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Influence of subsoil compaction on soil physical properties and on growing conditions of barley

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Abstract. In 1997, 1998 and 1999 field experiments were carried out to investigate the effect of soil compaction on the soil properties and on the composition of phytocoenosis in barley fields. The field trials were completed on sandy clay Haplic *Stagnosol* (by WRB 2006) which is quite characteristic for Estonia, and sensitive to compaction. The results of the investigations at Eerika (near Tartu, Estonia) demonstrated a strongly negative effect of subsoil compaction on soil characteristics and were associated with the number of compaction events carried out. Furthermore, the amount of aggregates of the 0.25–7 mm decreased by 14.4%. The penetration resistance in subsoil was 1.7–2.6 times higher compared with the non-compacted area. The results indicated that adaptability of weeds on the soil degraded by excessive compaction was remarkably strong, thus increasing their competitiveness in association with barley, especially under conditions unfavourable to the plants.

Key words: soil compaction, penetration resistance, water content, barley, weeds

INTRODUCTION

Soil compaction is one of the most important factors responsible for physical degradation of soil. The use of heavy agricultural machinery with a mass often exceeding 10–30 Mg leads to soil compaction which is not only more frequently described in the literature but which also persists for many years, causing extensive and long lasting soil degradation, especially in the deeper soil layers. Soil compaction affects all soil properties and processes, sometimes positively but mostly negatively: in a compact dry soil the main problem is high mechanical resistance to root growth; in a compact wet soil – poor aeration (Håkansson, 1993). Reduced soil porosity, higher penetration resistance and bulk density, caused by destruction of soil aggregates, are the results of compaction (Håkansson et al., 1989). Mechanical influence considerably affects soil physical and chemical properties, air and water fluxes, as well as moisture and nutrient parameters. A soil with poor physical condition resulting from compaction has smaller pore spaces and soil particles which are packed closer together. Excessive soil compaction impedes root growth and therefore limits the amount of soil explored by roots (Van Lynden, 2000).Soil compaction causes stress to the plants: the intracellular pH increases and inhibits plant nutrient uptake and through that decreases yield (Kuht & Reintam, 2004;Reintam & Kuht 2004;Kuht et al., 2003). Soil structure influences its water movement and retention, erosion, crusting, nutrient recycling, root penetration and crop yield. Disturbance of soil structure through compaction or tillage can result in the rapid recycling of nutrients, crusting, reduced water and air availability to roots (Bronick & Lal, 2005).

The aim of this work was to investigate the effect of soil compaction on specific soil properties and on growing conditions of barley.

MATERIALS AND METHODS

Characteristics of trials area. Location: Southern Estonia, Tartu County, Eerika Experimental station of the Department of Field Crop Husbandry of the Estonian University of Life Sciences. The experimental area is situated near Tartu, to the west (58°23´N and 24°44´E) on the glacial plain dismembered by ancient valleys.

Classification: *Haplic Stagnosol* (WRB 2006). Some soil characteristics of the field trials area are as follows: average depth of A horizon 27 cm: humus content, 1.88 %; pH_{KCl}6.12 and C:N 10.7. *Stagnic* transition layer between adjoining layer Eg and Btx. In early spring and late autumn the stagnation (*stagnic* properties) of surface water can be seen at the transition of the Eg and Btx horizon. These soils are sensitive to compaction as well as to surface chemical contamination (Reintam, 1996).

The field trial was established in 1997 using a heavyweight tractor with a special loader weighing about 2.5 Mg attached in front. Total tractor weight was 17.4 Mg. The method used was a multiple tyre-to-tyre passing. The tractor passed over the field correspondingly two, four and six times by single tyres (23- 1/18- 26 carrying 3.7 Mg or 37 kN). Soil water content at compaction time was 21.6% (by weight) for 0–10 cm, 22.1% 10–20, 20.0% 20–30 cm and 21.4% 30–40 cm.

Barley (*Hordeum vulgare* L.) was sown by drilling barley (crosswise to compaction variants) with 450 germinating seeds per m^2.

Penetration resistance was measured with a cone penetrometer (cone angle 60º, stick diameter 12 mm) in every 5 cm layers down to 45 cm in six replications. The soil volume moisture was measured from the same samples.

Soil aggregate composition of the investigated areas was determined by dry sieving through 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mm sieves. The soil was air-dried before sieving, and the amount of soil on every sieve weighed.

Data regarding the content of the plant community was obtained from taking vegetation samples (plant shoots) from a plot of 0.25 m^2 (n=4). The various types (barley and different weed species) were determined, counted, measured, weighed and dried.

RESULTS AND DISCUSSION

The average soil hardness in different depths of subsoil (25–40 cm) was by 1.4–2.0 times higher after double compaction, 1.5–2.1 times after four wheeling events and 1.7–2.6 times after six compaction events, compared with the non-compacted variant (Fig. 1). The upper limit of soil hardness which the roots are able to penetrate, varied from 0.3 and 1.4 MPa, the wide range reflecting differences among species (Whalley et al., 1993). Soil penetration resistance influenced plants and their root growth through plant hormones, therefore the growth is inhibited even if the water, air and nutrients are not limited (Tardieu, 1994).

Remarkable changes due to the soil compaction of soil volumetric water content became evident in 10–20 cm soil depth, where significantly lower water content was detected by six times compacted soil with insufficient porosity compared to uncompacted porous soil (Fig. 2).

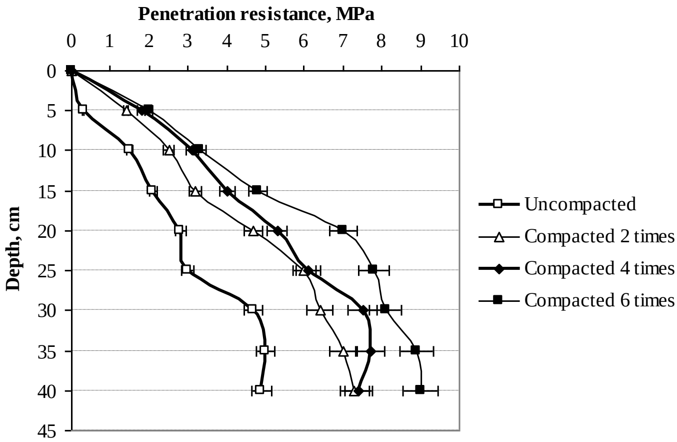

Figure 1. Soil penetration resistance after compaction depending on different rates of compaction in earing phase of barley. Bars denote 0.95 confidence intervals.

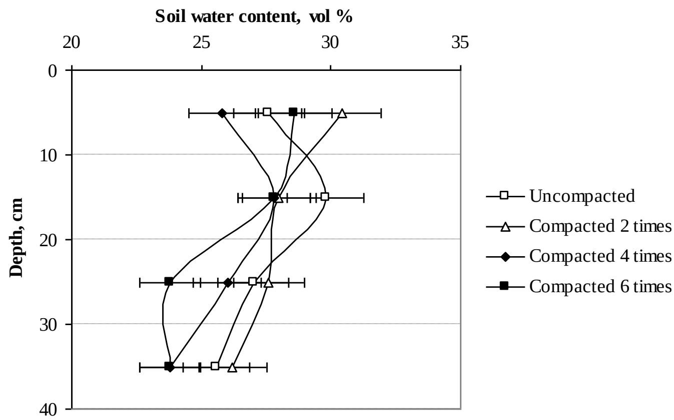

Figure 2. Soil water content (vol %) depending on different rates of compaction in earing phase of barley. Bars denote 0.95 confidence intervals.

The bulk density of the subsoil on the area that had been wheeled six times by a heavy tractor had increased by 0.11–0.24 Mgm^{-3} compared to the area that had not been compacted (Kuht & Reintam, 2004). This, in turn, caused the significant decline in general porosity of the soil; the negative aspect of additional compaction was revealed in a decline in the aeration porosity of the soil.

The water potential at sampling ranged between pF2.3 and 2.5; in uncompacted and two times compacted soil pF2.3, in four times compacted soil pF2.4 and in six times compacted soil pF2.5. Data in Figure 3 showed that the soil compaction had a significant effect on soil crumbling. The fractional condition of the un-compacted variant (content of soil aggregates of 0.25–7 mm was 40%) can be considered satisfactory. Double compaction diminished the content of the fractions to 28% and six times compaction to 14.4%. Soil structure refers to the size, shape and arrangement of solids and voids, continuity of pores and voids, their capacity to retain and transmit fluids and organic and inorganic substances, and ability to support vigorous root growth and development (Lal, 1991).

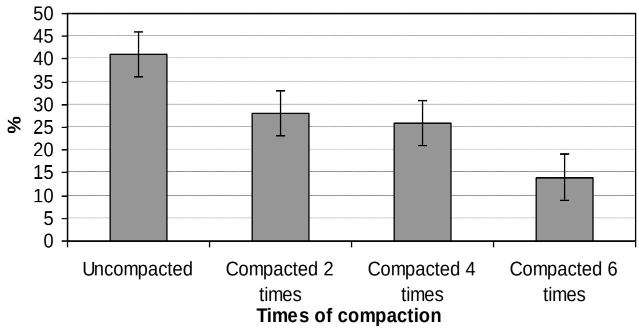

Figure 3. Effect of soil compaction on the amount of 0.25–7 mm soil aggregates as a function of wheeling frequency. Bars denote the 0.95 confidence intervals.

These numerical values, particularly the last, are not satisfactory, as further proved by a reduced barley yield. The spread of plant roots is prevented by soil that is too hard. Relatively weak barley roots could not penetrate the compressed soil and thus did not obtain water and nutrients, as capillaries of compressed soil contain little water and have insufficient capability of inflow. The existence of macropores in soil is essential for root growth: they are greater in diameter than roots, providing a chance for undisturbed root growth and the ability to evade the zone with high mechanical impedance (Hatano et al., 1988).

Although the dry mass of plants on the superficial unit decreased on higher bulk density, the relative importance of weeds in phytocoenosis increased by 13.7–32.4% (Table 1).

Table 1. The share of components of phytocoenosis (%) on different levels of soil compaction on the basis of dry mass.

Species of plants	Times of compaction			
	Uncompacted	Two times	Four times	Six times
Matricaria inodora L.	14.2	18.7	18.7	17.6
Spergula arvensis L. (Coll.)	2.1	10.7	8.6	10.8
Chenopodium album L.	2.5	1.1	1.0	1.0
Other annual weeds	1.5	4.0	4.8	13.1
Perennial weeds	0.1	0.8	1.1	10.5
Barley (*Hordeum vulgare* L.)	79.5	64.7	65.8	47.1

Annual weeds, *Spergula arvensis* L. and *Matricaria inodora* L. withstood the compaction quite well, and their importance increased. We can state that in addition to impairing soil characteristics, compaction also decreases the competitive advantages of grain crops compared to weeds, assimilation of several important nutrients and will also make weakened plants more susceptible to diseases (Kuht et al., 2000).

Compaction may create better growth conditions for weed seeds by improving the physical characteristics of the soil. The number of germinated weed seeds in the field depends on their density, vitality and local soil conditions (Wilson et al., 1985).The share of *Matricaria inodora* L. in the plant community remained stable (14.2%–18.7%) against a background of every bulk density. *Elytrigia repens* L. had the highest competitiveness in compacted soil, *Chenopodium album* L. – the lowest (Kuht et al., 2000). The obtained results indicate that the adaptability of weeds on the soil degraded by excessive compaction was remarkably better than on non-compacted fields, thus increasing their competitiveness in association with barley, especially in unfavourable conditions for the plants (Kuht & Reintam, 2000).

Laboratory experiments indicated that the low total porosity and poor aeration at low capillary water-retaining capacity of compacted soil inhibited the growth of vegetative parts, especially the roots of barley. The gutta-diagnostic determination after the germination of barley in dense soil showed a low flux of water to the roots and/or uptake. This was revealed in the lower percentage of guttation water that was pressed out of hydathodes by the root pressure of plants, forming drops on the surfaces of plants (Kuht & Reintam, 2001). Relatively weak barley roots cannot penetrate compressed soil and thus fail to obtain the necessary water and nutrients, as capillaries of compacted soil contain little water and have insufficient capability of inflow (Kuht, et al., 1999). Many weed species are well able to develop their root systems in compacted soil. In the areas of higher than optimum density the share of barley plants diminished continuously, as the weeds were more adaptive. Barley lost more than 50% of its dry mass on very dense soils, whereas weeds could even increase their dry mass, due to reduced dominance of the grain. Yield losses amounted to 5% from one pass to 90% from several passes (Arvidsson, 1999). Our long term experiments show that excessive soil compaction decreased the quantity of grain shoots, their phytomass, and grain yield more than 80% (Reintam et al., 2009).

CONCLUSIONS

Excessive compaction of soil had the worst effect on subsoil properties. Soil compaction had a significant effect on soil crumbling. The content of the 0.25–7 mm soil aggregates diminished to 14,4 %. Penetration resistance in subsoil was a maximum of 1.7–2.6 times compared with the uncompacted area. Lower water content was detected by six times compacted soil with insufficient porosity compared with the uncompacted area. Dry mass of plants on the superficial unit decreased on higher bulk density: the relative importance of weeds in phytocoenosis increased by 13.7–32.4%. In the compacted areas the share of barley plants diminished continuously, as the weeds were more adaptive.

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