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Structural properties of the soil seedbed submitted to mechanical and biological chiseling under no-tillage

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ABSTRACT

Tensile strength and aggregate stability are two of the most important structural properties that may affect the physical environment of the soil seedbed for germination and initial plant development. The objective of this study was to determine the tensile strength, friability, and aggregate stability of the seedbed of an Oxisol after a long-term no-tillage. The experiment was carried out in Ponta Grossa, Paraná State, Brazil, at the farm belonging to Ponta Grossa State University. The treatments were no-tillage for 18 years, no-tillage submitted to mechanical chiseling at 0.25 m soil depth and no-tillage submitted to biological chiseling by a forage radish crop. The experimental design was in randomized blocks with four replications, resulting in 12 plots. Soil samples were collected at six and 18 months after the treatments were applied, corresponding to a maize seedbed (October 2009) and soybean seedbed (November 2010), for the 0 to 5 and 5 to 10 cm soil depths. Tensile strength was determined in 2400 aggregates with a diameter of 2 to 4 mm using the indirect tension test through an electronically controlled loading frame with a displacement speed of 0.03 mm s^{-1}. Aggregate stability was determined by the water percolation method in acrylic columns filled with aggregates of 1 to 2 mm diameter. The data were submitted to the variance analysis and, when significant, the means were compared by the Tukey test ($p < 0.05$). Tensile strength and friability did not differ among the evaluated treatments and periods. The soil was classified as friable in all evaluated treatments, periods and depths. Aggregate stability was significantly reduced under no-tillage after six months of mechanical chiseling, while at 18 months, the soil under no-tillage submitted to biological chiseling had greater aggregate stability. Aggregate stability was classified as of rapid or moderate percolation in all evaluated treatments, periods and depths. Among the evaluated soil structural properties, aggregate stability was the most sensible indicator of the soil physical quality for the seedbed. The cultivation of the forage radish crop as an alternative of biological chiseling can be included on the crop rotation system in no tillage once it promoted an improvement on the soil seedbed structural quality.

1. Introduction

The seedbed is defined as a biologically active soil layer that determines germination, seedling emergence and crop establishment (Atkinson et al., 2007). It is considered the most agronomical important layer for grain production, because it provides the main elements that determine plant growth: water, air, nutrients, mechanical support for roots and heat to initiate chemical and biological actions (Atkinson et al., 2009; Nasr and Selles, 1995; Tapela and Colvin, 2002).

The success of crop production depends on the physical quality of the soil seedbed. In soils under conventional tillage, the seedbed is result of the soil tillage operations, such as plowing and harrowing, and seed furrowing. Several works in, mainly, temperate regions, evaluated the conditions of the seedbed under different tillage systems (Arvidsson et al., 2000; Atkinson et al., 2007; Comia et al., 1994). In no-till soils, as there is no complete disturbance, the seedbed results only from a partial soil mobilization which is applied in the sowing lines. Therefore, the seedbed is strongly influenced by the biological activity of roots, earthworms, microorganisms as well as disturbance induced by the seeder. There are no studies about the seedbed quality under no-till, which has been more and more applied over the years in tropical and subtropical regions (Febrapdp, 2012), although there are some works that show the visual soil quality of the seedbed under no-tillage management (Giarola et al., 2010; Guimarães et al., 2013). Hence, it is essential to evaluate the physical condition of the

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soil seedbed under no-tillage to better understand the physical environment where germination and seedling emergence take place.

Aggregate stability and tensile strength are two of the most important structural properties that may affect the physical quality of the soil seedbed for plant development. The aggregate size determines the soil porous space, which in turn, affects the movement and distribution of water, air and heat in the soil (Skidmore and Powers, 1982). Aggregate stability and, therefore, the arrangement of the porous system derive from the cohesive forces among particles to support the application of a disruptive force (Kemper and Rosenau, 1986). Among the aggregate features, the tensile strength is defined as the stress or force per unit area required to fracture the soil aggregates when submitted to the action of a pressure (Dexter and Watts, 2000). This indicates the soil easiness for fragmentation or aggregate size reduction by different processes (Kay et al., 1994) such as wetting and drying cycles, freezing and thawing, machine traffic, tillage and management of soil practices (Skidmore and Powers, 1982).

Aggregate stability and tensile strength can be considered important indicators of the soil physical quality, especially of the structural condition of the soil seedbed (Snyder et al., 1995; Watts and Dexter, 1998). Generally, the tensile strength of aggregates represents the force that the seedling should apply to be able to emerge. Thus, this soil property can be used as an indicator of the management effects on soil quality because of the soil specific response to physical and mechanical processes that are linked to its manipulation, such as tillage, surface sealing, root penetration and seedling emergence (Tormena et al., 2008a). The aggregate stability, on the other hand, is a physical property that determines the soil sustenance so that the seedling emergence process may properly occur.

Tensile strength of aggregates is a dynamic property that takes place under field conditions (Kay and Dexter, 1992). The rupture of aggregates occurs in brittle fractures derived from cracks and microcracks that create zones of minor strength inside the aggregates. The heterogeneity resulting from the soil aggregate flaws and microcracks has been identified as the soil friability (Dexter and Watts, 2000). Friability is defined as the tendency of a mass of unconfined soil to disintegrate and crumble under an applied stress (Watts and Dexter, 1998) into a particular size range of smaller fragments (Utomo and Dexter, 1981) which is of fundamental importance during plant emergence. Hence, soil friability may be considered an important indicator of the soil physical quality (Utomo and Dexter, 1981) and is desirable for an appropriate plant establishment (Watts and Dexter, 1998). High values of friability indicate that larger aggregates have smaller resistance to rupture than smaller aggregates (Tormena et al., 2008b).

Aggregate stability is usually determined by the methods described by Kemper and Rosenau (1986) and Yoder (1936). The method developed by Becher and Kainz (1983) is based on the amount of percolated water along time through a column of aggregates and, because of this, it is known as percolation stability. As the aggregates are moistened, the water is attracted inside by adhesive forces that displace and compress the air inside the aggregates (Mbagwu and Auerswald, 1999). If such intra-aggregate pressure is high enough to overcome the cohesion forces, the aggregates break up, resulting in microaggregates of different sizes and cohesion forces. The microaggregates are then displaced to the bottom of the soil column, blocking the water conductive pores. Consequently, there will be a reduction on the amount of percolated water per unit time. In summary, the water flow through the aggregate column will increase with increased aggregate stability (Mbagwu and Auerswald, 1999). The determination of the aggregate stability by the percolation method is not much used in studies on tropical soils. However, several studies stated that the determination of the aggregate stability by the percolation method is very sensible to detect differences among cropping systems and soil management (Fiener and Auerswald, 2006; Mbagwu and Auerswald, 1999; Siegrist et al., 1998; Vakali et al., 2011).

Soil physical quality has been widely studied in the last decades; however, it was observed that little emphasis has been given to the physical quality of the seedbed, especially in soils under no-tillage. It has been common, then, to find an area under such management with a compacted surface layer due to machinery traffic and a direct compaction effect of the seeder. As a means of alleviating this possible soil compaction under no-tillage, mechanical chiseling or subsoiling has been a common practice (Busscher et al., 2002; Evans et al., 1996; Vieira and Klein, 2007). Another alternative is to cultivate plants that produce aggressive root systems with the objective to promote soil biological chiseling (Abreu et al., 2004; Nicoloso et al., 2008; Willians and Weil, 2004).

The established hypothesis for this study was that both mechanical and biological chiseling in no-till soils would result in a better soil physical quality of the seedbed, which was evaluated by structural soil properties: tensile strength, friability and aggregate stability by the percolation method. The objective of the study was to determine and evaluate the tensile strength, friability and aggregate stability in an Oxisol cultivated under a long-term no-tillage system and submitted to mechanical and biological chiseling.

2. Material and methods

2.1. Description of the experimental area

The study was carried out at Ponta Grossa State University (UEPG), in Paraná State, Brazil (25° 05′ 52″ S and 50° 02′ 43″). The soil in the study area is classified as a Rhodic Hapludox with clay-sandy texture. The slope of the area varies from 3 to 8% and the altitude is 1080 m. The predominant climate in the region, according to the Köppen classification, is humid subtropical mesothermal (Cfb), with an annual mean rainfall of 1545 mm and an annual mean temperature of 18.7 °C (Iapar, 2000).

The area has been cultivated under no-tillage for 18 consecutive years with the following crop rotation: maize (*Zea mays* L.) and soybean (*Glycine max* L.) in spring/summer; wheat (*Triticum aestivum* L.), and the intercropped with black oat (*Avena strigosa* Schreb) + vetch (*Vicia sativa* L.), in autumn/winter (Table 1). Mechanical chiseling and forage radish crop cultivation (*Raphanus sativus* L.) respectively as agents of soil mechanical and biological loosening were introduced in the area. The experiment was implemented in May 2009, considering three treatments: no-tillage submitted to mechanical chiseling (NT-M), no-tillage

Table 1
Summary of the management of the area cultivated under no tillage system for 18 consecutive years.

Crop rotation system	
Season	Crops
Spring/summer	Maize (*Zea mays* L.)
Autumn/winter	Wheat (*Triticum aestivum* L.)
Spring/summer	Soybean (*Glycine max* L.)
Autumn/winter	Black oat (*Avena strigosa* Schreb) + intercropped Vetch (*Vicia sativus* L.)
Date	Treatment
Treatment application	
May, 2009	Mechanical chiseling at 25 cm soil depth cultivated with black oat + vetch
May, 2009	Biological chiseling by forage radish (*Raphanus sativus* L.) cultivation
May, 2009	No tillage without any chiseling cultivated with black oat + vetch
Soil sampling	
October, 2009	Maize seedbed (six months after treatments application)
November, 2010	Soybean seedbed (18 months after treatments application)