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Soil compaction effect on soil physical properties and the content of nutrients in spring barley (*Hordeum vulgare* L.) and spring wheat (*Triticum aestivum* L.)

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Abstract. The long-term use of heavy-weight agricultural machinery has caused extensive and lasting phenomena of degradation, especially in the basic layer of soil. The influence of soil compaction by heavy tractor on spring wheat and barley has been investigated. The field trials were completed on a Stagnic Luvisol (WRB), quite characteristic of Estonia but sensitive to compaction. The results of soil measurements demonstrated a strongly negative effect of wet soil compaction on soil physical characteristics and were in good connection with the number of compactions carried out. In order to find out the nutrient assimilation ability of plants on these soils, the amount of elements (N; P; K; Ca; Mg) in the dry matter of spring wheat and spring barley was determined. It appeared that the nitrogen uptake ability of spring wheat plants decreased almost by 30% and that of barley by 40% in the case of heavy soil compaction (4 and 6 times). As a result of compaction, the content of potassium and calcium in barley and spring wheat was decreased as compared with the non-compacted area.

Key words: soil compaction, soil properties, spring barley, spring wheat, nutrients

INTRODUCTION

The long-term use of heavy-weight agricultural machinery has caused extensive and lasting phenomena of degradation, especially in the basic layer of soil. Soil compaction, as used here, implies dynamic densification by use of moved loads on the soil mass. Compaction is the process of densifying a soil mechanically and influencing thus physical properties of the soil. Physical properties influence all biological and many chemical processes in the soil. Root function may also be impaired by soil compaction. Research studies conducted in northern latitudes show that the effect of severe subsoil compaction may affect crop yields for years and show a similar trend of initially lower yields following compaction with axle loads of 10 Mg ha^{-1} or more. The data from Waseca suggests that there is sufficient "residual" subsoil compaction to reduce crop yields in years where there are environmental stresses (Voorhees et al., 1986). The effect decreases over time, and yields on compacted soil approach the yields on non-compacted soil after two to seven years, depending on the soil and climate. The impact of soil compaction on the uptake of nutrients has been observed nine years later after the compaction (Alakukku & Elonen, 1996).

Mechanical resistance and poor aeration may restrict root growth, which especially affects the uptake of nutrients (Lipiec & Stepniewski, 1995).

The basis of the research work were field trials performed in different years and weather conditions in sections of the vegetation period and study trips made to production fields. The data gathered enable us to establish the direct and after-effect of soil compaction on soil characteristics and the dynamics of their changes, the composition of phytocoenose and the productivity indices of different plant species. It also enables us to study their interaction on the assimilation of nutrients and resistance to plant diseases on the background of different rates of soil compaction.

The aim of this work was to investigate soil compaction effect on soil properties and on nutrient uptake by spring barley (*Hordeum vulgare* L.) and spring wheat (*Triticum aestivum* L.).

MATERIALS AND METHODS

The field trials were completed on a Stagnic Luvisol (WRB), quite characteristic of Estonia but sensitive to compaction.

The field trial was established in 1997 with a heavy-weight tractor (total weight 17.4 Mg); the method used was a multiple tyre-to-tyre passing. The tractor passed the field two, four and six times, correspondingly, by single tyres. On such a background wheat and barley were sown (450 germinating seeds per m^2). No mineral fertilisers or herbicides were used.

The chemical soil properties of the plough layer (0–25 cm) were as follows: pH_{KCl} – 6.12, humus content – 1.88%, C – 15.0 ± 0.6 Mg ha^{-1}; N – 1.4 ± 0.1Mg ha^{-1}; C/N – 10.7; P – 126 ± 21 mg kg^{-1}; K – 140 ± 10 mg kg^{-1}; Ca – 1450 ± 152 mg kg^{-1}; Mg – 81 ± 7 mg kg^{-1}; Ca/Mg – 18.

The soil and plant samples were taken in the earing phase of barley and wheat. Soil bulk density was measured with 500 cm^3 cylinders from two layers: 25–35 cm and 45–55 cm. For the same layers, the soil porosity was measured. Soil penetration resistance was measured with a cone (60º) penetrometer from each 5 cm layer up to 40 cm. Plant samples (plot of 0.25 m^2 in four replications) from each variant were taken for measuring their nutrient content and biomass. For the chemical analysis of plants (stalks, leaves and ears together), the Kjeldhal method was used to determine the content of total nitrogen. The content of phosphorus was determined calorimetrically on the basis of yellow phosphorus-molybdatic. The potassium content was determined by a flame photometer in a dipping solution diluted with distilled water.

To indicate changes in the nutrient content due to compaction, the relative contents were calculated. The nutrient content of the control variant was taken as 100% and, on the basis of this, the relative contents for other compaction variants were calculated.

The research data were statistically evaluated by an analysis of variances (ANOVA) to process the data collected. The factors were the times of compaction and the species (barley and wheat). To compare differences between the values, the standard Student's *t*-test was used and the least significant differences (LSD) at the significance of $P < 0.05$ were found.

RESULTS AND DISCUSSION

Influence of soil compaction on soil properties

The studies in Estonia showed that the compaction of a soil influenced the properties of both the epipedon as well as the subsoil. As a result of pressure caused by movement, every passing of the heavy tractor changed numerical values of the physical characteristics of the soil (density, porosity, hardness).

With axle loads greater than 6 Mg, compaction penetrated to depths > 40 cm, where it was very persistent or even permanent (Håkansson & Reeder, 1994).

Taking into account optimum parameters of numerical indices on field crops, it is possible to estimate the properties of compacted soil from the point of view of plant growth conditions. The results of the soil measurement demonstrated a strongly negative effect of wet soil compaction on soil characteristics and were in good correlation with the number of compactions carried out. The upper limit of optimum soil bulk density for grain was 1.40 Mg m^{-3}. At higher bulk density values, the yield of grains started to decrease. The investigation data indicated that soil conditions after the sowing met these demands in the upper soil layer of the uncompacted variant (Table 1). The indices of bulk density in the compacted soil were unfavourable in all measured soil depths as a result of the compaction of excessively wet soil. Earlier investigations have indicated that a relatively low pressure (2.5 kg cm^{-2}) on a sandy clay soil raised the density by ca 0.1 g cm^{-3} for every additional 10% of soil moisture (Vipper, 1979).

The bulk density of the plough layer increased by 0.16–0.26 Mg m^{-3}, compared with the non-compacted area, the total porosity of the topsoil decreased by 37.1–51.7%. It appeared that in the case of strong compaction, the pores pressed tight would prevent water from flowing to the zone reached by plant roots.

Concerning soil compression, it is shown (Table 1) that each subsequent compaction further compressed the subsoil and deteriorated the physical properties of the soil which are essential for the growth of plants. This table shows that the bulk density of the subsoil on the area overridden six times by a heavy tractor had increased by 0.11–0.24 Mg m^{-3}, compared to the uncompacted area. This, in its turn, caused a significant decline in the general porosity of the soil. The remarkably negative aspect of additional compaction was revealed in a remarkable decline in the aeration porosity of the soil.

In the case of average compaction during a dry year, the capillary water supply was better than on the background with less capillaries and no compaction, and the productivity indices were also better. The fractional condition of the soil in the plough layer of the non-compacted area (content of aggregates of 7–10 mm 49.6%) can be considered satisfactory. Double compaction diminished the content of the fractions to 35.5% and six-time compaction to 14.4% (Kuht et al., 1999).

Table 1. Some physical characteristics (averages, n = 6) of soil on different level of soil compaction.

	Characteristics	Depth, cm	Non-compacted	Number of passes		
				2	4	6
1	Bulk density, Mgm^{-3}	5–15	1.38	1.69	1.71	1.72
		20–35	1.58	1.74	1.81	1.82
2	General porosity, %	5–15	53.5	38.2	36.0	35.3
		25–35	41.4	34.4	31.7	30.6
3	Capillary porosity, %	5–15	22.3	24.1	25.8	25.5
		25–35	29.7	25.4	23.5	22.2
4	Aeration porosity, %	5–15	23.2	10.3	10.2	9.8
		25–35	11.7	9.0	8.2	8.6

The remarkably negative aspect of additional compaction was revealed in the marked decline in the aeration porosity of the soil.

As we can see (Fig. 1), average soil hardness in different layers of the subsoil (25–40 cm) was higher by 1.4–2.0 times in the case of double compaction, by 1.5–2.1 times in the case of four- time compaction and by 1.7–2.6 times in the case of six-time compaction, compared with the non-compacted area. The upper limit of soil hardness, which the roots are able to penetrate, varied between 0.3 and 1.4 MPa, the wide range reflecting differences among species (Whalley et al., 1993).

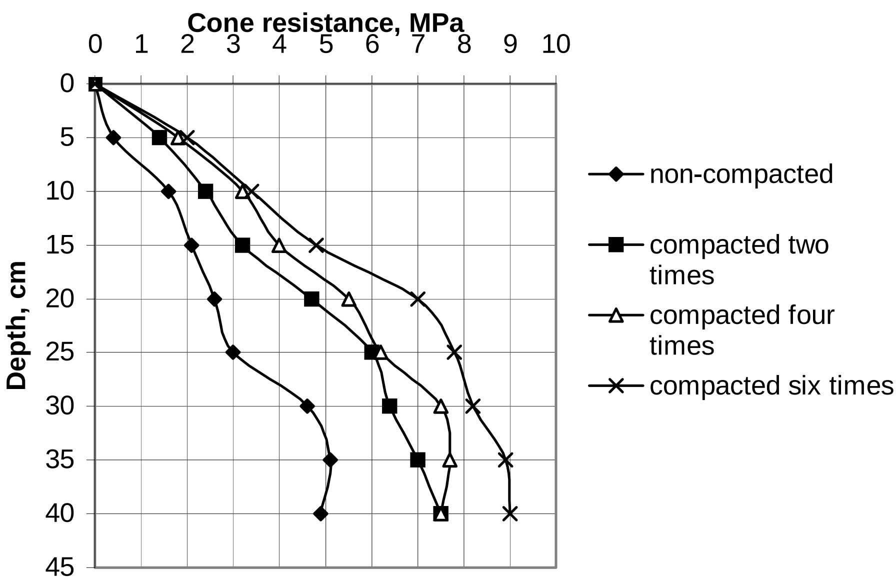

Fig. 1. Soil penetration resistance after compaction.

If plants are already stressed for water, subsoil compaction may add to the stress by limiting the growth of plant roots to additional water. If plants are growing in soils that have aeration problems due to high water content, subsoil compaction will slow drainage and could result in an anaerobic root environment that limits nutrient uptake (DeJong-Hughes et al., 2001).

Influence of soil compaction on the nutrient content

The results of the statistical analysis of variance showed that it was the individual characteristics of the studied plant species that had the greatest influence on their assimilation of nutrients, giving reliable results in the cases of nitrogen, phosphorus, potassium, calcium and magnesium contents in the plants (Fig. 2).

Poor aeration reduces the mineralisation of organic matter, which can reduce the mineralisation of nitrogen and other nutrients. The physical-chemical properties of subsoil influence the uptake of mineral nitrogen and other nutrients from the subsoil so that if the elongation of roots in the subsoil is inhibited by poor soil properties, mineral N accumulating in the subsoil cannot be absorbed and may be leached out (Saito & Ishii, 1987). Laboratory experiments indicated that the low total porosity and poor airing at low capillary water retaining capacity of compacted soil inhibited the growth of barley roots (Kuht et al., 2000).

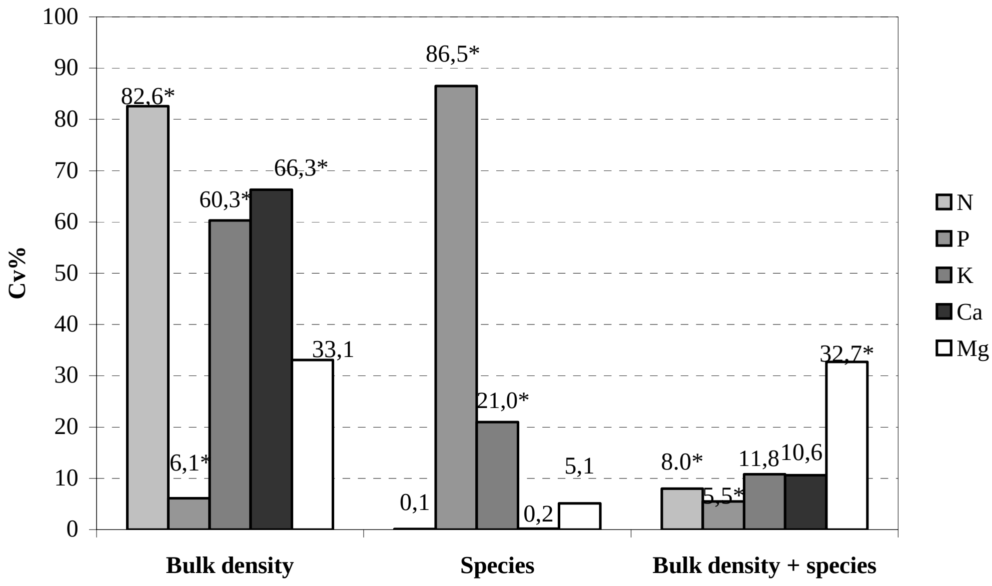

Fig. 2. Direct and co-effect of trial factors on the nutrient content of barley and wheat (Cv –changes caused by trial conditions; (LSD $_{95}$).

Table 2. Impact of soil compaction on the nutrient content in dry matter of barley (*Hordeum vulgare* L.) and wheat (*Triticum vulgare* L.).

Ele-ment	Species	Number of passes				LSD_{95}
		0	2	4	6	
N%	Barley	1.32	1.20	0.82	0.79	0.38
	Wheat	1.20	0.89	0.84	0.88	
P%	Barley	0.44	0.25	0.32	0.29	0.37
	Wheat	0.17	0.16	0.16	0.16	
K%	Barley	0.57	0.37	0.31	0.33	0.23
	Wheat	0.36	0.27	0.26	0.34	
Ca%	Barley	0.32	0.25	0.18	0.17	0.23
	Wheat	0.31	0.30	0.27	0.10	
Mg%	Barley	0.12	0.12	0.11	0.12	0.19
	Wheat	0.18	0.14	0.08	0.11	

As for grain crops, very strong compaction carried out several times decreased the assimilation of nitrogen two times both for wheat and barley. As a result of six-time compaction, the content of nitrogen, phosphorus, potassium and calcium in barley and in spring wheat (Table 2; Fig. 3 & 4) was decreased 1.7; 1.5; 1.7; 1.9 and 1.4; 1.1; 1.3; 3.0 times, respectively, compared with the non-compacted area. The lower concentration of nitrogen could have been caused partly by denitrification. The Mg assimilation of wheat was also impaired. A decrease in K assimilation was also noticed. No relations between the assimilation of P and compactions were noticed.

Still, such differences were hardly noticeable and, therefore, when speaking in averages in section of years, every compaction increased the problems plants had with water and nutrient supplies. Nutrients are transported to plant roots in soil by two mechanisms – mass flow and diffusion (Barber, 1962).

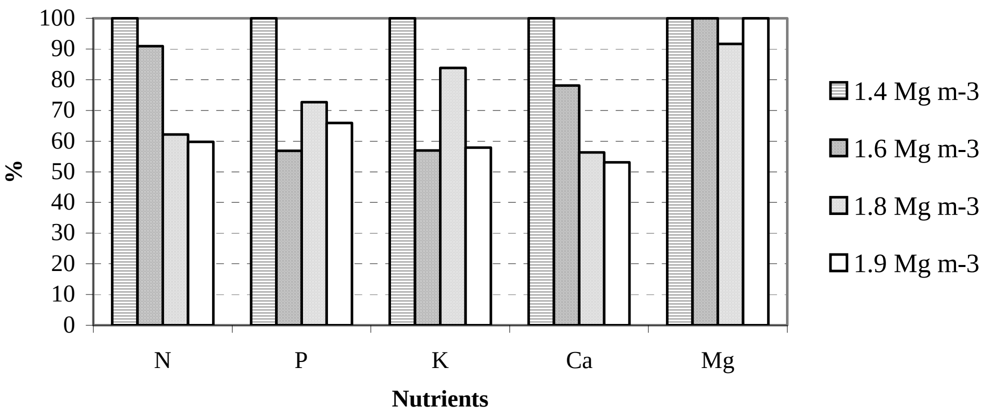

Fig. 3. Relative nutrient content of spring barley (*Hordeum vulgare* L.), depending on the average bulk density (Mg m^{-3}) of the compacted soil plough layer (average of three years).

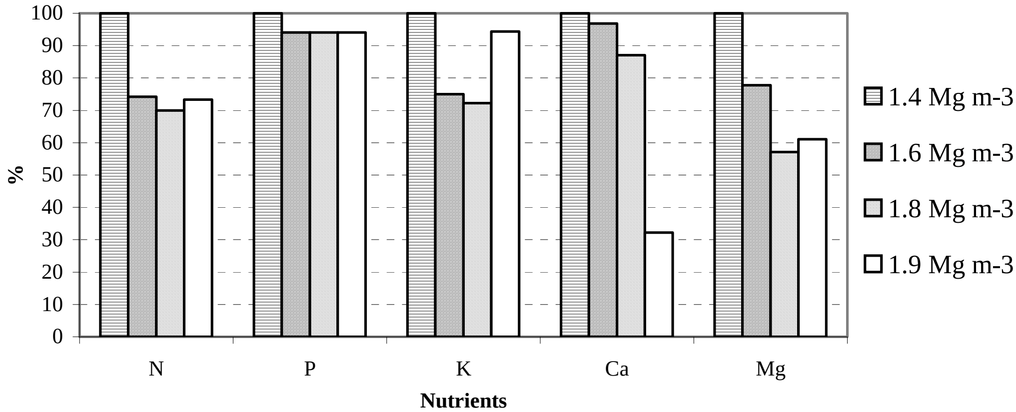

Fig. 4. Relative nutrient content of spring wheat (*Triticum aestivum* L.), depending on the average bulk density (Mg m^{-3}) of the compacted soil plough layer (average of three years).

The lower concentration of nitrogen could have been caused partly by denitrification. In 1980 (Voorhees et al., 1985), the percentage of protein in wheat yield was significantly lower on the spring-compacted (12.9%) and fall- and spring-compacted (12.7%) treatments, compared to the non-compacted treatment (13.6%). The lower concentrations of phosphorus and potassium were probably caused by restrictions in root development and/or root function (Arvidsson, 1997). One factor that favours development of calcium deficiency in plants is the restriction of root volume (Aloni, 1986). Magnesium assimilation of wheat was also impaired. A decrease in potassium assimilation was also noticed. With spring wheat, no relations between the assimilation of phosphorus (by barley magnesium) and compactions were noticed. The magnesium content of spring wheat declined as a result of soil compaction by 22.2–42.9 per cent, compared to the control.

CONCLUSIONS

Field overriding with a 17.4 Mg tractor affected all soil properties in the plough layer and also in the subsoil of all compaction variants. The highest negative effect on the soil and plants was caused by 6-time compaction. Soil compaction affected more spring barley than spring wheat nutrient uptake as wheat is more tolerant to dense soil than barley. The final effect of soil compaction on plant productivity depends on the soil moisture at the compaction time and on weather conditions during the vegetation period. For that reason it is very important to observe the right tillage time during a growing season.

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