The effect of tractor wheeling on the soil properties and root growth of smooth brome

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ABSTRACT

The objective of this work was to evaluate the effect of tractor wheeling with a light tractor on the root growth and soil properties of smooth brome in South Estonia. Field experiment was conducted on sandy loam Haplic Luvisol in 2007. Data were collected during September 2008 in both an uncompacted and compacted area. Because of the compaction, the precompression stress increased in the upper soil layer (0–10 cm) by 12.6% and 15.2% at a depth of 10–20 cm. Compaction had only a minor effect on the bulk density, values increased 4.7% in the upper soil layer and 1.8% in the deeper layer. Differences in the saturated hydraulic conductivity (k_s) were not significant; however, the decrease in the k_s was 26.6% in the upper level and 12.5% in the deeper (10–20 cm) layer. At a depth of 0 to 30 cm compaction decreased the root length by 44.7% and the root mass by 60.5% compared with the uncompacted soil. Altogether, this study confirms the unfavourable effect of wheeling on grasslands even when the wheeling is performed with a light tractor on dry soil.

Keywords: precompression stress; bulk density; saturated hydraulic conductivity; root length and mass

Human activity, particularly agricultural activity, has a strong influence on soil properties. During the last decades, changes in land use in Estonia have been characterised by an increase in the forest area and a decrease in the area of the grasslands (Antso and Hermet 2012). According to the Eurostat yearbook (2011), the total agricultural area in the 27 EU member states covered 172 Mha in 2007, of which 61% is arable land and 33% is permanent grassland. The strong demand for high quality fodder requires a more intensive use of grasslands. However, intensive use requires a high level of traffic. Over time, the power and weight of machines increased (Alakukku 1999, Batey 2009). In 1970, the mean wheel loads were 1 to 2 t, and in 2000, they ranged from 2 to 3 t (Sommer et al. 2003). Schrama et al. (2012) compared different cutting regimes, traditional versus mechanical mowing, on grasslands and showed that long-term (38 years) machine mowing causes compaction, particularly on organic soils. Krebstein et al. (2013) showed on sandy loam Calcaric Cambisol under lucerne that soil compaction is also a problem on farm-used grasslands. Because of soil compaction, the soil properties are altered, and a reduction in soil water and roots can occur (Baty 2009).

The grassland plant used in this study is smooth brome (*Bromus inermis* Leyss.). It is an invasive, cool-season perennial Eurasian grass that is strongly rhizomatous. We used a cool-season grass in this study because it is more winter resistant. Compared with cool season grasses, warm season grasses have better root growth in compacted soil (Matthieu et al. 2011); therefore, we expected less adaptation of the smooth brome. The smooth brome cultivar in our trial was Lehis.

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There are insufficient data on the effect of compaction with a light tractor on the soil properties of grasslands. Therefore, in this study, our objective was to investigate the effect of tractor wheeling on the soil used to cultivate smooth brome, even when soil compaction does not occur under extreme conditions. Wheeling was performed with a light tractor and small soil contact pressure of 118 kPa on dry soil (pF = 3). The hypothesis tested was that although the roots significantly contribute to soil stability, this stability can be destroyed by tractor wheeling in the grasslands. Here, the wheeling effects after a first year of compaction on the bulk density (BD), precompression stress (P_c), saturated hydraulic conductivity (k_s), root length and root mass on the grasslands are reported.

MATERIAL AND METHODS

Field site. A field experiment was performed at the Experimental Station in Rõhu, Estonia (latitude 58°21'N, longitude 26°31'E). The research field was established in 2007. The climate in Estonia is humid-temperate, the mean annual precipitation was 805 mm and the average temperature was 6.5°C during 2008.

Soil and sampling. The soil in the experimental area was Haplic Luvisol (IUSS Working Group WRB 2007). The average soil characteristics were measured prior to the beginning of the experiment in 2006. The texture of the soil was sandy loam containing 51.5% sand (0.063–2 mm equivalent particle diameter), 37.4% silt (0.002–0.063 mm) and 11.1% clay (< 0.002 mm). The average soil chemical characteristics of the experimental field were pH_{KCl} 5.6, C_{org} 13 g/kg, N_{org} 14 g/kg, available P 292 mg/kg, K 108 mg/kg, Ca 730 mg/kg and Mg 335 mg/kg.

The data were collected from the field after the third silage cut of smooth brome in September 2008. The sowing (38 kg/ha) was performed on 6 June 2007. The size of each experimental plot was 10.5 m^2 (1.5 × 7 m). There were two different levels of soil compaction, uncompacted and compacted. Soil compaction was generated tyre-to-tyre (tyres 8.3–20'' and 13.6–38'') two times using a tractor T-40 (2.3 Mg) with a water tank (3 t and tyres 7.50–20''). Trükmann (2011) calculated a soil contact pressure of 118 kPa for the water tank according to O'Sullivan et al. (1999a). The soil water content at a depth of 0–30 cm during the soil compaction in May was pF = 2.7, and at the end of July, the pF = 3 (these values do not promote the compaction). The undisturbed soil samples were taken with steel cylinders for BD, precompression stress and saturated hydraulic conductivity from depths of 10, 20 and 30 cm and for the root length and mass from depths of 5, 10, 15, 20, 25 and 30 cm on the 23rd and 24th September 2008. For the BD and k_s, we used 88.2 cm^3 cylinders (diameter 5.3 cm, height 4 cm), and we evaluated 96 samples for each measurement. There were 48 samples for the uncompacted area and 48 samples for the compacted area for each depth of 10, 20 and 30 cm, with 16 replications. We used a 235.5 cm^3 cylinder (10-cm diameter, 3 cm height) for the root length and mass measurements. For each measurement, there were 36 samples, of which 18 samples were from the uncompacted area and 18 samples were from the compacted area for each depth of 5, 10, 15, 20, 25 and 30 cm, with three replications. We used the same cylinders for measuring the P_c. We evaluated 16 samples, of which 9 samples were from the uncompacted areas at depths of 10, 20 and 30 cm with three replicates, and 7 samples were from the compacted area at a depth 10 cm with three replicates and from depths of 20 cm and 30 cm with two replicates.

Laboratory methods. Soil samples were measured in Germany at the Christian-Albrecht University of Kiel in 2009. The samples were dried in an oven at 105°C for 24 h to determine the BD. The P_c was measured on the undisturbed soil samples, which were predrained to a matric potential of –6 kPa. A confined multi-step compression device (odometer) was used to determine the P_c. The defined pressures of 10, 20, 30, 50, 70, 100, 150, 300 and 400 kPa were applied stepwise for 10 min to each soil sample, and after 400 kPa was applied for 10 min, no pressure was exerted. The k_s was measured using the falling-head method with a hood water permeameter device. The roots were washed out of the fresh soil on sieves with a 0.25 mm mesh size. A scanner and the WinRhizo software (Version 2004a, Regent Instruments Inc., Quebec, Canada) were used for the root analysis. The washed roots were spread out in approx. 15 mm of water in a scanner ray (Epson 1680, Regent Instruments Inc., Quebec, Canada). The scanner was used for creating a digital image of the roots that was then analysed with WinRhizo.

Statistical analysis. For statistical analysis, we used the ANCOVA to account for the combined

Table 1. *P*-values of different factors on investigated parameters

	The compaction effect was modified by depth	Soil depth	Compaction	Interaction between the soil depth and compaction
Precompression stress (kPa)	$P = 0.58$	$P = 0.6$	$P = 0.35$	$P = 0.36$
Bulk density (g/cm^3)	**$P = 0.004$**	**$P < 0.001$**	**$P = 0.005$**	**$P = 0.01$**
Saturated hydraulic conductivity (log, cm/day)	$P = 0.3$	$P = 0.2$	$P = 0.3$	**$P = 0.002$**
Root length (cm/cm^3)	**$P < 0.001$**	**$P < 0.001$**	**$P < 0.001$**	**$P = 0.04$**
Root mass (g/m^2)	**$P = 0.02$**	**$P < 0.001$**	**$P = 0.01$**	$P = 0.06$

The results were statistically significant when $P < 0.05$ (indicated in bold)

effects of the depth and compactions (compacted and uncompacted). The *P*-values were evaluated at a 5% significance level. The estimated values are reported in Table 1. Fisher's *LSD* post-hoc test was used to compare the differences between the values (arithmetic mean). The different letters on the BD, P_c and k_s graphs indicate significant differences between the soil compaction treatments at one depth. The statistical analyses were performed with the R software version 2.15.1 (R Core team, www.r-project.org, 2013).

RESULTS AND DISCUSSION

The effect of compaction varied based on the different parameters evaluated. The soil compaction had a statistically significant effect on the BD, root length and mass. The parameters evaluated are described in Table 1.

Soil precompression stress (kPa). Soil compaction had no statistically significant effect on the P_c because of the large variability in the field soil (Figure 1). However, the results showed that compaction had a negative effect on the P_c values. The median P_c values increased in the 0–10 cm upper soil layer by approximately 12.6% and at a depth of 10–20 cm by 15.2%. However, at a depth of 30 cm, the result was the opposite, the median P_c value in the uncompacted area was 19% higher than in the compacted area.

Bulk density (g/cm^3). Soil compaction and soil depth significantly increased the BD (Table 1). There was also a statistically significant difference between the uncompacted and compacted areas of the upper soil layer (0–10 cm) (Figure 2). The difference of the median BD values between the compacted and uncompacted areas was higher in the upper layer (0–10 cm), approx. 4.7%, and in the deeper layer (10–20 cm), approx. 1.8%. In the deepest layer (20–30 cm), compaction had no effect on the BD.

Saturated hydraulic conductivity (log, cm/day). The changes in k_s were not obvious (Figure 3). Between the two treatments (uncompacted and compacted), a statistically significant difference

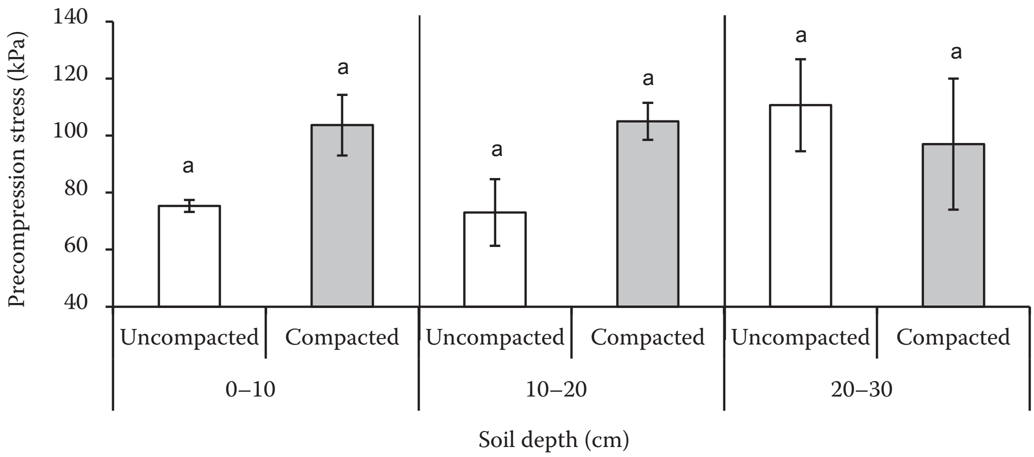

Figure 1. Soil precompression stress (measured at pF = 1.8) depending on soil compaction and soil depth. Error bars denote standard error of the mean

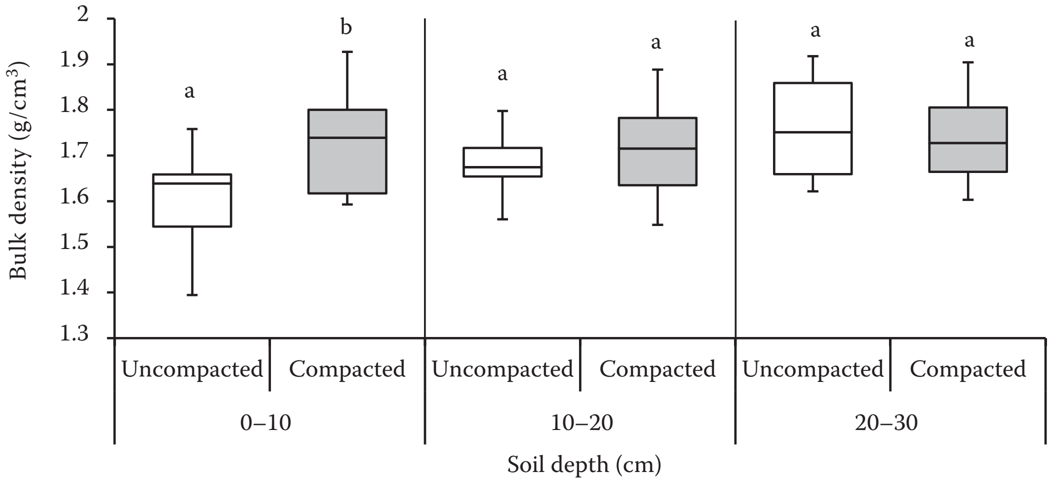

Figure 2. Soil bulk density depends on soil compaction and depth (uncompacted and compacted). In the box plot, the median (–) and lower – upper quartiles are shown

was observed at depths of 10 cm and 30 cm. In the upper layer (0–10 cm), the median k_s value was approx. 26.6% higher between the traffic lanes compared with no traffic lane, and in the deeper layer (10–20 cm), the median k_s value increased by 12.5%.

Because of compaction, the P_c values in the upper soil layer (0–20 cm) increased compared with the uncompacted area. Krebstein et al. (2013) found that due to soil compaction, the P_c increased in the upper soil layer to 60 kPa and to 30 kPa at a soil depth of 10 cm. According to our results, we can assume that the binding substances are not really changed, hence, the number of contact points must be increased (verified by BD). During soil deformation, the soil particles are pushed more closely towards each other, which leads to a higher BD with a greater number of contact points between the soil particles (Lebert and Horn 1991).

Wheeling with a light tractor increased the BD; however, the increase was small and better observed in the upper soil layer (0–10 cm). Based on our results, wheeling does not change the BD values in the deeper soil layer (20–30 cm). This is because soil compaction changes the soil structure, but this does not change the BD results as the BD does not reflect the soil structure. O'Sullivan et al. (1999b) demonstrated the influence of decreased pore continuity by shearing on the air conductivity at the same BD.

When the bulk soil is compacted, the k_s values are lowered. This is also consistent with the literature. Zhang et al. (2006) showed that soil compaction affected the hydraulic properties on loess soils.

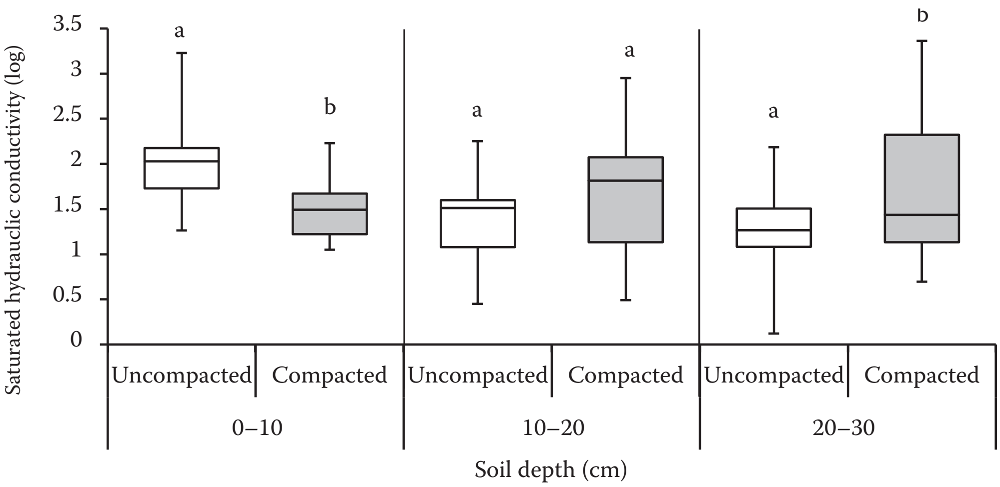

Figure 3. Saturated hydraulic conductivity depends on soil compaction and soil depth. In the box plot, the median (–) and lower – upper quartiles are shown

They showed that the k_s values decreased when the soil compaction increased. However, the increase in k_s values below 10 cm in our study may have occurred because the roots may block the pores (more roots in uncompacted soil), thereby reducing the k_s values, although they may have more large pores.

Root length (cm/cm^3) and root mass (g/m^2). Our results showed that after first year of compaction, the root length and mass changed because of compaction. The longest roots were in the upper soil layer (Figure 4a). The average root length in uncompacted area at all depths increased approx. 44.7% compared with the compacted area. In the upper uncompacted layer (0–15 cm), the roots were 47.6% longer than in the compacted area, and in the deeper soil layer (20–30 cm), the difference was 36.6%. The root mass in the compacted soil was less than in the uncompacted soil (Figure 4b). The average root mass in the compacted area at all depths was 60.5% less than the uncompacted area. The root mass of the smooth brome was greater in the upper soil layer (0–15 cm) compared with the deeper soil layer (20–30 cm), and for the compacted and the uncompacted areas, the difference in the root mass of the upper layer was 64.4%. In the deeper layer, the soil compaction decreased the root mass by 29.6%.

The alterations in the root length and mass are more pronounced in the upper soil layer (0–15 cm). This is because the light tractor had more influence on the soil surface than the subsoil. Tolón-Becerra et al. (2012) showed that the subsoil compaction is related to the tractor weight, with lightweight tractors exerting less pressure on the soil contact area. According to Lipiec et al. (2003), the root size of oats was more affected in the ploughed layer compared with the deeper soil. Because of compaction, the roots cannot penetrate the deeper layers and therefore stay at the top. This is also confirmed by literature. Lipiec et al. (1991, 2003) showed that soil compaction led to higher concentration of roots in the upper layer and reduced the roots in the deeper layer. In a greenhouse study, Matthieu et al. (2011) found that subsurface compaction impeded turf grass root growth in the deep layers. In a five-year trial on non-grazed temporary grassland (loamy sand) with different loads (0, 4.5, 8.5 and 14.5 t), Bouwman and Arts (2000) showed that when wheeling was performed with maximum load (14.5 t), the majority of the root mass was above 20 cm. Głąb (2008) showed that wheeling affected the root length on a silty loam Mollic Fluvisols, and the root length was shorter in all soil layers (0–30 cm) after wheeling.

Altogether, this study confirmed the unfavourable effect of tractor traffic even when soil compaction does not occur under extreme conditions on the grassland, such that the soil is dry and the tractor contact pressure is low. Our experiment shows that the precompression stress, soil bulk density, saturated hydraulic conductivity, root length and mass is significantly affected by wheeling. In response to the tractor traffic, the soil stability parameters, such as P_c increased. After the first year of compaction event, the effect of compaction

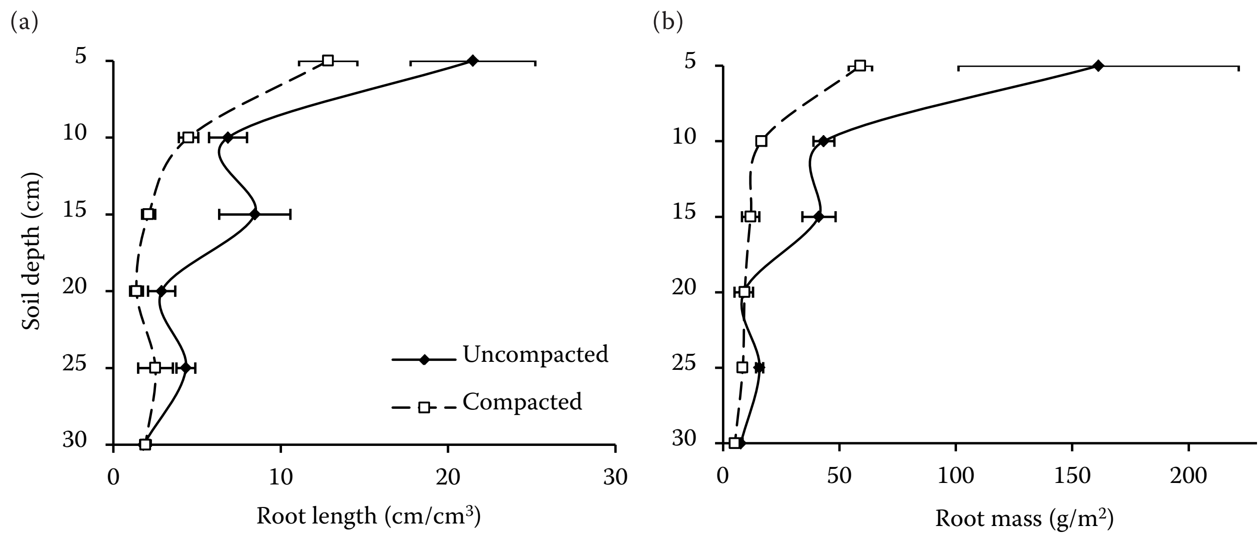

Figure 4. The average root length (a) in the soil and the average root mass (b) in the soil depend on the soil compaction (uncompacted and compacted) and depth. The horizontal bars denote the standard errors

was visible because the soil physical properties, such as BD, were increased on the compacted soil. As a result, the root systems adjusted to the new state and formed less roots in total, particularly in the topsoil. Soil compaction also decreased the k_s values in the upper soil layer, when the bulk soil is compacted, it lowers the k_s values. In conclusion, our results confirmed the negative effect of wheeling even when the wheeling does not occur under extreme conditions, on the root growth and soil properties of smooth brome.

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