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Changes in composition and functional soil properties in long-term no-till integrated crop-livestock system

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ABSTRACT

Integrated Crop-Livestock Systems (ICLS) are an important alternative to winter fallow and increase the sustainability of production systems, by combining agricultural with livestock production. The hypothesis of this study was that load applied by animals in moderate grazing does not promote further soil structural degradation. The objective of this study was to demonstrate changes in soil structure, mechanical behavior, and water and air permeability caused by different intensities of grazing in ICLS. The experiment consisted of a 15-years old ICLS, managed with soybean *Glycine* max in the summer and black oat *Avena strigosa* + ryegrass *Lolium multiflorum* in winter with continuous grazing by beef cattle. The treatments consisted of different grazing intensities determined by sward height, namely 0.10 m (heavy grazing) and 0.30 m (moderate grazing), and a control (without grazing), in an experimental design of randomized blocks with three replications. Undisturbed soil samples were collected in core samplers in the 0–0.05, 0.05–0.10, and 0.10–0.20 m soil layers, in two evaluation times: (i) post soybean (immediately after soybean harvest, and before pasture sowing or animal grazing), and (ii) after grazing (immediately after withdrawing the animals from the area and before soybean sowing), respectively in April and November 2015. Soil bulk density, macroporosity, microporosity, air permeability, saturated hydraulic conductivity, precompression stress, compressibility coefficient, decompression coefficient, and cyclic compressibility index were determined. The results indicate grazing increases the compaction state of the soil surface mainly in the post grazing period by the direct effect of animal treading. However, there is a mitigation effect during the soybean cycle, evidencing the soil's regeneration capacity in ICLS, provided by intense biological activity, wetting-drying cycles, and decomposition of pasture roots that regenerate soil structure. Moderate grazing is a better option than intense grazing, but without soil improvements when compared to the non-grazed system.

1. Introduction

Integrated Crop-Livestock Systems (ICLS) in the Brazilian subtropics are generally characterized by summer crops consisting of grains such as soybeans (*Glycine* max), corn (*Zea mays*) and rice (*Oryza sativa*), followed by the establishment of pastures with cold-season grasses, such as black oats (*Avena strigosa*) and ryegrass (*Lolium multiflorum*) intended for animal grazing (Moraes et al., 2014).

The ICLS are on the rise in recent years to diversify (Ternoski, 2014), intensify production (FAO, 2015), substitute winter fallow (Denardin et al., 2001), conserve soil and land (Albuquerque et al., 2002; Cardozo et al., 2012), and improve soil quality (Hebb et al., 2017). When properly managed, this system generates improvements in soil chemical, physical and microbiological properties (Carvalho et al., 2015).

Root growth in ICLS is stimulated by the presence of animals, by cutting and inducing new meristems (Anghinoni et al., 2013; Embrapa, 2014), with greater root density and biomass in grazing areas (Larreguy et al., 2014), where the grass rooting system acts directly on soil structuring. Conte et al. (2011) observed that increased grass root density in ICLS improves soil aggregation. Rotating pasture with soybean increased soil aggregation compared to annual crops, due to carbon input to the soil, especially by roots (Wohlenberg et al., 2004; Salton et al., 2008) that can exceed the contribution of the aerial part by 1.5 times (Balesdent and Balabane, 1996), and also because of more recalcitrant organic compounds in roots compared to canopy (de Neergaard et al., 2002).

Low-intensity grazing systems may have soil physical properties

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similar to non-grazed areas (Veiga et al., 2012), but without affecting the productivity of summer crops (Cecagno et al., 2016). Root growth alters soil structure and, after decomposition of the roots, the previously-occupied pores are unrestricted, improving soil permeability to water and air (Zúñiga et al., 2015). The ICLS provide permanent coverage and active rooting system compared to winter fallow, with high rates of organic material addition to the soil, contributing to reduce soil compression since surface residues attenuate the effect of surface-applied stresses (Braida et al., 2006; Reichert et al., 2016a, 2016b).

Excessive animal trampling deforms soil structure because of the pressure applied by animal hooves, potentially increasing soil bulk density and causing impediment to root growth mainly in surface soil layers (Moreira et al., 2012). Furthermore, soil compaction caused by cattle trampling in ICLS may result in negative changes in soil flow properties, such as hydraulic conductivity and air permeability (Krümmelbein et al., 2008; Collares et al., 2011).

Soil susceptibility to deformation under integrated systems depends on several factors, such as soil type, initial compression state, and water content (An et al., 2015). Soil deformation process in the field consists of rapid loading and unloading cycles, whether by farm machine traffic or animal treading, making the load-deformation relationship a very-dynamic process (Mordhorst et al., 2012). Increased animal stocking causes less pasture availability, and thus animals must move more within the field during grazing (Baggio et al., 2009). One strategy of obtaining results closer to field conditions is evaluating soil deformation by dynamic compressibility tests, where deformation cycles are tested and soil elasticity index is determined (Peth et al., 2010). Although recent studies highlighted that elasticity indexes (Gubiani et al., 2018) and precompression stress (Keller et al., 2011; Dastjerdi and Hemmat, 2015; Somavilla et al., 2017; Gubiani et al., 2018) fail to access soil elasticity and soil bearing capacity, respectively, the determination of both allow verifying their utility as a mathematical index for evaluating soil physical quality in ICLS.

The hypothesis of this study was: load applied by animals in moderate grazing does not promote further soil structural degradation. The objective of this study was to demonstrate changes in soil structure, mechanical behavior, and water and air permeability caused by different intensities of grazing in ICLS.

2. Methodology

2.1. Experiment conditions and soil sampling

The experimental area is located in the physiographic region of the "Planalto Central" of Rio Grande do Sul state, southern Brazil (29°03′10″ S, 53°50′44″ W). Altitude of the site is 465 m, and climate is characterized as mesothermal humid with mild summers, type Cfb according to the Köppen classification (Kottek et al., 2006), with average annual temperature of 19 °C and average annual precipitation of 1.850 mm (Cemetrs, 2015). The soil is classified as Rhodic Hapludox with a very-clayey texture (540, 190 and 270 $g\,kg^{-1}$ of clay, silt and sand, respectively). Since 2001, the site has been managed under ICLS, with black oats *Avena strigosa* + ryegrass *Lolium multiflorum* in the fall/winter period, and soybean *Glycine* max in the spring/summer period.

The treatments consisted of different grazing intensities characterized by pasture height management, arranged in a randomized complete block design with three replicates, namely intense grazing (0.10 m of pasture height), moderate grazing (0.30 m pasture height), and non-grazed (control).

The adopted grazing method was the continuous variable stocking, with neutered male steers (crossbred Angus, Hereford and Nellore) about 12-months old, approximately 200 kg (minimum of three steers per area, with one more test steers if needed to keep pasture height). That is, the number of animals normally does not vary, but the areas are of different sizes: the smaller the area, the greater the animal stocking per unit area. Over the experimental period of 15 years, the steers started grazing in the first half of July when the forage height reached approximately 20 cm (1.5 mg of dry matter ha^{-1}). Grazing extended until the first half of November, totaling 120 grazing days on average. Pasture height was controlled every 14 days by the sward stick method (Barthram, 1986). After the animals are removed from the field, the pasture is desiccated with herbicide to sow soybeans in no-tillage system in November/December, and this crop is harvested in April/May next year, constituting a pasture-soybean succession system.

For this study, undisturbed soil samples were collected in the center of the 0–0.05, 0.05–0.10 and 0.10–0.20 m soil layers, in two evaluation times: (i) post soybean (immediately after soybean harvest, and before pasture sowing or animal grazing), and (ii) after grazing (immediately after withdrawing the animals from the area and before soybean sowing), respectively in April and November 2015. Since the system is a pasture-soybean succession, time (i) was 5 months apart from the last grazing cycle in November 2014, and time (ii) was 7 months after the last soybean harvest in April 2015.

Furthermore, cylindrical samples of 0.057 m of diameter and 0.04 m of height were used for the determination of soil bulk density (*Bd*), microporosity (*Mi*), macroporosity (*Ma*), air permeability (*Ka*), and saturated hydraulic conductivity (*Ks*); and cylindrical samples of 0.10 m of diameter and 0.03 m of height were collected for the precompression stress (σ_p), compressibility coefficient (*Cc*), decompression coefficient (*Dc*), and cyclic compressibility index (*Cn*) analyses.

Soil properties were classified into two categories: composition and functional soil properties (Reichert et al., 2016a, 2016b, 2017, 2018; Holthusen et al., 2018), where the former are related to the composition of a soil volume, disregarding the internal organization, and the latter express the internal organization and soil functionality with greater variation in time and space.

2.2. Soil composition properties

The undisturbed soil samples were capillary-saturated for 48 h, and then water retention was determined at −6 and −10 kPa tension (*Wt*) in a sand column (Reinert and Reichert, 2006), whereas soil *Wt* at −100 kPa was determined in a pressure chamber (Klute, 1986). Finally, the samples were oven-dried at 105 °C for 48 h for density and porosity calculations.

Soil bulk density (*Bd*) ($g\,cm^{-3}$) was calculated by the ratio of dry soil mass to total sample volume, whereas microposity (*Mi*) ($cm^3\,cm^{-3}$) was determined as the volumetric content of water at −6 kPa *Wt*. Total porosity (*Tp*) ($cm^3\,cm^{-3}$) is relationship between and *Bd* and particle density (*Pd*) ($g\,cm^{-3}$) determined by the volumetric flask method (Embrapa, 1997). Soil macroporosity (*Ma*) ($cm^3\,cm^{-3}$) was calculated by the difference between *Tp* and *Mi*.

2.3. Soil functional properties

Soil saturated hydraulic conductivity (Ks) ($mm\,h^{-1}$) was determined using a falling-head permeameter (Hartge and Horn, 2009; Gubiani et al., 2010).

Soil air permeability (Ka) (μm^2) was determined with a constant-head permeameter at −6, −10 and −100 kPa *Wt*. The method quantifies air flowing through the soil sample, while maintaining a constant and low-pressure gradient (0.1 kPa) to avoid turbulent flow. The methodology and equipment were adapted from Vossbrink (2005). From air conductivity, *Ka* was calculated using the equation:

$$Ka = K_l(\eta/\rho_l g)$$

where $^{K}_{l}$ is air conductivity ($cm\,s^{-1}$), η is viscosity of air ($g\,s^{-1}\,cm^{-1}$), ρ_l is air density at the moment of measurement ($kg\,m^{-3}$), and *g* is acceleration of gravity (9.81 $m\,s^{-2}$).

For precompression stress (σ_p), compressibility coefficient (*Cc*), decompression coefficient (*Dc*), and cyclic compressibility index (*Cn*) determinations, the soil samples were saturated and then equilibrated