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Is chiseling or inverting tillage required to improve mechanical and hydraulic properties of sandy clay loam soil under long-term no-tillage?

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ABSTRACT

Dynamic soil properties as affected by machine-soil interaction are potential indicators for the evaluation of management and traffic effects on soil structure. Our objective was to determine compressive, shear, and hydraulic soil properties in a sandy clay loam Hapludalf, under continuous no-tillage and tillage operations to ameliorate soil physical conditions. The studied tillage systems were long-term (13 years) continuous no-tillage (NT_c); chisel tillage two years before the experiment (CH_2); inverting tillage performed on NT soil, 2 years before and just-before the experiment ($IT_{2,0}$); and chisel tillage performed on NT soil 3 years before and just-before the experiment ($CH_{3,0}$). Soil precompression stress, compressibility coefficient, cohesion, angle of internal friction, aggregate resistance, bulk density, porosity (total, macroporosity, microporosity), and water retention (field capacity, permanent wilting point, available water, and drainable water) were determined for 0.01–0.03 m (surface) and 0.10–0.12 m (subsurface) soil layers. The results show inverting and chisel tillage of soil previously under long-term no-tillage has little and/or short-lasting effect on soil composition and functional physical properties. Soil reconsolidation over time significantly affects soil structural condition. Thus, soil tillage is not need to improve soil structure of sandy clay loam subtropical soil. Furthermore, the terms capacity and intensity properties should not be used as synonyms to composition and functional properties, but they should rather be reserved to the thermodynamically basic quantity-intensity-capacity concept.

1. Introduction

Intense traffic of heavy agricultural machinery has significant impact on soil and crops (Berisso et al., 2013a). Soil compaction due high-load wheeling affects movement of water (Zink et al., 2011), gases (Kühne et al., 2012; Berisso et al., 2012, 2013b), and nutrients (Kuht et al., 2012) within soil and to roots, thus restricting crop growth and development (Letey, 1985; Collares et al., 2006, 2008; Reichert et al., 2009a) and causing environmental concerns (Stepniewski et al., 2002).

Soil properties affected by machine-soil interaction are potential indicators to evaluate management and traffic effects on soil structure (Silva et al., 2009), by simultaneously accounting for compressive and shearing deformation (Hemmat et al., 2009; Berisso et al., 2013a). Soil compressive behavior may be described by the mechanical parameters precompression stress (σ_p), and compressibility coefficient (Cc) that represents soil susceptibility to compaction when applied loads are greater than soil σ_p, and both are obtained from soil compression curve; soil shear strength is represented by particle cohesion and angle of internal friction between particles, and is defined as maximum shear stress that soil can withstand without failure (Holtz and Kovacs, 1981).

Soil compressibility is influenced by organic matter content (Braida et al., 2010; Islabão et al., 2016), clay mineralogy (Ajayi et al., 2013), soil granulometry (Silva et al., 2000, 2002a; Braga et al., 2015; Holthusen et al., 2017), soil moisture (Silva et al., 2000, 2002a; Horn and Fleige, 2003; Lamandé and Schjønning, 2011; Ajayi et al., 2013), soil bulk density (Silva et al., 2002b; Suzuki et al., 2008), soil tillage (Reichert et al., 2014), and traffic intensity (Horn et al., 2003; Peth et al., 2006).

Soil shear strength is influenced by particle-size distribution; shape, type and amount of clay minerals; exchangeable cations; attraction and repulsion forces between particles (McCormack and Wilding, 1979; Pértile et al., 2016); Fe, Si and Al oxides (Silva and Carvalho, 2007); soil moisture (Silva and Carvalho, 2007; Silva et al., 2015); soil structure (Horn et al., 1995; Silva and Carvalho, 2007; Bayat et al., 2015); soil

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tillage (Silva et al., 2015); and traffic intensity (Servadio et al., 2001; Peth et al., 2006).

Shear strength of sandy soils depends mainly on friction between soil particles, while in clay soils depends not only on friction between particles but also on soil cohesion (Lebert and Horn, 1991). In non-cohesive soils, such as in loose sands, shear strength has a maximum value for relatively small deformations, which later decreases and then remains constant. In cohesive soils, strength may not reach a maximum value and values increase continuously, showing an elasto-plastic behavior (Wiermann et al., 1999).

Compression and shear stresses arise simultaneously during and after soil tillage operations. However, most published literature describes compaction only by soil compressive deformation, resulting in an incomplete understanding of soil deformation and failure during machine-soil interaction as affected by different stress states (Berisso et al., 2013a). Lebert and Horn (1991) studied the combined effects of shear and compaction stresses on soil structural properties to link precompression stress to shear strength parameters.

Tillage operations change soil cohesion and strength. Schjønning and Rasmussen (2000) found that tillage systems affected shear strength in the 0.00–0.20 m soil layer after seeding operation in coarse sand, sandy loam and silty loam soils. In sandy loam soils cohesion decreased with an increase in moisture (Braida et al., 2007a) and tillage intensity (Munkholm et al., 2001). In soils with greater clay content, cohesion decreased with an augmentation in bulk density in clay soil (Secco et al., 2013) and traffic intensity in clay loam soil (Silva et al., 2009).

Soil tillage affects soil physical properties, especially those related to pore-size distribution (Berisso et al., 2012; Reichert et al., 2015a) and functioning (Horn, 2004; Dörner et al., 2010; Reichert et al., 2016). Total porosity was highest immediately after plowing or chiseling, reduced over time due to natural reconsolidation, and one year after soil tillage reached similar value as before tillage (Veiga et al., 2008). Changes in porosity correspond with changes in soil consolidation, which consequently affected soil water holding capacity and water availability (Reichert et al., 2015a).

There are numerous studies on compaction in different tillage systems, but there is scarce information on the effect of these tillage systems on both compressive and shearing properties, and probably inexistent for subtropical soils. Our objective was to determine compressive, shearing, and hydraulic soil behavior in two soil layers of four tillage systems in a sandy clay loam Hapludalf, under continuous no-tillage and tillage operations to ameliorate soil physical conditions.

2. Materials and methods

2.1. Soil and climate

The experiment was conducted on a Hapludalf according to Soil Taxonomy (USDA – Soil Survey Staff, 1999) or "Argissolo Vermelho-Amarelo Distrófico arênico" according to Brazilian Soil Classification System (EMBRAPA/CNPS, 2006), located in southern Brazil (29° 41′ 00″ S, 53° 48′ 00″ W), and elevation of 95 m. The soil profile had A horizon (0–0.20 m): clay 253 g kg^{-1}, silt 251 g kg^{-1}, sand 497 g kg^{-1}; Bt1 horizon (0.20–0.45 m): clay 538 g kg^{-1}, silt 265 g kg^{-1}, sand 198 g kg^{-1}; and Bt2 horizon (0.45–0.60 m): clay 610 g kg^{-1}, silt 275 g kg^{-1}, sand 115 g kg^{-1} (Albuquerque and Reinert, 2001).

The climate of the study area is humid subtropical (Cfa), according to classification of Köppen (1936) with no dry season (Álvares et al., 2013). Average temperature (1969–2011) of warmest month is 24.0 °C, while the average temperature of coldest month is 15.6 °C (Buriol et al., 2015).

The area had been managed for eleven years under no-tillage system prior to applying tillage systems, and cropped with black bean (*Phaseolus vulgaris* L.) during the summer and black oat (*Avena strigosa* Schreb) during the winter in the year of soil sampling.

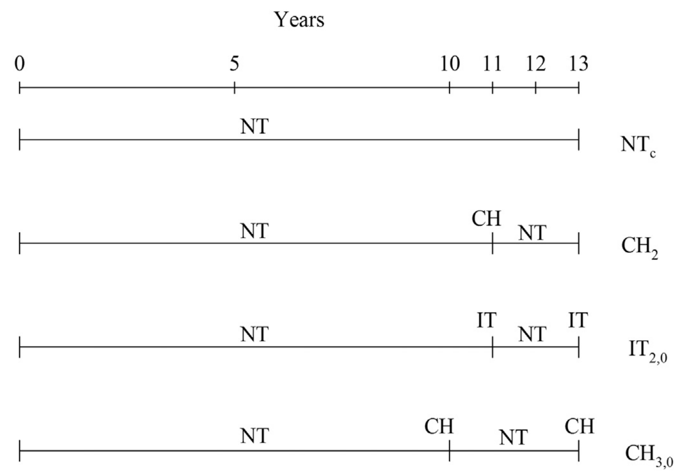

Fig. 1. Tillage systems used in the experiment. Recent inverting ($IT_{2,0}$) and chiseling ($CH_{3,0}$) tillage; two years after chisel tillage (CH_2); and long-term (13 years) of continuous no-tillage (NT_c).

2.2. Experiment design and tillage systems

A randomized complete block design was used to study tillage systems and time since last tillage, in 5 × 15 m experimental units, with three replications (blocks). The soil tillage systems include: long-term (13 years) continuous no-tillage (NT_c); chisel tillage two years before the investigation (CH_2) on 11-yrs old NT site; inverting tillage performed on a NT soil, 2 years before and just-before the investigation ($IT_{2,0}$) on a 11-yrs NT site; and chisel tillage performed on NT soil, 3 years before and just-before the investigation ($CH_{3,0}$) on a 10-yrs NT site (Fig. 1).

Inverting tillage consisted of plowing with a 3-disk plough operating at average depth of 0.20 m, while chiseling was performed using a chisel-plough with five shanks operating to a depth of 0.25 to 0.30 m. The inverting and chiseling treatment plots were disked once to break clods and level soil surface. All tillage operations were performed with a Massey Ferguson 275 tractor, 77.3-kW power with total mass of 5060 kg (where 41% of the mass was on the front axle and 59% on the rear axle). The tractor was equipped with front tires 9.14–24 R2 and rear tires 1.23–26 R2, all inflated to 200 kPa pressure.

2.3. Soil sampling and laboratory analysis

2.3.1. Soil compressibility (uniaxial compression test)

Undisturbed soil samples were collected in February (at 1.5 months after last tillage) during black-beans cycle; and in October i.e. 9.5 months after last tillage during black oat cycle for the determination of soil compressibility. Samples were collected in three replicates, one per layer per block, in metal rings (0.055 m wide and 0.020 m high) from soil layers 0.01–0.03 m, after residue removal, and 0.10–0.12 m, to determine soil precompression stress (σ_p) and compressibility coefficient (Cc) in uniaxial compression test. These two soil layers were chosen because the first layer, i.e. soil surface (0.00–0.07 m), experiences soil disturbance by seeder coulters and discs (Genro Júnior et al., 2009) and root growth; while the deeper layer (0.07–0.15 m) is within the no-tillage compacted layer of this soil, named "no-till pan layer" (Reichert et al., 2009b), resulting from load concentration from soil wheeling. For the tilled and chiseled soil, the same depths are as relevant as for NT to evaluate treatment residual ($IT_{2,0}$ and $CH_{3,0}$) and reconsolidations (CH_2) effects on soil structure stratification as described above.

The soil samples were capillary-saturated for 24 h and later equilibrated to − 6, − 100 and − 300 kPa matric potentials in Richards pressure plates (Klute, 1986). Subsequently, sequential static loads of 12.5, 25, 50, 100, 200, 400, 800 and 1600 kPa were applied on