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The Impact of Deep Rooted Plants on the Qualities of Compacted Soils

*Jaan Kuht and Endla Reintam**

ABSTRACT

Deterioration of arable soil properties as a result of the use of heavy agricultural machinery, improper cultivation and crop rotations have brought about the deterioration of soil quality and decline in crop yields. There is a wide amount of compacted soil in Estonia, while deep tillage to loosen compacted soil is expensive, energy consuming and cannot be applied to large areas. The effects of soil loosening by means of biological factors are more durable. Data to verify the given assumption have been collected in the course of field and laboratory experiments carried out on sandy clay soil (Stagnic Luvisol) at Eerika (County of Tartu, Estonia). The purpose of the present research was to determine the suitability of the use of plants with various types of root systems to improve soil quality and increase the durability of the positive effects on the physical properties of degraded soils. The measurements taken during the experiment showed that the horizontal and vertical roots of Canadian thistle (*Cirsium arvense* (L.) Scop.) had remarkable capacity to penetrate deep compaction caused by heavy tractor traffic. The average penetration resistance of soil in the fields where Canadian thistle was planted was 10–35% lower in epipedon and 15–25% lower in subsoil compared to the fields where only grain was grown. The plants induced the formation of biopores in soil, thus, creating a loosening effect. It was the creeping roots that spread horizontally and vertically in deep soil that produced the loosening effect. The deep and extensive root systems of Canadian thistle made the amelioration of soil properties possible – by increasing stable porosity and aeration in subsoil.

INTRODUCTION

Soil compaction affects all soil properties and processes, sometimes positively but mostly negatively. The main problem in compact dry soil is high mechanical resistance to root growth, while the major problem in compact wet soil is poor aeration (Håkansson, 1993; Håkansson et al., 1989; Wood et al., 1991). Numerous sources of literature refer to the economic and environmental damages of soil compaction caused by anthropologic factors. Van Ouwerkerk and Soane (1994), concluding the results of the International Soil Tillage Research Organization (ISTRO) Melitopol (Ukraine) workshop, have pointed out a number of trends in the latest studies: 1) environmental consequences of soil compaction on a global scale; 2) physical effects of soil compaction and their consequences on root development, runoff etc.; 3) chemical effects of soil compaction; 4) effect of soil compaction on soil biota and consequences on the physical and chemical properties of soil. It is first and foremost the biota of soil and the growing plants that suffer the most as a result of the negative biological effects of soil compaction. However, researchers have paid too little attention to reverse studies – to the impact of biological organisms on the properties of compacted soils. So far, most of the studies have been confined to their impact on the plough layer (epipedon) (Bakken et al., 1987; Kooistra et al., 1992; Lindstrom and Voorhees, 1994).

The impact of biological organisms on subsoil has primarily been studied as a phenomenon accompanying the former. While in the subsoil that is not cultivated the negative effects of compaction become permanent. One should pay greater attention to studies aimed at improving the properties of subsoil, especially those utilizing natural and biological methods.

In 1989 – 1994, a group of Estonian researchers developed and conducted a field trial to study the impact of deep and exuberant rooted plants on the properties of compacted soil. Although the crops used in the field trial (*Galega orientalis* L.*, Brassica napus* L. *and Trifolium pratense* L. (coll.)) did not eliminate all the deformations of excessively compacted soils, the results achieved were still promising (Kuht and Lopp, 1997).

Further studies were carried out to study the potential of using well-established roots of local natural or semi-natural plants to improve the properties of degraded soils. The measurements conducted by the authors of this paper in the summer of 1997 showed that the creeping roots of Canadian thistle (*Cirsium arvense* (L.) Scop.) had great capacity to penetrate deep compaction (Kuht and Reintam, 1998). However, one should very careful examine the ways of using Canadian thistle as a pedocentrically useful plant to improve the properties of degraded soil, to avoid any subsequent problems of controlling the thistle (bearing in mind the fact that Canadian thistle is a very troublesome weed).

Since the amount of compacted soil is large in Estonia, there is a need for a low-cost approved method for the farmers to restore their compacted soil.

METHODS

The experiments were conducted on Stagnic Luvisol (FAO/ISRIC; sandy loamy soil on loamy moraine) at the research station of the Department of Field Crop Husbandry of the Estonian Agricultural University. Stagnic Luvisol is

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the arable land in Estonia, of which 70 per cent is cultivated.

Since the subsoil of these soils is relatively compacted, periodically saturated conditions may occur when water forms ponds on the soil surface. These soils are sensitive to compaction as well as chemical contamination of the surface. Temporary excessive water is frequently complicating and hindering field works (Reintam, 1996).

The field trial was carried out using a heavy tractor (14,9 Mg). A special loader was attached to the front of the tractor with total weight of 2,5 Mg. The multiple tire-to-tire passing method was used. Each tire (23- 1/18-"6 carrying 3,7 Mg or 37 kN) of the tractor passed the field two, four or six times, respectively.

Canadian thistle plants used for the study were planted at the density of 9 plants per m^{-2}, to a depth of 15 cm, leaving 50 cm between each patch, on the following four types of soil: 1) non-compacted (control); 2) after 6 times of compaction (compacted in 1997); 3) compacted 3 times in the spring of 1998; 4) after 6 times of compaction (compacted in 1997) and 3 times of compaction in 1998. The fields of Canadian thistle were compared with the fields of barley that had been compacted in the same manner. A hydraulic penetrometer was used to measure the penetration resistance of soil (n=6).

By laboratory tests using an indicator method (Reppo, 1981; Reppo, 1977) the relative guttation (the exudation of water from leaves as a result of root pressure) was predicted. Following the general principles of the above-mentioned method, the graminaceous seeds were put into soil and grown at constant temperature (+23ºC) and high air humidity (99–100%). Water droplets (guttata) appeared on the seedlings in 48-hours time. It is clear that the intensity of gutta secretion depends on the physical conditions of soil (moisture, compaction). The soil was compacted in 500 cm^3 cylinders where ten seedlings were planted. The height of the plants was measured when barley (*Hordeum vulgare* L.) and spring wheat (*Triticum vulgare* L.) plants were three days old and Canadian thistle plants four weeks old. The amount of guttation water of barley and spring wheat was measured on three days.

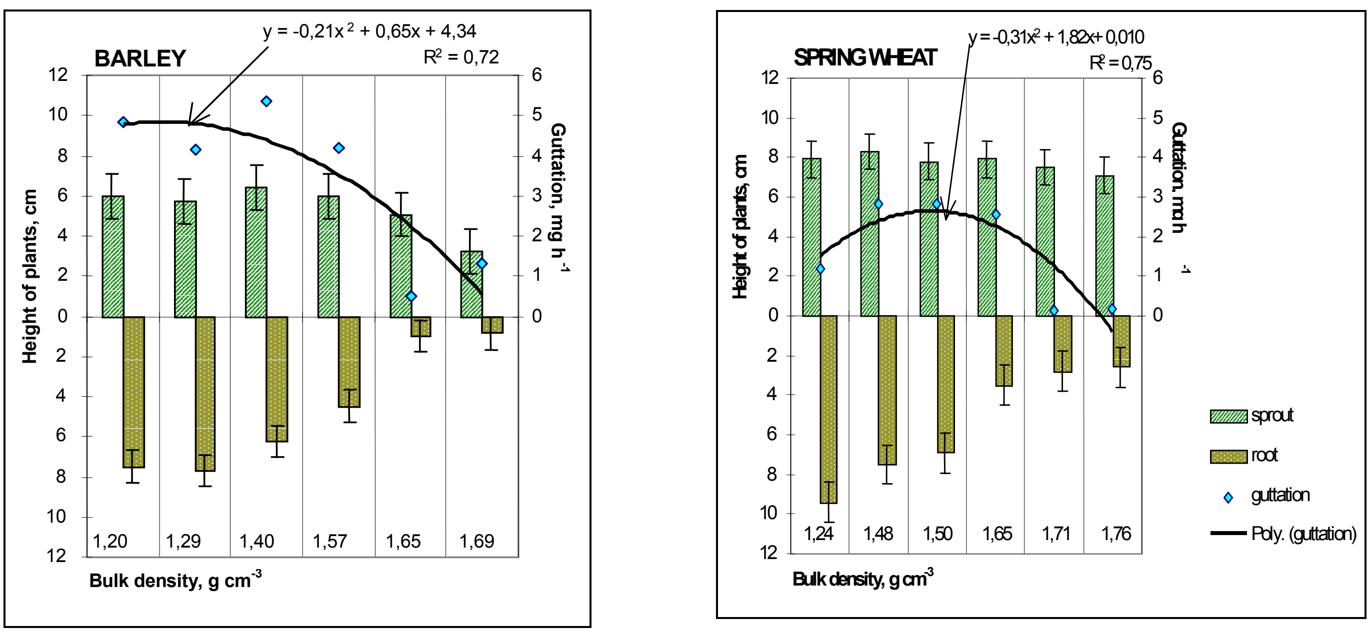
RESULTS AND DISCUSSION

Effects of compaction on soil and its impact on the growth of grain.

The conducted study showed that the compaction of soil influenced the properties of both epipedon and subsoil. The after-effect of compaction was clearly revealed in the uncultivated subsoil. Penetrometric measurement (at 18% water content in soil) showed that double compaction increased the average penetration resistance of subsoil in the 20–40 cm layer by 72.5%, four-times compaction - 84%, and six-times compaction - 113%, compared to the non-compacted areas. When axle loads of vehicles were increased, the compaction affected deeper soil layers.

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

The bulk density of the subsoil had increased in the area



Total porosity %	53.9	50.4	46.0	39.4	38.5	34.7	52.2	42.8	42.3	36.3	34.2	32.1
Aeration porosity %	25.3	18.7	9.7	4.3	1.9	0.0	23.9	7.1	6.3	0.0	0.0	0.0
Capillary water-retaining capacity %	23.9	24.6	25.9	22.4	22.9	20.5	22.7	24.1	24.0	23.6	23.0	21.8

Figure 1. Height of plants, length of roots and guttation of barley (*Hordeum vulgare* L.) and spring wheat (*Triticum vulgare* L.) on the different agrophysical characteristics of soil by laboratory experiments.

that had six times been driven across by a heavy tractor in the previous spring. The bulk density of the subsoil on the area that had six times been driven across by a heavy tractor increased by 0.09–0.13 g cm^{-3} compared to the area that had not been compacted. Further compaction by driving across for three more additional times, in addition to the six previous passes, increased density as much as 0.08–0.09 g cm^{-3}. This caused a significant decrease in soil porosity. The negative impact of additional compaction was revealed in a remarkable decline in the aeration porosity of the soil.The aggregate content of the soil in the plough layer of the non-compacted control (content of aggregates of 0.25–10 mm 49.6%) can be considered satisfactory. Double compaction reduced 0.25–10 mm aggregates to 35.5% and six times compaction to 14.4%. It is not desirable to have such a small percentage of aggregates for the 0.25–10 mm range. The given compaction level also decreased grain yield. Compared to barley, spring wheat suffered less as a result of compaction. Depending on the degree of compaction, yield declined by 27.6–68,4% and 38.4–87.0%, respectively, compared to the yield in non-compacted fields.

The experiments showed that the roots of spring wheat developed somewhat better in the compacted soil compared to the roots of barley (Fig. 1). At the same time, the study of guttation after the germination of spring wheat in dense soil (over 1.4 g cm^{-3}) showed a somewhat lower assimilation of water in soil. This was revealed in the lower percentage of guttation water that was pressed out of hydatodes by the root pressure of plants, forming drops on the surfaces of plants.

Additionally, it turned out (Fig. 1) that the low total porosity and poor aeration at low capillary water retaining capacity of compacted soil inhibited the growth of vegetative parts and the roots of both grain species. Grain plants developed weak roots in compacted soils. Microorganisms of rhizosphere influence the availability of plant nutrients, root growth and plant nutrients (Marshner, 1997).

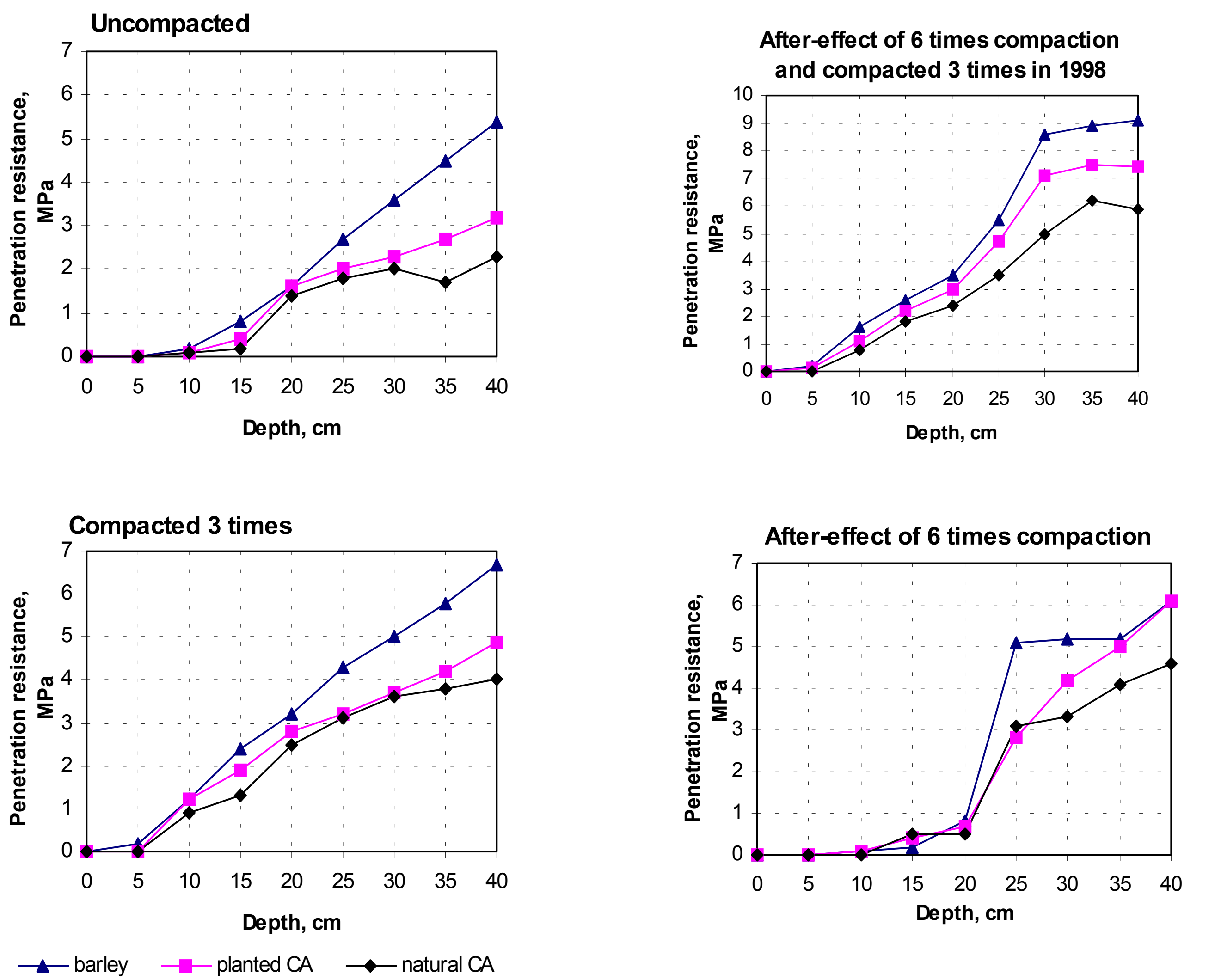
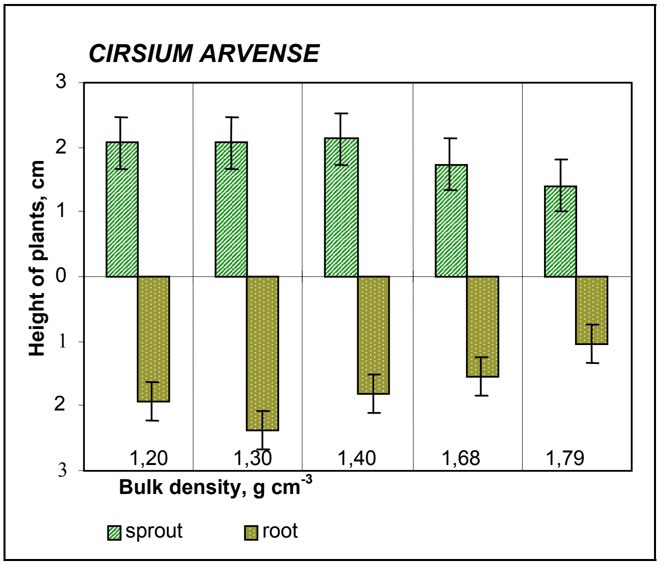


Figure 2. Effect of barley (*Hordeum vulgare* L.), planted Canadian thistle (*Cirsium arvense* (L.) Scop.; *CA*) and natural Canadian thistle on the penetration resistance of compacted soil.

Table 1. Number of young plants of Canadian thistle (*Cirsium arvense* (L.) Scop.) in fall 1998 and in spring 1999 on the four variants of compaction (n=9)

Variant	Number of plants per m^{-2}			
	In fall 1998	Standard error ±	In spring 1999	Standard error ±
1. Uncompacted	8	3	55	8
2. Compaction by 6 passes in 1997*	4	0	59	5
3. Compaction by 3 passes in 1998	14	4	104	10
4. Compaction by 6 passes in 1997 and by 3 passes in 1998	12	3	88	6

- Soil is compacted by a 14.9 Mg tractor



Total porosity %	53.6	50.2	46.0	35.1	30.9
Aeration porosity %	26.3	20.6	9.7	3.1	0.0
Capillary water-retaining capacity %	22.7	22.7	25.0	19.0	17.7

Figure 3. Height of plants and root length of Canadian thistle (*Cirsium arvense* (L.) Scop.) on different agrophysical characteristics of soil by laboratory experiments.

As grain plants are not able to form a sufficient root system in compacted soil or create biopores in compacted soil, it is not possible to alleviate the consequences of compaction in subsoil by growing only grain.

Impact of Canadian thistle root system on properties of compacted soil

Canadian thistle is spread both by seeds and in a vegetative manner. It grows mostly in colonies and forms a strong root system, the principal mass of which is situated in the top 40 cm of soil. However, a single root can reach up to the depth of several meters. Horizontally spreading roots grow in layers and to all directions. They grow buds that develop into new plants, which have vertical roots that form their own lateral branches.

The study of the authors of the present paper carried out in 1997 on different types of soils (Dystric-Gleyc Podzoluvisol, Eutric Podzoluvisol, Calcaric Regosol, etc.) in Estonia showed that the average penetration resistance of soil in the fields with Canadian thistle was 10–35% lower in epipedon and 15–25% lower in subsoil compared to grain fields, depending on the tillage of the soil. The measurements were carried out in fields that had been compacted by heavy agricultural machinery (Kuht and Reintam, 1998).

The results of the field trials with Canadian thistle plants that had been planted to areas of different degree of compaction confirmed the capability of the thistle root system to improve the properties of compacted soils. In the area planted with Canadian thistle, the penetration resistance (with 20% water content in soil) declined considerably in all compaction variants compared to areas where only barley was grown (Fig. 2). Improved soil properties could be seen both in plough layer and subsoil at the end of the first year of growth. Penetration resistance declined by 18.5% in epipedon and 18.0% in subsoil in the fields compacted with six passes and three more passes in 1998, compared to the soil in barley fields. In the fields compacted for three times, the corresponding indicators were 21.7% and 36.8%, respectively, and for six times - 33.3% and 12.7%, respectively. Considerable reduction in the compaction of soil was also noted in the non-compacted field where Canadian thistle was grown compared to the barley field. The compaction of soil that had Canadian thistle growing for extended periods was even lower. It was extremely interesting to note that the number of young plants that developed from the buds of Canadian thistle roots was high in the areas of compacted soil at the end of the first and at the beginning of the second year of growth (Table 1). In the fall of 1998, there were 4–6 more young plants and in the spring of 1999, 33–49 more young plants in the compacted areas compared to the non-compacted area. The deepest horizontal roots of the planted thistle were located as deep as 26–29 cm. In all variants, the vertical roots reached as deep as over 0,5 m. In the first year, the Canadian thistle roots could vertically grow up to 1–2 meters, later up to 4–6 m long.

The results of laboratory experiments showed that the Canadian thistle roots were able to penetrate compacted soil with bulk density of over 1.7 g cm^{-3} already at the tillage stage (Fig. 3).

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). The number of seeds germinating is quite variable and depends on the density and viability of the seed bank and the environmental conditions of the soil (Wilson et al., 1985). The soil loosening effect of Canadian thistle can be attributed to the biopores formed by the roots. Biopores formed by the roots of the plants can be very stable and they are more resistant compared to biopores formed by earthworms (Mc Kenzie and Dexter, 1998a, 1998b). The biopores with the diameter of over 4 mm formed by alfalfa (*Medicago sativa* L.) tolerate the pressure of over 200 kPa (Blackwell et al., 1990). Dead plant roots increase the amount of organic matter in soil and thereby increase the resistance to compaction.

CONCLUSION

1. Excessive compaction of soil by heavy tractor (total weight 14.9 Mg) had negative effect on soil properties compared to non-compacted areas. The penetration resistance of subsoil increased by 72–113% depending on the degree of compaction.
2. Low total porosity and poor aeration at low capillary water retaining capacity of compacted soil inhibited the growth of grain roots. Grain was not capable of forming a decent root system in compacted soil. Thus, it was not possible for grain roots to alleviate the consequences of compaction in subsoil.
3. The results of field trials with Canadian thistle plants that had been planted on areas of different levels of compaction confirmed the capability of Canadian thistle root system to improve the properties of compacted soils. In the area planted with Canadian thistle, the penetration resistance declined considerably in all compaction treatments compared to the areas where only grain was grown.

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