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STATIC PRESSURE DISTRIBUTION IN THE SOIL UNDER THE WHEEL OF A SPRAYING MACHINE

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Abstract: Current farming practices using heavy machinery are associated with soil compaction. The paper presents the results of tests aiming to determine in field the contact area and pressure distribution in the contact area between MSL machinery (for the precise application of the phytosanitary treatments in orchards) and the agricultural soil, respectively the determination in laboratory, on Hidropuls, of pressure distribution at 0 - 45 cm deep into the soil under the wheel of the MSL machine. The tank of the machine was loaded with 750 litres of water (wheel load 9.81 kN) and tire inflation pressures were 100, 150 and 200 kN.
Keywords: soil, compaction, pressure, mesh sensor, Hidropuls

INTRODUCTION

Several years ago, compaction would have been relatively shallow because farm equipment weighed less and many cover crops were grown in rotation (Sivarajan et al, 2018). Nowadays, the risk of soil compaction increases with the growth of farm operations and the drive for greater productivity causing farmers to use heavier machinery, with repeated passes, most often on soils with high moisture content. The heavier equipment used today for different agricultural practices increases the negative effects of artificial compaction both on agriculture and the environment. Preventive measures should be taken to avoid soil compaction because targeted amelioration of this type of degradation of soil is complex, costly and rarely long- lasting (Rücknagel et al, 2015).

Surface soil compaction takes place until a depth of 0.3 m or in the topsoil (soil tillage layer) and subsoil compaction takes place to depth under soil tillage layer. Soil compaction in cropping systems affects mostly the upper layer of soil (topsoil compaction) but it is also observed at certain depth (subsoil compaction) (Nawaz et al, 2013). The increase in the size and weight of agricultural machinery calls for accurate measurements of stresses applied by machinery in the tire-soil interface and in the soil profile (Lamande et al, 2014). During compaction, stress distribution is influenced by factors such as tire inflation pressure, wheel load, tire–soil contact area, lug, tire stiffness (bias or ply), single or dual tire and soil conditions, e.g. soil type, soil texture and soil strength (Schjonning et al, 2008). In order to predict the stress in soil due to wheel pressure, the stress has to be determined on the soil and on the contact area. The shape and area of the tire footprint and the magnitude and distribution of stresses distributions have practical implications on the topsoil compaction. These factors are also decisive for the pressures reaching the subsoil, as well as the potential of improving our understanding of contact pressures propagation to the soil (Cueto et al, 2016).

The effect of surface stress distribution on soil stress decreases with increasing depth. The vertical stress in the upper subsoil (down to 1 m depth) depends on both soil contact stress and wheel load (Nankali et al, 2012). Arvidsson and Keller (2007) found that tire inflation pressure has a great influence on contact pressure at the depth of 100 mm, but has a very low influence on the subsoil stresses (at 300 mm and deeper). When doubling the wheel load, the contact area increases by 30-40%, while at the doubling of the tire inflation pressure, the contact area drops by 70-80% (Ekinci and Çarman, 2011). Way and Kishimoto (2004) have shown that the stress in the contact area is not uniformly distributed and the maximum stress may be many times greater than tire inflation pressure. Most of the contact pressures researches were done in experimental conditions, because in field conditions, is difficult to measure and maintain the experimental parameters during testing.

During agricultural works, using higher tire inflation pressure results in smaller footprint area, soil deformation increases and the pressure is distributed deeper into the soil (in this case, deep loosening is needed to alleviate the compaction). Using lower tire inflation pressure, tire deformation increases, footprint area increases, contact pressure decreases, soil deformation are smaller and the pressure is transmitted to shallower depths (Ungureanu et al, 2018; Kenarsari et al, 2017).

Quantitative understanding of stress transmission and deformation processes in arable soils remains limited. Yet such knowledge is essential for better predictions of effects of soil management practices such as agricultural field traffic on soil functioning (Keller et al, 2013). Strategies for prevention of soil compaction often rely on simulation models that are able to calculate stress propagation in soil profile for certain mechanical loading (agricultural machinery) and soil conditions (e.g. soil moisture), and may help farmers and advisors in planning and making decisions about specific traffic situations in the field (Keller and Lamande, 2010).

MATERIAL AND METHOD

A. In the first set of tests, carried out in the field, were determined the size of contact area and the distribution of contact pressure under the wheel of MSL spraying machine for precise application of the phytosanitary treatments in orchards. The tire is Danubiana Superfront Tractor, size 6.00-16, profile F-2. The total weight of the machinery with empty tank is 4.90 kN (2.45 kN wheel load). The tank was filled at with 750 litres of tap water litres (maximum capacity is 1000 litres) and then the load on each wheel was measured, resulting in a total of 9.81 kN wheel load. Tire inflation pressure varied to 100, 150 and 200 kPa. Contact pressure and the size of contact area were measured by mesh-type pressure sensor Tekscan Industrial Sensing coupled to the VersaTek Handle electronic data acquisition system (Figure 1) and to a laptop.

Figure 1 – Field testing of the MSL spraying machine

B. The second set of tests was conducted in laboratory conditions, using a complex testing system that works in simulated and accelerated regime, Hidropuls type (Figure 2), which can simulate the static pressure at compression of the tires on the soil (stationary machinery). A container made of reinforced sheet with thickness of 3 mm was filled with soil (Figure 3).

Figure 2 - Installation for testing in simulated and accelerated regime, Hidropuls type

Figure 3 - Container filled with soil

Eight sensors for force measurement, Flexi Force Tekscan type W-B201-L (Figure 4) with the maximum domain of 10 N / 50.24 mm^2 and the diameter of contact button of 0.8 cm, were mounted in the container at depths of 5, 10, 15, 20, 30, 35, 40 and 45 cm. The connection between the laptop and force measurement sensors was achieved through an adaptation module, formed by amplifiers and analog-to-digital converter, coupled to a serial interface 4RS232 to coupling view (USB), an adaptation module (acquisition system) and laptop. A hydraulic cylinder with a force of 10 kN, close to the wheel load determined in field testing and some intermediate devices in the Hidropuls (Figure 5) were used to simulate the static compression pressure of the MSL wheel on the soil.

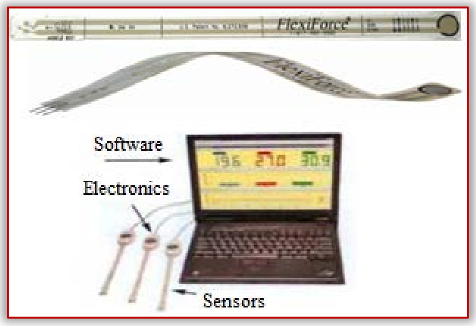

Figure 4 – Flexi Force Tekscan type W-B201-L sensor

Figure 5 – Stand for static compression pressure

RESULTS

The experimental data obtained from field testing of the MSL spraying machine are given in Table 1.

Table 1. Compaction characteristics under the wheel of MSL machinery in field testing

Wheel load Q [kN]	Tire inflation pressure p_i [kPa]	Size of contact area A [m^2]	Contact pressure p_c [kPa]
9.81	100	0.0619	159
	150	0.0546	180
	200	0.0539	182

Figure 6 shows the mapping of pressure distribution in the footprints obtained in field testing. It can be seen that at soil surface, for 9.81 kN wheel load and tire pressure ranging from 100 - 200 kPa, were obtained contact areas between 0.0539 - 0.0619 m^2 and the contact pressure ranged between 159 - 182 kPa.

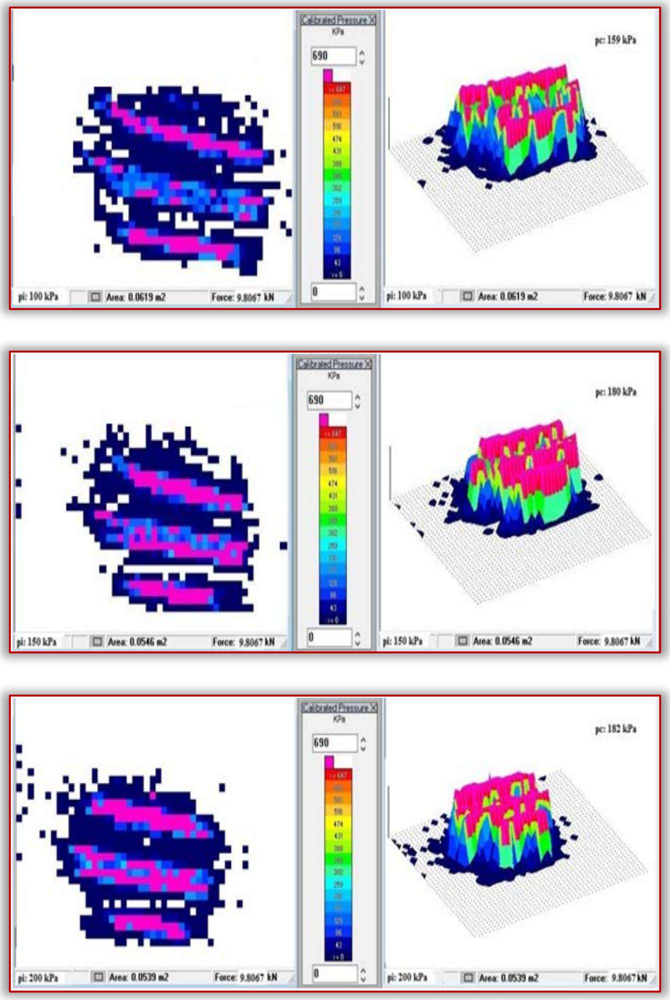

Figure 6 – Field mapping of pressure distribution in the footprint between tire and soil

The shape of footprint tends to be rectangular at 100 kPa wheel load, but with increasing tire inflation pressure, it changes into an elliptical shape. Also, the maximum contact pressure values are recorded close to the tire's edges.

Referring to the results obtained in the second set of tests, pressure distribution was determined at eight soil depths where the force sensors were applied, in the direction of action of the compressing force (vertical direction). At each tire inflation pressure, three replication tests were made. Vertical stresses measured at each tire inflation pressure for one of the replicate measurements are presented next. In Table 2, the size of contact area at soil surface was recorded during field testing, using the mesh-type pressure sensor Flexi Force Tekscan. For depths between 5 – 45 cm, the size of contact area reffers to the surface of FlexiForce sensor in contact with the soil, which was computed as: $S = \pi \cdot R^2 = 3.14 \cdot 0.16 = 0.5024\ cm^2$.

To simulate the pressure applied by the wheel of the MSL machine, for each tire inflation pressure, a compressive force was progressively applied to the wheel by a hydraulic cylinder until it reached the value determined in real conditions (by weighing the machine after filling the tank with 750 litres of water) and determining the distribution on axles and on the wheels), when the forces were measured at each of the 8 depths using the Flexi Force Tekscan W-B201-L sensors. Thus, at tire inflation pressure of 100 kPa, the duration of load was 33.5 seconds, until the compressive force of 9842 N was reached; at tire inflation pressure of 150 kPa, the duration of load was 33.3 seconds, until the compressive force of 9828 N was reached, respectively at tire inflation pressure of 200 kPa, the duration of load was 39.7 seconds, until the compressive force of 9810 N was reached.

Table 2. Laboratory testing of static compression for the MSL spraying machine

Sensor no.	Depth of sensor [cm]	Compressing force [N]	Size of contact area [cm^2]	Presssure in the soil [N/cm^2]
Tire inflation pressure 100 kPa				
-	0	9842	619	15.9
1	5	19.3633	0.5024	38.5416
2	10	13.8288	0.5024	27.5255
3	15	19.7474	0.5024	39.3031
4	20	5.7194	0.5024	11.3842
5	30	10.3005	0.5024	20.5026
6	35	10.1156	0.5024	20.1346
7	40	10.8269	0.5024	21.5504
8	45	11.7232	0.5024	23.3344
Tire inflation pressure 150 kPa				
-	0	9828	546	18
1	5	23.2473	0.5024	46.2725
2	10	15.1613	0.5024	30.1777
3	15	22.0238	0.5024	43.8372
4	20	5.6389	0.5024	11.2240
5	30	10.1873	0.5024	20.2773
6	35	9.8149	0.5024	19.5360
7	40	10.9587	0.5024	21.8127
8	45	11.4109	0.5024	22.7128
Tire inflation pressure 200 kPa				
-	0	9810	539	18.2
1	5	23.7458	0.5024	47.2647
2	10	15.5888	0.5024	31.0287
3	15	22.9301	0.5024	45.6411
4	20	5.7703	0.5024	11.4855
5	30	10.4681	0.5024	20.8362
6	35	10.0451	0.5024	19.9942
7	40	10.7853	0.5024	21.4676
8	45	10.8004	0.5024	21.4976

Variation of pressure with soil depth under the wheel of MSL spraying machine, obtained in laboratory testing, is presented in Figure 7.

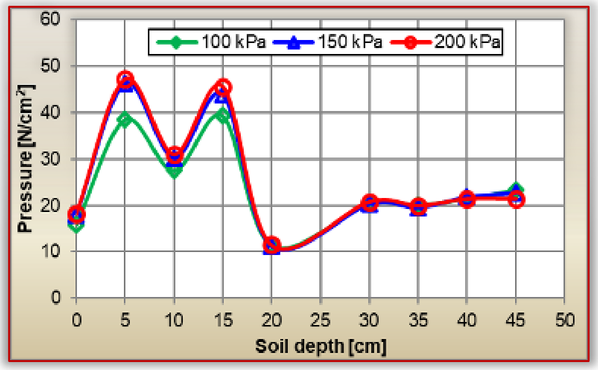

Figure 7 - Variation of pressure with soil depth, under the wheel of the MSL machine, in laboratory conditions

It can be seen that for the tested tire inflation pressures, the variation curves follow a similar trend. The pressure applied to the soil tends to decrease suddenly as soil depth increases to 10 cm, and then rises to a depth of 15 cm, after which they follow a sharp downward curve to a depth of 30 cm, and then there is a slight increase at the maximum tested depth of 45 cm.

CONCLUSIONS

Soil compaction mainly depends on the compression applied on the soil surface by agricultural machines. Hence, contact pressure at the soil-machine interface can be measured as a good indicator of the potential compaction on agricultural soils.

We conclude that a traffic event in the tested conditions is likely to induce serious impacts on soil properties and functions to a depth of least 45 cm. Our results show that at 45 cm soil depth, wheel loads of 9.81 kN may induce vertical stresses around 233, 227 and 215 kPa, for tire inflation pressures of 100, 150 respectively 200 kPa. Maximum stresses in the tire-soil contact area were as high as 182 kPa.

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