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Influence of soil compaction by farm machinery and livestock on water infiltration rate on grassland

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Abstract. The objective of this study was to investigate the rate of water infiltration into the soil under different soil compaction levels caused by livestock and farm machinery. Measurements were performed on grassland which is situated at Harper Adams University, UK. The soil type is classified as a sandy loam – *Eutric Cambisols*. The following treatments were evaluated: non-compacted soil, compaction by cattle hooves and compaction by tractor with trailer. Infiltration rate was measured by simplified falling-head and cone index to a depth of 0.3 m using a cone penetrometer.
Results of the simplified falling-head infiltration method showed a significantly higher water infiltration rate in the non-compacted soil than the compacted soil. There was no statistical difference in the infiltration rate following compaction by cattle hooves and compaction by tractor. The mean values of water infiltration rate measured on compacted soil by cattle hooves and tractor with trailer showed 2.6% difference. The measurements of cone index showed a significant difference only in the case of compaction by cattle hooves, where a decrease of cone index values by approximately 20% in the depth from 0.15 to 0.25 m occurred. Overall it was found that the ground pressure of 200–250 kPa reduces water infiltration properties of the soil more than 80% in comparison to the non-compacted soil.

Key words: cone index, saturated hydraulic conductivity, soil compaction, water infiltration rate.

INTRODUCTION

Soil compaction is an important factor that influences the water infiltration rate and is one of the factors responsible for the degradation of the physical quality of soils. Soil compaction is mainly caused by agricultural machinery, which reduces porosity and increases the density of soils, thus reducing water infiltration rate in comparison with non-compacted soil (Liebig et al., 1993; Yuxia et al., 2001; Hamza & Anderson, 2005; Raper & Kirby, 2006). A non-compacted soil has 4–5 times higher water infiltration rate than the soil compacted by agricultural machines. Yuxia et al. (2001) showed that the effect of agricultural machinery on soil has a greater influence on water infiltration rate than soil tillage.

Soil compaction is not only caused by farm machinery, but also by livestock trampling. Preliminary results on the impact of livestock on bulk density and soil infiltration were obtained by Castellano & Valone (2007) on gravelly sandy loam soils. In this experiment it was found that free-moving livestock increases soil infiltration in comparison with non-compacted soil and thus also increase the abundance of grass on the land. It was also found that the cone index values of soil compacted by cattle hooves and tractor with trailer had lower values than non-compacted soil in the upper layer of soil (0–0.1 m). Da Silva et al. (2003) conducted an experiment evaluating the influence of the animal unit per hectare on soil cone index. The results showed that there was no difference between 3.5 and 4.42 of livestock unit per hectare, however, the load of 5.68 of animal unit per hectare showed significant increase cone index by 88%. Another experiment showed that a grazed site has a 16% higher value of cone index and about 60% lower water infiltration rate than the non-grazed sites (Moret-Fernández et al., 2011). A cone index increase on grazed sites was also observed by Evans et al. (2012) and Schmalz et al. (2013).

MATERIALS AND METHODS

Bird´s Nest field is situated at Harper Adams University farm, Shropshire, UK (latitude 52.776; longitude -2.430). The grassland test areas were prepared by a grassland subsoiler (OPICO sward lifter) to the depth 0.12–0.15 m. The soil water infiltration rate and cone index measurements were performed on sandy loam soil (Beard, 1988) – *Eutric Cambisols* (World Reference Base for Soil Resources – WRB). The average annual rainfall of 653.2 mm and mean annual temperature of 10.1°C. Further soil characteristic is given in Table 1. The measurements were performed on non-compacted soil, soil compacted by cattle hooves with the target ground pressure of 200–250 kPa and compaction by loaded tractor and trailer with the target ground pressure of 200–250 kPa. Both types of soil compaction were conducted three times with a ten day interval in February 2012 and the measurements were taken in June 2012.

Table 1. The soil of Bird´s Nest (Beard, 1988)

Topsoil characteristics	Subsoil characteristics	Soil water regime
Very slightly stony sandy loam	Deep permeable very slightly stony sandy loam often becoming loamy sand below 0.6 m depth.	Well drained. Subsoil is rarely wet.

The simplified falling-head method (SFH) was used for assessment of water infiltration rate into the soil. The SFH method measures saturated hydraulic conductivity (K_{fs}). K_{fs} was measured using a ring of known diameter A [mm] (for this measurement the ring diameter was 0.152 m). The ring was inserted into the soil down to 0.05 m (encloses an area for application of water on the soil surface). SFH uses a small water volume V [l] which is applied to the soil surface. The time t_a [s] was measured from pouring water onto the soil surface until complete water absorption by soil. The soil moisture content was measured before and after water application by Theta Probe (type HH2 Moisture meter, Delta T Devices). The saturated hydraulic conductivity was calculated based on the equation of Bagarello et al. (2004):

$$K_{fs} = \frac{\Delta\theta}{(1-\Delta\theta)t_a}\left[\frac{D}{\Delta\theta} - \frac{\left(D+\frac{1}{\alpha^*}\right)}{1-\Delta\theta}\ln\left(1+\frac{(1-\Delta\theta)D}{\Delta\theta\left(D+\frac{1}{\alpha^*}\right)}\right)\right] \quad (1)$$

where $\Delta\theta$ [$m^3 \cdot m^{-3}$] is the difference between the saturated water content (inside the cylinder θfs) and initial water content (outside the cylinder θi), $D = V / A$ [$1\ mm^{-1}$] is the depth of water in the cylinder at the beginning of measurement and α^* [m^{-1}] is saturation potential coefficient for K_{fs} (Elrick et al., 1989). All measurements used the same volume of water of 0.3 litres and five replications were conducted for each measurement. Saturation potential coefficient of $\alpha^* = 12\ m^{-1}$ was selected (structured sandy loam soils).

An Eijkelkamp penetrologger (ART.NR. 06.15.01) with a 30° cone with an area of 100 mm^2 was used for the cone index determination. The measurements were conducted based on the ASABE standard S313.3 (ASAE Standards, 2004).

STATISTICA 12 software with ANOVA and graph tools was used to analyse the data statistically.

RESULT AND DISCUSSION

The values of saturated hydraulic conductivity measured by the SFH method are shown in Fig. 1. The results show that the non-compacted soil has higher values of saturated hydraulic conductivity (5.62 mm h^{-1}) than the soil compacted with cattle hooves (1.09 mm h^{-1}) and tractor with trailer (1.12 mm h^{-1}), which equates for an 80% decrease in soil infiltration rate. There is no significant difference between the levels of soil compaction caused by cattle hooves and compaction caused by the tractor with trailer.

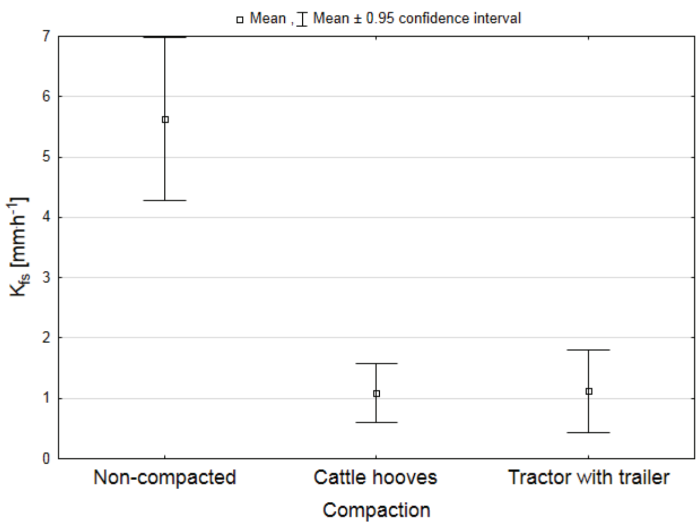

Figure 1. Relationship between different compaction levels and saturated hydraulic conductivity.

Tukey´s HSD test of homogenous groups (Table 2) confirmed that there is no significant statistical difference between compaction types levels (compaction by cattle hooves and compaction by tractor with trailer) and non-compacted soil is in its own homogenous group.

Table 2. *Tukey´s* HSD test of homogenous groups for saturated hydraulic conductivity

Homogeneous groups, α = 0.05			
Compaction type	Mean of K_{fs} [mm h^{-1}]	1	2
Non-compacted	5.626206	****	
Cattle hooves	1.088804		****
Tractor with trailer	1.121352		****

The penetrometer results showed that there was no significant statistical difference between compaction type levels at depths from 0 to 0.10 m, where the upper layer of the soil (from 0 to 0.05) was less compacted for all treatments due to the presence of root concentration and activity of micro-organisms. The results also showed that there were no statistically significant differences between the non–compacted soil and compaction by tractor with trailer in the entire observed depth of the soil profile. The only exception was compaction by cattle hooves, where there was a reduction in cone index values at the depth of 0.10–0.25 m. This is confirmed by *Tukey´s HSD* test of homogenous groups which is shown along with the average values of cone indexes in Table 3.

Similar reduction in cone index values at the depths from 0.10 to 0.35 m, under the soils compacted by cattle hooves, were observed by Martínez & Zinck (2002) on fine- and coarse-textured soils (Acrisols).

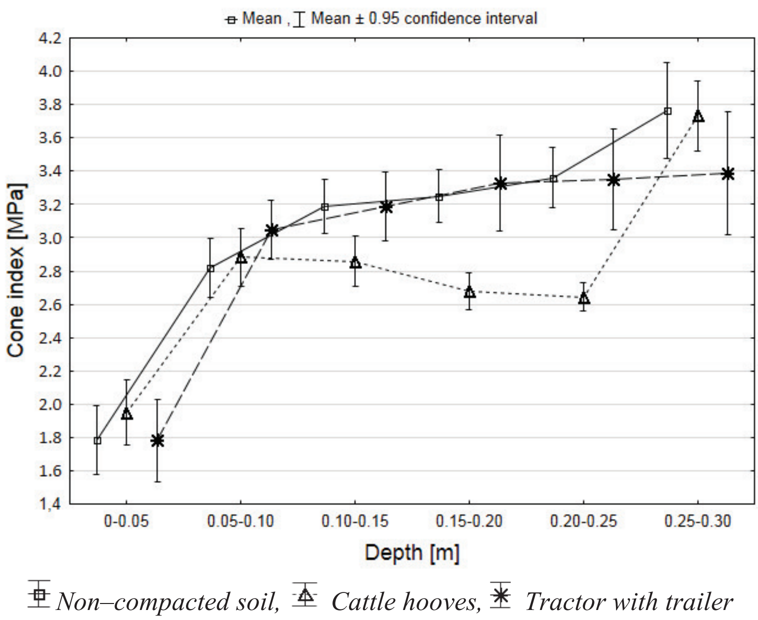

Figure 2. Values of cone indexes for different compaction levels.

Table 3. *Tukey´s HSD* test of homogenous groups for cone indexes
a, b – *homogenous groups in rows;* 1, 2, 3, 4 – *homogenous groups in columns;* α = 0.05

	Cone indexes for different types of soil compaction [MPa]					
Depth	Non-compacted		Cattle hooves		Tractor with trailer	
0–0.05	1.78	a 1	1.95	a 1	1.78	a 1
0.05–0.10	2.82	a 2	2.88	a 2	3.04	a 2
0.10–0.15	3.19	b 2, 3	2.86	a 2	3.19	b 2
0.15–0.20	3.25	b 3	2.68	a 2	3.33	b 2
0.20–0.25	3.36	b 3	2.64	a 2	3.35	b 2
0.25–0.30	3.77	a 4	3.73	a 3	3.39	a 2

CONCLUSIONS

The results showed that the water infiltration rate was influenced by soil compaction. Compaction by cattle hooves and tractor with trailer caused a decrease in saturated hydraulic conductivity values by 80%. However, there were no statistically significant differences between the compaction by cattle hooves and tractor with trailer at the same ground pressure. Further research of the differences between these types of soil compaction and its influence on saturated hydraulic conductivity is recommended.

The cone index values revealed only one case of a statistical difference between the types of soil compaction, as observed with compaction by cattle hooves at a depth of 0.10 to 0.25 m. All variants were influenced by root system in topsoil to a depth of 0.05 m.

Based on these results it can be concluded that there was no statistical difference in penetrometer resistance between the non-compacted soil and compaction by tractor with trailer. However, the saturated hydraulic conductivity measurements confirmed the negative effect of soil compaction on soil water infiltration.

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