Effect of soil compaction on growth of narrow–leafed lupine, oilseed rape and spring barley on sandy loam soil

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Abstract. Soil compaction is an environmental problem and has been recognized as the main form of soil degradation in Europe. Soil compaction may increase soil strength and compacted soil layers can affect root and shoot growth. The aim of this work was to investigate the effect of soil compaction on soil properties and on the growth of narrow–leafed lupine (*Lupinus angustifolius* L.), spring oilseed rape (*Brassica napus* ssp. *oleifera* Hertzg.), and spring barley (*Hordeum vulgare* L.). The experiment was carried out on the research field of the Estonian University of Life Sciences in the summers of 2004 and 2005 on the sandy loam Stagnic Luvisol. The field was compacted by tractor MTZ-82 (total weight 4.84 Mg) characterized by multiple tire-to-tire passing. Parameters such as plants biomass (roots and shoots) and the changes in physical properties, bulk density and penetration resistance of soil were measured. The results of the present study revealed that the highest increase of penetration resistance and soil bulk density due to the soil compaction occurred in growing spring barley. Although the roots and shoots mass of lupine and oilseed rape increased with increased soil bulk density, there was a very strong negative linear correlation between the roots and shoots weight and soil bulk density on spring barley. A positive correlation was detected between the roots and shoots mass of narrow–leafed lupine and soil bulk density, and soil compaction had a positive effect on the roots and shoots mass of oilseed rape. The study indicates that oilseed rape and narrow–leafed lupine can grow more successfully on compacted soils than can barley.

Key words: soil compaction, lupine, oilseed rape, spring barley, bulk density, penetration resistance

INTRODUCTION

Soil compaction of agricultural soils is a global concern (Soane & van Ouwerkerk, 1994) due to adverse effects on the environment: it is estimated to be responsible for the degradation of an area of 33 million ha in Europe (Akker & Canarache, 2001) and is one of the major problems facing modern agriculture. Overuse of machinery, intensive cropping and short crop rotations, intensive grazing and inappropriate soil management leads to compaction (Hamza & Anderson, 2005) ,which affects key soil properties – porosity, bulk density, mechanical impedance, hydraulic conductivity and plant-available water (Passioura, 2002). From an agronomic point of view, the results of soil compaction are decreased root growth and development, and consequently, a reduction in crop yield (Håkansson & Reeder, 1994). Subsoil compaction may persist for a long time and is hence a threat to the long-term productivity of the soil (Etana & Håkansson, 1994).

This study was conducted to determine the influence of soil compaction on soil bulk density and penetration resistance and on the growth of narrow–leafed lupine (*Lupinus angustifolius* L.), spring oilseed rape (*Brassica napus* ssp. *oleifera* Hertzg.), and spring barley (*Hordeum vulgare* L.).

MATERIALS AND METHODS

Data were collected from the research field (58°23´N, 26°44´E) of the Estonian University of Life Sciences with different levels of soil compaction on sandy loam soil, in 2004 and 2005. The size of experimental plots was 3x9 m (27 m^2). The soil type was Stagnic Luvisol according to the WRB 1998 classification (FAO, 1998). From the diagnostic and genetic horizons the humus (Ap), ferralic (Bw), stagnic (Ew) and argillic (Bt) horizons were found in soil of the experimental areas. The soil characteristics of the humus horizon were: C 1.4%, N 0.11%, K 164 mg kg^{-1}, P 183 mg kg^{-1}, Ca 674 mg kg^{-1}, Mg 101 mg kg^{-1}, pH_{KCl} 6.2, sand (2.0–0.02 mm) 67.9%, silt (0.02–0.002 mm) 22.9% and clay (<0.002 mm) 9.2%. A detailed description of the soil in the experimental area is presented by Reintam and Köster (2006). Soil compaction has occurred before sowing each spring since 2001. Compaction was generated using a tractor MTZ-82 provided with a front loader with 2.25 Mg on the first axle and 2.55 Mg on the rearward axle. Four different levels of soil compaction were produced using the following treatments: uncompacted – control, no pass of tractor wheels; compacted 1 time – one pass of tractor wheels; compacted 3 times – three passes of tractor wheels; compacted 6 times – six passes of tractor wheels. Data from the vegetation presented in this paper were collected from 2 treatments: uncompacted and 6 times compacted. Data from all compaction treatments were used in the correlation analysis between root growth and soil bulk density.

Seeds of lupine were sown by 56, and spring barley, by 450 germinating seeds per m^2 (250 kg ha^{-1}); seeds of spring oilseed rape were sown by 12 kg ha^{-1}. Sowing took place mid-May. For barley, complex fertilizer was used at the rate of $N_{40}P_7K_{20}$ kg ha^{-1} before sowing. No herbicides or other pesticides were used on barley or other cultures. The samples of soil from plant roots were taken in the earing phase of barley (mid-July) in growth stage 75–79 according to the numeric code description according to the BBCH Growth Scale of plants (Lancashire et al. 1991). Root samples and soil bulk density were taken with 1131 cm^3 steel cylinders (h = 15 cm, Ø = 9.8 cm) in 15 cm layers down to 60 cm in 4 replications. The probes were weighed before washing roots to determine the bulk density of the soil. In the field, special probes were taken to detect the soil moisture content in spring before soil compaction and in the earing phase of barley. Soil probes were dried at 105°C. The roots were washed out from fresh soil with water on 0.5 mm sieves, then were dried at 60°C and weighed. Penetration resistance was measured with a cone penetrometer (cone angle 60°, stick diameter 12 mm) in every 5 cm layer down to 60 cm in 4 replications. All statistical measures were treated with the software Statistica 7.0 and analysis of variance (ANOVA) was implemented (StatSoft, 2006). To compare the differences between values the Fisher LSD post-hoc test was used.

In both years, the soil moisture content at the moment of compaction was similar in the topsoil (0–30 cm) 175–180 g kg^{-1} and in the subsoil (30–60 cm) 120–130 g kg^{-1}. The weather in 2004 was very rainy. The water content at the time of measurements was 190–200 g kg^{-1} in topsoil and 150 g kg^{-1} in subsoil. During the vegetation period there were 582 mm of precipitation and the average air temperature was 13°C. In 2005 there was 254 mm of precipitation; the average air temperature was also 13°C. In 2005, compared with 2004, the soil was dry at the time of measurements – in topsoil 140–150 g kg^{-1} and in subsoil 110–110 g kg^{-1}.

RESULTS

The ANOVA measurements of the soil penetration resistance and bulk density revealed that culture, treatment of compaction and the investigated soil layer were significant factors in accounting for differences between treatments (Table 1). The treatment of compaction significantly affected the shoot weight, but not the root weight. The most significant factor affecting soil penetration resistance, bulk density (in year 2005) and root weight was the soil depth.

Table 1. Direct and co-effect of trial factors from total environmental impact and significance of factors on soil penetration resistance, dry bulk density, plants' roots and shoots weight in the experiment.

Factor	Direct and co-effect of trial factors from total impact (%)			
	Penetration resistance	Bulk density	Root weight	Shoot weight
Year 2004				
C	9.4***	24***	4**	15***
T	16***	4*	2.3	35***
L	56***	9***	52**	
C x T	2***	7**	2	37***
C x L	2*	2	6**	
T x L	5***	1	5	
C x T x L	5***	8	3	
Year 2005				
C	1*	13***	1	76***
T	11***	14***	1	8***
L	73***	36***	72***	
C x T	1	5**	7***	11***
C x L	1	1	7*	
T x L	2**	5	3	
C x T x L	2	5	2***	

Significance * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

C – Culture; T – Compaction treatment; L – Soil layer

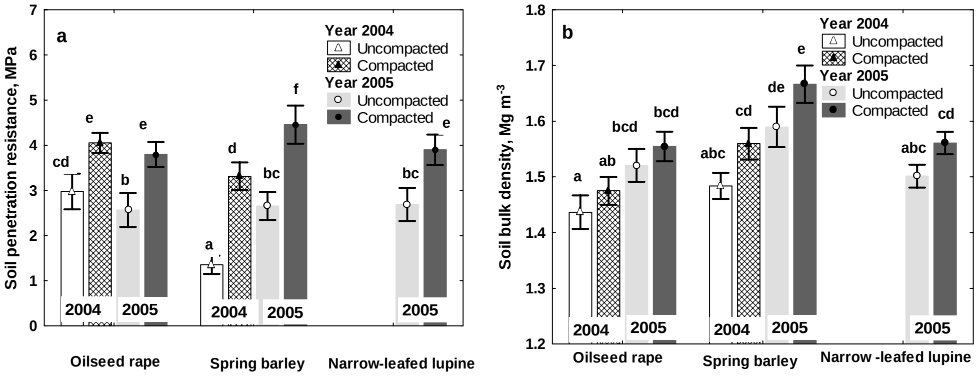

Fig. 1. Soil penetration resistance (a) and dry bulk density (b) depending on the soil compaction, year and culture in average of 0–60 cm soil layer. The error bars indicate SE (P<0.05). Means with the same letter do not differ statistically according to the Fisher LSD post-hoc test.

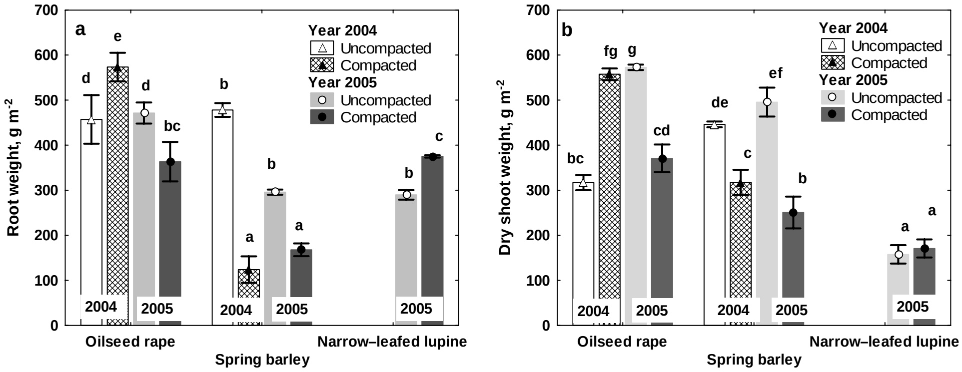

Fig. 2. Root dry weight (a) and shoot dry weight (b) depending on the soil compaction, year and culture in average of 0–60 cm soil layer. The error bars indicate SE (P<0.05). Means with the same letter do not differ statistically according to the Fisher LSD post-hoc test.

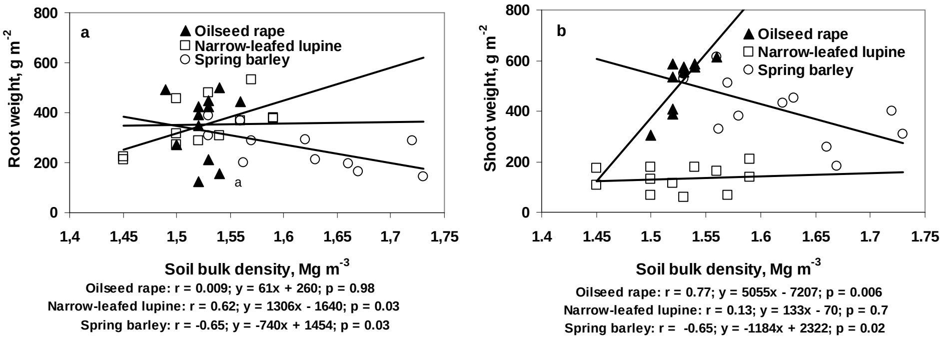

Fig. 3. Correlations between the root weight and dry soil bulk density (a) and between shoot weight and the dry soil bulk density (b) in 2005. Soil bulk density is presented as an average of 60 cm.

As expected, the average (60 cm soil layer) values of soil penetration resistance and bulk density were significantly increased on the compacted area compared with control in both years and in growing all investigated cultures (Fig. 1, a, b). The highest increase in average soil penetration resistance (by 1.8–1.96 MPa) and in average bulk density (by 0.08 Mg m^{-3}) was detected in the soil underneath spring barley. A smaller increase of penetration resistance (1.07–1.23 MPa) was detected in soil underneath oilseed rape and lupine. The average soil bulk density was 0.06 Mg m^{-3} higher under lupine and 0.03–0.04 Mg m^{-3} higher under oilseed rape in compacted soil than in the uncompacted soil.

Of the plant species investigated, soil compaction had most affect on the growth of spring barley roots and shoots (Fig. 2, a, b). The root mass of barley decreased by 74% (in 2004) due to compaction compared with control. The growth of oilseed rape differed between years. As in the first year, soil compaction increased the shoot and root mass of oilseed rape; in the second year, following compaction, the mass decreased. Soil compaction had positive effect on the growth of narrow-leafed lupine roots and shoots. Root mass of lupines increased by 23% and shoot weight by 7.6% due to the compaction.

The root and shoot weight of spring barley was negatively correlated with soil bulk density: the decrease was 2.3% per 0.01 Mg m^{-3} (Fig. 3, a, b). Soil bulk density had no impact on the root weight of oilseed rape but was positively correlated with shoot mass (r = 0.77) which increased 13.5% per 0.01 Mg m^{-3}. For lupine, the correlation between soil bulk density and shoot mass was not significant. The root weight of lupine was increased 5% per 0.01 Mg m^{-3} (r = 0.62).

DISCUSSION

Mechanical impedance of soil is an important constraint to root (Glinski & Lipiec, 1990) and shoot growth (Townend et al., 1996). Usually the mechanical impedance of a soil is described in terms of soil bulk density and/or soil strength (Pabin et al., 1991). Soil bulk density is inversely related to total porosity (Carter & Ball, 1993), which provides a measure of the porous space left in the soil for air and water movement (Lampurlanes & Cantero-Martinez, 2003).

Soil water content is the most important factor influencing soil compaction processes (Soane & van Ouwerkerk, 1994) because cone resistance is highly dependent on soil water content at the time of measurements (Abu-Hamdeh, 2003). Mechanical impedance increases as soil bulk density increases and water content decreases (Ehlers et al., 1983). In the current experiment, 2004 was very rainy and the soil moisture content was higher during the taking of samples than in the second experimental year, possibly explaining the higher average soil bulk density and penetration resistance values in 2005 (Fig. 1, a, b).

In comparing the compacted and uncompacted soil, the highest increase of average soil penetration resistance and bulk density values was detected in spring barley growth in both years. The rise in soil penetration resistance and bulk density was relatively smaller under oilseed rape and lupine. The range of average soil bulk density values on oilseed rape plots was very narrow (1.49–1.56 Mg m^{-3}); this limits interpretation of correlation results (Fig. 3, a, b).

Compacted soil layers which are highly resistant to penetration are one of the most common problems that affect root systems (Rosolem et al., 2002), decreasing length and rooting depth, and concentrating roots in the top layer (Lipiec et al., 1991). Soil compaction caused a rapid decrease in spring barley root weight (Figs. 2, a; 3, a), but had a positive effect on the root mass of narrow-leafed lupine and oilseed rape. The strong correlation between the root weight of lupine and soil bulk density indicates that the roots of lupine are better able to penetrate compacted soil.

Root and crop growth limiting bulk densities and soil strengths have been studied for several crops. Decreased root penetration by cotton was associated with an increase in soil bulk density to 1.65 Mg m^{-3} (Taylor & Gardner, 1963). In Australia, Reeves et al. (1984) found that spring wheat grown in soil with a bulk density of 1.52 Mg m^{-3} in the 0–20 cm depth had less root growth than that grown in soil with a bulk density of 1.32 Mg m^{-3}. Jones (1983) found that bulk densities greatly reducing root density varied with soil texture; these critical bulk densities decreased as the percentage of clay and silt increased.

According to Kooistra et al. (1992) and Ehlers et al. (1983), a reduction in pore size and continuity increases the probability that plant roots will encounter and penetrate soil cracks or biopores thus creating new root channels. Different cultures respond differently to high soil strength. Materachera et al. (1991) examined the effect of increased soil strength on 22 monocotyledons and dicotyledonous species: the effect of increased soil strength on elongation rates of roots was less pronounced on dicotyledonous species than on the monocotyledonous. They attributed the greater ability of the dicotyledonous to their greater increase in diameter. Cochrane and Aylmore (1994) reported that legumes are more effective for stabilizing soil structure than non-legumes: lupines were the most efficient species. The current study agrees with that finding.

Soil compaction may also affect shoot growth (Wolfe et al., 1995). In the current study the highest decrease due to soil compaction was detected in the shoot weight of spring barley (Fig. 2, b). Conversely, the shoot weight of oilseed rape and lupine on the compacted area increased. Decreasing effects are often explicable in terms of the inability of the hampered roots to supply the shoot with water or nutrients (Taylor & Brar, 1991). In many studies both the height and weight of shoots were reduced in strong soils when compared to those grown in weak soils (Atwell, 1990; Lowery and Schuler, 1991). However, other studies conclude that shoot growth was not affected by soil strength (Oussible et al., 1992) and was even promoted in strong soils compared with weak soils (Iijiema et al., 1991). Reintam et al (2006) also detected that there was only a slight decrease in root mass (in upper 15 cm soil layer) and shoot mass (by 10%) in the yellow lupine growing on the most compacted area, as compared with control.

CONCLUSIONS

Soil compaction adversely affected soil penetration resistance and soil bulk density under narrow–leafed lupine, spring oilseed rape and spring barley. Soil compaction decreased the root and shoot weights of spring barley and there was a strong negative linear correlation between the biomass and soil bulk density. The positive correlation between root and shoot mass and soil bulk density was detected by growing narrow-leafed lupine on compacted soil. Soil compaction had positive effect on the roots and shoots mass of oilseed rape. Narrow–leafed lupine and oilseed rape have the ability to penetrate strong and compact soil and without negative impact on the biomass. Additional experiments are needed to verify the current results and expand studies on different soils and cultures.

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