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Response of different crops to soil compaction—Short-term effects in Swedish field experiments

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ABSTRACT

Soil compaction is generally regarded as negative for crop growth, although many studies show a curvilinear relationship between bulk density and crop yield. In the literature, there are few systematic studies of differences between crop species in their response to compaction. This study used results from short-term Swedish field experiments to analyse the sensitivity of different crops to compaction. The crops included were barley (*Hordeum vulgare* L.), horse bean (*Vicia faba* L.), oilseed rape (*Brassica napus* L.), oilseed turnip rape (*Brassica rapa* ssp. *oleifera* (DC.) Metzg.), oats (*Avena sativa* L.), peas (*Pisum sativum* L.), potato (*Solanum tuberosum* L.), rye (*Secale cereale* L.), sugar beet (*Beta vulgaris* L.), and wheat (*Triticum aestivum* L.).

In total 39 experiments were analysed, in two series with spring-sown crops and one with autumn-sown crops, all on soils loosened by mouldboard ploughing. The experiments included different levels of tractor traffic applied track-by-track at the time of seedbed preparation, and a control treatment with no traffic. Bulk density was determined after traffic and expressed as degree of compactness (DC), which is the bulk density in percentage of a reference density.

With moderate recompaction, wheat and barley showed a yield increase compared with untrafficked soil, while other crops showed little or no yield increase on average. Oats reacted more negatively to compaction than wheat and barley. Monocots generally had a higher optimum DC than dicots, but the differences were small. Yield losses at high DC values were greater for dicots, especially pea and horse bean crops, although for sugar beet and oilseed rape there was no clear difference compared with cereal crops.

1. Introduction

Soil compaction is generally regarded as a problem in agriculture, especially due to the effects on crop growth. A decrease in porosity leads to poorer aeration (McAfee et al., 1989) and reduced saturated hydraulic conductivity, while an increase in soil strength can reduce root growth (Boone and Veen, 1994). However, it is also widely recognised that recompaction of loosened soil can improve crop growth (Carter, 1990; Håkansson, 1990; Lindstrom and Voorhees, 1994; Lipiec and Simota, 1994; Arvidsson, 1998; Reichert et al., 2009). The mechanism for this yield increase is not clear, but it can probably be attributed to increased unsaturated hydraulic conductivity and improved root–soil contact (Håkansson, 1990; Kooistra et al., 1992; Veen et al., 1992). The transport of nutrients in the soil is also affected; compaction normally increases mass flow transport (Kemper et al., 1971) and the diffusion coefficient at a given gravimetric water content (So and Nye, 1989; Bhadoria et al., 1991). Voorhees (1987) found an increase in yield due to compaction during dry conditions and a decrease during wet conditions.

The yield response to different levels of compaction is often found to be parabolic (Lipiec and Simota, 1994; Håkansson and Lipiec, 2000), with an optimum at intermediate levels. To make results more comparable between soils, the bulk density can be expressed relative to a reference value, i.e. the bulk density obtained in a standardised procedure, such as a Proctor test or a uniaxial compression test (Riley, 1988; Håkansson, 1990; Lipiec et al., 1991; Da Silva et al., 1997).

The effects of compaction on crop yield have been studied in most agricultural crops, but there have been very few systematic studies concerning differences between crops in their response to soil compaction. Dicots are often considered more sensitive than monocots (Lindstrom and Voorhees, 1994). A review by Lipiec and Simota (1994) of crop responses in Central and Eastern Europe concluded that maize (*Zea mays* L.) and root crops such as sugar beet (*Beta vulgaris* L.) were among the most sensitive to compaction. Soybean (*Glycine max* L.), peas (*Pisum sativum* L.) and oilseed rape (*Brassica napus* L.) were more sensitive than

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small-grained cereals such as barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.).

In Sweden, a large number of experiments examining short-term effects of plough layer compaction on crop yield were carried out in the period 1969–1977 (Håkansson, 1990; Arvidsson, 1998). In most of these experiments barley was used as the test crop, but some experiments included several crops, to make it possible to compare the sensitivity of different agricultural crops to plough layer compaction. The results of this comparison are presented for the first time in this paper, the objective of which was to assess the sensitivity of different crops to soil compaction. This is done even though the experiments were carried out many years ago, since very few recent comparisons of this kind are found in the literature.

2. Materials and methods

2.1. Experimental design

One-year field experiments in a randomised block design with four replicates were conducted from 1969 to 1977. Traffic was applied with a tractor, run track-by-track to cover the soil surface uniformly. There were four treatments:

- A = No traffic.
- B = One pass track-by-track by a tractor with low tyre inflation pressure.
- C = One pass track-by-track by a tractor with moderate tyre inflation pressure.
- D = Three passes track-by-track by a tractor with high tyre inflation pressure.

A somewhat heavier tractor was used in treatments C and D compared with B, although the weight was low compared with that of tractors commonly used today. Average values of tractor weight and tyre inflation pressure for treatments B, C and D are given in Table 1. Seedbed preparation and sowing were carried out using a tractor with extended axles, leaving the central part of the plots to be harvested untrafficked apart from the experimental traffic. Before applying experimental traffic, all fields were mouldboard ploughed in autumn to a depth of 20–25 cm.

In experiments with Spring-sown crops, traffic was applied before appreciable drying of the central and deeper part of the plough layer after winter. Therefore, the water content in these parts of the plough layer was near field capacity (matric tension near 10 kPa). At the time of traffic, soil samples for determination of gravimetric water content were taken, in most cases from three layers: 0–5 cm, 5–12 cm and 12–20 cm. Within one week, before further appreciable drying and shrinking of the soil had occurred, bulk density and volumetric water and air content were determined from harrowing depth (about 5 cm) to the latest ploughing depth (about 25 cm), which was usually easily identified. This was done using a 0.5-m^2 frame hammered down past the base of this layer (Håkansson, 1990). Total volume, weight and gravimetric water content of the soil in the layer within the frame were determined, and after determining the particle density, the bulk density and volumetric water and air content were calculated. To obtain a reference bulk density, representative samples of loose soil from the ploughed layer was brought to the laboratory, and maximum bulk density obtainable in a 200 kPa uniaxial compression test was determined (Håkansson, 1990). The 'degree of compactness' (DC) (Håkansson, 1990), i.e. the bulk density in the field expressed as a percentage of the reference bulk density, was then calculated.

The experiments presented here comprised three series with different crops, Spring crops I (Table 2), Spring crops II (Table 3) and Winter crops (Table 4). They were carried out on mineral soils in different parts of Sweden with clay content ranging from 70 to 680 g kg^{-1} and organic matter content from 15 to 83 g kg^{-1}. No soil classification was made, but based on classification of similar soils, most can be classified as Eutric Cambisols (FAO-UNESCO, 1994).

The Spring crops I series included 13 experiments with barley, wheat, oats (*Avena sativa* L.) and peas (*Pisum sativum* L.), but not all crops were included in all experiments. Data on soil properties and crops grown are presented in Table 2. The Spring crops II series included 14 experiments with barley, oilseed rape, sugar beet, potato (*Solanum tuberosum* L.) and horse bean (*Vicia faba* L.). In some experiments, turnip rape (*Brassica rapa* ssp. *oleifera* (DC.)

Table 1
Average tractor weight and inflation pressure in front and rear tyres in treatments B, C and D in the Spring crops I, Spring crops II and Winter crops series of experiments.

	B	C	D
Spring crops I			
Tractor weight (kg)	1590	2980	3130
Inflation pressure, front (kPa)	70	90	190
Inflation pressure, rear (kPa)	50	90	190
Spring crops II			
Tractor weight (kg)	2099	3010	3140
Inflation pressure, front (kPa)	78	90	191
Inflation pressure, rear (kPa)	58	90	160
Winter crops			
Tractor weight (kg)	1900	2650	3900
Inflation pressure, front (kPa)	95	105	195
Inflation pressure, rear (kPa)	55	95	155

Table 2
Reference bulk density (Ref BD), particle size distribution, organic matter content and crops included in the Spring crops I series of experiments.

Site	Ref BD	Particle size (mm), g 100 g^{-1}				Organic matter	Crops included			
	Mg m^{-3}	<0.002	0.002–0.02	0.02–0.2	0.2–2	g 100 g^{-1}	Barley	Oats	Wheat	Peas
Badene	1.42	47	27	19	7	2.9	x		x	x
Viken1	1.44	13	23	43	22	4.3	x	x	x	x
Kvänum1	1.40	57	27	12	4	4.5		x	x	x
Forsby1	1.41	27	55	8	9	3.1		x		x
Viken2	1.49	18	15	48	19	6.4	x	x	x	x
Kvänum2	1.63	32	27	24	17	2.2	x	x	x	x
Viken3	1.45	19	17	49	14	5.9	x	x	x	x
Karlsäng	1.50	11	6	30	53	2.3	x	x		
Vreta	1.68						x	x	x	
Malmslätt1	1.48	47	25	20	8	3.2	x	x	x	
Malmslätt2	1.38	53	16	22	9	4.0	x	x	x	
Näsby	1.60	40	26	24	10	1.8	x	x	x	
Högåsa	1.60	7	5	52	36	2.8	x	x	x	
Mean	1.50	29	21	27	16	3.6				