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Soil structure changes induced by tillage systems

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ABSTRACT

Structure represents one of the main soil physical attributes indicators. The soil porous system (SPS) is directly linked to the soil structure. Water retention, movement, root development, gas diffusion and the conditions for all soil biota are related to the SPS. Studies about the influence of tillage systems in the soil structure are important to evaluate their impact in the soil quality. This paper deals with a detailed analysis of changes in the soil structure induced by conventional (CT) and no-tillage (NT) systems. Three different soil depths were studied (0–10, 10–20 and 20–30 cm). Data of the soil water retention curve (SWRC), micromorphologic (impregnated blocks) (2D) and microtomographic (μCT) (3D) analyses were utilized to characterize the SPS. Such analyses enabled the investigation of porous system attributes such as: porosity, pore number and shape, pore size distribution, tortuosity and connectivity. Results from this study show a tri-modal pore size distribution (PSD) at depths 0–10 and 10–20 cm for the soil under CT and a bi-modal PSD for the lower layer (20–30 cm). Regarding the soil under NT, tri-modal PSDs were found at the three depths analyzed. Results based on the micromorphologic analysis (2D) showed that the greatest contribution to areal porosity (AP) is given by pores of round (R) shape for CT (52%: 0–10 cm; 50%: 10–20 cm; 67%: 20–30 cm). Contrary to the results observed for CT, the soil under NT system gave the greatest contribution to AP, for the upper (0–10 cm) and intermediate (10–20 cm) layers, due to the large complex (C) pore types. For the μCT analysis, several types of pores were identified for each soil tillage system. Small differences in the macroporosity (MAP) were observed for the 0–10 and 20–30 cm between CT and NT. A better pore connectivity was found for the 0–10 cm layer under NT.

1. Introduction

Water infiltration and retention are directly affected by the soil porous system (SPS) (Kodešová et al., 2011; Pagliai and Vignozzi, 2002). The transmission of water through the soil is important for the plant development and also to avoid environmental problems such as erosion. The water retention is important to supply water for plants, to stabilize the soil temperature and to maintain soil stability (Lipiec et al., 2006).

Pore size distribution (PSD) and its continuity control the water infiltration and retention (Hillel, 1998; Kutílek and Nielsen, 1994). Pores of different sizes present distinct functions in the soil. Pores with equivalent cylindrical diameter (ECD) > 50 μm are classified as transmission pores and <0.50 μm as residual + bonding pores. While the former is responsible for air movement and drainage of excess water, the latter provides retention and diffusion of ions in solutions. The intermediate pore size between 0.50 and 50 μm is responsible for the retention of water against gravity and release (Lal and Shukla, 2004).

The use of PSD to infer soil structure changes induced by different phenomena is becoming more and more common in the soil science (Cássaro et al., 2011; Dal Ferro et al., 2014). The methods utilized to obtain pore size distribution are based on the soil water retention curve (SWRC), mercury porosimetry, nitrogen adsorption and image analysis techniques such as the conventional resin impregnated block methodology or computed microtomography (μCT) (Hajnos et al., 2006; Imhoff et al., 2010; Kutilek et al.,

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2006; Lipiec et al., 2007; Ogunwole et al., 2015; Pagliai et al., 2004; Pires et al., 2013; Rab et al., 2014; Taina et al., 2010).

The derivative of the SWRC is used for the indirect computation of PSD. On the other hand, methods based on image analysis allow the direct SPS characterization in 2D (impregnated blocks) and 3D (μCT) with spatial resolutions from centimeters to micrometers (Helliwell et al., 2013; Pires et al., 2010).

The μCT is interesting because it is a non-invasive technique that allows the soil pores characterization of macro aggregates and micro aggregates (Brown et al., 2014; Dal Ferro et al., 2012; Pagenkemper et al., 2015). Among the different pore sizes, macropores have, as their main function, a fast drainage of water under saturation condition (Allaire-Leung et al., 2000; Anderson et al., 2010; Guérif et al., 2001). The number, volume, shape, orientation, continuity, tortuosity and macropore size distribution control the intake rate of water drainage and solute flux processes, such as the hydraulic conductivity (Amer et al., 2009; Kutílek, 2004).

Tillage systems present great influence in the SPS and consequently in the PSD (Kay and VandenBygaart, 2002; Kravchenko et al., 2011; Peth et al., 2008; Schjønning and Rasmussen, 2000). Tavares Filho and Tessier (2009) observed important changes in the structure of a Brazilian Oxisol induced by conventional (CT) and no-tillage (NT) systems. The authors observed a disaggregated microaggregate structure between 0 and 20 cm for CT and the presence of fissures and biopores for NT. The volume of pores with ECD > 100 μm was practically nonexistent under CT and those <100 μm were practically not affected by the type of soil management. Portella et al. (2012), also working with a Brazilian Oxisol, described changes in the aggregate stability index, mean weighted diameter and mean geometric diameter induced by the tillage systems. More intense soil preparation (CT) resulted in a decrease in soil stability, which directly affected the SPS.

Thus, the study of micromorphological attributes of the soil pore system has shown to be quite relevant, particularly concerned to the SPS, as it is important to the transport and drainage of solutes (Hillel, 1998; Kodesova' et al., 2008). Knowledge about how the pore shape, connectivity, anisotropy and alignment along the sample volume, in conjunction with porosity, PSD and other features is essential to define, with improved precision, the soil structure and its physical attributes, foreseeing the physical-hydraulic behavior along the transversal directions as well as in depth.

Therefore, the main goal of this work was to investigate and explore several tools to characterize the changes in the soil porous system, caused by conventional and no-tillage systems, at three different soil depths. Pore size distributions derived from soil water retention data and image analysis techniques were utilized. Pore shape, size distribution and its connectivity and tortuosity were analyzed. This study is a first report of a detailed analysis of changes in the structure of Brazilian soil due to tillage systems at different scales.

2. Material and methods

2.1. Experimental area and soil samples

This study was carried out with samples collected on the experimental farm of the Agricultural Research Institute of Parana (IAPAR) in the city of Ponta Grossa, PR, Brazil (25°06′S, 50°10′W, 875 m above sea level). The soil under investigation is classified as Red Latosol according to the Brazilian Soil Classification System (EMBRAPA, 2013); Oxisol (Typic Haplorthox) according to the USDA soil taxonomy (Soil Survey Staff, 1998); and Rhodic Ferralsol according to FAO classification (FAO, 1998). Based on textural analysis the soil was classified as having clay texture (Table 1).

Table 1
Characteristics of the soil studied for the different tillage systems.

Property	CT			NT		
	0–10	10–20	20–30	0–10	10–20	20–30
Clay ($g\,kg^{-1}$)		610			650	
Silt ($g\,kg^{-1}$)		220			240	
Sand ($g\,kg^{-1}$)		170			110	
TP (%)	55.8	51.7	51.7	60.2	54.5	57.1
Ma (%)	12.5	7.7	8.1	12.7	11.0	10.8
Mi (%)	43.3	44.0	43.6	47.6	43.5	46.3

Textural (clay, silt, sand) analysis at the 0–10 cm depth; TP: total porosity; Ma: macroporosity; Mi: microporosity (h=100 cm of water); CT: conventional tillage; NT: no-tillage.

The climate in the region, according to the Köeppen classification, is a humid mesothermal Cfb-subtropical with mild summers. The annual average rainfall is approximately 1550 mm, with a maximum average annual temperature of 22 °C and minimum 18 °C, with frost occurrence in the coldest months (June–August).

Soil samples were collected from two areas, one submitted to NT (10,000 m^2) and the other to CT (6000 m^2). Both tillage systems have been used in the areas for over 25 years. NT has been conducted continuously in the area for 26 years. In these areas, crop rotation is practiced, with cover crops such as oats or vetch in winters and corn or soybeans in summers. In addition to practices for planting and cleaning, CT is also submitted to disk plowing (up to 25 cm) followed by 2 harrowing procedures.

For SWRC evaluation, soil samples (n = 5) were collected in volumetric rings (5.0 cm high and 4.8 cm internal diameter) made of steel in 2010. The undisturbed soil samples were collected using a cylindrical Uhland sampler. The soil excess outside the cylinder was carefully trimmed off and top and bottom surfaces of the sample were made flat to be sure that the soil volume was equal to the internal volume of the cylinder. Since the soil water content is very important at sampling time to minimize impact effects, samples were collected near their plastic limit, about three days after a high intensity rainfall event (approximately 50 mm).

For the micromorphologic analysis of impregnated blocks, soil samples (n = 3) were collected in 2012 as blocks of approximately 345 cm^3 (7 × 7 × 7 cm). Small trenches were opened in the experimental field and the sample blocks were carefully hand-cut with the use of special knifes and palette knifes. After sampling, the samples were wrapped in foil.

For μCT analysis, trenches were opened and soil blocks (n = 3) were carefully extracted in 2013 by using palette knifes (approximately 20 × 20 × 10 cm). After sampling, the samples were wrapped in foil. The blocks were thoroughly molded and later placed into acrylic tubes of 6.4 cm internal diameter and 15.0 cm height.

Sampling was carried out after harvest (normally ryegrass – *Lolium multiflorium*) in all the procedures described. Three different soil depths were sampled: 0–10, 10–20 and 20–30 cm.

2.2. Soil water retention curve

SWRC data were obtained by using a commercial tension table (Eijkelkamp) (10; 30; 40; 60 and 80 cm of water) and commercial pressure extraction vessels (Soil Moisture Equipment Co.) (100; 330; 500; 800; 1000; 4000; 8000 and 15,000 cm water).

The wetting procedure to saturate the samples consisted in soaking them using a tray with the water level just below the top of the cylinders. This procedure is carried out over a period of 1 or 2 days to allow saturation of the soil and to avoid the presence of the entrapped air bubbles. After the wetting procedure soil