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EFFECTS OF INTENSIVE TRACTOR TRAFFIC ON SOIL PHYSICAL PROPERTIES AND PLANT YIELD

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A b s t r a c t. In recent years, increasing attention is being paid to soil compaction. The question arises as to whether deterioration of soil structure and other physical properties resulting from heavy kneading are permanent or whether the soil will recover its properties during one vegetative period as a result of cultivation. A field experiment was set up on Orthic Luvisol formed from loess-like silts. Spring barley was sown on a production farm. Immediately after sowing, five plots of 4.5 x 150 m were established and the whole area was compacted by tractor wheels according to the following scheme: A - one pass of a 2 170 kg tractor, B - one pass of a 3 700 kg tractor, C - three passes of a 3 700 kg tractor, D - eight passes of a 3 700 kg tractor. After the barley was harvested a shallow ploughing was performed. Before winter, the soil was ploughed to a depth of 25 cm. The next, after shallow cultivation (8 cm), spring wheat was sown. Soil samples for the determination of physical properties were taken directly after compaction and three times (May, June, August, 1989) in the first year and twice (April, August 1990) in the second year. The yield of grain from each plot was determined. The experiment showed that the effects of compaction remained in the soil in the second year after compaction, and that soil compaction contributed to a decrease in cereal yield. The grain yield in compacted soil was lower by about 10-50 % in the first year after compaction and by 4-30 % in the second year.

INTRODUCTION

Many factors influence the degradation of soils as manifested by deterioration of their properties and productivity [4,11]. In recent years, increased attention has been paid to excessive compaction of soil. Domżał and Hodara [2] have shown that during cultivation of plants, the soil area is on average covered 2-5 times by the wheels of agricultural implements. This usually causes unfavourable changes in the soil structure and its physical properties [1,3,6,8,9,10]. These changes usually result in decreased yields [5,7].

The question arises as to whether these changes are permanent, or whether the soil will recover during subsequent vegetative periods and return to its precompaction condition. This requires long-term field studies. The results of the first two years of such an experimentation are presented in this paper.

METHODS

The experiment was set up in 1989 on a field with Orthic Luvisol formed from loess-like silts. In November, 1988, the field was cultivated to a depth of 10 cm. In March, 1989, the soil was cultivated using a rigid tine cultivator and a culti-packer in order to mix mineral fertilizers into the seedbed. Spring barley was sown in April 1989.

Immediately after sowing, five plots of 4.5 x 150 m were establised and the whole area was compacted by tractor wheels with the following traffic intensities.

0 - control - without compaction,
A - one pass of a 2 170 kg tractor,
B - one pass of a 3 700 kg tractor,
C - three passes of a 3 700 kg tractor,
D - eight passes of a 3 700 kg tractor.

After the barley was harvested, the soil was shallow ploughed (8 cm). Before winter the soil was ploughed again to a depth of 25 cm. In spring, 1990, the same tillage operations were performed as before the 1989 barley sowing. At the beginning of April 1990, spring wheat was sown. Nitrogen fertilizers, herbicides, fungicides and insecticides were applied.

Soil samples for the determination of physical properties were taken directly after compaction (April, 1989), three times (May, June, August, 1989) in the first year and twice (April, August, 1990) in the second year. The August samples were taken before the cereals were harvested. Samples of 100 cm volume were taken from the middle of each of the following depth layers: 0-10, 10-20, 20-30 cm. Bulk density, total porosity, air capacity and air permeability were determined. Grain yield from the plots was determined. In 1989 and 1990 the grain yield of barley and wheat respectively were measured at harvest in mid-August.

RESULTS

Soil compaction from tractor wheels resulted in a significant increase in bulk density to a depth of 20 cm (Fig. 1). The bulk density of the compacted soil in layers 0-10 and 10-20 cm varied from 1.59-1.67 Mg m^{-3}, as compared to 1.30-1.45 Mg m^{-3} in the control plot, and was equal to the bulk density of sub-arable layers. In the layers 20-30 cm no significant changes in bulk density caused by traffic were noted.

The results show that a significant increase in soil bulk density is caused even by a light tractor. Much heavier kneading (3 and 8 passes of the 3 700 kg tractor) increased soil compaction, but the increase in soil bulk density was not proportional to the mass of the tractor and the number of passes. Measurement of total porosity (Fig. 2) also confirmed that some soils can be significantly compacted even in the spring by light tractors and agricultural machines.

The changes in the soil bulk density caused by tractor wheels remained throughout the vegetative season in the first year after compaction. The processes taking place in the soil and the development of plant root systems did not lead to alleviation of the compacted condition of the soil structure. Bulk density of the compacted soil was still much higher than that of the uncompacted soil. Throughout 1989 the differences between the soil on the plots compacted with different intensity were evident (Fig. 3). In the second year after compaction, as a result of pre-winter and spring tillage, the differences in soil bulk density between the compacted and uncompacted soil were not as high as in the first year (Fig. 3). However, on the plot trafficted eight times, the bulk density was much higher than on all of the

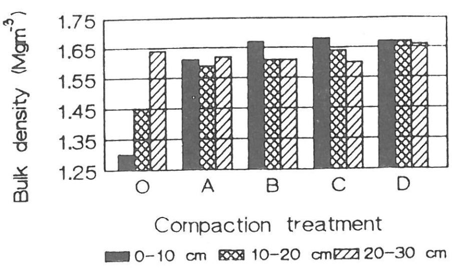

Fig. 1. Comparison of bulk density between control plot and plots kneaded by tractor wheels immediately after compaction. Explanations: 0 - control (without compaction), A - plot trafficted once 2 170 kg tractor, B - plot trafficted once 3 700 kg tractor, C - plot trafficted three times 3 700 kg tractor, D - plot trafficted eight times 3 700 kg tractor. Soil bulk density was measured at the middle of 0-10, 10-20, 20-30 cm layers.

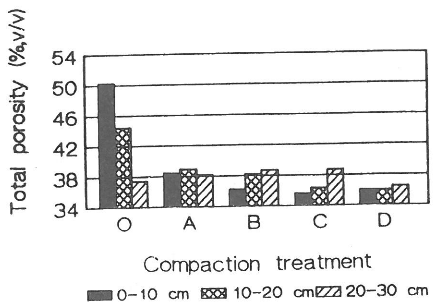

Fig. 2. Comparison of soil total porosity between control plot and plot trafficted by tractor wheels immediately after compaction. Explanations as in Fig. 1.

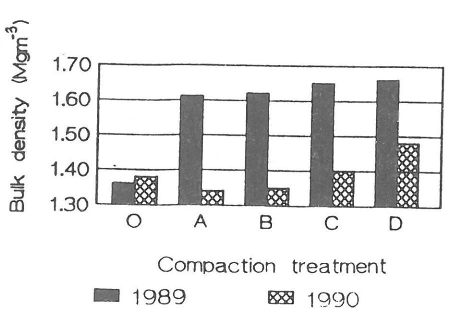

Fig. 3. Comparison of soil bulk density in 0-20 cm layers between control plot and plots trafficked by tractor wheels throughout vegetative seasons. 1989 - first year after compaction, $LSD_{0.05}$ - 0.02, 1990 - second year after compaction, $LSD_{0.05}$ - 0.03. Explanations: 0 - control plot (without compaction), A - plot trafficted once 2 170 kg tractor, B - plot trafficted once 3 700 kg tractor, C - plot trafficted three times 3 700 kg tractor, D - plot trafficted eight times 3 700 kg tractor.

other plots, showing that post-harvest and pre-sowing cultivation did not restore soil structure in highly compacted soil.

Likewise, the total soil porosity on the plots trafficted eight times was the lowest in both the first and second years after compaction (Fig. 4). The difference in total porosity between untrafficted soil and soil trafficted eight times was still statistically significant in the second year after compaction.

The decrease in soil porosity due to kneading by the tractor wheels results from a substantial reduction in soil air capacity.

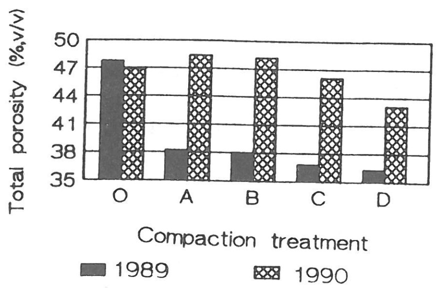

Fig. 4. Comparison of soil total porosity in 0-20 cm layer between control plot and plots trafficked by tractor wheels throughout vegetative seasons. Explanations: $LSD_{0.05}$ in 1989 year - 0.7, $LSD_{0.05}$ in 1990 year - 1.2. Other explanations as in Fig. 3.

In the first year after compaction, air capacity at a water potential of -15.5 kPa on the compacted plots did not exceed 3.5 % (v/v), while on the uncompacted plots it was 8.5 % (v/v). In the second year after compaction differences in air capacity in the 0-20 cm layer on the uncompacted and compacted plots were not significant; however, lower air capacity was evident on the plots compacted by the heavy tractor (Fig.5).

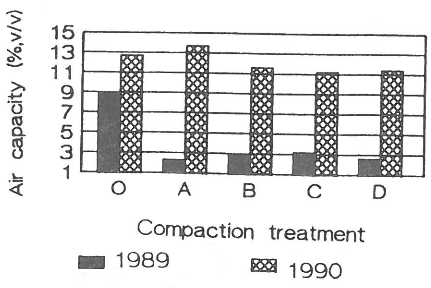

Fig. 5. Comparison of soil air capacity at a water potential of -15.5 kPa in 0-20 cm layers between control plot and plots trafficked by tractor wheels throughout vegetative seasons. Explanations: $LSD_{0.05}$ in 1989 year - 0.8, $LSD_{0.05}$ in 1990 year - 1.6. Other explanations as in Fig. 3.

Air permeability was very low on all plots in the first year with the more heavily trafficted areas exhibiting lower permeability. In the second year results of air permeability in the 0-20 cm layer were variable; hence, no clear conclusions could be drawn (Fig. 6).

Soil compaction also influenced the grain yield of both barley and wheat crops. In the first year (1989) a heavy storm caused the barley to lodge, especially on the control and lightly-compacted plots (0, A); hence, the yield differentiation was not proportional to the intensity of compaction.

On the soil compacted three times the grain yield was about 10 % lower (4.83 t/ha) than on the soil compacted once (5.59 t/ha); on the plots compacted eight times, the yield was almost 50 % lower (2.76 t/ha) (Fig 7).

In the second year after compaction (1990) the wheat grain yield in the compacted soil was lower than in the uncompacted soil by about 4 % (once compacted with a light tractor), 7.2 % (once and three

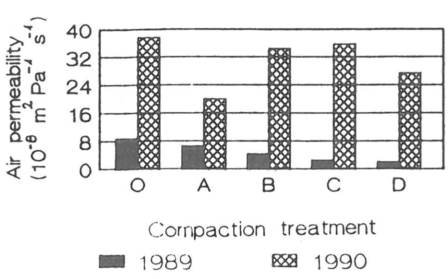

Fig. 6. Comparison of soil air permeability at a water potential of -15.5 kPa in 0-20 cm layers between control plot and plots trafficted by tractor wheels throughout vegetative seasons. Explanations: $LSD_{0.05}$ in 1989 year - 5.7, $LSD_{0.05}$ in 1990 year - 17.5. Other explanations as in Fig. 3.

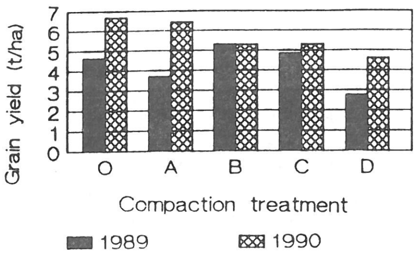

Fig. 7. Comparison of grain yield between control plot and plots trafficted by tractor wheels. Explanations: 1989 - grain yield of spring barley in first year after compaction, 1990 - grain yield of spring wheat in the second year after compaction. 0, A, B, C, D - compaction treatments.

times compacted with the 3 700 kg tractor) and up to 30 % (eight times compacted).

CONCLUSIONS

1. Soil compaction by the wheels of tractors caused a significant increase in bulk density and a deterioration of other physical properties of the soil (total porosity, air capacity at a water potential of -15.5 kPa, air permeability) to a depth of 20 cm.

2. The effects of compaction were still evident in the soil in the second year after compaction. In spite of mechanical tillage, bulk density of the compacted soil was higher two years after compaction than in the uncompacted soil.

3. The grain yield in the compacted soil was lower by 10-50 % in the first year after compaction and by 4-30 % in the second year after compaction. The more heavily compacted the soil, the greater the decrease in the grain yield.

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