire of the U445 Romanian agricultural tractor was tested at five tire inflation pressures: 100, 150, 200, 250 and 300 kPa, obtaining contact areas between 0.0252 – 0.0349 m^2 and contact pressures between 98 - 136 kPa.

REZUMAT

În ultimele decenii, mărimea și greutatea mașinilor agricole au crescut în mod semnificativ și, în consecință, au crescut severitatea și adâncimea la care se propagă tensiunile în solul agricol. Obiectivul determinărilor experimentale îl constituie studiul influenței unor factori caracteristici ai compactării, precum: presiunea din pneu, încărcarea pe roată și presiunea de contact asupra ariei de contact dintre pneu și sol, precum și obținerea hărților 2D și 3D ale distribuției presiunilor în pata de contact. S-a testat pneul față al tractorului agricol romanesc U445, la cinci presiuni în pneu: 100, 150, 200, 250 și 300 kPa, obținându-se suprafețe de contact între 0.0252 – 0.0349 m^2 si presiuni de contact intre 98 - 136 kPa.

INTRODUCTION

Worldwide, soil compaction has become a concern and is recognized as one of the major problems in modern agriculture associated with soil degradation. Soil compaction is an increase of soil wet density, and it occurs mostly when a vehicle operates on soil with increased soil moisture or due to improperly dimensioned running gear of heavy field machinery, though loaded and inflated according to manufacturers' technical instructions (*Grecenko and Prikner, 2014*).

Soil compaction due to external mechanical stress applied by wheeling deforms the pore space, which affects soil aeration, water and solute transport, nutrient availability (*de Pue and Cornelis, 2019*), it reduces fertiliser use efficiency, increases the risk of run-off and erosion and reduces crop productivity (*Bluett et al., 2019*), it reduces pesticide decomposition and increases pesticide leaching into groundwater, it accelerates the potential pollution of surface water by organic waste.

Soil compaction under the wheels of agricultural field vehicles such as tractors with mounted or trailed implements is of special concern (*de Lima et al, 2018*), because of demand for mechanization, hence increased field traffic under predominantly all-weather operations.

In European agriculture, tractor weight increased from 3 tons (in 1940) to 7 tons (in 1998) respectively 20 tons (at present). Although with the increasing adoption of precision agriculture that can confine the traffic, modern tractors are heavier, their available power and load carrying/pulling capacity is greater, so current field machines have the potential to cause much more site disturbance and damage (*Mohsenimanesh and Ward, 2010*).

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Soil compaction due to the traffic of agricultural machinery on fields is observed as sinkage at soil surface, which is the cumulative effect of deformation beneath soil surface (*Elaoud and Chehaibi, 2011*).

The vulnerability of soil to become compacted has been observed as an interaction of numerous factors, including soil moisture, soil organic matter, soil type, wheel load, size and shape of the footprint area formed between the tire and soil, tire inflation pressure, contact pressure, number of passes of agricultural machinery, tillage system, machine speed and even the treading of animals on pastures.

In contact with the soil, the tire of agricultural machinery forms a footprint whose shape and size depend on several categories of factors: the type of soil and its physical characteristics, the type of tire (rigidity, tread pattern), tire inflation pressure, wheel load. The contact area is the part of the tire that comes into contact with the soil and is calculated as the ratio between the wheel load and the tire inflation pressure. Static contact area is the contact area between the tire and a rigid or deformable surface when the tire is statically loaded without movement (*Wulfsohn D., 2009*). The contact area between has a major influence on the distribution of stress in the soil. The increase in the contact area does not necessarily lead to the decrease of the stress in the soil, but to the limitation of the distribution of the large stresses in the depth, respectively to their extension in horizons close to soil surface. The problem of deep distribution of large stress can be solved by adopting double-drive wheels for which the contact area doubles.

Tire inflation pressure is, along with soil moisture, one of the most important factors influencing soil compaction (*Batey T., 2009*) because it influences the contact area and the contact pressure at the soil-tire interface for a given wheel load (*Xia K., 2011*). By lowering the tire inflation pressure, soil-tire interaction can be modified by altering soil-tire interface pressure, tire performance and rutting effect (*Pytka, 2005*).

Contact pressure can be determined as ratio between wheel load and the contact area between the wheel and the soil. Contact pressure causes topsoil compaction, while high wheel load leads to subsoil compaction. The contact pressure at the soil-tire interface is a good indicator of the potential for compaction of agricultural soils. In order to reduce the contact pressure and therefore to reduce the artificial compaction, it is recommended to use machines and agricultural equipment fitted with tracks or tires higher than the standard ones and with low tire inflation pressures (radial tires) (*Ziyaee and Roshani, 2012*). As the vertical contact pressure is distributed over the contact area unevenly, the vertical resultant reaction force tends to shift toward the leading edge (*El-Sayegh et al, 2018*). One of the approaches to reduce the risk of soil compaction is to reduce tire pressure on soil either by decreasing axle load and/or increasing the contact area of wheels on the soil (*Kenarsari et al, 2017*).

Studying the tire-soil interaction in agricultural soil is important because the vertical deformation of soil (as a deformable material) is sometimes larger than tire deflection (*Farhadi et al, 2018*). Soil-tire interaction is complex and difficult to quantify by direct measurements and also by modeling.

Knowledge of stress distribution in the soil is important for understanding soil compaction due to vehicle traffic (*Keller et al, 2018*). To obtain a precise definition of the extent of compacted layers of soil, it is important to determine its vertical and horizontal spatial distribution (*Lamandé and Schjønning, 2011*). For example, it was found that in coarse-textured soils, wheel load gives stresses distributed in vertical direction, while in fine-textured soils, stress distribution would be multidirectional (*Shah et al, 2016*). Understanding the stresses at the soil–tire interface would provide insight into the current state of tire traction development, data for soil–tire interface discrete and finite element models, and information for future tire designs (*Roth and Darr, 2011*).

MATERIALS AND METHODS

Experimental research was carried out at the National Research - Development Institute for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest.

Initial characterization of the tested plot of soil resulted in the following characteristics: the upper layer of soil (0-20 cm deep) is loamy clay with glomerular rugged structure, medium and fine texture, moderately plastic and adhesive, 2.49 g/cm^3 density, 1.22 g/cm^3 bulk density and 51 % total porosity; between 20-35 cm deep, the soil is clayey loam, with high angular glomerular structure and fine texture, is moderately compact, plastic and adhesive, with total porosity of 46 %; between 35-80 cm the soil is clayey loam, with medium prismatic structure and fine texture, compact, plastic, adhesive and dry, 2.69 g/cm^3 density, 1.75 g/cm^3 bulk density and 36 % total porosity.

At the time of experiments, the plot of soil was cultivated with red basil. It was tested the pressure distribution under the left front wheel of the Universal 445 tractor (Fig. 1), which is a small agricultural tractor equipped with a 33 kW engine. On the front axle, the tires are type Danubiana Superfront Tractor, size 6.00-16, profile F-2.

The weight of the Universal 445 tractor, determined by the electronic weighing platform type RW-10PRF, was 2041 kg, of which 700 kg were distributed on the front axle (350 kg or 3.43 kN on each front wheel) and 1341 kg on the rear axle (670.5 kg or 6.57 kN on each rear wheel).

Fig. 1 – Universal 445 Romanian tractor

The pressure at the interface between the agricultural soil and the front wheel of the tractor and the sizes of contact area were established by interpolating between the two elements a Tekscan Industrial Sensing sensor for measuring the pressure distribution (sensor size: 600 x 500 mm).

After calibration, the pressure sensor was coupled to the VersaTek Handle electronic data acquisition system (Fig. 2) and to a laptop.

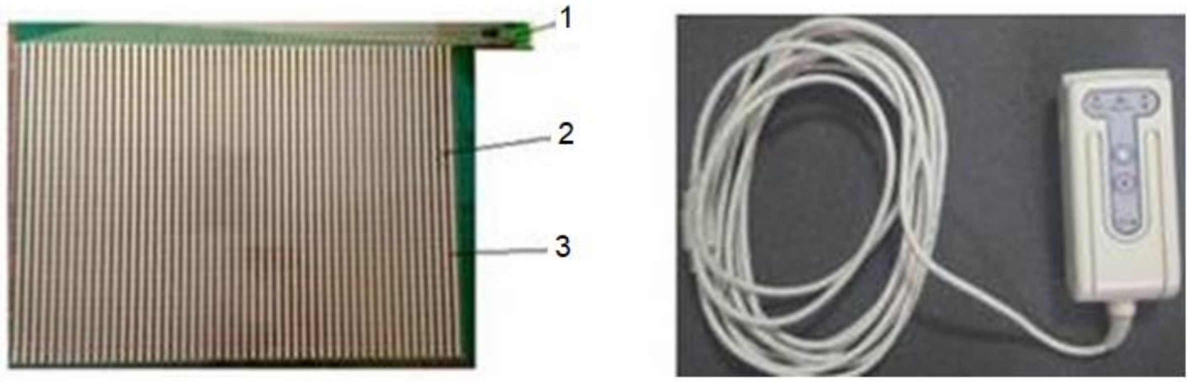


Fig. 2 – Tekscan pressure sensor and VersaTek Handle data acquisition system
1 – connection to the data acquisition system; 2 – sensitive elements;
3 – connecting threads between sensitive elements

Data acquisition was done in the I-Scan software, which displays the 2D and 3D pressure distribution in the contact area, as well as the values and variations in time of some parameters such as contact area, contact pressure, maximum pressure, force on the soil, etc.

During the experiments, tire inflation pressure values were varied five times and measured with the aid of the compressor and the pressure gauge: 100 kPa, 150 kPa, 200 kPa, 250 kPa and 300 kPa.

Fig. 3 – Variation of tire inflation pressure

Figure 4 shows the under-wheel placing of the mesh-type pressure sensor and the profile of the front tire of the U445 tractor at the minimum tested tire inflation pressure of 100 kPa.

Fig. 4 – Front tire at minimum inflation pressure (100 kPa)

RESULTS

The experimental data for both the input and output parameters monitored and analyzed are presented in Table 1.

Table 1

Compaction characteristics under the front wheel of U445 tractor

Wheel load Q [kN]	Tire inflation pressure p_i [kPa]	Size of contact area A [m^2]	Contact pressure p_c [kPa]	Footprint length l_c [m]	Footprint width l_w [m]
3.43	100	0.0349	98	0.241	0.179
	150	0.0314	109	0.214	0.170
	200	0.0298	115	0.246	0.161
	250	0.0290	118	0.223	0.165
	300	0.0252	136	0.212	0.162

As it can be seen from Table 1, by varying the tire inflation pressure from 100 kPa to 300 kPa, contact areas ranging from 0.0252 - 0.0349 m^2 were obtained, with the corresponding contact pressures varying between 98 kPa and 136 kPa.

Studies in the literature mention that the agricultural soil is compacted if the contact pressure exceeds 85 kPa. Considering that, it can be said that in all tested situations, compaction would mainly affect the arable layer of soil, but its negative effects can usually be alleviated by moldboard or chisel plowing.

However, repeated passes of the tractor on the same traffic lanes would intensify the effects of compaction, and stresses could affect the subsoil. Subsoil compaction persists for longer periods and the compacted layers are difficult to alleviate, resulting in increased fuel consumption and reduced crop yields.

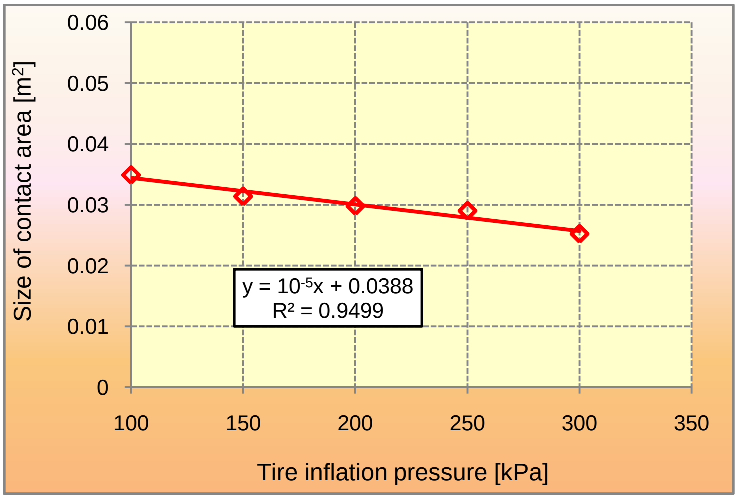


Fig. 6 – Influence of tire inflation pressure on the contact area of the U445 tractor

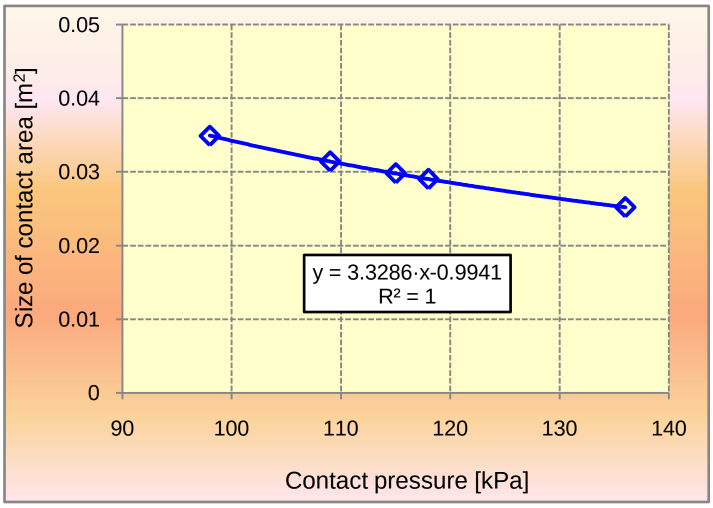


Fig. 7 – Influence of contact pressure on the contact area of the U445 tractor

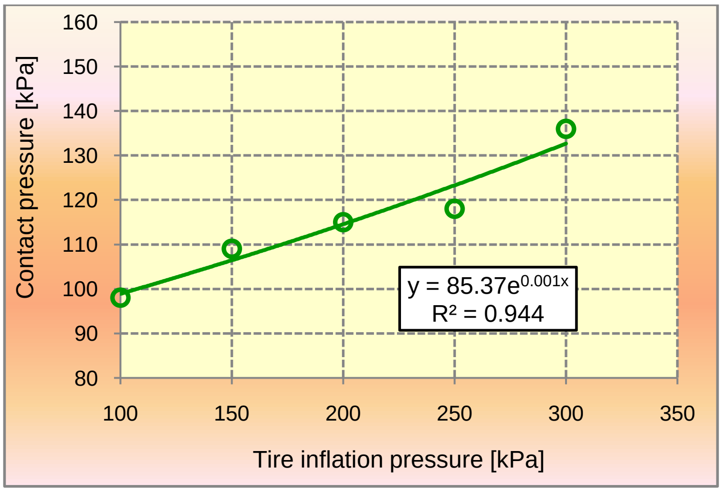
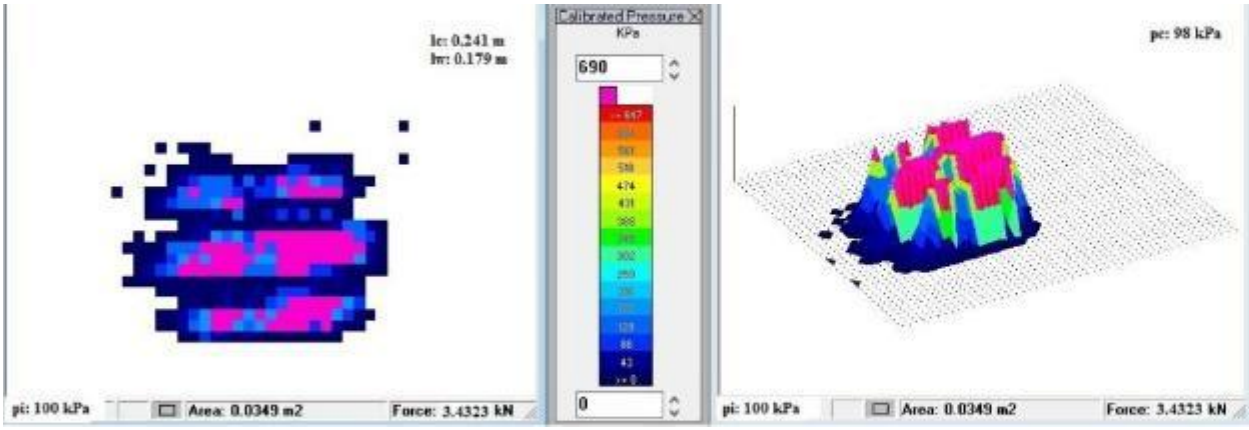


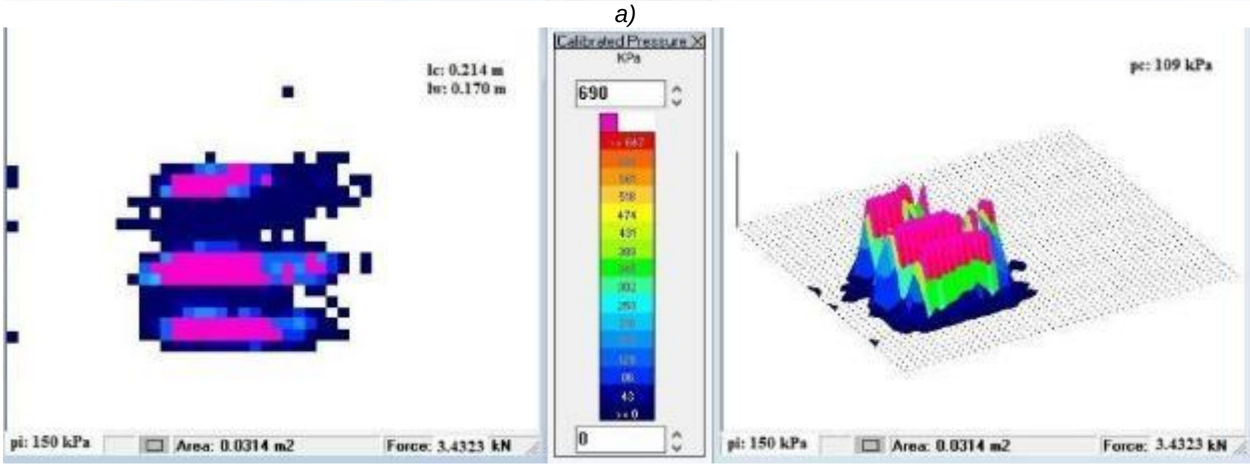
Fig. 8 – Influence of tire inflation pressure on the contact pressure of the U445 tractor

With the I-Scan software were recorded the 2-D and 3-D distribution maps of contact pressures at the tire-soil interface. It should be noted that the value of the contact pressure indicated by the data acquisition software represents an average of the pressure recorded on each sensitive element of the Tekscan Industrial Sensing Pressure Sensor which was in contact with the tire of the Universal 445 tractor during testing.

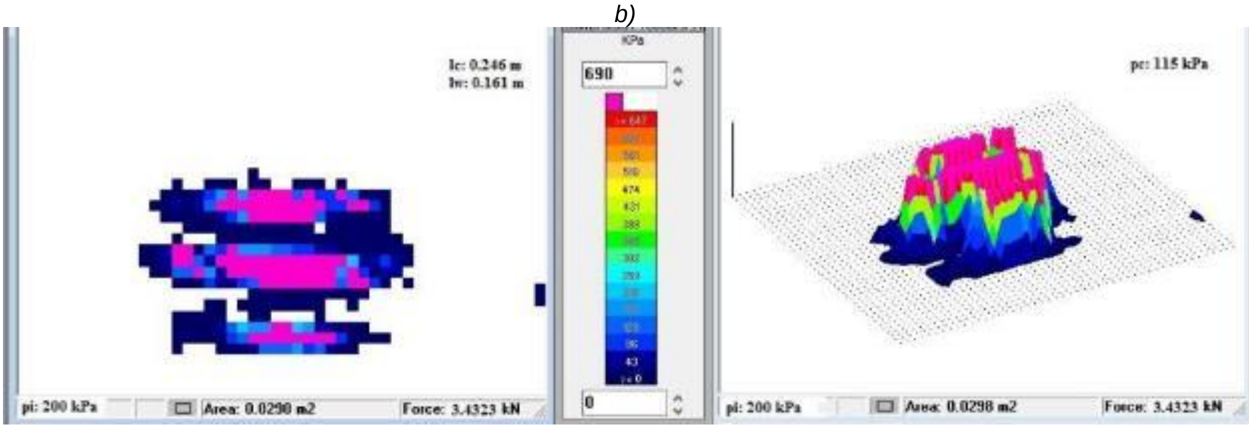
Thus, for the front wheel of the U445 tractor (wheel load Q = 3.43 kN), were obtained the pressure distributions in the contact area shown in Figure 9 and Figure 10.



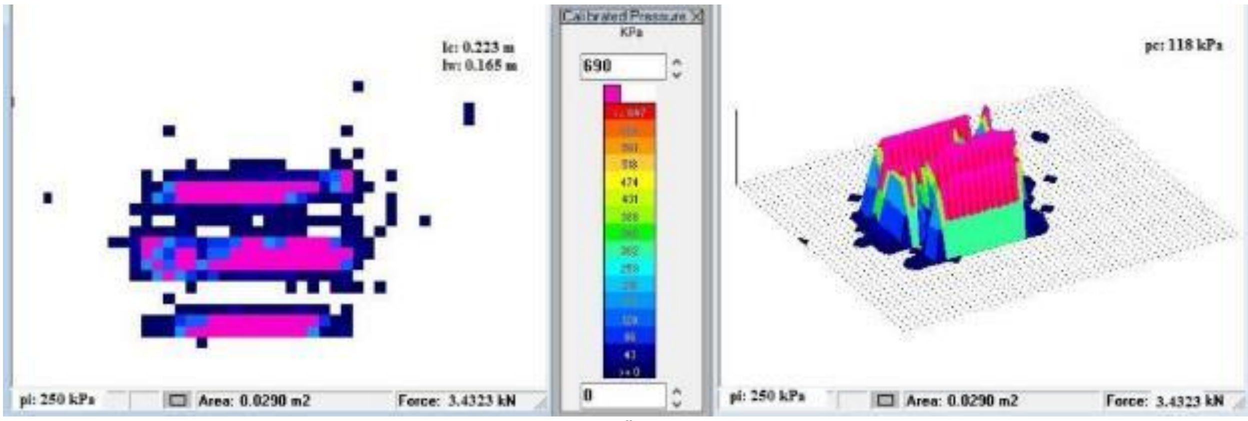
a)



b)

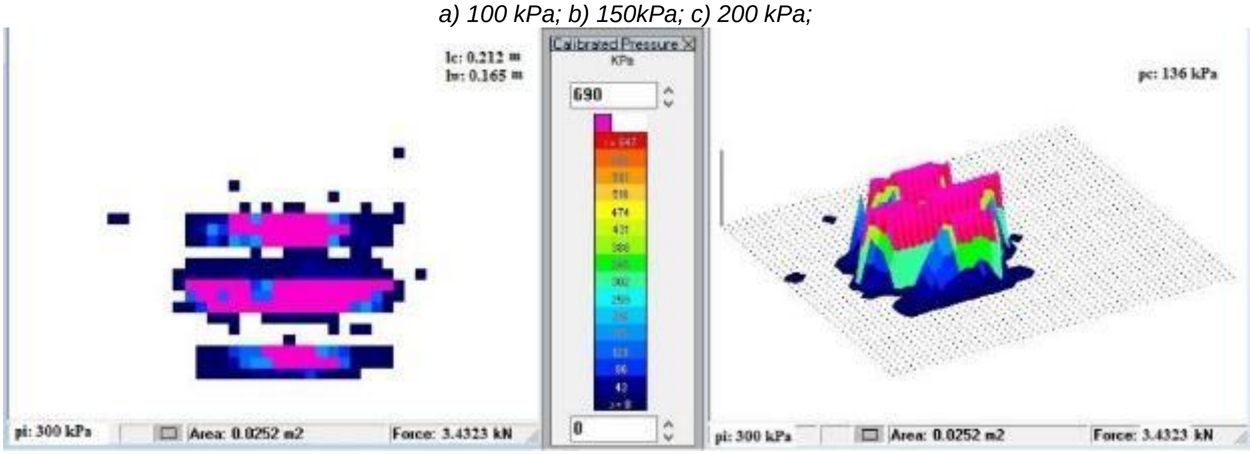


c)



d)

Fig. 9 – Maps of pressure distribution in the contact area, at 3.43 kN wheel load and tire inflation pressures:
a) 100 kPa; b) 150kPa; c) 200 kPa;



a)

Fig. 10 – Maps of pressure distribution in the contact area, at 3.43 kN wheel load and tire inflation pressures: *300kPa*

As it can be seen from Figure 9 and Figure 10, the shape and size of the tire-soil contact have changed in the tested conditions. Under the influence of tire pressure and wheel load, the tire deforms both longitudinally and transversally and the contact area tends to have a rectangular shape with rounded corners (more or less) and less towards an elliptical shape.

CONCLUSIONS

The shape and size of the tire-soil contact contour changed with tire inflation pressure which in turn affects the soil-tire interface pressures across the surface of the tire. The benefits of low inflation pressure of farm tractor tires may include decreased soil-tire interface pressures, increased tire performance, and decreased soil compaction and a smoother ride.

Compaction in the plow layer is largely related to contact pressure of the tire on the soil. Compaction below the plow layer is related to total wheel load. Considering that the agricultural soil is compacted if the contact pressure exceeds 85 kPa, it can be said that in all tested situations, compaction would mainly affect the upper soil layer, but its negative effects can usually be alleviated by moldboard or chisel plowing.

Proper tractor and machine set up and operation can minimize the effect of compaction, but improved management of agricultural works is the best solution for addressing compaction.

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