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Assessment of soil compaction using soil shrinkage modelling: Experimental data and perspectives

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Abstract

Soil compaction assessment is an important and difficult issue. In particular, it is difficult to quantify separately the compaction of macro-pores and micro-pores in the soil, and to account for spatial variability in soil properties at field scale. According to recent publications, the measurement and modelling of soil shrinkage curves (ShC) could help to overcome these difficulties. This is discussed in this paper on the basis of a field study. Control and compacted undisturbed samples originating from the surface layer of a cropped field are compared. The methods for measurement and modelling of the ShC are presented. Calculations of the micro-porosity, identified to be the soil plasma-porosity, and of the macro-porosity in the soil samples, at any water content, are described, and the accuracy of the results is discussed. A good agreement between field observation and ShC modelling is observed. The method allows for quantifying the compaction, with distinction between plasma-porosity and macro-porosity compaction. The forming of occluded macro-pores is also detected and quantified. The presented method offers numerous advantages in soil compaction assessment. It is precise, simple and easy to operate. It can be realized on clods of unspecified shape and containing a coarse fraction, and can be calculated for the fine earth fraction without the coarse fraction. The pore systems are quantified at any water content, and the determination covers the full range of pore sizes with quantitative distinction between the plasma-porosity and the macro-porosity compaction. According to previous results, it is possible to remove a certain amount of spatial variability in soil clay content by scaling the shrinkage parameters with clay content. The measurement and modelling of soil ShC is, therefore, a promising tool for soil compaction assessment.

Keywords: Soil shrinkage; Compaction assessment; Macro-porosity; Plasma-porosity; Soil structure

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1. Introduction

Soil compaction is one of the major concerns in intensive agriculture and in land use, in general. It arises from intensive tillage by heavy machines or by trafficking with construction machinery and other vehicles. The tendency to use heavier agricultural and construction machinery is not likely to reverse as economic pressure increases. Consequently, compaction reaches deeper soil layers (Håkansson and Reeder, 1994). Although abiotic and biotic regeneration processes are quite effective in alleviating topsoil compaction (e.g. Bullock et al., 1985; Von Albertini et al., 1995; Werner and Werner, 2001), subsoil compaction can persist over many years, decades and possibly even centuries (Etana and Håkansson, 1994; Håkansson and Reeder, 1994; Alakukku, 1996b; Sharratt et al., 1998). Compaction impacts the soil pore space and thus may cause a whole series of modified soil physical properties. For example, saturated hydraulic conductivity (Logsdon et al., 1992; Arvidsson, 2001) and air permeability (Blackwell et al., 1990; Kirby, 1991; Ball and Robertson, 1994) can be reduced. This in turn may lead to increased surface runoff and erosion (e.g. Fullen, 1985; Croke et al., 2001). Such changes may also modify the soil as a habitat and thus change or reduce biological activity of soil flora and fauna (Brussaard and Van Faassen, 1994; Whalley et al., 1995). As a result yield losses (e.g. Håkansson and Reeder, 1994; Schjønning and Rasmussen, 1994) as well as negative impacts on the environmental quality in general (Soane and van Ouwerkerk, 1995) may occur. Therefore the assessment, understanding and prediction of soil compaction and associated changes in pore space are very important issues to prevent permanent soil degradation.

Compaction causes a reduction in total porosity (e.g. Alakukku, 1996a; Arvidsson and Håkansson, 1996). This reduction not only may associate with altered pore morphology (e.g. Murphy et al., 1977; Bullock et al., 1985; Wiermann et al., 2000; Kremer et al., 2002, Horn et al., 1994) but also the pore size distribution may be changed (Gupta et al., 1989; Alakukku, 1996a; Richard et al., 2001), as macro-pores and micro-pores are not equally affected by compaction (e.g. Horn and Domzal, 1995). A complete picture of the effects of compaction on pore space must, thus, include the separate consideration of both pore classes.

Several distinctions exist between macro-pores and micro-pores. However, on the soil clod or sample scale (i.e. from tens to hundreds of cm^3), which is usual for the study of soil compaction, a certain agreement exists on the major pore sizes and types. At this scale, the soil structure was long ago recognized as the result of the combination of aggregates of soil plasma and skeleton, separated by macro-pores. The plasma is the 'material, mineral or organic, of colloidal size and relatively soluble material that is not contained in the skeleton grains' (SSSA glossary), i.e. the association of the soil swelling factors. With respect to porosity, the plasma can be defined as the combination of silt- and clay-size particles independently of the coarser fractions, and its porosity is composed of small inter-particle voids with maximum pore diameters of 10–15 μm on oven dried soil (Fies and Bruand, 1998). The walls of these pores are composed of coated phyllosilicates, which are very reactive. Because of their small diameter and swelling properties, these pores remain saturated over a large range of soil water contents (Boivin et al., 2004). Therefore, the plasma-porosity (or micro-porosity) plays an important role in water storage and soil reactivity. The macro-porosity can be defined as the porosity complementary to the plasma-porosity. It is composed of pores larger than 50–100 μm, which are either lacunar pores between skeleton and plasma (Fies and Bruand, 1998) or structural pores such as cracks, biopores, packing voids and vughs (Brewer, 1964; Bouma et al., 1977; Ringrose-Voase and Bullock, 1984). These pores are important for rapid air and water transfer in the soil.

Whereas there are many studies regarding macro-pore compaction, the soil plasma or soil clay–matrix compaction and its reversibility are poorly documented (Diamond, 1971). Most of the knowledge on the reversibility of clay compaction comes from civil engineering studies on the stabilization of artificially compacted clay (Howell et al., 1997; Bains et al., 2001; Rao and Tripathy, 2003; Romero et al., 2003), and we lack field data on soil plasma compaction and its reversibility.

To date, soil compaction was often assessed using bulk parameters like bulk density, total porosity and the like. Although easily assessed, they do not allow identifying the class of pores impacted or the