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Capacity and intensity soil aeration properties affected by granulometry, moisture, and structure in no-tillage soils

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ABSTRACT

Soil surface is the locus of complex apportioning of mass and energy reaching the Earth. Pore system functioning of the surface soil, particularly airflow within the soil matrix, is affected by soil deformation. Our objective was to evaluate the effect of soil structure, moisture, and granulometry on soil aeration properties of three Oxisols and one Ultisol managed under no-tillage. Undisturbed samples (572), collected from loose (0.00–0.075 m) and compact (0.075–0.15 m) soil layers, were capillary saturated for 24 h and equilibrated to nine water tensions, from 1 to 500 kPa, to determine capacity (bulk density, volumetric moisture, air-filled porosity, and degree-of-compactness) and intensity (air conductivity and permeability, blocked porosity, and pore continuity) soil physical properties related to aeration; whereas disturbed soil samples were used for soil granulometry analysis. Soil granulometry, moisture, and structure (soil compaction) affect aeration capacity and intensity properties. Regardless of soil wetness, soil compaction reduces air-filled porosity, pore continuity, and air permeability. As soil moisture decreases, air permeability increases because of greater amount and continuity of soil pores available for air flow, and this increase in permeability is greatest in sandy-textured soil compared with clay-textured soils. Intensity properties are better descriptors of the time-variable aeration status of long-term no-tilled soils.

1. Introduction

Soil aeration is a complex physical phenomenon, where aeration properties change in space and time and are affected by soil structure. Pore system functioning, particularly airflow within the soil matrix, is affected by soil deformation. Humankind changes air flow in soil matrix as a consequence of machinery traffic and cropping systems.

Soil porous system significantly affects aeration (Schjønning et al., 2002; Tuli et al., 2005; Deepagoda et al., 2011), whereas the ability of soils to promote adequate gases exchange between the atmosphere and root environment directly affects plant growth and crop yield (Stepniewski et al., 1994; Tang et al., 2011). Soil air permeability is advocated as one of the most appropriate parameters for evaluating changes caused by management practices (Tang et al., 2011). Air permeability characterizes the ability to conduct gas by mass flow in response to pressure gradients (Stepniewski et al., 1994), and its behavior depends on size and continuity of pores (Tuli et al., 2005).

Soil moisture influences air permeability (Seyfried and Murdock, 1997; Moldrup et al., 2001; Schjønning et al., 2002; Silva et al., 2009; Rodrigues et al., 2011), as water coordinates the amount of pores occupied by air, which is directly related to tortuosity, continuity, number and diameter of pores responsible for air flow and blocking of airspace. Soil particle size affects air space, mainly due to differences in water retention, distribution and continuity of pores (Mosaddeghi et al., 2007; Deepagoda et al., 2011), thus affecting air flow in the soil.

A stable and functional pore system is expected to develop under continuous use of soil conservation practices such as no-tillage system, which could contribute positively to fluxes in soil (Horn, 2004). However, studies have shown reduction in air permeability of soils under no-tillage, mainly by decreasing air-filled porosity, effective pore diameter, and continuity of soil pores, and increasing their tortuosity (Rodrigues et al., 2011).

To improve our understanding of soil physical properties dynamics (Horn and Kutilek, 2009), the concept of intensity and capacity soil properties contributes. A capacity property is calculated as mass/volume relationship, ignoring pore structure and distribution of mineral and

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organic particles into space, whereas an intensity property considers the dynamic properties/processes, variable in time and space. As such, soil aeration has both capacity (total, saturated, and air-filled porosity) and intensity (blocked porosity, pore continuity, and air conductivity and permeability) properties.

We hypothesized soils under no-tillage, compacted, wet soils have increased blocked porosity and reduced pore continuity, thus possessing reduced air conductivity and permeability. Our objective was to evaluate the effect of changes in soil structure, and water and clay contents on soil aeration properties of three Oxisols and an Ultisol managed under no-tillage.

2. Materials and methods

2.1. Study sites and soils

Samples were collected from four soils in Rio Grande do Sul State (RS), southern Brazil. All soils have been under no-tillage system, grown to commercial crops. Details of cultivation period, and integration with livestock are presented in Table 1. These soils were classified according to Soil Taxonomy (USDA – Soil Survey Staff, 1999) and Brazilian System of Soil Classification (Embrapa, 2006) as follows:

(i) Paleudult or "Argissolo Vermelho-Amarelo Distrófico típico", located in Santa Maria - RS (29° 43′ 36.93″ S, 53° 45′ 17.75″ W), herein named PALEUDULT SM, where the soil texture ranges from loam to sandy loam;

(ii) Hapludox or "Latossolo Vermelho Distrófico típico", located in Passo Fundo - RS (28° 16′ 39.99″ S, 52° 37′ 22.62″ W), herein named HAPLUDOX DYSTROPHIC PF, where the soil texture ranges from sandy clay loam to sandy loam;

(iii) Hapludox or "Latossolo Vermelho Distroférrico típico", found in Victor Graeff - RS (28° 28′ 44.43″ S, 52° 50′ 55.75″ W), herein named HAPLUDOX DYSTROFERRIC VG, where the soil texture ranges from clay to silty clay;

(iv) Hapludox or "Latossolo Vermelho Distroférrico típico", located in Não-Me-Toque - RS (28° 33′ 14.16″ S, 52° 45′ 06.08″ W), herein named HAPLUDOX DYSTROFERRIC NMT, where the soil texture ranges from clay to clay loam.

The studied soils are formed from different parent materials. PALEUDULT SM is derived from sandstone, HAPLUDOX DYSTROPHIC PF was formed from a mixture of sandstone and basalt, and HAPLUDOX DYSTROFERRIC VG and NMT were originated from basalt. These parent materials provide a wide range in particle size distribution and, associated with soil management practices, different soil structural properties, as was observed in a preliminary soil evaluation study.

Two soil layers were chosen for sampling: 0.00–0.075 and 0.075–0.15 m layers, to obtain samples with a wide range of bulk density and particle size distribution (Table 2). The first layer was selected because no-tillage has low bulk density and high total porosity, due to biological activity and direct seeding mechanisms (Genro Júnior et al., 2004). The second layer has the highest soil bulk density and mechanical penetration resistance under no-tillage due to the concentration of loading by farm machinery traffic and absence of soil tillage (Reichert et al., 2009).

2.2. Soil sampling

Soil samples were collected in two layers on three sites for PALEUDULT SM and HAPLUDOX DYSTROPHIC PF soils, and in six sites for HAPLUDOX DYSTROFERRIC VG and HAPLUDOX DYSTROPHIC PF soils, to obtain a wide range in physical properties. Sites were defined based on penetration resistance maps on a portion of the field with different traffic intensities.

Disturbed and undisturbed soil samples were collected in May 2010, from 0.00–0.075 m and 0.075–0.15 m soil layers in each sampling site. Air-dried, 2-mm sieved disturbed soil samples were used to analyze particle size distribution according to Embrapa (1997) (Table 2), and total organic carbon (TOC) in an autoanalyzer (Table 3).

Undisturbed samples were collected using core samplers of 0.057 m diameter and 0.04 m high in each sampling site, in a total of 572 soil samples (18 sites × 2 layers per site × ~18 replications per layer per site). These undisturbed samples were used to determine soil capacity (bulk density, volumetric moisture, air-filled porosity, and degree-of-compactness) and intensity (air conductivity and permeability, blocked porosity, and pore continuity) aeration properties.

2.3. Soil physical properties analyses

Undisturbed soil samples were saturated by capillary action for 24 h to determine total porosity. Later, these samples were equilibrated to nine different water tensions, namely: 1, 3, 6 and 10 kPa applied in a sand column (Reinert and Reichert, 2006) and 33, 50, 100, 300 and 500 kPa in Richard's pressure plates (Klute, 1986), to determine the capacity and intensity aeration properties.

2.4. Soil intensity properties: air conductivity and permeability, blocked porosity, and pore continuity

After soil samples equilibration to each water tension, air conductivity (k_a) was measured with a constant-head permeameter. The equipment

Table 1
Time of field under no-tillage, crops used, and integration with livestock for four soils.*

Crops		No-tillage (years)	Integration with livestock
Winter	Summer		
PALEUDULT SM			
Black oats (all years)	Soybean (all years)	8	No
HAPLUDOX DYSTROPHIC PF			
Black oats/Ryegrass (2005)	Soybean (2005/06)		
Black oats/Ryegrass (2006)	Maize (2006/07)		
Black oats/Ryegrass (2007)	Soybean (2007/08)	20	Yes
Black oats/Ryegrass (2008)	Soybean (2008/09)		
Black oats/Ryegrass (2009)	Soybean (2009/10)		
HAPLUDOX DYSTROFERRIC VG			
Fallow	Maize (2007/08)		
Black oats (2008)	Soybean (2008/09)	3	No
Wheat (2009)	Soybean (2009/10)		
HAPLUDOX DYSTROFERRIC NMT			
Wheat (2007)	Soybean (2007/08)		
Wheat (2008)	Maize (2008/09)	10	No
Forage turnips/Wheat (2009)	Soybean (2009/10)		

* Information supplied by the farmers.