Soil & Tillage Research 127 (2013) 34–44

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

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

Using a morphological approach to evaluate the effect of traffic and weather conditions on the structure of a loamy soil in reduced tillage

Hubert Boizard [a,*], Sung Won Yoon [b], Joel Leonard [c], Sylvain Lheureux [a], Isabelle Cousin [b], Jean Roger-Estrade [d], Guy Richard [b]

[a] INRA, US1158 Agro-Impact, Estrées-Mons, BP 50136, F-80203 Péronne, France
[b] INRA, UR272 Unité de Science du Sol, Ardon, BP 20619, F-45166 Olivet Cedex, France
[c] INRA, US1158 Agro-Impact, Pôle du Griffon, 180 rue Pierre-Gilles de Gennes, 02000 Barenton-Bugny, France
[d] AgriParisTech, Département SIAFEE, Bâtiment EGER, BP 01, 78850 Thiverval-Grignon, France

ARTICLE INFO

Article history:
Received 8 November 2011
Received in revised form 25 April 2012
Accepted 27 April 2012

Keywords:
Soil structure assessment
Reduced tillage
Soil compaction
Platy soil structure
Soil cracks
Soil structure

ABSTRACT

A morphological approach and soil porosity have been used to evaluate the effect of compaction and climate on the soil structure of a loamy soil in a reduced tillage system. The study was carried out between 2000 and 2006 as part of the long-term "cropping systems and soil structure" experiment conducted in Estrées-Mons in northern France. Soil hydraulic, mechanical and pore morphological properties were also measured to characterise the effects on soil structure dynamics. A complementary characterisation of the soil structure was conducted on a microscale.

The method for morphological description of the soil macrostructure was well suited to studying soil structure dynamics in reduced tillage systems. Results showed that the soil structure in the layer without tillage depended in the first instance on compaction intensity. Structural porosity was partly preserved in the cropping system with little compaction. In contrast just one operation, such as the harvest of sugar beet (*Beta vulgaris L.*), was sufficient to reduce structural porosity for 5 years even though no further compaction occurred during this period. Morphological analysis revealed the evolution of highly compacted zones under the effects of weather conditions. Platy soil structures were systematically observed in the upper part of the highly compacted zones under the tilled layers, with cracking slowly penetrating deeper into the soil with time. The structure types observed corresponded to specific soil properties resulting from the transformation of the soil structure over time. A micromorphological assessment was performed to get detailed information about the network of cracks. The morphological characterisation showed that a visual morphological approach was insufficient for revealing the entire network of cracks.

1. Introduction

The soil structure of the tilled layer of cultivated fields shows spatio-temporal heterogeneity due to anthropogenic (*i.e.* tillage and compaction) as well as natural processes (*i.e.* climate, root growth and fauna activity). These processes alter the spatial arrangement, size and shape of soil aggregates as well as the inter- or intra-aggregate pore system (Dexter, 1988). Soil compaction is a major process. It can significantly alter the physical, chemical and biological properties of soil (Oades, 1993; Hakansson et al., 1995), with negative environmental impacts such as increasing nitrous oxide gas emissions (Soane et al., 1995; Ball et al., 1999; Bessou et al., 2010) or leading to runoff and downslope erosion (Batey, 2009).

However, whilst many studies have focused on the origins behind compaction and its effects (Ball et al., 1997; Smatana et al., 2010), few have dealt with structure regeneration by natural agents such as soil biota, roots and climate, although these processes are considered essential in reduced tillage (Utomo and Dexter, 1982; Oades, 1993; Taboada et al., 2004). Weather conditions in particular – through drying–wetting and freezing–thawing cycles – have a marked influence on the formation of soil cracks of various kinds and consequently on the physical and hydraulic properties of the soil (Hussein and Adey, 1998; Rajaram and Erbach, 1999). The development of horizontal cracks near the soil surface has often been observed during the transition to reduced tillage. Alvarez and Steinbach (2009) and Sasal et al. (2006) observed for example a platy structure in the soil in most situations in the Argentinean Pampas in no-tillage systems, and near-surface soil layers in no till for 4 and 6 years also exhibited this kind of structure in the study by VandenBygaart et al. (1999). Stengel et al. (1984) studied cracking in swelling clay soils

* Corresponding author. Tel.: +33 3 22 85 75 12.
E-mail address: boizard@mons.inra.fr (H. Boizard).

0167-1987/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2012.04.007

(11%, 30% and 53% of clay) in field conditions and showed that the network of cracks is denser when the clay content is high in a reduced tillage system.

However, beyond punctual characterisations, it remains difficult to evaluate the dynamics of changes in soil structure over time. Boizard et al. (2002) used a morphological approach proposed by Manichon (1987) called "profil cultural". This method allowed to evaluate the cumulative effects of cropping systems on the structure of the ploughed layer under different plough tillage systems. The change of soil structure over time was evaluated by a field visual assessment indicator referring to the proportion of compacted clods (called Δ) in the tilled layer. This indicator provided a more detailed description of changes in the soil structure over time than the mean soil bulk density. The main advantage of this method is that it takes into account the spatial variations in soil structure caused by tillage, wheeling and weather conditions. However since its development in plough tillage systems in 1982, its applicability to describe the evolution of soil structure accurately in situations with reduced tillage remains to be seen.

The objective of this paper is to evaluate (i) the effect of compaction and weather conditions on the soil structure of a loamy soil in reduced tillage and (ii) the ability of the morphological approach to describe properly the changes in the soil structure over time. The study was conducted between 2000 and 2006 as part of the long-term "cropping systems and soil structure" experiment in loamy soil in northern France. We have confined this paper to the effect of compaction and weather conditions, excluding the effect of earthworms, other soil fauna and roots.

2. Materials and methods

2.1. Site description and experimental design

The site is located in northern France, at Estrées-Mons (50°N latitude, 3°E longitude, 85 m elevation). The soil is an Orthic Luvisol (FAO classification). The 0–30 cm horizon has a silt loam texture (19% clay, 76% silt, 5% sand and 1.7% organic carbon) and a pH of 7.6. The gravimetric soil water contents (SWC) measured at −10, −32, −50, −100 and −1500 kPa were 0.253, 0.229, 0.208, 0.175 and 0.084 g g^{-1} respectively. Water content at field capacity, measured in the field 2–3 days after excess water had drained away during the winter season (Hillel, 1971), was 0.24 g g^{-1}. The Atterberg plastic and liquid limits were 0.29 and 0.23 g g^{-1} respectively. The coefficient of linear extensibility (COLE, Gray and Allbrook, 2002) ranged between 0.06 and 0.07, indicating a moderate to high shrinking potential.

The experiment was conducted as part of the long-term "cropping systems and soil structure" field experiment (Boizard et al., 2002). Three cropping systems were compared between 1999 and 2008 with a wide range of soil compaction intensities, depending on crop rotation and decision-making rules. In 1999, a new treatment with superficial tillage at a depth of only 6 cm was introduced into the experiment in order to compare the effects of annual ploughing and reduced tillage on soil structure evolution.

In 2006 we selected three plots with reduced tillage (plot numbers 8, 9 and 12) to study the effects of compaction and weather conditions on the evolution of soil structure and physical properties of the 6–30 cm layer without tillage. The soil textures were very similar between the plots 8, 9 and 12 (19.9, 19.1 and 18.7% clay respectively). The crops and main characteristics of the cultural operations of the three plots are described in Table 1. Seedbed preparation was performed with a light disc harrow. Maize (*Zea mays L.*) and sugar beet were sown using a precision drill. Pea (*Pisum sativum* L.), flax (*Linum Usitatissimum*) and wheat (*Triticum aestivum*) were sown using a combined rotary harrow and disc drill. The mean depth of stubble tillage and seed bed preparation was 6 cm, varying between 4 and 8 cm.

We calculated a compaction index (CI) to characterise the compaction intensity caused by each cultivation operation (Table 1). The index was described in Boizard et al. (2002) and corresponds to an expected proportion of severely compacted zones (Δ) created under wheel tracks in the 0–30 cm layer of the plot for each operation. The areas of Δ zones under wheel tracks is estimated from an empirical relationship (Roger-Estrade et al., 2000) between the relative area of Δ zone created during traffic and the soil water content at the time of traffic; the compaction index is calculated for each field operation as the ratio of the areas of Δ zones created by the two main wheels of each equipment used relative to the total area of 0–30 cm layer. In plot 8 (named LC for low compaction), the risk of compaction was low and the compaction index (CI) was close to zero except in 2000 and 2001. In contrast, the compaction risk was high in plots 9 and 12, with the late harvesting of sugar beet and maize in the autumn during wet periods of the year. But the CI differed between plots 9 and 12. The scheduling of cultivation operations led to variable soil moisture conditions during harvesting. High compaction occurred in plot 9 (named HC for high compaction) only once in late autumn 2001 during sugar beet harvesting, whilst repeated compaction events occurred in plot 12 (named RC for repeated compaction). These differences allowed comparisons to be made between a situation without severe compaction, a situation with severe compaction but only at the beginning of the period studied, and a situation with severe compaction on several occasions during the period studied.

2.2. Weather conditions

The average atmospheric temperature between 1999 and 2006 was 11.1 °C and the average annual rainfall was 713 mm. Table 2 shows rainfall amounts and mean temperatures by season. The first years of the experiment were rather humid, with annual rainfall between 810 mm and 936 mm in 1999–2002, whilst the 2003–2005 period was quite dry (490 mm, 569 mm and 578 mm in 2003, 2004 and 2005 respectively). So the annual climatic deficit evaluated as the differences between rainfall and potential evapotranspiration (E_{TP}) was higher from 2003 to 2005. The total number of days on which the air temperature was below 0 °C varied between 10 days during the winter of 2002–2003 and 23 days during the winter of 2003–2004.

2.3. Characterisation of the soil structure

2.3.1. Morphological characterisation of the field soil structure on a macro-scale

Dry bulk density was measured after each sowing in the unwheeled zones using a gamma ray transmission probe (10 replicates per plot) at a depth of 0.125 m, 0.175 m and 0.225 m from the soil surface (probe with two tubes placed 0.30 m apart). Total porosity estimated from the bulk density was divided into the textural and structural pore space.

The structural void ratio (*e*S) was calculated from field bulk density ρ_a and textural soil density ρ_t, both measured at the same water content, as:

$$eS = \frac{\rho_s}{\rho_a} - \frac{\rho_s}{\rho_t}, \quad (1)$$

with ρ_s being the particle density.

The textural soil density was measured as a function of soil water content using 2–3 mm aggregates as described by Monnier et al. (1973). The initially saturated aggregates were gradually