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Soil physical attributes under different grazing management of winter forage crops in crop-livestock system at Southern Brazil

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The effects of different species and grazing management of winter forage crops on the physical properties of a clayey Red Latosol of the western region of Parana State under crop-livestock integration systems were investigated in the present study. Treatments consisted of three different winter crops [white oat (*Avena sativa*), dual-purpose wheat (*Triticum aestivum*) and triticale (X *Tritico secale*)] and three grazing management (one and two grazing with 15 cm of residue height, and without grazing), followed by soybean cultivation, in a randomized block design. Undisturbed soil samples were collected at 0.00-0.10 and 0.10-0.20 m depths, after the winter crops harvest (October/2012) and soybean harvest (March/2013) and was determined the soil bulk density until 0.35 cm depth. The soil macroporosity in the 0.00-0.10 and 0.10-0.20 m soil layers and the total soil porosity in the 0.10-0.20 m layer, after winter crops harvest, were influenced by the crops and management of winter forage. In the evaluation performed after the soybean harvest, there were changes in the soil macroporosity in the 0.0-0.10 m layer and for microporosity and total soil porosity in the 0.10-0.20 m soil layer. The soil bulk density was not affected by the crops and management of winter forage. The different species and grazing management of winter crops in integrated crop-livestock systems promoted changes in soil penetration resistance in the 0.20-0.30 m soil layer. The cultivation of white oat during winter and management with two grazing resulted in lower soil penetration resistance levels.

Key words: Physical quality, soil structure, soil penetration resistance, conservation cropping systems.

INTRODUCTION

Integrated crop-livestock systems (ICLS) could provide opportunities to capture ecological interactions among different land use systems to make agricultural ecosystems more efficient at cycling nutrients, preserving natural resources and the environment, improving soil quality, and enhancing biodiversity (Lemaire et al., 2013). Moreover, diversifying agricultural production could utilize labor more efficiently at farm and/or regional scales (Hoagland et al., 2010). However, depending of management system that the soil is subjected, the ICLS

Table 1. Soil chemical attributes and particle size at the beginning of the experiment.

Depth (m)	pH	O.M.	P	H+Al	K	Ca	Mg	CEC	V	Textural		
										Clay	Silt	Sand
		g kg^{-1}	mg kg^{-1}	---------------- cmol$_c$ kg^{-1} ----------------					%	------- g kg^{-1} -------		
0.0–0.10	4.5	32.6	24.5	9.40	0.53	4.56	1.54	16.02	42	680	265	55
0.10–0.20	4.6	32.6	25.9	8.62	0.44	5.32	1.67	16.04	46	750	200	50
0.20–0.30	4.8	32.5	12.1	7.47	0.25	5.49	1.75	14.95	50	705	240	55

pH in $CaCl_2$ 0.01 M. O.M.: organic matter. P and K: Mehlich-1. H+Al: pH SMP (7,5). Ca and Mg: KCl 1 mol L^{-1}. CEC: cation exchange capacity. V: soil base saturation.

can lead to soil degradation or recovery of its structure, this because chemical, physical and biological attributes are continually interacting.

In Brazil southern, there is high potential for milk and beef production in annual winter pastures (white and black oat, dual-purpose wheat and annual ryegrass) (Balbinot et al., 2009). Additionally, the appropriate animal grazing during the winter, ICLS can result in the increase in nutrients cycling particularly nitrogen and maize yield (Silva et al., 2012). However, issues surrounding the soil-plant-animal system are not yet well understood, implying for more research with different forages species and agricultural crops, and pasture systems (Balbinot et al., 2009).

The presence of the animal cause amendments on sustainability and production capacity, as well as in functioning of the system, that depending on the grazing intensity is able of determine the animal production, soil conditions and the amount of straw that is transferred to the agricultural phase (Balbinot et al., 2009). The presence of animals in the appropriate amount does not affect both the production of forage biomass in winter and subsequent crop yields. However, overcrowding of animals grazing can cause changes on the physical properties, particularly in the surface soil compaction (Araújo et al., 2008) and content of soil organic matter, affecting the root growth (Souza et al., 2009) and crop yields cultivated after grazing (Albuquerque et al., 2001). The study of the changes resulting from the soil use and managements is of great importance for the adoption of management systems more compatible with the characteristics of each region and soil (Rozane et al., 2010), providing less impact on native soil characteristics. Soil attributes such as soil bulk density (Balbino et al., 2004), macroporosity, microporosity and total soil porosity (Karlen and Stott, 1994), has been frequently used as indicators of soil physical quality, mainly due to low cost and facility of obtaining measurements (Schiavo and Colodro, 2012). In addition, the soil penetration resistance of the soil has been used to identify compacted layers (Cunha et al., 2002).

Considering the risk of soil compaction on ICLS and the lack of information about the recommendations for the proper management of winter pastures, was idealized this study to evaluate the effects of different species and management of winter forage crops on the physical properties of a clayey Red Latosol of the western region of Paraná State under crop-livestock integration systems.

MATERIALS AND METHODS

The experiment was carried out in Marechal Cândido Rondon, Paraná, Brazil, on a clayey Rhodic Hapludox (Red Latosol in the Brazilian classification), in an area (24° 31' 58'' S, 54° 01' 10'' W, altitude of 400 m) where soybean/wheat/corn had been sown in no-till rotation as of 2008. Before starting the experiment (autumn-winter 2012), the soil was sampled for chemical and physical analysis (Embrapa, 1997) up to 0.30 m (Table 1). The regional climate, according to Köppen's Cfa type mesothermal humid subtropical dry winter, with well distributed during rains and hot summers. The 30 years mean annual temperature is 21.4°C with a July minimum of 14.7°C and a January maximum of 28.6°C, and mean annual precipitation of 1,500 mm. Rainfall and temperature data gathered during the experiment are shown in Figure 1.

The experimental design was a split-plot in randomized blocks with four replicates. In the A bands, were established the three winter crops (that is, white oat, dual-purpose wheat and triticale) and the different management of winter crops (started when the winter crops reached 35 cm) was established as B bands. Management regimes of winter crops investigated were: (i) one grazing with 15 cm of residue height; (ii) two grazing with 15 cm of residue height; and (iii) without grazing. The A bands were 10.0 × 15.0 m, the B bands were 5.0 × 30.0 m, and 10.0 x 5.0 the experimental plots. Before the establishment of the experiment, 4.2 Mg ha^{-1} of lime was applied on the soil surface to elevate the soil base saturation to 70%. Experimental area was desiccated with glyphosate (1.20 kg ha^{-1} a.i.) at a spray volume of 250 L ha^{-1}. Thirty days after the desiccation, winter crops were sown. White oat (cv. IPR 126), dual-purpose wheat (cv. BRS Tarumã) and triticale (cv. IPR 111) were sown in April 19, 2012 in 0.17 m spaced rows at densities of 60, 90 and 50 kg seeds ha^{-1}, respectively. The fertilization was carried out by applying 200 kg ha^{-1} 08-20-20 formulation at sowing, and 120 kg ha^{-1} N topdressing as urea (spitted after management of winter crops).

The management of winter crops was initiated when plants had 25 to 35 cm of height. For the grazing, nine Holstein cows with mean body weight of 663±52.4 kg were used. Cows remained in

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subplots for four hours daily (two in the morning and two in the afternoon period) or until desired height of 15-20 cm, not to damage the apical meristem.

Soybean [*Glycine max* L. (Merrill), cv. BMX Potência RR] was cropped in the summer (November through March) in all the plots under crop residues of winter crops. Soybean was sown in rows spaced 0.45 m with 14 seeds m^{-1}, fertilized with 350 kg ha^{-1} 02-20-20 formulation, applied in the seed furrows. After the winter crops harvest (October 2012) and soybean harvest (March 2013), undisturbed soil samples were collected at 0.00-0.10 and 0.10-0.20m depths from each experimental unit, using a 90.5 cm^3 cylindrical sampler, to determine soil bulk density (BD), macroporosity (Ma) and microporosity (Mi) by the tension table method (Embrapa, 1997), and total soil porosity (TSP) by summing the values for macro- and microporosity.

Soil penetration resistance (PR) down to the 0.35 m depth was established in three points per experimental unit using an impact penetrometer (model STOLF; base diameter 13.0 mm, angle 60°). The calculations were made in line with Stolf (1991), and the results presented in MPa. Original data were submitted to analysis of variance and the results of different winter crops and management of grazing were compared using the Tukey test ($p < 0.05$). All analyses were performed using Sisvar 5.1 software for Windows (Statistical Analysis Software, UFLA, Lavras, MG, BRA).

RESULTS AND DISCUSSION

Total soil porosity (TSP), macroporosity (Ma), microporosity (Mi) and soil bulk density (BD)

After harvest of winter crops, the results for soil porosity in the 0.00 to 0.20 m soil layer under the different management of winter crops (Table 2) showed that for the Ma, there was significant interaction between the factors studied. For the TSP, in the 0.10-0.20 m soil layer there was significant difference in grazing management of winter crops (Table 2). Different species and management of winter forage crops did not affect the Mi, BD and TPS in the 0.00-0.10 m layer (Table 2). In the evaluation performed after the soybean harvest data showed that there was significant interaction between the winter crops and grazing management for the Ma in the 0.00-0.10 m layer, and for Mi and TSP in the 0.10 to 0.20 m soil layer (Table 3). Soil physical attributes were not affected by the isolated effect of the experimental treatments (Table 3).

In general, the results observed for the physical attributes (Tables 2 and 3) soil layers studied are consistent with results reported by other authors as Flores et al. (2007) who studied the changes introduced by animal trampling on soil physical properties and the changes resulting from this trampling influence on the establishment and yield of soybean, already Spera et al. (2009) studied the effect of grain production and grazing winter annual and perennial pasture systems under no-tillage system, after ten years of cultivation on soil physical properties and confirm the small magnitude of the changes caused by adequate animal trampling. These small changes, when present, does not reach critical levels for the root growth of crops grown in succession, since the pressure applied by the animal paws is not greater than the soil resistance to plastic deformation (Conte et al., 2011).

It was expected that in the management with two grazing of winter crops there were changes on soil physical attributes. In ICLS, changes in physical properties can occur in the surface layer, more or less intensely, due to animal trampling that depends upon the intensity and frequency of pasture (Flores et al., 2007). The great magnitude of these changes is connected to the management that is applied to areas under pasture grazing, which may vary according to texture, organic matter content, soil water content, species of plants, pasture intensity and pasture grazing time and also animal species and category (Flores et al., 2007; Lanzanova et al., 2007; Defossez and Richard, 2002). In part, the absence of changes on the soil physical properties was due to the grass species used in this study. According to Albuquerque et al. (2001), in ICLS, the presence of forage grass roots improve soil structure, mitigating the impact of animal trampling, as a result of vigorous root systems and soil descompaction of forage plants (Castagnara et al., 2012). After the harvest of winter crops, the highest Ma values were found for white oat and dual-purpose wheat, in the 0.00-0.10 m soil layer, when these crops were subjected to the one and two grazing, respectively (Table 2). In the 0.10 to 0.20 m soil layer, the highest Ma values were verified for white oat and dual-purpose wheat subjected to the grazing, and for triticale, when this crop was not grazed (Table 2).

In the evaluation after soybean harvest, the cultivation of triticale during the winter without grazing provided the highest amount of macropores in the 0.00 to 0.10 m soil layer compared to the wheat crop (Table 3), while the cultivation of white oats provided intermediate Ma. Growing plants with vigorous root system is important in developing a net of biopores in the soil profile (Williams and Weil, 2004), and this feature can affect the amount of soil macropores. Calonego and Rosolem (2010) verified that soybean root growth in the soil profile was increased under rotation with triticale due to the presence of biopores and a decrease in soil penetration resistance.

The Ma values ranged from 0.06 to 0.10 m^3 m^{-3}, and are situated in the range considered optimal for the proper development of plants which varies from 0.07 to 0.17 m^3 m^{-3} (Drewry et al., 2008). Macroporosity is a of soil properties more susceptible to changes imposed by soil management (Spera et al., 2012). In general, the absence of soil disturbance can induce to soil compaction and reductionof Ma. However, the low soil moisture during grazing (Figure 1), combined with the ability to soil restructure in over time, may have contributed to this result. Flores et al. (2007) investigating changes in the soil physical properties promoted by animal treading, verified that the soil density and compressibility were higher and the porosity lower in the grazed areas, compared to non-grazed. The increase of macropores on

Table 2. Soil physical attributes at 0.0-0.10 and 0.10-0.20 m depths under different management of winter crops. Measurements were taken after harvest of winter crops (October, 2012).

Crop	Management of winter crops							
	One grazing	**Two grazing**	**No grazing**	**Mean**	**One grazing**	**Two grazing**	**No grazing**	**Mean**
	Macroporosity (m^3 m^{-3}) (0.0–0.10 m)				**Macroporosity (m^3 m^{-3}) (0.10–0.20 m)**			
Oat	0.09^{aA}	0.07^{bA}	0.08^{aA}	0.08	0.08^{aA}	0.07^{aA}	0.05^{bB}	0.07
Wheat	0.06^{bA}	0.10^{aA}	0.08^{aA}	0.08	0.09^{aA}	0.07^{aB}	0.05^{bB}	0.07
Triticale	0.06^{bA}	0.07^{bA}	0.08^{aA}	0.07	0.06^{bA}	0.05^{bA}	0.07^{aA}	0.06
Mean	0.07	0.08	0.08		0.07	0.06	0.06	
	Microporosity (m^3 m^{-3}) (0.0–0.10 m)				**Microporosity (m^3 m^{-3}) (0.10–0.20 m)**			
Oat	0.46	0.45	0.47	0.46	0.45	0.46	0.46	0.46
Wheat	0.47	0.45	0.47	0.47	0.45	0.43	0.45	0.44
Triticale	0.47	0.45	0.46	0.46	0.46	0.46	0.45	0.46
Mean	0.47	0.45	0.47		0.45	0.45	0.45	
	Total soil porosity (m^3 m^{-3}) (0.0–0.10 m)				**Total soil porosity (m^3 m^{-3}) (0.10–0.20 m)**			
Oat	0.55	0.52	0.55	054	0.53	0.53	0.51	0.52
Wheat	0.53	0.55	0.56	0.55	0.54	0.50	0.50	0.51
Triticale	0.53	0.52	0.54	0.53	0.52	0.51	0.51	0.51
Mean	0.54	0.53	0.55		0.53**A**	0.5**1B**	0.51**B**	
	Soil bulk density (Mg m^{-3}) (0.0–0.10 m)				**Soil bulk density (Mg m^{-3}) (0.10–0.20 m)**			
Oat	1.21	1.31	1.24	1.25	1.32	1.28	1.31	1.30
Wheat	1.36	1.19	1.18	1.24	1.26	1.29	1.29	1.28
Triticale	1.30	1.24	1.18	1.24	1.33	1.37	1.27	1.32
Mean	1.29	1.25	1.20		1.30	1.31	1.29	

Values represented by the different lower case letters in the column and upper case letters in the lines, show significant differences (Tukey test, $p < 0.05$).

the ICLS is important for the conservation of soil and water, because it is directly related to improve of aeration and water infiltration into the soil (Schiavo and Colodro, 2012).

Regarding Mi, the cultivation of triticale during winter provided the highest values in the 0.10–0.20 m soil layer, after soybean harvest, when this crop was subjected to the two grazing (Table 3). Investigating different ICLS, Spera et al. (2009) found that animal trampling increased soil Mi and decreased Ma and TSP, however, without reaching levels capable of causing soil degradation. Soil compaction resulting from animal trampling during grazing can increase the BD and Mi and decrease Ma and TSP (Spera et al., 2004).

The Mi values ranged from 0.44 to 0.50 m^3 m^{-3}, and are above the value considered optimal for the proper development of plants, which is, 0.33 m^3 m^{-3} (KiehL, 1979). These results were expected, because according to Viana et al. (2011), the Mi is inversely proportional to the soil Ma. The management of winter crops with one grazing resulted in the higher TSP value in the 0.10-0.20 m soil layer, in evaluation performed after the winter crops harvest (Table 2). After soybean harvest, the highest TSP values, in the 0.10 to 0.20 m soil layer, were found for triticale and white oat, when these crops were subjected to the two grazing and without grazing, respectively (Table 3). According to Bertol et al. (2004), the soil porosity is influenced by soil management based on changes in soil bulk density. Changes in soil porosity limit nutrient uptake, water infiltration and redistribution, gas exchange and root growth. However, soil attributes present high spatial variability, due to environmental conditions, types and sizes of machines and equipment and systems used crops.

The different species and grazing management of winter crops did not affect the BD (Tables 2 and 3). The BD is a property considered in the evaluation of soil physical quality (Klein and Camara, 2007) because, in ICLS under no-till the increasing BD, when this system is used without technical criteria for pasture management, can cause negative impacts on soil structure and reduce productivity (Costa et al., 2009). The soil compaction caused by animal trampling has been identified as a major cause of degradation of cultivated areas in ICLS (Albuquerque et al., 2001). The BD values ranged from 1.13 to 1.36 Mg m^{-3} (Tables 2 and 3). In an experiment

Table 3. Soil physical attributes at 0.0-0.10 and 0.10-0.20 m depths under different management of winter crops. Measurements were taken after soybean harvest (March 2013).

Crop	Management of winter crops							
	One grazing	Two grazing	No grazing	Mean	One grazing	Two grazing	No grazing	Mean
	Macroporosity (m^3 m^{-3}) (0.0–0.10 m)				Macroporosity (m^3 m^{-3}) (0.10–0.20 m)			
Oat	0.06^{aA}	0.07^{aA}	0.07^{abA}	0.07	0.06	0.06	0.07	0.06
Wheat	0.06^{aA}	0.07^{aA}	0.05^{bA}	0.06	0.06	0.07	0.06	0.06
Triticale	0.07^{aA}	0.07^{aA}	0.09^{aA}	0.07	0.06	0.07	0.07	0.07
Mean	0.06	0.070	0.07		0.06	0.07	0.07	
	Microporosity (m^3 m^{-3}) (0.0–0.10 m)				Microporosity (m^3 m^{-3}) (0.10–0.20 m)			
Oat	0.47	0.48	0.50	0.48	0.46^{aAB}	0.44^{bB}	0.48^{aA}	0.46
Wheat	0.50	0.47	0.50	0.49	0.46^{aA}	0.45^{bA}	0.47^{aA}	0.46
Triticale	0.47	0.48	0.46	0.47	0.45^{aA}	0.49^{aA}	0.46^{aA}	0.47
Mean	0.48	0.48	0.49		0.46	0.46	0.47	
	Total soil porosity (m^3 m^{-3}) (0.0–0.10 m)				Total soil porosity (m^3 m^{-3}) (0.10–0.20 m)			
Oat	0.53	0.55	0.57	0.55	0.52^{aAB}	0.50^{bB}	0.55^{aA}	0.52
Wheat	0.56	0.54	0.55	0.55	0.52^{aA}	0.52^{abA}	0.53^{aA}	0.52
Triticale	0.54	0.55	0.54	0.54	0.52^{aA}	0.55^{aA}	0.52^{aA}	0.53
Mean	0.54	0.55	0.56		0.52	0.53	0.53	
	Soil bulk density (Mg m^{-3}) (0.0–0.10 m)				Soil bulk density (Mg m^{-3}) (0.10–0.20 m)			
Oat	1.29	1.23	1.12	1.21	1.33	1.33	1.28	1.31
Wheat	1.23	1.21	1.24	1.23	1.30	1.30	1.25	1.28
Triticale	1.27	1.20	1.13	1.20	1.30	1.26	1.27	1.28
Mean	1.26	1.22	1.16		1.31	1.29	1.27	

Values represented by the different lower case letters in the column and upper case letters in the lines, show significant differences (Tukey test, $p < 0.05$).

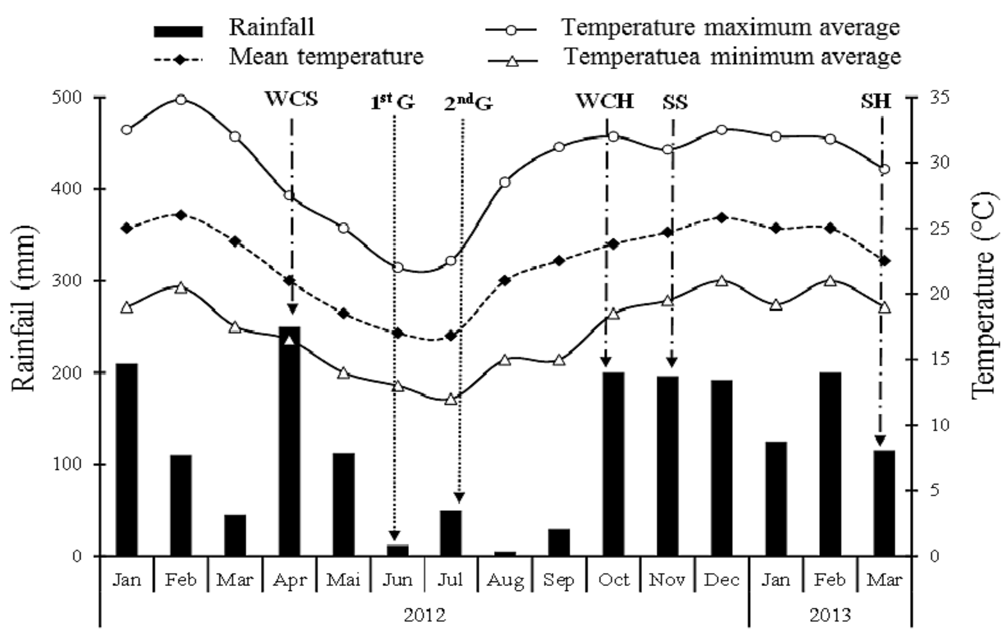

Figure 1. Total monthly rainfall (mm) and monthly average temperature (°C) during the experiment. WCS: winter crops sowing; 1st and 2nd G: first and second grazing; WCH: winter crops harvest; SS: soybean sowing; SH: soybean harvest.

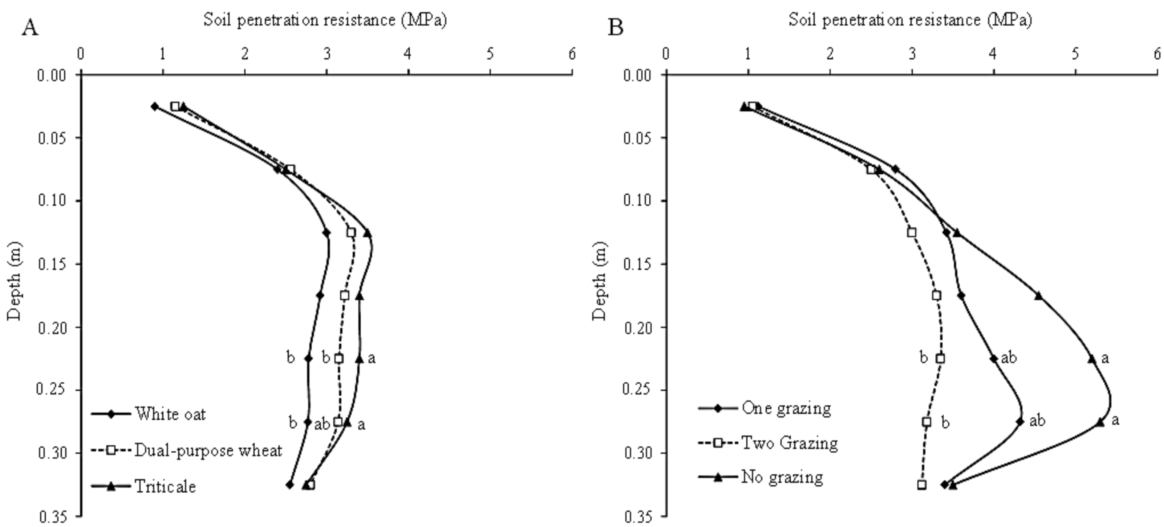

Figure 2. Soil penetration resistance (PR) in soil profile after soybean harvest, as affected by winter crops (A) and grazing management of winter crops (B). Different letters at each depth, show significant differences (Tukey test, $p < 0.05$).

with crop rotation in a Red Nitosol with 590 g kg^{-1} clay, Calonego and Rosolem (2011) found similar BD values from 1.22 to 1.39 Mg m^{-3} to a depth of 0.60 m. In this study, these same authors also determined the critical soil bulk density. During the three years of experiment, the values of the critical bulk density ranged from 1.22 to 1.37 Mg m^{-3}, in the 0.10-0.20 m soil layer. For Klein and Camara (2007), the value considered limiting to the growth of plant roots in clayey Latosols is around 1.40 Mg m^{-3}. Considering these values of critical soil bulk density can be inferred in this study there was no limitation to the plant root growth.

Penetration resistance (PR)

The different species and grazing management of winter crops affect the PR in the 0.20 to 0.25 m and 0.25 to 0.30 m soil layers of profundity (Figure 2). The lower PR values were found for the cultivation of white oat and the highest values for triticale (Figure 2A). For grazing managements, the lowest PR values were found when the winter crops were subjected to two grazing and the highest values when there was no grazing (Figure 2B).

In ICLS under no-till, the grazing intensities influence the stability of large aggregates (> 2 mm), which represent more than 50% of the soil mass (Souza et al., 2010). These large aggregates or stable aggregates are crucial for a good soil structure, providing pore space for root and fauna growth and development and water and air circulation (Salton et al., 2008). Thus, it is found that the greater number of grazing provided less PR, which can improve the development of the culture grown in succession.

The compaction level caused by animal trampling is influenced by several factors; especially the height of pasture management and the amount of plant residue deposited on the soil surface (Braida et al., 2006) and soil moisture. Thus, should emphasize the importance of continuous use of winter forage crops in ICLS under no-till, and the monitoring of the physical conditions of the soil over time, essential for the evaluation of management systems (Costa et al., 2011). Most of the obtained PR values are above 2.0 MPa (Figure 2), value cited by the United States Department of Agriculture (1993) as limiting to the root growth of most cultivated annual crops. Lipiec and Hatano (2003) argue that the PR values ranging from 1.0 to 1.7 MPa begin restricting the plant root growth, and that values between 3.0 and 4.0 MPa paralyze root growth. However, according to Canarache (1990), only PR values above 2.5 MPa impair plant growth, or from 2.0 to 3.0 MPa limited to soybean yield (Beutler et al., 2006).

The importance of determining PR is the correlation with the effect of animal trampling in the ICLS, affecting root growth and the soil physical properties, and is a way of rapidly obtaining results. However, PR is influenced by a number of soil properties such as density, moisture content, water potential, texture, aggregation, cementation, organic matter content and mineralogy. Soil moisture content and bulk density are considered the most significant of these properties (Tavares-Filho et al., 2012).

The PR indicates that evaluations of BD determined in the 0.00 to 0.10 m are suitable for characterizing the effect of animal trampling on soil compaction, since this effect usually restricted to this layer. However, its magnitude is not reflected in the subsequent crop yield to grazing, in this case, soybean crop, which is evaluated annually (Conte et al., 2011). Moreover, the intensity of the damage caused by compaction is directly influenced by the soil water availability and the plant development stage; because the occurrence of low water availability in stages of greater plant growth can cause drastic reductions in plant yields grown in compacted soils (Castagnara et al., 2012). However, as in this study there was no influence of grazing down to the 0.20 m depth, one can use the ICLS without causing negative impacts on soil physical quality for subsequent culture.

Conclusions

Soil porosity in the 0.00 to 0.20 m soil layer in integrated crop-livestock systems under no-till was influenced by the crops and grazing management of winter forage. The different species and grazing management of winter crops in integrated crop-livestock systems did not affect the soil bulk density. The annual winter cereals, managed in no-till with different numbers of grazing, promoted changes in resistance to penetration in the layer 20 to 25 cm and 25 to 30 cm depth.

Conflict of Interest

The authors have not declared any conflict of interest.

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