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IMPACT OF THE REPEATED TRACTOR PASSES ON SOME PHYSICAL PROPERTIES OF SILTY LOAM SOIL

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SUMMARY

The aim of this paper was to quantify soil compaction induced by tractor traffic on untilled wet silty loam soil (Mollic Fluvisol). Changes in penetration resistance, bulk density and total porosity were measured for detecting the soil compaction. Treatments include ten passes of a four-wheel drive tractor with the engine power of 54.0 kW and weight of 3560 kg (1580 kg on the front axle and 1980 kg on the rear axle, 2.41 m distance between axles). The tyres on the tractor were cross-ply, front 11.2-24 and rear 16.9-30, with the inflation pressure of 160 kPa and 100 kPa, respectively. The speed of tractor during passes over experimental plots was 5.0 km h^{-1}. In comparison to control, each tractor pass induced an increase in soil penetration resistance at all depths, and the average increment ratios, determined as the average of all layers, were 9.8, 18.5 and 26.1% after one, five and ten passes, respectively. The bulk density also increased with number of tractor passes, but with less percentage increasing. The increment ratios comparison to the control were 3.6, 9.5 and 12.9% after one, five and ten passes, respectively. The total porosity decreased with the number of passes, and the decrement ratios were 4.5, 16.5 and 20.8% after one, five and ten passes, respectively.

Key-words: soil compaction, tyres, penetration resistance, bulk density, total porosity

INTRODUCTION

Soil compaction caused by machinery traffic in agriculture is a well recognised problem in many parts of the world as one of the most important factor responsible for soil physical degradation and has important consequences on crop production and environment (Soane and van Ouwerkerk, 1994; Keller and Arvidsson, 2004). It is estimated to be responsible for the degradation of an area of 68 million hectares worldwide (Flowers and Lal, 1998), of which 33 million hectares were located in Europe (van den Akker and Canarache, 2001). Soil physical properties represent a group of properties having a substantial impact on the different physical-chemical and biological processes in soil and hence they should be kept optimal (Lal, 1991). Soil compaction induced by vehicle traffic has adverse effects on a number of key soil propreties such as bulk density, mechanical impedance, porosity and hydraulic conductivity (Radford et al., 2000; Hamza and Anderson, 2005). It may decrease soil porosity and change pore shape and size distribution (Pagliai et al., 2003), decrease aeration (Czyz et al., 2001), decrease water infiltration and increase preferential flow (Kulli et al., 2003), including increase surface runoff resulting in soil erosion (Feige and Horn, 2000).

From a management point of view, it is useful to identify the process responsible for changes in soil physical properties so that farming systems and practices can be adopted to either ameliorate, avoid or minimise soil compaction problems and reduce the subsequent risk of poor agronomic performance (Chan et al., 2006). Trends in machinery development over the last few decades, introducing machines of a greater size and weight, have increased the problems of finding tyres and inflation pressures, capable of keeping soil compaction low (Pagliai et al., 2003). In order to reduce the

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risk of soil compaction, a vehicle ground contact stress should be as low as possible (Servadio et al., 2005). The risk of subsoil compaction may be considerable for soils with high moisture content under vehicles with high axle loads (Håkansson and Reeder, 1994). Other important factors, apart from axle load and moisture content, are tyre dimensions, contact stresses, number of passes, soil strength and stress history (Hadas, 1994). Intensity of trafficking (number of passes) plays an important role in soil compaction because deformations can increase with the number of passes (Bakker and Davis, 1995). Experimental findings have shown that all soil parameters become less favorable after the tractor passage (Chygarev and Lodyata, 2000) and subsoil compaction may be induced by repeated traffic with low axle load and the effects can persist for a very long time (Balbuena et al., 2000).

In order to evaluate the impact of traffic on soil it is necessary to quantify modifications to soil structure (Pagliai et al., 2003), which can be measured by studying the changes in one or more soil parameters such as cone penetration resistance, bulk density, porosity, hydraulic conductivity and air permeability. Many researches have used these parameters to measure vehicle-soil interaction (Servadio et al., 2005). Many researches have used the cone penetrometer because it provides a rapid, simple and economical means of indicating soil compaction (Perumpral, 1987). According to Campbell (1994) the measurement of soil bulk density is an important strategy when quantifying changes in soil compactness due to vehicle traffic, while Pagliai et al. (2003) claimed that porosity is the best indicator of soil structure condition because it is the size, shape and continuity of pores that affect many of the important processes in soils. So, for soil compaction evaluating in this experiment cone penetration resistance, bulk density and total porosity were measured before and immediately after the application of a known compaction force to a wet silty loam soil. The aim of this study was to determine the changes in these soil physical properties as a consequence of the compacting effects of four wheel drive tractor in the medium power range, commonly used by Croatian farmers.

MATERIAL AND METHODS

The experiment was carried out in October 2008 at Tractor Testing Station of Agricultural Engineering Department, Faculty of Agriculture, University of Zagreb, Croatia (latitude 45ı ı 3’N, longitude 16ı 02’E, altitude 152 m). The climate is semihumid with average annual precipitation of 852.2 mm and average annual temperature of 10.7 °C. The soil at the site was classified as Mollic Fluvisol (Humic, Hypereutric, Siltic), according to WRB clasification (IUSS Working group WRB, 2006), and by its texture belongs to the silty loam. Basic soil physical properties are shown in Table 1.

Table 1. Basic soil physical properties

Tablica 1. Osnovna fizikalna svojstva tla

Soil properties	Depth (cm)			
	0 - 10	10 - 20	20 - 30	30 - 40
Particle size distribution (%)				
Clay (<0.002 mm)	8.5	9.8	13.2	14.3
Silt (0.06-0.002 mm)	69.1	69.2	67.3	68.8
Sand (2.0 –0.06 mm)	22.4	21.0	19.5	16.9
Texture	Silty loam	Silty loam	Silty loam	Silty loam
Consistency limits (%)				
Liquid limit	26.9	27.7	29.8	29.6
Plastic limit	19.3	20.8	22.1	22.4
Plasticity index	7.6	6.9	7.7	7.2
Specific gravity (Mg m^{-3})	2.58	2.67	2.71	2.70

According to the basic chemical properties data presented in Table 2, this soil has pH neutral and is moderately rich in physiological nutrients, phosphorus and potassium. It also belongs to a group of soil with moderately level of organic matter. This experimental field has been untilled and only glyphosate was applied to remove grass and weeds without traffic over plots for many years. The soil water contents at the time of tractor traffic were 40.4%, 39.3%, 39.5% and 40.1% on dry mass basis in the layers 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm, respectively. In all layers soil water content was about 89% of field capacity.

Table 2. Basic soil chemical properties

Tablica 2. Osnovna kemijska svojstva tla

Depth (cm)	pH		Organic matter (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)
	Water	MKCl			
0 – 10	7.35	6.81	3.9	17.5	21.5
10 – 20	7.36	6.83	3.8	18.2	23.0
20 – 30	7.34	6.57	1.5	11.3	16.2
30 – 40	7.37	6.74	0.9	7.6	11.8

The experimental field consisted of 3 plots with dimensions of 25 m in length and 3 m in width each, and organized as randomized blocks with three replications and between plots were buffer zones of 3 m. Ten tractor passes were in the same tracks in each plot traffic frequency. A four-wheel drive tractor Torpedo TD 7506 A with the engine power of 54.0 kW and weight of 3560 kg (1580 kg on the front axle and 1980 kg on the rear axle, 2.41 m distance between axles) was used in this experiment. The tyres on the tractor were cross-ply, front 11.2-24 and rear 16.9-30. The inflation pressure of front and rear tyres was 160 kPa and 100 kPa, respectively. The tractor speed during passes over experimental plots was 5.0 km h^{-1}. The contact area between tyre and soil was 0.087 m^2 and 0.163 m^2 (estimated according to McKyes, 1985), whereas ground pressure was 91 kPa and 61 kPa at front and rear tyre, respectively. The average ground pressure was estimated as the total axle load divided by the contact area between tyre and soil for both tyres on the axle.

Aiming to determine soil physical properties, undisturbed soil samples were taken before tractor passes as control and immediately after each tractor pass from centre line of tyre tracks by sampling cylinders of 100 cm^3 volume by Kopecky method at soil layers 0-10, 10-20, 20-30 and 30-40 cm in three replicates per each plot and layer. Soil physical properties were determined as follows: soil texture analysis was carried out by pipette method whereas samples were prepared by Na-pyrophosphate, bulk density by Kopecky's cylinders, total porosity was calculated from bulk density and particles density, and soil moisture content was determined by gravimetric method. Soil penetration resistance was measured in each plot in centre line of tyre tracks in ten replicates using a mechanical cone penetrometer till 40 cm depth with 1 cm reading intervals. This penetrometer has a circular cone with an apex angle of 30° and base diameter of 12.83 mm (0.505 in.) according to ASAE Standard (ASAE, 1993). As for soil chemical properties, soil reaction was determined with pH meter, physiological active phosphorus and potassium by Al-method, and organic matter content by bichromath Tjurin method.

Statistical analysis was done applying the analysis of variance (ANOVA). The F-test was used to determine significant effects of tractor passes on different soil physical properties, and the least significant difference test was used to separate means at a 1% level of significance.

RESULTS AND DISCUSSION

Mean values of soil penetration resistance at various depths, from 0 to 40 cm in increments of 5 cm, are showed in Figure 1. It is evident that soil penetration resistance without tractor traffic was increased with soil depth, especially below 30 cm. According to Botta et al. (2006), this was expected because some resistance depends on the weight of soil above the depth of measurement. Lateral forces on the penetrometer cone increase with depth increase. Therefore, more force is needed for the cone to displace soil. In comparison to control, each tractor pass induced an increase in soil penetration resistance at all depths. After first pass the increase of penetration resistance was significant till 30 cm. The second pass caused significant increase till 25 cm in comparison with the first one. The third pass caused significant increase only at 30 cm depth in comparison with the second one. However there were no significant differences between the fifth and the third pass. After ten passes penetration resistance was increased at all depth in comparison with the fifth pass. The average increment ratios of penetration resistance after tractor traffic with respect to the control were 9.8, 18.5 and 26.1% after one, five and ten passes, respectively. The increment ratios in the upper layers (0–20 cm depth) were 24.9, 42.7 and 58.3%, whereas the increment ratios in the deeper layers (20–40 cm depth) were 3.6, 8.4 and 12.8% after one, five and ten passes of the tractor, respectively.

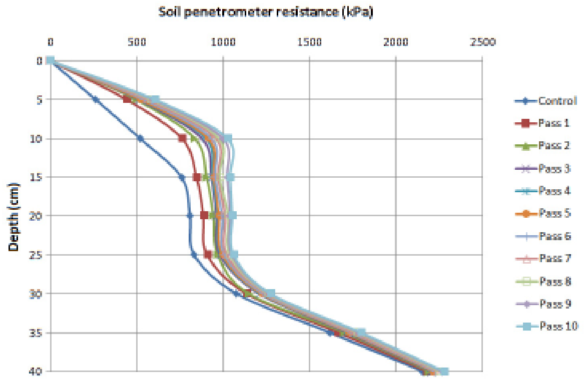

Figure 1. Average soil penetrometer resistance (kPa) after tractor passes

Slika 1. Prosječni penetrometarski otpor tla (kPa) nakon prohoda traktora

Mean values of bulk density at various depths are reported in Table 3. Bulk density like penetration resistance increased with number of passes, but with much less percentage increase. After the first pass bulk density increased on the average 3.6% in comparison to control, but significant difference was only in surface layer (0-10 cm). After the second pass bulk density increased additional 2.7%, and differences were significant in comparison to the control in all layers. The significant increase after five passes in comparison to soil condition after the second pass was again only in surface layer. Additional five passes significantly increased bulk density till 30 cm depth. The increment ratios of bulk density values, determined as the average of all layers, after tractor passes with respect to the control were 9.5 and 12.9% after five and ten passes, respectively. The increment ratios in the upper layers (0–20 cm depth) were 5.3, 13.1 and 18.4%, while the increment ratios in the deeper layers (20–40 cm depth) were 2.1, 6.7 and 8.1% after one, five and ten passes of the tractor, respectively. These results indicated that the effect of traffic on soil bulk density was much obvious in the top layer.

Figure 2. Soil surface before and after ten tractor passes

Slika 2. Površina tla prije i nakon deset prohoda traktora

Table 3. Average soil bulk density (Mg m^{-3}) after tractor passes

Tablica 3. Prosječna volumna gustoća tla (Mg m^{-3}) nakon prohoda traktora

Depth (cm)	Control	Tractor passes					
		1	2	3	4	5	10
0 - 10	1.10 a	1.18 b	1.23 b	1.26 c	1.28 c	1.29 c	1.38 d
10 - 20	1.34 a	1.39 a	1.43 b	1.45 b	1.46 b	1.47 b	1.51 c
20 - 30	1.38 a	1.41 a	1.44 b	1.46 b	1.47 b	1.49 b	1.52 c
30 - 40	1.45 a	1.48 a	1.51 b	1.52 b	1.53 b	1.53 b	1.54 b

Values followed by the same letter within each column are not significantly different ($P<0.01$)

Vrijednosti označene istim slovima unutar kolone nisu signifikantno različite ($P<0,01$)

Mean values of total porosity before and after tractor traffic are showed in Table 4. It is evident that total porosity decreased with the number of passes, but the tractor traffic caused a significant reduction of total porosity after one pass in comparison to the control only in the surface layer (0–10 cm). After the second pass total porosity decreased significantly in comparison to the control in all layers. Additional three passes significantly decrease total porosity only in surface layer, while ten tractor passes significantly decrease it in all layers. The decrement ratios of total porosity, determined as the average of all layers, after tractor passes with respect to the control were 4.5, 16.5 and 20.8% after one, five and ten passes, respectively. The decrement ratios in the upper layers (0–20 cm depth) were 6.1, 16.2 and 22.3%, while the decrement ratios in the deeper layers (20–40 cm depth) were 2.8, 14.6 and 19.0% after one, five and ten passes of the tractor, respectively.

Table 4. Average soil total porosity (%) after tractor passes

Tablica 4. Prosječni ukupni porozitet tla (%) nakon prohoda traktora

Depth (cm)	Control	Tractor passes					
		1	2	3	4	5	10
0 - 10	59.1 a	54.6 b	52.3 b	51.5 b	50.1 c	49.6 c	46.2 d
10 - 20	49.4 a	47.7 a	45.1 b	44.6 b	44.2 b	43.8 b	42.5 c
20 - 30	48.9 a	47.2 a	43.2 b	42.7 b	42.3 b	41.9 b	40.3 c
30 - 40	46.2 a	45.3 a	42.4 b	41.9 b	41.7 b	41.1 b	39.6 c

Values followed by the same letter within each column are not significantly different ($P<0.01$)

Vrijednosti označene istim slovima unutar kolone nisu signifikantno različite ($P<0.01$)

Similar results were obtained by some authors who investigated soil compaction by tractor tyres. Seker and Isildar (2000) reported that the number of tractor passes increased soil compaction and bulk density and decreased total porosity. The detrimental effects of soil compaction caused by traffic increased bulk density and decreased porosity being confirmed by Flowers and Lal (1998), Radford et al. (2000) and Richard et al. (2001). Balbuena et al. (2000) reported that ten passes significantly affected soil properties of the surface layer to 50 cm depth compared to one pass and no-traffic control treatments. According to Jorajuria and Draghi (2000), the critical number of passes was ten, beyond where advantages from the use of a light tractor were lost. Håkansson and Reeder (1994) also confirmed that a greater number of passes, even with a lighter vehicle, caused subsoil compaction. Marsili et al. (1998) reported that the decrease of soil porosity and the increase of penetration resistance following traffic of agricultural machinery were strongly correlated. On the other hand, results obtained by Tarawally et al. (2004) suggested that soil total porosity wasn't a good indicator of compaction effects. However, Green et al. (2003) stated that field traffic had significant effects on soil compaction and physical propertises in some soils and climates, whereas in others landscape and temporal variations were so strong that any effects of wheel tracks were relatively negligible.

CONCLUSION

Aiming to detect the soil compaction, changes in penetration resistance, bulk density and total porosity were measured before and after each of ten tractor passes. The results obtained in this experiment on silty loam soil showed that each tractor pass induced an increase in soil penetration resistance in all depths in comparison to the control, but the compacting effects were more significant in the upper layer (0-20 cm). Bulk density as a penetration resistance was also increased with the number of passes, but with much less in percentage, and contrary, total porosity decreased with the number of passes. Due to the results indicating that ten tractor pass influence significant increase of soil penetration resistance and bulk density and decrease of total porosity, it can be concluded that repeated tractor passes have great influence on soil physical properties.

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UTJECAJ PONAVLJANJA PROHODA TRAKTORA NA NEKA FIZIKALNA SVOJSTVA PRAŠKASTO-ILOVASTOGA TLA

SAŽETAK

Cilj ovoga rada bio je odrediti zbijanje tla prouzročeno kretanjem traktora po neobrađenome vlažnome praškasto-ilovastom tlu (Mollic Fluvisol). Za određivanje zbijenosti tla praćene su promjene u penetrometarskom otporu, volumnoj gustoći i ukupnome porozitetu tla. Postupci uključuju deset prohoda traktora s pogonom na sva četiri kotača, snage motora 54,0 kW i mase 3560 kg (1580 kg na prednjoj osovini i 1980 kg na stražnjoj osovini, međuosovinskoga razmaka 2,41 m). Na traktoru su bili dijagonalni pneumatici, sprijeda 11.2-24, a straga 16.9-30, s tlakom od 160 kPa i 100 kPa. Brzina kretanja traktora tijekom prohoda preko pokusnih parcela bila je 5,0 km h^{-1}. U usporedbi s početnim stanjem tla, svaki prohod traktora prouzročio je povećanje penetrometarskog otpora na svim dubinama, a prosječno povećanje, ako se računaju svi slojevi, bilo je 9,8, 18,5 i 26,1% nakon jednog, pet i deset prohoda. Volumna se gustoća također povećala nakon prohoda traktora, ali je povećanje u postocima bilo manje. Prosječno povećanje, u usporedbi s početnim stanjem, bilo je 3,6, 9,5 i 12,9% nakon jednog, pet i deset prohoda. Ukupni se porozitet tla smanjio nakon prohoda traktora, a prosječno je smanjenje iznosilo 4,5, 16,5 i 20,8% nakon jednog, pet i deset prohoda traktora.

Ključne riječi: zbijanje tla, pneumatici, penetrometarski otpor, volumna gustoća, ukupni porozitet

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