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Vulnerability of Bavarian silty loam soil to compaction under heavy wheel traffic: impacts of tillage method and soil water content

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Abstract

Soil compaction caused by traffic of heavy vehicles and machinery has become a problem of world-wide concern. The aims of this study were to evaluate and compare the changes in bulk density, soil strength, porosity, saturated hydraulic conductivity and air permeability during sugar beet (*Beta vulgaris* L.) harvesting on a typical Bavarian soil (Regosol) as well as to assess the most appropriate variable factors that fit with the effective controlling of subsequent compaction. The field experiments, measurements and laboratory testing were carried out in Freising, Germany. Two tillage systems (conventional plough tillage and reduced chisel tillage) were used in the experiments. The soil water contents were adjusted to 0.17 g g^{-1} (w_1), 0.27 g g^{-1} (w_2) and 0.35 g g^{-1} (w_3).

Taking the increase in bulk density, the decrease in air permeability and reduction of wide coarse pore size porosity (−6 kPa) into account, it seems that CT (ploughing to a depth of 0.25 m followed by two passes of rotary harrow to a depth 0.05 m) of plots were compacted to a depth of at least 0.25 m and at most 0.40 m in high soil water (w_3) conditions. The trends were similar for "CT w_1" (low soil water content) plots. However, it seems that "CT w_1" plots were less affected than "CT w_3" plots with regard to bulk density increases under partial load. In contrast, diminishments of wide coarse pores (−6 kPa) and narrow (tight) coarse pores (−30 kPa) were significantly higher in "CT w_1" plots down to 0.4 m. Among CT plots, the best physical properties were obtained at medium soil water (w_2) content. No significant increase in bulk density and no significant decrease in coarse pore size porosity and total porosity below 0.2 m were observed at medium soil water content. The soil water content seemed to be the most decisive factor.

It is likely that, CS (chiselling to a depth of 0.13 m followed by two passes of rotary harrow to a depth 0.05 m) plots were less affected by traffic treatments than CT plots. Considering the proportion of coarse pore size porosity (structural porosity) and total porosity, no compaction effects below 0.3 m were found. Medium soil water content (w_2) provides better soil conditions after traffic with regard to wide coarse pore size porosity (−6 kPa), air permeability (at 6 and 30 kPa water suction), total porosity and

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bulk density. Proportion of wide coarse pores, air permeability and bulk density seems to be suitable parameters to detect soil compaction under the conditions tested.

Keywords: Soil compaction; Soil water content; Tillage system; Sugar beet harvester; Soil properties

1. Introduction

Problems of soil degradation resulting from compaction during crop production are now recognised as having a much wider impact than merely on the growth and yield of the crop in question. Some effects in the soil are likely to be cumulative and long lasting and may cause serious decline in the quality of the environment through a number of mechanisms.

Evidence for the widespread occurrence of soil compaction during the production of a wide range crops have been extensively searched and reviewed (Raghavan et al., 1990; Soane and van Quwerkerk, 1995; Yavuzcan et al., 2002).

Soils are three-phase systems that undergo changes as soon as the external stresses exceed the internal soil strength defined by the pre-compaction stress value. Soil compaction can result either in a higher bulk density or, when soil loading is attended with retarded water fluxes and high dynamic forces, in a completely homogenised soil characterised by a lower bulk density and a predominance of fine pores (Horn et al., 1995).

Soil compaction caused by traffic of heavy vehicles and machinery results in soil structure deterioration, both in the topsoil and in the subsoil. In soil compaction, not only pure static stress, but also dynamic forces play a role, caused by vibration of the engine and the attached implements and by wheel slip. Owing to dynamic loading, soil physical properties such as pore size distribution and pore continuity are negatively affected, which entails decreases in air and water permeability and results in increased soil strength or, in the presence of excess soil water, decreased soil strength due to kneading (Horn et al., 1995).

Changes in agricultural production techniques have been dramatic over the past few decades. Tillage intensity has increased or decreased depending on local circumstances, but in all cases there has been a steady upward trend in tractor power and machinery axle load. Increased loads are causing damage to the structure of the soil. This damage has increased the risk of soil erosion and raised the energy demand for cultivation (Chamen and Audsley, 1993). Modern agricultural machines help to reduce labor cost and to perform field operations in a precise timeframe. To counter the increasing weight of large machines, low-pressure tires have been developed. This helped to keep constant contact pressure on the soil surface and the topsoil stress. Calculations and measurements show, however, that subsoil stress depends more on axle loads than on contact pressure (Landefeld and Brandhuber, 1999). Several studies confirmed a compaction effect of heavy agricultural equipment on the subsoil, the detrimental effects of which might last for years (Alakukku and Elonen, 1995; Hakansson and Reeder, 1994).

Trafficability and load bearing capacity of bare and arable land are mainly governed by soil structure and soil strength, being primarily associated with moisture content and density. In addition, plant roots may reinforce field soils. However, the vegetation component will not be further considered here. Weather conditions such as rainfall events, drought periods, frost actions etc. cause temporal and special changes in soil moisture and pore volume. Moreover, agricultural soils are subject to loosening processes by tillage and load bearing processes by traffic during the seasonal production cycle. As a result of the above natural and man-induced changes in soil structure and strength, trafficability, in turn, follows a dynamic pattern during a year (Perdok and Kroesbergen, 1999).

The farmer's aim during primary tillage in Germany is to produce and maintain a loosened soil by ploughing once or sometimes twice a year to the full depth of the arable layer (20–35 cm). This practice has resulted in a special soil compaction problem. It is recognised that many arable soils have a severely compacted layer below the plough depth created by the standard practice of ploughing with two tractor wheels running in the furrow. Farmers try to remove