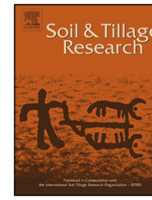
Soil & Tillage Research 173 (2017) 4–14

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still



Subsoil compaction assessed by visual evaluation and laboratory methods

Peter Bilson Obour*, Per Schjønning, Yi Peng, Lars J. Munkholm

Aarhus University, Department of Agroecology, Research Centre Foulum, Blichers Allé 20, P.O. Box 50, DK-8830 Tjele, Denmark, Denmark

ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form 17 August 2016
Accepted 19 August 2016
Available online 1 September 2016

Keywords:
Subsoil compaction
SubVESS
Soil pore characteristics

ABSTRACT

Subsoil compaction is one of the major causes of land degradation worldwide and therefore a major threat to future crop productivity. The objective of this contribution was to evaluate the effects of compaction treatments on soil structure based on the numerical visual evaluation of subsoil structure (SubVESS) method and on quantitative measurements of soil pore characteristics. The effect of soil compaction was evaluated using treatments from a compaction experiment initiated in 2010 at Research Centre Flakkebjerg, Denmark, on a sandy loam soil using five levels of compaction. In this study we used i) non-compacted reference, ii) Treatment M3, where soil was subjected to multiple passes (five wheel passes per compaction event annually) of a tractor-trailer combination with max. wheel load of ~3 Mg, and iii) M8, with multiple passes (four wheel passes per compaction event annually) of a tractor-trailer combination with max. wheel load of ~8 Mg. The tire inflation pressure was generally above the recommended pressure in order to mimic the inflation pressures commonly used in practice. The treatments were applied track-by-track in the spring of 2010–2013 when the soil water content was close to field capacity. Spring barley (*Hordeum vulgare L.*) was established every year after a shallow secondary tillage to ~0.05 m depth to loosen the uppermost layer. Sampling and field evaluation were done on May 7, 2014, i.e. after four years of compaction treatments (2010–2013) and one year of recovery. The soil profiles were evaluated at the same time as soil cores were sampled at 0.3, 0.5 and 0.7 m depth. In the laboratory, we measured water content, total porosity, air-filled porosity (ε_a), air permeability (k_a) and calculated pore organization indices ($PO_1 = k_a/\varepsilon_a$ and $PO_2 = k_a/\varepsilon_a^2$) on the soil cores. We estimated the blocked air-filled porosity and pore continuity index from the relationship between air permeability and air-filled porosity for −30 to −300 hPa matric potentials. Assessment using the SubVESS method showed a marked effect of the M8 treatment on soil structural quality down to ~0.65 m depth, but the effects of the M3 were not significantly different from the control at any depth. This was confirmed by the laboratory-measured data, which showed that the M8 treatment drastically reduced total porosity, air-filled porosity, air permeability, pore size distribution, pore tortuosity and continuity, especially at 0.3 and 0.5 m depths.

Detailed measurements of the anisotropy of soil pore characteristics at 0.3–0.4 m depth showed that for PO_2 (pore size distribution) and blocked air-filled porosity the control soil was significantly anisotropic. Although compaction with the ~8 Mg wheel load affected the vertically and horizontally-oriented pores differently, it did not significantly affect the anisotropy of the different pore characteristics. Our results showed that in general, there was a good agreement between the field and laboratory methods and thus, the two can be combined to evaluate the effects of compaction in the subsoil.

1. Introduction

Subsoil compaction is one of the major causes of land degradation worldwide. Over the years, the problem of subsoil compaction has worsened due to the growing weight of agricultural machinery (Alakukku, 1996; Schjønning et al., 2015). In Europe, for instance, about 33 million hectares of agricultural soil are degraded by soil compaction, including subsoil compaction (Oldeman et al., 1990).

Compaction increases soil bulk density and deforms soil, which affects physical functions such as air and water transport. Reduced aeration due to compaction may create anoxic microsites within the subsoil that contribute to the emission of greenhouse gases

* Corresponding author.
E-mail addresses: peter.bilson.obour@agro.au.dk, kopbilson@yahoo.com (P.B. Obour).

http://dx.doi.org/10.1016/j.still.2016.08.015
0167-1987/

such as N_2O and CH_4 (O'sullivan and Vinten, 1999). Densification of soil layers and degradation of physical subsoil properties resulting from compaction may slow crop emergence and root proliferation, which will have adverse effects on crop yields (Hamza and Anderson, 2005; Arvidsson and Hakansson, 2014).

Unlike erosion, salinization and topsoil compaction, the effects of subsoil compaction are generally invisible and can persist for many years since recovery by natural processes is slow (e.g., Berisso et al., 2012). Moreover, the alleviation of subsoil compaction by natural and mechanical subsoiling is problematic and expensive as the benefits are usually short-lived (Olesen and Munkholm, 2007). Subsoil compaction has been shown to affect soil anisotropy (Berisso et al., 2013), which is defined as the ratio of given soil properties in the horizontal direction to those in the vertical direction (Pozdnyakov et al., 2009). Changes to soil anisotropy, particularly the pore system, can have adverse effects on soil properties such as flow and transport processes and put crucial ecosystem services at risk (Berisso et al., 2012).

There have been several studies on subsoil compaction, but only few have quantified the effects of compaction induced by heavy field traffic in the soil profile (e.g., Arvidsson, 2001; Berisso et al., 2012). Traditionally, the effects of soil compaction have been assessed by measuring changes to bulk density and penetration resistance (e.g., Schjønning and Rasmussen, 1994). However, more detailed information on the effects of compaction on the pore system is needed to quantify effects on air and water transport, and root growth, especially at different depths in the soil profile. Moreover, assessment of the effects of soil compaction using field and laboratory methods are often done separately. However, a combination of the two methods is needed to understand how the results from the field method and laboratory measurements correspond to each other. It will also help to capitalize on the respective strengths of the methods in evaluating soil physical properties.

Visual assessments have proven valuable in detecting compaction in the topsoil and different methods have been developed for assessing the effects of management practices on soil quality. For instance, the visual evaluation of soil structure (VESS) (Ball et al., 2007) was developed purposefully to evaluate topsoils, whereas the SOILpak method (McKenzie, 1998) is useful for evaluating both top and subsoils. The methods have their respective strengths and weaknesses in application. See Batey et al. (2015) for a detailed description of the methods as well as the strengths and limitations.

In general, visual evaluation of subsoil compaction is more challenging, and the Visual Soil Examination and Evaluation Working Group of ISTRO has therefore encouraged its development at their meetings in Peronne, France, in 2005 and in Flakkebjerg, Denmark, in 2011, resulting in the development of the numeric visual evaluation of subsoil structure (SubVESS) method as a tool for assessing the quality of subsoils in relation to crop growth (Ball et al., 2015a). Further studies are needed to evaluate the ability of the method to assess the effects of severe soil compaction. This paper presents the results from a field experiment with repeated traffic passes over a four-year period on a sandy loam arable soil in Flakkebjerg, Denmark. The effects of compaction on crop yields and the natural amelioration of traffic-induced subsoil compaction are reported in separate studies by Schjønning et al. (2016a) and Schjønning et al. (2016b), respectively.

In this study, we combined field (SubVESS) and laboratory methods to assess the effects of subsoil compaction induced by the traffic treatments. The objectives were to: (1) conduct a visual evaluation of the subsoil structure of soils exposed to traffic with heavy agricultural machinery, (2) quantify the effects of field traffic on subsoil pore characteristics, and (3) quantify the effects of field traffic on upper subsoil (~0.3–0.4 m depth) pore system anisotropy. The following hypotheses were explored:

H_1: There is a correspondence between subsoil structural properties evaluated by the SubVESS method and in the laboratory.

H_2: Compaction due to field traffic affects subsoil pore characteristics.

H_3: Upper subsoil pore characteristics become more anisotropic due to compaction.

2. Materials and methods

2.1. Soils

The soils used in this study were obtained from a compaction experiment at Flakkebjerg, Denmark (WGS-83 coordinates: 55°19′42″N; 11°24′28″E). The experiment was initiated in 2010 and compaction treatments were carried out in each of the years 2010–2013. Average annual precipitation and temperature (1961–1990) at the site are 586 mm and 7.5 °C, respectively (Patil et al., 2012). The soil is a sandy loam developed on Weichselian moraine deposits and classified as a Glossic Phaeozem according to the World Reference Base system (Krogh and Greve, 1999). Table 1 shows the predicted clay and soil organic carbon (SOC) contents of the investigated field. Clay content varies between 12% in the upper subsoil (0.3–0.4 m depth) to 23% in the subsoil, (0.7 m depth) and SOC decreasing from 0.8% to 0.1% at the same depths. There is variability of clay and SOC content, especially in the upper subsoil for the experimental blocks (Further details of the predicted clay and SOC of the investigated soil are provided in Supplementary material, Table D). Schjønning et al. (2016a) reported a measured soil texture of the same soil. The authors reported increasing clay content from approximately 150 g kg^{-1} in the plough layer to about 190 g kg^{-1} in the 0.5–0.75 m layer. The coefficient of variation of clay from 0 to 0.75 m depth was between 12 and 24%. Please consult Table 1 of Schjønning et al. (2016a) for details.

2.2. Experimental treatments

The design of the field experiment was a randomized blocked design in four replicates. Each block comprised five plots measuring approximately 10 × 30 m. Treatment 1 represented in all blocks the control treatment, which was not subjected to compaction treatment, and treatments 2, 3, 4 and 5 represented different wheel loads. For this study, only treatments 1, 3 and 5 were included. Treatment 3 consisted in all blocks of multiple (M) wheel passes (five wheel passes per compaction event annually) of a tractor-trailer combination with a ~3 Mg wheel load (denoted M3), and treatment 5 was in all blocks multiple passes (four wheel passes per compaction event annually) of a tractor-trailer combination applying a maximum wheel load of ~8 Mg (denoted

Table 1
Predicted clay and organic carbon contents of the investigated field in Flakkebjerg. Depth (m)

	Block	Clay (<2 μm) (kg 100 kg^{-1})	SOC (kg 100 kg^{-1})
0.3	1	14	0.8
	2	12	0.7
	3	23	0.3
	4	20	0.6
0.5	1	22	0.3
	2	19	0.3
	3	24	0.2
	4	22	0.3
0.7	1	23	0.1
	2	20	0.2
	3	22	0.2
	4	22	0.2