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A contribution to understanding the origin of platy structure in silty soils under no tillage

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ABSTRACT

In silty soils under no tillage (NT), platy (P) soil structure is widespread and constrains water infiltration. Our objectives were (i) to evaluate how traffic and the presence of crop residues influence P structure development in the field and (ii) to characterize changes in soil structure caused by alternation of wetting and drying (w-d) periods for two topsoil layers of a silty soil and two compaction levels in the laboratory. The five-year field experiment was carried out on a Typic Argiudoll under NT and the structure of the A horizon was analyzed using visual soil evaluation (VSE) both before and five years after two traffic levels were applied to four crop sequences. The laboratory experiment of w-d cycles was carried out with two disturbed layers of a Typic Argiudoll, which was repacked to achieve two different bulk densities, and the columns were subjected to 5, 10, or 15 w-d cycles. In the field experiment, the P structure was clearly identified by VSE and corroborated by shear strength and bulk density measurements. The proportion of P structure increased until about 50% of the A horizon after 5 years, irrespective of the traffic or presence of crop residues at the expense of the Φ structure proportion. In the laboratory, consecutive w-d cycles caused changes in soil volume, cracking of the soil surface, and formation of P structure of variable thickness up to 20 mm, confirming that alternation of w-d periods can cause structural modification of the silty soil, in particular horizontally oriented cracks. The number of w-d cycles increased the thickness of the P structure in the upper layer ($R^2 = 0.55$) and in the compacted treatment ($R^2 = 0.81$). The results obtained constitute important progress in the understanding of the evolution of P structure of silty soils under NT.

1. Introduction

Silty soils are characterized by their compaction vulnerability and a marked trend to form a massive and homogeneous soil structure (Fernández et al., 2015; Topp et al., 2002; Voorhees and Lindstrom, 1984). However, the evolution of the soil structure following compaction has not been much studied (Alakukku, 1998). This becomes especially relevant under no tillage (NT), where the regeneration of the structure after compaction depends on the effect of the crop sequences and the weather, and concerns the sustainability of the farming system.

In the Argentinean Rolling Pampas, silty soils are predominant and mainly cropped under NT. Their silt fraction has a high content of biotic material –bioliths–, which causes soil structural fragility when exposed to external stresses like traffic (Cosentino and Pecorari, 2002; De Battista et al., 1994). This problem is accentuated by the widespread non-controlled traffic system and the repeated passes on the land during the harvest of main summer crops (soybean and maize) in humid falls, when the surface soil is wetter than optimal for wheel traffic. In addition, soil management with NT emphasizes the low ability of the soil structure to regenerate naturally because of the absence of freeze-thaw processes and the illite type clay, which has low shrinkage-swelling capacity (Senigagliesi and Ferrari, 1993; Taboada et al., 1998).

Many authors have reported the presence of platy (P) soil structure under NT (Alvarez et al., 2014, 2009; Ball and Robertson, 1994; Bonel et al., 2005; Morrás et al., 2004; Shipitalo and Protz, 1987; Soracco et al., 2010). Although some of them attribute the formation of P structure to reconsolidation following thawing of winter-formed ice lenses (Hussein and Adey, 1998; Pardini et al.,

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1995; Sveistrup et al., 2005; VandenBygaart et al. 1999), this explanation is not applicable to the soil temperatures of the Argentinean Pampas, which are rarely below 0. Boizard et al. (2013) reported that the P structure is systematically associated with the compacted volumes in the soil below and to climatic conditions. Other authors attribute the P structure to the shearing produced by the action of tires or to planes of weakness induced by compaction due to traffic (Alvarez et al., 2009; Bullock et al., 1985; Horn et al., 2003; Pagliai et al., 2003), whereas some others observed P structure in NT silty topsoils even in non-wheel-track areas (Drees et al., 1994; Miller et al., 1998).

Soil regeneration after compaction depends on the type of soil and on the degree of damage to the soil (Pagliai et al., 2003). Some studies have reported that in expansive clay soils, the cracking process during wet-dry (w-d) cycles is a key factor for soil structure regeneration, especially near the soil surface (Hussein and Adey, 1998; Stengel and Bourlet, 1987; Wang et al., 2016). Also in silty soils, since drying is usually not uniform, unequal strains arise throughout the soil mass, which causes the development of incipient failure zones and cracks (Denef et al., 2001; Taboada et al., 2004, 2008). Considerably less attention has been paid to the effect of the alternation of w-d periods on the formation of a specific type of P structure in silty soils.

In previous studies, we observed that such P structure from the soil surface was the main constraint to water infiltration (Sasal, 2012; Sasal et al., 2006). By using micromorphometric analyses, several authors have observed a reduction in macroporosity under NT and a tendency of pores to become more elongated and horizontally oriented (Alvarez et al., 2014; Drees et al., 1994; Pagliai et al., 1983; VandenBygaart et al., 1999). This can make these pores less effective for vertical water movement and gas exchange, and could also limit downward proliferation of plant roots compared to vertically oriented pores of the same size and shape. To develop crop management practices under NT that promote water infiltration and root growth, the origin of the P structure needs to be better understood.

Thus, to identify the drivers of P structure development and its evolution, in this work, we tested two hypotheses about P structure formation. The first hypothesis is based on the development of a P structure under NT as a case of soil structure degradation: compaction and shear stresses caused by traffic lead to the stratification of aggregates in the first centimeters of the soil, especially when the soil surface is bare or the mulch of crop residues is very scarce. The second hypothesis is based on the development of a P structure under NT as a case of structure regeneration: cracking associated with the alternation of w-d periods in a massive or compacted soil evolves towards a P type of structure.

Our objectives were (i) to evaluate how traffic and the presence of crop residues influence P structure development in the field and (ii) to characterize changes in soil structure caused by w-d cycles for two topsoil layers of a silty loamy soil and two compaction levels in the laboratory. Both approaches will contribute to a better understanding of how P structure develops under NT.

2. Materials and methods

The field and laboratory experiments were carried out at the Pergamino Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA) of the province of Buenos Aires, Argentina (33° 51′ S and 60° 40′ W) in the center of the Humid Pampas. The climate is mesothermal humid (Cfa), with annual rainfall of 946 mm and average temperature of 16.4 °C.

The soils of the Pergamino Series (Luvic Phaeozem, WRB) are fine, illitic, thermic Typic Argiudolls (US Soil Taxonomy). The soil texture of the A horizon is silty loam with 230 and 650 g kg^{-1} of clay and silt, respectively (INTA, 1972). Mineralogical analysis of clays by X-ray diffraction indicated that the predominant clay type is illite (>80%), followed by montmorillonite (15%), kaolinite and interstratifications (Iñiguez and Scoppa, 1970).

2.1. Effects of traffic and crop residues in the field experiment

The five-year field experiment started in 2005. In the previous five years, the field had been cultivated under NT, with a maize (*Zea mays* L.)-wheat (*Triticum aestivum*)/soybean (*Glycine max* L.) succession. Previous to that, crop residues from non-harvested wheat due to an epiphyte (1996) and a two-year white clover (*Trifolium repens*) pasture (1997–1999) were incorporated into the soil in 1999, with a double-action disc plow + teeth-harrow, an eccentric disc plow + teeth-harrowand two passes of disc harrow + teeth-harrow. Between 2003 and 2006, a drought affected the region and some crops were not harvested. In December 2005, the structure of the A horizon was analyzed using the visual structure evaluation (VSE) “le profil cultural” (Boizard et al., 2013; Manichon and Gautronneau, 1987; Peigné et al., 2013; Roger-Estrade et al., 2004). No P structure was present in the A horizon at the beginning of the experiment. Table 1 shows some soil properties.

The experimental design was a systematic arrangement of traffic (split-plot) applied to four experimental strips with different crop sequences and three replicates (one in each of three blocks). Each of the 12 experimental plots (14 × 20 m) was divided in half (7 × 20 m) and the following traffic treatments applied: initial traffic (Tf), where a tractor of 7000 kg mass passed twice consecutively over the entire area of the sub-plot at the beginning of the experimental treatment with soil at field capacity (26.6 ± 1.3% w/w); and no initial traffic (nTf). After that, the traffic for crop planting and harvest was not controlled. The four crop sequences implemented in the strips were: soybean monoculture (SM), maize-wheat/soybean cropping sequence (M-W/S), maize-wheat/soybean cropping sequence with crop remains removed (M-W/S.r), and bare soil with no crops (BS). Weeds were chemically controlled with glyphosate 46% in all treatments.

Soil structure was assessed in each sub-plot using VSE initially in 2005, and then every two rotation cycles in 2006, 2008 and finally in 2010 (n = 24). In 2006, six months after the treatments were set up and after the soybean harvest, only SM and BS were sampled because the remaining treatments were sampled after the two rotation phases were completed. At each time, pits of 1 m wide and 0.3 m deep were dug perpendicularly to the sowing direction and placed 3 m apart with respect to the ones of the previous assessments to avoid overlaps.

The first step was to identify with a knife the soil structure variations present in the A horizon and particularly to point out the area covered by the P structure, with flat aggregates and pores mainly horizontally oriented. During this phase of observation, many clods were broken apart to characterize more accurately their internal state and the way the fragments are assembled together, with pores mainly horizontally oriented. The specific

Table 1
Initial characterization of the soil in the field experiment.

Depth	m	0–0.2	0.2–0.27	0.27–0.57	0.57–0.82	0.82–1
Horizon		A	BA	Bt_1	Bt_2	B_3
Clay	g kg^{-1}	221	303	435	302	170
Silt		600	568	475	564	655
Sand		179	129	90	134	175
FC	% (w/w)	27.4	27.8	29.3	30.0	27.6
PWP		14.4	14.3	16.6	17.3	10.6
pH	1:2.5	5.8				
OC	g kg^{-1}	15.8				

FC: field capacity, PWP: permanent wilting point; OC: organic carbon.