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Changes in soil density under influence of tractor wheel pressures

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Abstract: *Changes in soil density under influence of tractor wheel pressures.* The results of investigations on the effect of passages of two agricultural tractors MF255 and Ursus 1234 on changes in soil bulk density under the wheel track are analyzed in the paper. The carried out measurements showed that in spite of substantially higher tractor weight and the resulted axle loads, the compaction of particular soil profile layers under the wheels of tractor U1234 were lower than the soil compaction after passages of tractor MF255. The soil density found after passages of tractor MF255 was higher than the respective value for tractor U1234 by about 1 to 6%.

Key words: soil, density, wheel pressures

INTRODUCTION

The soil bulk density is among the soil properties that are most often used to characterize the field conditions. This parameter reflects the soil structure as a degree of "packing density of particles". When density increases, the soil particles are compressed and the volume of pores is reduced; their structure, arrangement and continuity are changed [Defossez and Richard 2002, Teepe et al. 2004]. The air-water relations change with compaction, influencing conditions of soil fauna and flora development. Under field conditions, these changes result most often from the pressure of agricultural outfits' wheels [Powałka 2005, Śnieg et al. 2008].

Soil density is regarded as one of more important factors of environment that influence the soil functions and conditions of plant growth and development. Optimal soil density for plants ranges to 1.51–1.53 $g \cdot cm^{-3}$ for sandy soils and from 1.41 to 1.46 $g \cdot cm^{-3}$ for heavy clayish soils [Sommer and Petelkau 1990].

The density values given above are not constant, since they depend on the action of remaining factors, e.g. moisture content. One can distinguish the notion of soil moisture content optimal for the plants, however, it can vary depending on the soil structure, especially on the structure of pores. Elongation of pores, that is characteristic for highly compacted soils, leads to reduction of water content in soil, resulted from limited storing ability.

The plant response to soil compaction is highly connected with dynamics of moisture content conditions during the vegetation period [Håkansson and Lipiec 2000]. The highest soil compaction occurs under conditions of increased soil moisture content, especially in heavy and clayish soils of high water capacity [Buliński and Niemczyk 2007]. Bearing capacity of the ground of small water content is higher than that at bigger water content. Defossez et al. [2003] think that besides soil moisture content, the tractive system characteristics of agricultural vehicles and its loading are the main factors that shape soil compaction intensity. According to Buliński et al. [2009], the soil state is highly influenced by field conditions during traffic, including type of soil, moisture content, plant rooting intensity and depth of the roots' reach. Dawidowski et al. [2001] and Canillas and Salokhe [2002] maintain that the wheel axle load, number of passages over the same track, state of soil during traffic, especially moisture content, significantly affect soil compaction in the zone of passage. It is evident from investigations of Grečenko [2003] that after from two to four wheel passages, the wheel – ground contact area and specific pressure values were close to the values that would occur on a hard surface. An increase in pressures is a natural result of the decreased tyre – ground contact area on more and more hard ground surface [Powałka 2005]. Way et al. [1998] found, that the values of stress created in soil under the wheel increased with an increase in tractor weight.

The undertaken investigations aimed at determination of the effect of traffic of two tractors that differed in weight and axle loading on the soil compacting by wheels.

MATERIAL AND METHODS

The investigations were carried out under field conditions on clayish sandy soil of the following grain composition: 47% (1–0.1 mm), 34% (0.1–0.02 mm), and 19% (<0.02 mm).

Prior to investigations the field was ploughed to a depth of 35 cm and left for about two weeks to be settled down naturally. The measuring lengths were selected randomly to limit the effect of soil variability. Outside the measuring lengths there were left places for tractor outfits' maneuvering and other operations connected with measurements.

During measurements the average soil moisture content in the profile 0––30 cm ranged from 8.9 to 10.4% by weight (mean 9.6%, $\sigma = 0.39$).

The soil was compacted with two agricultural tractors MF255 and Ursus 1234; their specification is presented in Table 1.

TABLE 1. Selected technical and exploitation parameters of tractors used in investigations

Item		Unit	Tractor	
			MF255	Ursus 1234
Weight		kg	2,342	5,853
Axle load	front	kN	8.68	23.58
	rear		14.30	33.84
Tyre size	front	inch	6.00-16	14.9-24
	rear		12.4-32	18.4 R34
Tyre width	front	m	0.165	0.378
	rear		0.315	0.467
Tyre diameter	front	m	0.735	1.265
	rear		1.360	1.645
Tyre inflation pressure	front	kPa	210	120
	rear		120	120

Selection of tractors for investigations resulted from differences in their mass (twofold difference) and axle load (almost threefold difference on front axle and twofold on rear axle). Condition of tractor tyres was good and their wear was insignificant.

The soil was compacted by making 1, 2, 4, and 8 passages of each tractor on the measuring length over the same track at constant speed 5 km·h^{-1} (±0.1). The soil density was measured in three randomly selected places after each tractor passage, however, different in each passage.

The soil bulk density under track was measured with the use of Eijelkelkamp probe for taking undisturbed samples; it was equipped with cylindrical containers of volume 100 cm^3 and reach of up to 30 cm, every 5 cm. These soil samples were used also for current determination of soil moisture content, by drying at temperature 105°C (weighing-and-drying method).

For each passage there was determined the tyre – soil contact area for front and rear tyres. Basing on average results obtained for tyres of both axles there were calculated the specific tyre pressures for a given passage and the total tractor pressures.

RESULTS OF INVESTIGATIONS

The results of soil density measurements on measuring lengths prior to compacting passages are characterized by a substantial scatter of values ($\sigma = 0.0933$) at particular depths of the profile.

One can find that soil samples taken from the same depth of measuring length, but from its different places are characterized by the range of scatter from about 1,170 to about 1,480 kg·m^{-3}. This situation should be regarded as typical for heavier soils after ploughing, where as a result of breaking ridge with a passive implement, under field surface there is a lot of bigger soil particles, that are strongly coupled together in natural way. The mean value of soil bulk density (1,331 kg·m^{-3}), determined for the entire profile and all measurement repetitions, is marked with a broken line on Figure 1.

The results of soil density measurements in the track of tractor MF255

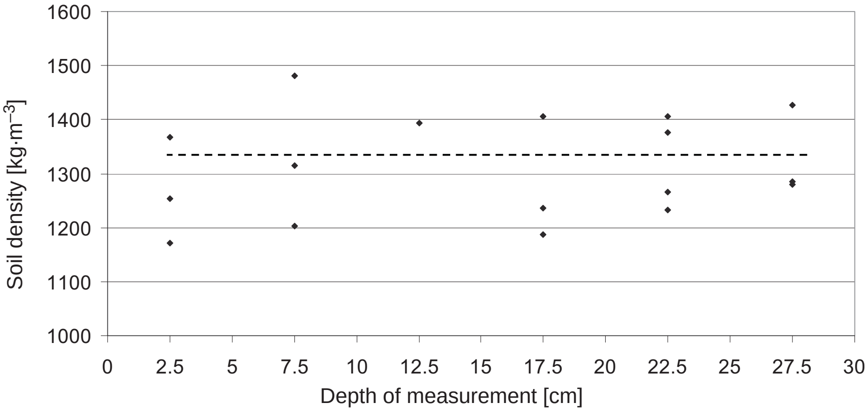

FIGURE 1. Bulk density of not compacted soil in profile 0–30 cm

passage are presented in Figure 2. It is evident that at all depths of profile the soil density increases with the number of passages, from 1,419 to 1,657 kg·m^{-3} in the surface layer of 2.5 cm (0–5 cm) and from 1,330 to 1,587 kg·m^{-3} in the deepest layer of 27.5 cm (25–30 cm). In relation to not compacted soil, tractor passages caused an increase in soil density from 39 to 62% in the surface layer (2.5 cm) and by 7–8% in the deepest layer (27.5 cm). These values decreased systematically with depth, while with an increase in number of passages this trend was opposite. In relation to the initial state (not compacted soil) a single passage increased the soil density from 7% (in the deepest layer) to 39% (in the surface layer), on the average by 21%. Changes in soil density after subsequent passages ranged from 14 to 47% (average 27%), after four passages from 17 to 53% (average 32%), after eight passages from 27 to 62% (average 42%).

Relative changes in soil density between subsequent passages ranged from 2.6 to 6.6%. Statistical analysis of the entire measuring material (Table 2) showed a statistically significant difference at confidence level 95% between mean values of soil density obtained after subsequent passages of tractors.

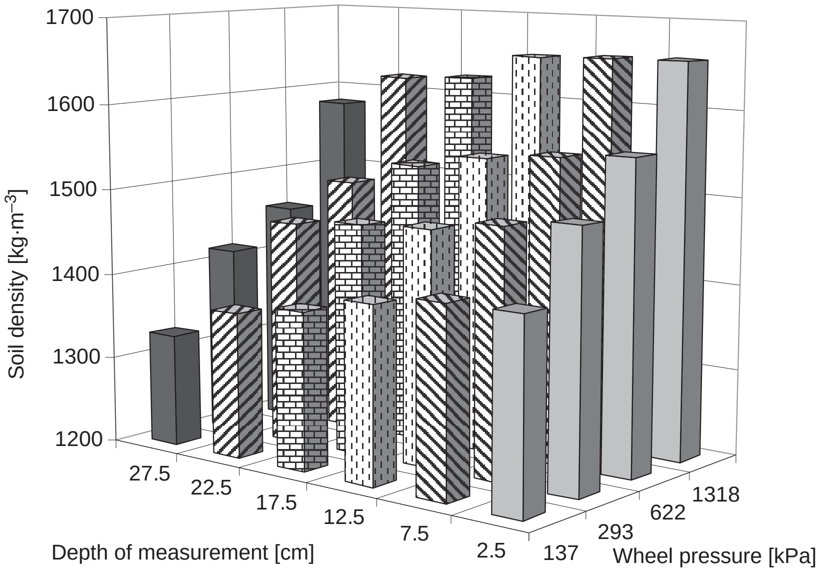

FIGURE 2. Changes in density of soil compacted with tractor MF255

TABLE 2. Analysis of variance for soil density after passages of tractor MF255

Source	Sum of squares	Df	Mean square	F-ratio	P-value
Between groups	189,597.0	3	63,198.9	58.44	0.0000
Within groups	21,629.7	20	1,081.48	×	×
Total (Corr.)	211,227.0	23	×	×	×

The results of analysis were confirmed with multiple range test by 95% Tukey HSD method, where the homogeneous groups from the viewpoint of investigated feature were determined (Table 3) and strong diversification of values for particular measuring variants was found.

The same investigations were executed for the heavier tractor U1234. Density measurements of soil compacted with tractor U1234 (Fig. 3) showed, that in spite of considerably bigger weight and the resulted axle loads, compaction of particular profile layers was lower than that after passages of tractor MF255. The mean soil density values in the layer

TABLE 3. Homogeneous groups and comparison between soil density mean values after passages of tractor MF255

Factor	Mean	Homogeneous Groups	Contrast	Difference	+/– Limits
137 kPa	1,387.17	non	137 – 293	–80.1667*	53.1603
			137 – 622	–135.833*	
			137 – 1,318	–244.333*	
293 kPa	1,467.33	non	293 – 622	–55.6667*	
			293 – 1,318	–164.167*	
622 kPa	1,523.0	non	622 – 1,318	–108.5*	
1,318 kPa	1,631.5	non			

* Denotes a statistically significant difference.

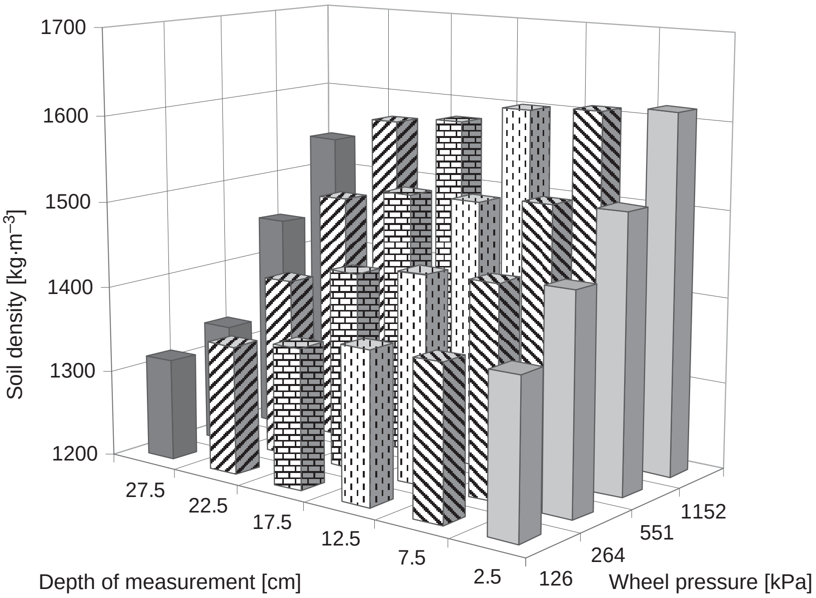

FIGURE 3. Changes in density of soil compacted with tractor U1234

0–30 cm ranged from 1,318 kg·m^{-3} in the deepest layer (27.5 cm) after single passage of tractor to 1,616 kg·m^{-3} in the surface layer after eight compacting passages. As it is evident from comparison between soil density values obtained for both tractors, the passages of tractor MF255 increased soil density more than passages of tractor U1234 by 1–6% (on the average by 2.5%).

Considering an increase in soil density in relation to not compacted field one can find the similar dynamics of changes as after passages of the lighter tractor. A single passage increased the soil density in investigated profile on the average by 18%, two passages by 23%, four passages by 30% and eight passages by 38%.

In this case also the statistical analysis (Table 4) showed the occurrence of statistically significant differences in soil density between group means after subsequent passages of tractor U1234.

The multiple range test by 95% Tukey HSD method (Table 5) showed – similarly to the lighter tractor – that all variants of tractor U1234 passages resulted in substantial and statistically significant diversification of soil density under the track.

Since statistical evaluation of measurement results for both tractors showed significance of the effect on soil state changes under the track, and similar soil density distributions and ranges were obtained, there was formulated a hypothesis on the lack of principal differences in soil compacting intensity, in spite of different weight and axle loads of both tractors. Comparison between the selected parameters that characterize the data sets for both tractor is presented in Table 6.

To confirm this hypothesis (mean values of soil density after passages of tractor MF255 do not differ significantly

TABLE 4. Analysis of variance for soil density after passages of tractor U1234

Source	Sum of squares	Df	Mean square	F-ratio	P-value
Between groups	174,632.0	3	58,210.7	62.64	0.0000
Within groups	18,586.5	20	929.325	×	×
Total (Corr.)	193,219.0	23	×	×	×

TABLE 5. Homogeneous groups and comparison between soil density group mean values after passages of tractor U1234

Factor	Mean	Homogeneous Groups	Contrast	Difference	+/– Limits
126 kPa	1,360.17	non	126 – 264	–58.00*	49.279
			126 – 551	–138.333*	
			126 – 1152	–226.50*	
264 kPa	1,418.17	non	264 – 551	–80.333*	
			264 – 1152	–168.50*	
551 kPa	1,498.5	non	551 – 1152	–88.167*	
1,152 kPa	–	non			

* Denotes a statistically significant difference.

TABLE 6. Statistics of soil density measurement value for both tractors

Item	Characteristics of measurement results	
	MF255	U1234
Average soil density [kPa]	1,502.25	1,465.88
Median [kPa]	1,492.0	1,451.0
Standard deviation [kPa]	95.832	91.656
Standard error [kPa]	19.562	18.709
Minimum [kPa]	1,330.0	1,318.0
Maximum [kPa]	1,657.0	1,616.0
$t_{\alpha=0.05}$	1.3438	
P-value	0.1856	

from mean values of soil density after passages of tractor U1234) the obtained values were analyzed by testing the hypothesis on equality of two mean values, with the use of Statgraphics statistical package for data processing. The results of analysis ($P > 0.05$) showed that there was no ground for rejection of the hypothesis on equality of mean values.

As one of the main reasons for this state one can consider small differences (from 9 to 14%) between the summary specific pressures of wheels in the subsequent passages of tractors MF255 and U1234. Application of larger tyres in the heavier tractor enabled to maintain pressures of the level close to tractor MF255.

Therefore, application of a heavier tractor that allows for better utilization of tractor power and the reduced number of passages in the field by coupling with larger and more efficient machinery is justified; no additional threat of soil damage by increasing its compaction is introduced.

CONCLUSIONS

1. The carried out investigations enabled to compare the effect of traffic of two tractors on soil density in the track. The investigations showed that soil density caused by passages of tractor MF255 was by 1 to 6% higher (on the average by 2.5%) than that found after passages of tractor U1234.
2. In relation to the initial state (not compacted soil), a single passage of tractor MF255 increased the soil density on the average by 21%, two passages by 27%, four passages by 32%, and eight passages by 42%.
3. In relations to not compacted soil, a single passage of tractor U1234 increased the soil density in the investigated profile on the average by 18%, two passages by 23%, four passages by 30% and eight passages by 38%.
4. Statistical analysis of all measurement results showed the lack of statistically significant diversification between mean soil densities found in subsequent measuring variants for both tractors.

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Streszczenie: *Zmiany gęstości gleby pod wpływem nacisków kół ciągnika.* W pracy dokonano analizy wyników badań związanych z wpływem przejazdów dwóch ciągników rolniczych MF255 i Ursus 1234 na zmiany gęstości objętościowej gleby w koleinie. Przeprowadzone pomiary wykazały, że mimo znacznie większej masy i związanych z tym obciążeń osi zagęszczenia poszczególnych warstw profilu kołami ciągnika U1234 były mniejsze niż po przejazdach ciągnika MF255. Gęstości gleby po przejazdach ciągnika MF255 były od ok. 1 do ok. 6% większe niż odpowiednie gęstości gleby rozpatrywanego profilu, otrzymane po przejazdach ciągnika U1234.

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