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Chemical and physical soil attributes in integrated crop-livestock system under no-tillage[1]

Atributos químicos e físicos do solo em sistema integrado de produção agropecuária sob plantio direto

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ABSTRACT - Although integrated crop-livestock system (ICLS) under no-tillage (NT) is an attractive practice for intensify agricultural production, little regional information is available on the effects of animal grazing and trampling, particularly dairy heifers, on the soil chemical and physical attributes. The objective of this study was to evaluate the effects of animal grazing on the chemical and physical attributes of the soil after 21 months of ICLS under NT in a succession of annual winter pastures (2008), soybeans (2008/2009), annual winter pastures (2009), and maize (2009/10). The experiment was performed in the municipality of Castro (PR) in a dystrophic Humic Rhodic Hapludox with a clay texture. The treatments included a combination of two pasture (annual ryegrass monoculture and multicropping - annual ryegrass, black oat, white clover and red clover) with animal grazing during the fall-winter period with two animal weight categories (light and heavy), in a completely randomized block experimental design with 12 replications. After the maize harvest (21 months after beginning), soil samples were collected at 0-10 and 10-20 cm layers to measure soil chemical and physical attributes. The different combinations of pasture and animal weight did not alter the total organic carbon and nitrogen in the soil, but they influence the attributes of soil acidity and exchangeable cations. The monoculture pasture of ryegrass showed greater soil acidification process compared to the multicropping pasture. When using heavier animals, the multicropping pasture showed lesser increase in soil bulk density and greater macroporosity.

Key words: Tropical soil. Integrated production system. Conservationist agricultural. Soil acidity.

RESUMO - Apesar de o sistema integrado de produção agropecuária (SIPA) sob plantio direto (PD) ser uma prática atrativa para intensificação das áreas agrícolas, faltam informações regionalizadas concernentes aos efeitos do pastejo/pastoreio animal, particularmente de novilhas leiteiras, sobre os principais atributos químicos e físicos do solo. Objetivou-se, neste trabalho, avaliar os efeitos do pastejo animal sobre alguns atributos químicos e físicos do solo, após 21 meses de SIPA sob PD, em uma sucessão pastagens anuais de inverno (2008) / soja (2008/09) / pastagens anuais de inverno (2009) / milho (2009/10). O experimento foi realizado no município de Castro (PR), em um Latossolo Bruno Distrófico com textura argilosa, empregando-se delineamento experimental de blocos completos ao acaso com 12 repetições. Os tratamentos incluíram combinações de duas pastagens (azevém anual solteiro, e azevém anual consorciado com aveia preta, trevo branco e trevo vermelho) submetidas ao pastejo animal durante o período outono-inverno e duas e categorias de animais (leves e pesados). Após a colheita do milho (2010), amostras de solo foram retiradas visando determinar os atributos químicos e físicos do solo nas camadas de 0-10 e 10-20 cm. Os tipos de pastagens e categorias animais não alteraram as concentrações de carbono orgânico e nitrogênio total, mas influenciaram os atributos acidez e cátions trocáveis. O cultivo de azevém solteiro favoreceu mais a acidificação do solo em relação ao consórcio de pastagens. Este, por sua vez, resultou em menor densidade e maior macroporosidade do solo no tratamento com animais mais pesados.

Palavras-chave: Solo tropical. Sistema integrado de produção. Agricultura conservacionista. Acidez do solo.

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INTRODUCTION

Traditional agricultural systems based on monoculture and short, continuous crop rotations have increased agricultural yields in Brazil, particularly in recent decades. However, this model of agricultural exploitation has resulted in environmental problems, such as: (i) reduction in biodiversity; (ii) greater incidence of pests, diseases, and weeds in agroecosystems; (iii) loss of soil organic carbon, which decreases soil quality; and (iv) contamination of surface and ground water with nutrients, pesticides, and sediments from erosion (LANDERS, 2007; RUSSELE; FRANZLUEBBERS, 2007).

One of the options for increasing the intensity of land use with economic and ecological sustainability is the adoption of integrated crop-livestock systems (ICLS) under no-tillage (NT) (LANDERS, 2007). This technique allows for: (i) biological and economic advantages (BALBINOT JUNIOR *et al.*, 2009); (ii) maximization of the use of farmland (LANDERS, 2007); (iii) increase in profitability and a decrease in risk of the agricultural activities (FONTANELI; SANTOS; MORI, 2006); (iv) decrease of greenhouse gas emissions throughout carbon sequestration (CERRI *et al.*, 2010); and (v) improvement in nutrient cycling (ASSMANN *et al.*, 2003) and soil quality (ANGHINONI *et al*., 2011). The main limitations of ICLS management under NT are: lack of technical-scientific knowledge, paradigm shifts, complexity of the production system, and readjustment of the property to the new management system (MORAES; BANDEIRA; SILVA, 2008). The advantages and limitations vary according to the regional characteristics and need to be further studied under the distinct soil and climatic conditions (BALBINOT JUNIOR *et al*., 2009).

In this short-term study of ICLS under NT, it was expected that the large-scale grazing of dairy heifers during the fall-winter period would not affect negatively the soil chemical and physical attributes or the nutrient availability for the crop cultivated in succession. The objective of this study was to evaluate the effects of the grazing of light and heavy animals on pastures of ryegrass and multicropping species on same chemical and physical attributes of the soil after 21 months of ICLS under NT in the region of *Campos Gerais* of Paraná, southern Brazil.

MATERIAL AND METHODS

This experiment was carried out in the municipality of Castro (PR), Southern Brazil, in the geographic coordinates of 24°47’28” S and 50°00’25” W, with average altitude of 1005 m. This area is located in the physiographic region called First Parana Plateau, with a humid subtropical climate with mild summers and winters with severe and frequent freezing, without defined dry season, of the Cfb type according to the Köppen classification (IAPAR, 1994). During the experimental period (from May 2008 to April 2010), the average monthly rainfall was 133.4 mm and the average air temperature was 17.6 °C in the experimental area.

The experimental area had been managed under NT for more than five years before, growing maize (*Zea Mays* L.) or soybean (*Glycine max* L.) for grain production in the spring-summer period and annual ryegrass (*Lollium multiflorum* L.) and/or black oat (*Avena strigosa* Schreb) for pasture, managed with direct grazing (dairy heifers) during the fall-winter period. For the maize, it was used 300 kg ha^{-1} of 10-20-20 (N-P_2O_5-K_2O) of fertilizer at sowing and 400 kg ha^{-1} of 22-00-21 (N-P_2O_5-K_2O) as a topdressing fertilization. For the soybean, it was used 300 kg ha^{-1} of 00-20-20 (N-P_2O_5-K_2O) of fertilizer at sowing and 150 kg ha^{-1} of potassium chloride (600 g kg^{-1} of K_2O) as topdressing fertilization. In addition, 50 m^3 ha^{-1} year^{-1} of pig slurry was applied for ten years prior to the beginning of the experiment. In July of 2009, dolomitic limestone (3.0 Mg ha^{-1}) was applied at surface, without incorporation, with effective calcium carbonate equivalent of the lime (ECCE), calcium oxide (CaO) and magnesium oxide (MgO) of 898, 286, and 195g kg^{-1}, respectively.

According to Embrapa/Fundação ABC (2001), the predominant soil in the experimental area is dystrophic Humic Rhodic Hapludox with clay texture and a gently undulating relief (0.02 to 0.04 m m^{-1}). When the experiment began, the soil exhibited the following attributes in the 0-20 cm superficial layer: 4.9 of pH ($CaCl_2$); 86 mmol$_c$ dm^{-3} of total acidity (H+Al); 1,0 mmol$_c$ dm^{-3} of exchangeable acidity (Al); 52 mmol$_c$ dm^{-3} of exchangeable calcium (Ca); 17 mmol$_c$ dm^{-3} of exchangeable magnesium (Mg); 7 mmol$_c$ dm^{-3} of exchangeable potassium (K); 111 mg dm^{-3} of available phosphorus (P) (Mehlich-1); 36 g dm^{-3} of total organic carbon (TOC - by Walkley-Black method); 2.6 g dm^{-3} of total nitrogen (TN) concentration; 47% of base saturation (V); and 384, 439, and 177 g kg^{-1} of sand, clay and silt content, respectively.

The experiment had a complete random block design with four treatments and 12 replicates. During the fall-winter period, four treatments were studied: DPLA - light animals (192 ± 40.9 kg live weight and an age of 9.4 ± 2.31 months) with multicropping pasture composed of annual ryegrass (*Lollium multiflorum* L.), black oat (*Avena strigosa* Schreb), white clover (*Trifolium repens* L.) and red clover (*Trifolium pratense* L.); DPHA - heavy animals (278 ± 41.2 kg live weight and an age of 19.6 ± 2.47 months) with the same multicropping pasture; MPLA - light animals with a monoculture pasture of annual ryegrass; and MPHA - heavy animals with a monoculture pasture of annual ryegrass. The fenced areas with light animals and heavy animals covered 1.2 (± 0.42) and 1.4 (± 0.59) ha, respectively. Further details on the management and gain of animal weight have been reported in Silva *et al.* (2011).

In the first year, the multicropping pasture was sown (with a 0.17-m spacing between the rows) on May 15th 2008, using 50, 80, 1.7, and 2.0 kg ha^{-1} of seeds, respectively of annual ryegrass, black oat, white clover and red clover. The monoculture pasture (annual ryegrass) was sown on May 12th 2008, using 80 kg ha^{-1} of seeds. In the second year, the multicropping pasture was sown on May 6th 2009, using 60, 60, 4, and 8 kg ha^{-1} of seeds, respectively of annual ryegrass, black oat, white clover and red clover. The monoculture pasture of annual ryegrass was sown on May 5th 2009, using 60 kg ha^{-1} of seeds. All the pastures were sown with 17 cm inter rows. During the two-year period, both types of pasture were fertilized at doses of, respectively, (i) 12 and 76 kg ha^{-1} of N and P_2O^5 at sowing; and (ii) 54 and 54 kg ha^{-1} of N and K_2O as coverage fertilizer, applied 16 days after emergence (DAE).

During the fall-winter period of 2008 and 2009, the average animal stocking rates were respectively of 910 and 1151 kg ha^{-1} day^{-1} and the dairy heifers used were of the races Dutch Black Pied (DBP) and DBP x Jersey crosses. It was adopted the continuous stocking grazing method, using the “put and take” technique (MOOT; LUCAS, 1952) with a set of four experimental animals per parcel and a variable number of regulator animals. The animal-stocking rate was adjusted weekly to maintain an average pasture height of 20 cm, with the introduction or removal of regulator animals after measurement of the pasture height (CARVALHO, 2005). The height measurements were performed weekly at 100 random points per parcel, using a “sward stick” device (BARTHRAM, 1985).

The animals were removed from the experimental area on October 22nd 2008, and the pasture was then desiccated with 1,440 g ha^{-1} of active ingredient (a.i.) of glyphosate. Soybean (cv. CD 205) was sown 33 days after desiccation, with 40 cm inter rows and fertilized with 300 kg ha^{-1} of 00-20-20 (N-P_2O_5-K_2O) applied at sowing (5.0 cm below and to the side of the seeds). In the second year, the animals were removed from the experimental area on October 5th 2009, 23 days before the desiccation of the pasture with 1,200 g a.e. ha^{-1} of glyphosate. Twenty-five days after the animals removal, a simple modified hybrid of maize (ATL 200) was sown with 80 cm inter rows, expecting a final stand of 67,500 plants ha^{-1}. The maize was fertilized with 320 kg ha^{-1} of 10-20-20 (N-P_2O_5-K_2O), applied at sowing (5 cm below and to the side of the seeds). Coverage fertilization was applied over the entire area 18 DAE at a dose of 400 kg ha^{-1} of 22-00-21 (N-P_2O_5-K_2O). Other standards cultivation practices were employed to allow enough growth and development of the maize and soybean crops.

In March 2010, 21 months after the beginning of the experiment, twelve soil sub-samples were collected at the 0-10 cm and 10-20 cm layers to obtain a single composite sample per plot. These samples were dried in a convection oven at 40 °C for 48 hours and after that broken apart and sieved through a 2.0 mm open screen, to obtain stove-dried soil (SDS).

The samples of SDS were used to determine analytically the following: (i) the pH in a 0.01 mol L^{-1} solution of calcium chloride ($CaCl_2$); (ii) H+Al estimated by potentiometry in an SMP buffer solution; (iii) exchangeable aluminum (Al), calcium (Ca), and magnesium (Mg) concentrations by extraction with a solution of 1.0 mol L^{-1} of potassium chloride (KCl) and quantification by titration with 0.025 mol L^{-1} sodium hydroxide (NaOH) for Al and complexometric titration with 0.025 mol L^{-1} ethylenediaminetetraacetic acid (EDTA) for Ca and Mg; (iv) exchangeable K and available P concentrations by extraction with a Mehlich-1 solution (0.05 mol L^{-1} hydrochloric acid - HCl + 0.025 mol L^{-1} sulfuric acid - H_2SO_4) and quantification by flame emission spectroscopy for K and molecular absorption spectroscopy for P; (v) TOC concentration using the Walkey-Black method; (vi) TN concentration with sulfuric digestion and quantification by the Semimicro-Kjeldahl distillation method; (vii) available sulfur concentration in the form of sulfate (S-SO_4^{2-}) by extraction with 0.25 mol L^{-1} ammonium acetate (NH_4OAc) in 0.5 mol L^{-1} acetic acid (HOAc) with quantification using turbidimetry with barium sulfate; and (viii) available concentrations of the cationic micronutrients copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) in 0.005 mol L^{-1} diethylenetriaminepentaacetic acid + 0.1 mol L^{-1} triethanolamine + 0.01 mol L^{-1} $CaCl_2$ (DTPA-TEA) at a pH of 7.3, with quantification by flame atomic absorption spectroscopy. The measurements of pH, H+Al, Ca, Mg, K, P, and TOC were performed according to the methods described in Pavan *et al.* (1992); of TN according to Cantarella and Trivelin (2001); of S-SO_4^{2-} according to Vitti and Suzuki (1978), and cationic micronutrients according to Lindsay and Norvell (1978).

Undisturbed soil cores (four replicates per experimental unit) were collected in stainless steel rings with a internal volume of 100 cm^3 in the center of the 0-10 and 10-20 cm layers, at the time of the soil sampling to soil fertility evaluation. The samples were packed in plastic films and kept at 5 °C until they were processed. After preparation, the samples were slowly moistened by capillarity in a stream of water until reach complete saturation. The total pore volume was determined using the equation recommended by Danielson and Sutherland (1986). The microporosity corresponds to the water retained in the soil cores after reaching equilibrium at 60 cm tension in a table tension, and the macroporosity to the difference between total porosity and microporosity (GROHMANN, 1960). The volumetric water content at 6 kPa tension (θ_{cc}) was determined by the difference between core mass before and after samples were dried in an oven at 105 °C, and the soil bulk density was calculated by the relation from the mass of dry soil core and core volume (BLAKE; HARTGE, 1986).

Analysis of variance was performed from a randomized complete block design that considered the sampled layers (0-10 and 10-20 cm) as split-plot. When the F value was significant, the means were compared using a Tukey's test ($\alpha = 0.05$). All of the statistical analyses were performed using SAS Version 9.1 (SAS, 2004).

RESULTS AND DISCUSSION

Soil acidity and exchangeable cations

The soil pH values were higher and the total acidity concentrations (H + Al) were lower in the 0-10-cm layer, especially for the DPLA and DPHA treatments (Table 1). Lower soil pH values and greater H+A1 were found in the 10-20-cm layer, especially for the MPLA and MPHA treatments (Table 1). The exchangeable acidity (Al) was higher for the MPLA than for the DPHA treatment; however, the concentration of exchangeable Al with the DPHA treatment was similar to that found with the DPLA and MPHA treatments (Table 1). The active acidity, Al and the H+A1 concentrations were also higher in the 10-20-cm layer (Table 1).

The concentrations of exchangeable Ca were greater in the 0-10-cm layer, especially with the DPHA treatment, and lower in the 10-20-cm layer, especially with the MPLA treatment (Table 1). The concentrations of Mg were also greater in the 0-10-cm layer, especially with the DPLA and DPHA treatments, and lower in the 10-20-cm layer, especially with the MPLA treatment (Table 1).

Similar to exchangeable Ca and Mg, greater concentrations of exchangeable K were observed in the 0-10-cm layer (Table 1). The concentration of exchangeable K in the MPHA treatment did not differ from that observed in the DPHA and MPLA treatments, but it was greater than that obtained with the DPLA treatment. The base saturation was higher in the 0-10-cm layer, especially for the DPLA and DPHA treatments, and lower in the 10-20-cm layer, especially for the MPLA treatment (Table 1). The applied treatments did not alter the cation exchange capacity (CEC); however, higher values for this attribute were observed in the 0-10-cm layer (Table 1).

Nitrogen fertilization with fertilizers containing ammonium or urea has been implicated as the main cause of soil acidification in agricultural systems (COSTA *et al*., 2008). Depending on the production system, the magnitude of the acidification generated by nitrogen fertilization may vary according to the degree of acidity and the soil type, the source and the dosage of nitrogen used and the frequency of nutrient application (CAIRES, 2010). In this study, soil acidification was only observed in the monoculture pasture of annual ryegrass, independent of the animal weights. In this case, the lower soil pH was accomplished by higher total acidity (H + Al) and exchangeable acidity (Al), lower concentrations of exchangeable Ca and Mg and a lower percent of base saturation (Table 1). The multicropping pasture, composed of ryegrass, black oat, white clover and red clover, did not significantly affect soil acidification with the grazing of light or heavy animals, and the soil pH in $CaCl_2$ kept around of 4.9 in the 0-20 cm layer, like before the beginning of the experiment. The no change in pH probably occurred because the different plant residues have different capacities for H^+ neutralization and for decreasing the exchangeable Al in the soil solution. The acid neutralization capacity of the plant residues is associated with the concentrations of cations and soluble organic carbon compounds, which are normally greater for green manure residues (MIYAZAWA; PAVAN; CALEGARI, 1993) and for plants with grazing potential. The species that accumulate more cations also display a greater concentration of organic ligands and are more efficient in the neutralization of soil acidity. Thus, the residue from the multicropping pasture was able of mitigating the acidification generated by nitrogen fertilization. Because this the acidifying effect of fertilization was quite evident in the ryegrass monoculture pasture.

The changes in exchangeable K in the soil were small in magnitude and had no practical effects, because the existing concentrations of exchangeable K were considered to be either high or very high for soybean and maize crops (PAULETTI, 2004). Additionally, the (Ca+Mg)/K ratio remained between 10 and 40, which is considered to be the optimal range for these plants (MALAVOLTA, 2006).

The upper layer (0-10 cm) displayed higher fertility indices (Table 1). The lower acidity of the soil (active, total and exchangeable), and consequently the greater concentrations of exchangeable cations (Ca, Mg, and K) and base saturation in this layer, are expected for soil under NT. In this cropping system, limestone is applied at the surface, without incorporation, which results in a gradual correction of the acidity from the superficial to the subsuperficial soil layer (CAIRES *et al*., 2002). In addition, the accumulation of phytomass on the soil surface under NT, provided primarily by the pastures, increased the nutrient cycling, particularly of Ca, Mg, and K (BORKERT *et al*., 2003).

Table 1 - Soil pH, total and exchangeable acidity, exchangeable cations (Ca, Mg and K), cation exchange capacity and base saturation in two soil layers of combinations of pasture types and animal weight in integrated crop-livestock system under no-tillage

Layer (cm)	Combinations of pasture types and animal weights(1)				Mean
	DPLA	DPHA	MPLA	MPHA	
Active acidity (pH)(2)					
0-10	5.2 Aa	5.2 Aa	4.5 DEa	4.7 CDa	4.9 a
10-20	4.8 CDb	4.8 BCb	4.4 Eb	4.5 Eb	4.6 b
Mean	5.0 A	5.0 A	4.5 B	4.6 B	
Total acidity (H+Al), $mmol_c\ dm^{-3}$					
0-10	69.3	71.3	101.6	92.3	83.6 b
10-20	85.4	92.5	104.6	99.1	95.4 a
Mean	77.3 B	81.9 B	103.1 A	95.7 A	
Exchangeable acidity (Al), $mmol_c\ dm^{-3}$					
0-10	1.8	1.4	4.4	3.1	2.7 b
10-20	3.9	3.1	6.4	5.3	4.7 a
Mean	2.9 AB	2.3 B	5.4 A	4.2 AB	
Exchangeable calcium (Ca), $mmol_c\ dm^{-3}$					
0-10	55.0 ABa	58.8 Aa	40.4 CDa	44.8 BCa	49.8 a
10-20	31.3 DEb	36.9 CDb	25.3 Eb	34.9 CDEb	32.1 b
Mean	43.2 AB	47.9 A	32.9 C	39.8 B	
Exchangeable magnesium (Mg), $mmol_c\ dm^{-3}$					
0-10	25.8 Aa	22.8 Aa	20.2 Ba	20.6 Aba	22.4 a
10-20	18.8 Bb	18.9 Bb	13.7 Cb	20.6 ABb	18.0 b
Mean	22.3 A	20.9 A	16.9 B	20.6 A	
Exchangeable potassium (K), $mmol_c\ dm^{-3}$					
0-10	4.2	4.9	5.4	5.5	5.0 a
10-20	3.1	3.6	4.4	4.1	3.8 b
Mean	3.6 C	4.3 B	4.9 A	4.8 AB	
Cation exchange capacity (CEC) at pH 7, $mmol_c\ dm^{-3}$					
0-10	154.2	157.9	167.6	163.1	160.7 a
10-20	138.6	151.9	148.0	158.6	149.3 b
Mean	146.4 A	154.9 A	157.8 A	160.9 A	
Base saturation (V), %					
0-10	56.4 Aa	56.1 Aa	39.3 Ca	43.2 BCa	48.7 a
10-20	39.7 Cb	40.3 Cb	29.4 Db	37.1 Cb	36.6 b
Mean	48.0 A	48.2 A	34.3 C	40.1 B	

(1)DPLA: multicropping pasture (annual ryegrass, black oat, white clover, and red clover) subjected to grazing by light animals (192 ± 40.9 kg); DPHA: multicropping pasture subjected to grazing by heavy animals (278 ± 41.2 kg); MPLA: monoculture pasture (annual ryegrass) subjected to grazing by light animals; MPHA: monoculture pasture subjected to grazing by heavy animals. (2)The values of the coefficients of variation for the attributes of pH, H+Al, Al, Ca, Mg, K, CEC, and V are 4.0, 19.9, 105.1, 20.9, 21.1, 18.5, 14.8, and 11.6%, respectively. (3)Means followed by the same letters, capitals in the rows and lowercase in the columns, do not differ statistically (Tukey, $\alpha = 0.05$)

The greater CEC in the 0-10 cm layer (Table 1) arose from the greater concentrations of TOC in this layer (Table 2). Sá *et al.* (2009) showed a positive correlation between TOC and CEC for soils under NT. The functional groups of the soil organic matter (SOM) include those that contribute to the most to the CEC of tropical soils (SPARKS, 2003). Moreover, this correlation demonstrates that the results of this study are consistent because neither the CEC nor the TOC was influenced by the treatments.

Availability of phosphorus, sulfur, and cationic micronutrients

The concentration of P in the soil was greater in the surface layer (0-10-cm) compared with the 10-20-cm layer (Table 2). The MPHA treatment provided a greater concentration of P in the soil than the DPHA and DPLA treatments, although there was no difference in the concentration of P between the MPHA and MPLA treatments. Then, the four treatments in this study resulted in changes in the concentrations of available P in the soil (Table 2). Independent of the treatment, these changes had no practical implications, because the existing concentrations of available P in the soil were considered to be very high for the soybean and maize crops (PAULETTI, 2004). The high concentrations of available P in the soil probably is a result of the 50 m^3 ha^{-1} $year^{-1}$ of pig slurry application in the experimental area prior to this study, which contains 1.75 kg m^{-3} of P on average (PAULETTI, 2004). Greater concentrations of P were observed in the 0-10 cm layer than in the 10-20 cm layer (Table 2). The increase in the TOC concentration in the surface layer due to NT (SÁ *et al.*, 2009) implies less specific absorption of orthophosphate ($H_2PO_4^-$) in the soil and greater availability of this nutrient (GUPPY *et al.*, 2005).

The concentration of S in the soil was similar in the 0-10 and 10-20 cm layers, and higher and lower concentrations of S in the soil were observed for the MPLA and DPHA treatments, respectively (Table 2). However, the concentration of S in the DPLA treatment was not different from that observed with the DPHA and MPHA treatments, although it was lower than that with the MPLA treatment.

The average concentrations of available S were close to the critical level (25.8 mg dm^{-3} in the 0-20 cm layer) for NT in the soil of Campos Gerais do Paraná (CAIRES *et al.*, 2002), and the concentrations of available S did not differ between layers (Table 2). The absorption of sulfate (SO_4^{2-}) tends to decrease when there are high concentrations of P and TOC in the soil, as found in the 0-10 cm and 10-20 cm soil layers. Consequently, a greater proportion of this anion is absorbed in the sub-superficial layers (HAVLIN *et al.*, 2005).

The concentrations of cationic micronutrients (Cu, Fe, Mn, and Zn) were higher in the surface layer of the soil (0-10 cm) than in the 10-20 cm layer (Table 2). The concentration of Cu in the soil was greater in the DPLA treatment than in the MPLA and MPHA treatments, but there was no significant difference in the concentration of Cu between the DPLA and DPHA treatments (Table 2). A greater concentration of Fe was found in the MPAP treatment relative to the other treatments, which did not differ from one another (Table 2). The concentration of Mn was greater in the MPHA treatment than in the DPLA and DPHA treatments, but there was no difference in the concentration of Mn between the MPAP and MPLA treatments (Table 2). The concentration of Zn was greater in the MPLA treatment relative to the DPHA treatment, but there were no differences in the concentration of Zn among the MPLA, DPLA, and MPHA treatments (Table 2).

The available cationic micronutrients (Cu, Fe, Mn and Zn) were influenced by the treatments (Table 2), but there are no practical implications for the management of these nutrients in the NT. Independent of the treatment, the concentrations of Cu, Fe, and Zn were greater than, respectively, 0.8, 12, and 1.2 mg dm^{-3}, remaining within a range that is considered high (PAULETTI, 2004). For Mn, all of the treatments provided available concentrations within the range which is considered to be medium (1.3 to 5.0 mg dm^{-3}) according to Pauletti (2004). The concentrations of cationic micronutrients were greater in the 0-10 cm layer because of the greater cycling and accumulation of nutrients in this layer in the NT, and soil pH was not high enough to limit the availability of these micronutrients. In an area under NT stabilized, Da Fonseca, Caires and Barth (2010) showed that the availability of Cu, Fe, Mn and Zn was greater in the superficial layers (0-5 and/or 5-10 cm) than in the 10-20 cm layer.

Total nitrogen and total organic carbon

The concentrations of TOC and TN were not changed by the treatments (Table 2), presumably because the experiment was of a relatively short term (21 months), while changes in the TOC and TN concentrations under NT have been demonstrated over longer periods (SÁ *et al.*, 2009). According to these authors, the improvement in soil fertility from the accumulation of TOC was significant only after 15-20 years of NT. Souza *et al.* (2009), on the other hand, showed that the changes in the concentrations of TN in ICLS under NT occurred after the third year.

Greater concentrations of TOC and TN were observed in the 0-10 layer (Table 2). These effects are consistent, which suggests that the grazing management strategy and the animals used did not constrain the concentrations of TOC and TN in the short term. Souza *et al.* (2010) and Nicoloso *et al.* (2008) observed similar results under managements appropriates for grazing.

Physical attributes of the soil

The total porosity and microporosity of the soil were not changed by the treatments (Figure 1). The

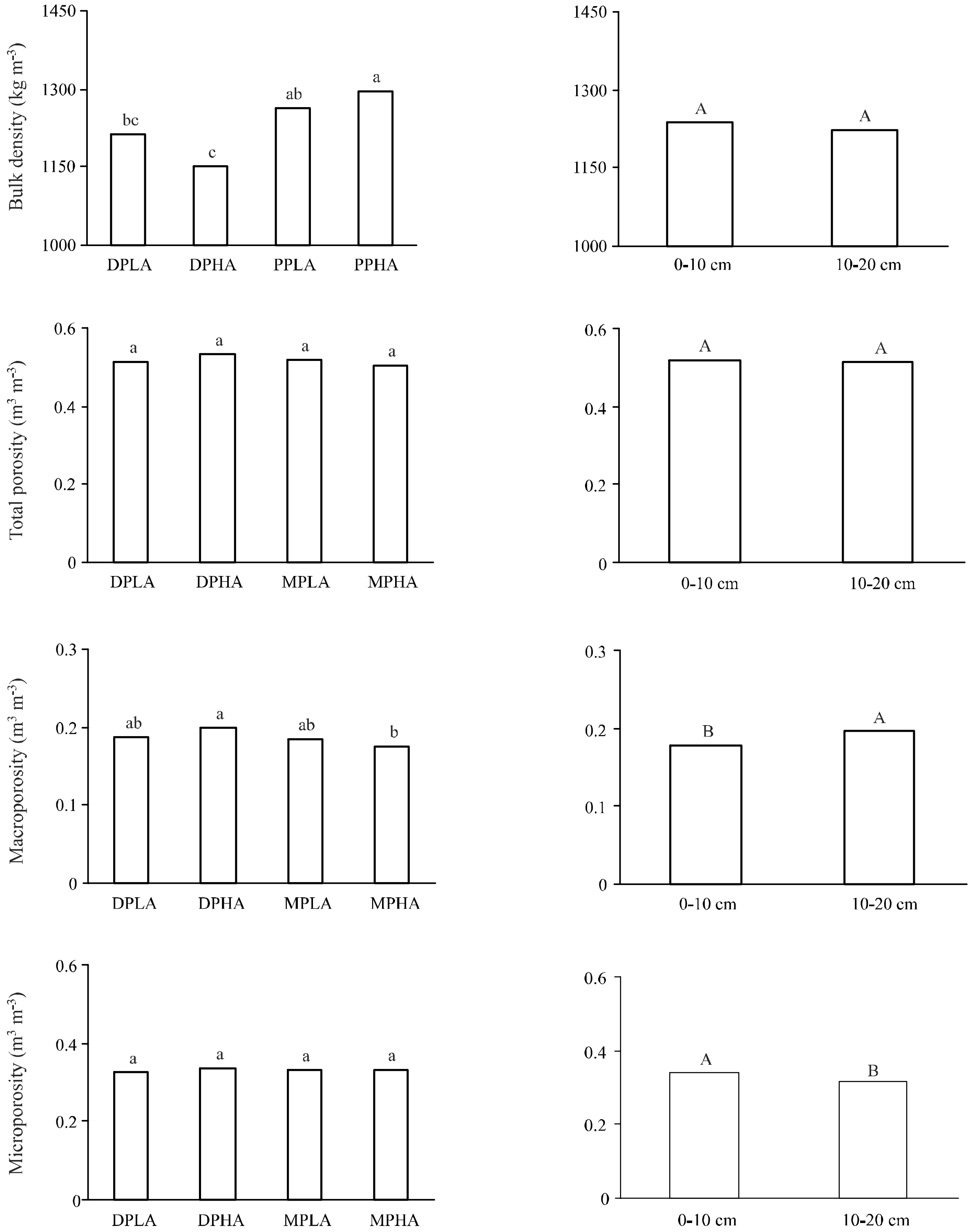
Table 2 - Phosphorus, sulfur, cationic micronutrients, nitrogen and total organic carbon in two soil layers of combinations of pasture types and animal weights in integrated crop-livestock system under no-tillage

Layer (cm)	Combinations of pasture types and animal weights(1)				Mean
	DPLA	DPHA	MPLA	MPHA	
Available phosphorus (P), mg dm^{-3}(2)					
0-10	42.9	50.0	72.0	91.0	64.0 a
10-20	13.2	20.9	27.1	37.8	24.8 b
Mean	28.0 C	35.5 BC	49.6 AB	64.4 A	
Available sulfur (S), mg dm^{-3}					
0-10	22.9	15.8	36.7	30.4	26.5 a
10-20	22.6	20.6	30.1	25.7	24.7 a
Mean	22.8 BC	18.2 C	33.4 A	28.0 AB	
Available copper (Cu), mg dm^{-3}					
0-10	4.9	4.4	3.7	3.7	4.2 a
10-20	3.2	3.0	2.5	2.4	2.8 b
Mean	4.1 A	3.7 AB	3.1 BC	3.0 C	
Available iron (Fe), mg dm^{-3}					
0-10	82.7	101.1	119.5	173.7	119.2 a
10-20	71.5	79.2	77.0	113.2	85.2 b
Mean	77.1 B	90.1 B	98.3 B	143.5 A	
Available manganese (Mn), mg dm^{-3}					
0-10	5.1 BCa	4.3 Ca	6.2 Aba	7.1 Aa	5.7 a
10-20	2.3 Db	1.8 Db	2.1 Db	2.3 Db	2.1 b
Mean	3.7 BC	3.1 C	4.2 AB	4.7 A	
Available zinc (Zn), mg dm^{-3}					
0-10	5.4	4.6	6.4	5.8	5.5 a
10-20	2.6	1.8	2.5	2.3	2.3 b
Mean	4.0 AB	3.2 B	4.4 A	4.1 AB	
Total nitrogen (TN), g dm^{-3}					
0-10	1.8	2.3	2.2	2.2	2.1 a
10-20	1.4	1.5	1.5	1.6	1.5 b
Mean	1.6 A	1.9 A	1.8 A	1.9 A	
Total organic carbon (TOC), g dm^{-3}					
0-10	27.8	26.9	27.3	27.2	27.3 a
10-20	25.0	25.1	24.3	25.5	25.0 b
Mean	26.4 A	26.0 A	25.8 A	26.3 A	

(1)DPLA: multicropping pasture (annual ryegrass, black oat, white clover, and red clover) subjected to grazing by light animals (192 ± 40.9 kg); DPHA: multicropping pasture subjected to grazing by heavy animals (278 ± 41.2 kg); MPLA: monoculture pasture (annual ryegrass) subjected to grazing by light animals; MPHA: monoculture pasture subjected to grazing by heavy animals. (2)The values of the coefficients of variations for the attributes of P, S, Cu, Fe, Mn, Zn, TN, and TOC are 51.5, 40.9, 24.6, 52.9, 27.1, 34.1, 24.4, and 15.6%, respectively. (3)Means followed by the same letters, capitals in the rows and lowercase in the columns, do not differ statistically (Tukey, $\alpha = 0.05$)

bulk density (BD) in the MPHA treatment was greater than that in the DPLA and DPHA treatments; however, the BD of the MPHA treatment did not differ from that obtained in the MPLA treatment (Figure 1). The macroporosity value was greater in the DPHA treatment than in the MPHA treatment, but the macroporosity

Figure 1 - Physical attributes of the soil in integrated crop-livestock system under no-tillage resulting from combinations of pasture types and animal weights. DPLA: multicropping pasture (annual ryegrass, black oat, white clover, and red clover) subjected to grazing by light animals (192 ± 40.9 kg); DPHA: multicropping pasture subjected to grazing by heavy animals (278 ± 41.2 kg); MPLA: monoculture pasture (annual ryegrass) subjected to grazing by light animals; MPHA: monoculture pasture subjected to grazing by heavy animals. Means followed by the same letters, capitals in the rows and lowercase in the columns, do not differ statistically (Tukey, α = 0.05)



did not differ among the DPHA, DPLA, and MPLA treatments. The values of BD and of the total porosity did not differ between the studied soil layers (0-10 and 10-20 cm); however, greater microporosity values were observed in the 0-10-cm layer, and greater macroporosity values were observed in the 10-20-cm layer (Figure 1).

The changes in BD caused by the treatments (Figure 1) had no practical implications, as the maximum observed value (1,300 kg m^{-3} with the PPHA treatment) is below the critical level for the development of roots, which is 1,750 kg m^{-3} (REINERT *et al.*, 2008). The no variations in BD between layers (Figure 1) does not agree with the observations of Lanzanova *et al.* (2007) and Spera *et al.* (2010), which found greater soil BD in the superficial layer. This could be due to the high TOC concentrations, associated with appropriate crop succession strategies, and grazing and animal management, which did not result in critical values of BD in the layers evaluated.

The treatments changed the macroporosity values, although these were not enough to change total porosity (Figure 1). The reduction in macroporosity and increasing in microporosity in the 0-10 cm layer may be the result of animal trampling. The presence of animals, regardless of the degree of control and efficiency of the adopted grazing strategy, implies the application of a load that may result in a short-term decrease in the macroporosity and/or an increase in the microporosity in the superficial layer (0-10 cm). In the 10-20 cm layer, on the other hand, the influence of the animals on macroporosity and microporosity was clearly smaller and/or negligible. The values of macroporosity in this study were close to 0.20 $m^3 m^{-3}$ and similar to those observed by Lanzanova *et al.* (2007) for a wild field (0.20 $m^3 m^{-3}$) and by Spera *et al.* (2010) in a forest (0.22 $m^3 m^{-3}$), and they were above the critical level 0.10 $m^3 m^{-3}$ proposed for Bertol *et al.* (2004). The results of this study agree with the observations of Spera *et al.* (2009), that the total porosity, microporosity and macroporosity were changed with ICLS, although they did not reach critical levels.

CONCLUSIONS

1. The treatments of pasture type (monoculture and multicropping) and animal weight (light and heavy) did not affect the concentrations of total organic carbon or total nitrogen, although they influence the attributes of soil acidity and exchangeable cations. The multicropping pasture decreased the rate of soil acidification compared to monoculture one;
2. For the grazing of heavy animals, the use of multicropping pasture showed a lower soil bulk density and higher macroporosity. Independent of the pasture type or animal weight, the soil physical attributes did not reach critical levels during this short-term study (21 months).

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REFERENCES

ANGHINONI, I. *et al.* The benefits of crop-livestock integration in soil fertility under no-till system. *In:* DA FONSECA, A. F.; CAIRES, E. F.; BARTH, G., eds. **Fertilidade do solo e nutrição de plantas no sistema plantio direto**. Ponta Grossa: Impag/ Associação dos Engenheiros Agrônomos dos Campos Gerais, 2011. p. 273-309.

ASSMANN, T.S. *et al.* Corn yield on no tillage crop-pasture rotation in presence and absence of white clover, grazing and nitrogen. **Revista Brasileira de Ciência do Solo**, v. 27, n. 4, p. 675-683, 2003.

BALBINOT JUNIOR, A. A. *et al.* Crop-livestock system: intensified use of agricultural lands. **Ciência Rural**, v. 39, n. 6, p. 1925-1933, 2009.

BARTHRAM, G. T. **Experimental techniques; the HFRO sward stick**. Aberdeen, United Kington, Hill Farming Research Organization/Biennial Report, 1985, p. 29-30.

BERTOL, I. *et al.* Physical soil properties of conventional tillage and no-tillage, in crop rotation and succession, compared with natural pasture. **Revista Brasileira de Ciência do Solo**, v. 28, n. 1, p. 155-163, 2004.

BLAKE, G. R.; HARTGE, K. L. Bulk density. *In*: KLUTE, A., ed. **Methods of soil analysis**. 2. ed.: Madison, USA: American Society of Agronomy, 1986, p. 363-373.

BORKERT, C.M. *et al.* Mineral nutrients in the shoot biomass of soil cover crops. **Pesquisa Agropecuária Brasileira,** v. 38, n. 1, p. 143-153, 2003.

CAIRES, E. F. Management of soil acidity. *In*: PROCHNOW, L. I.; CASARIN, V.; STIPP, S., eds. **Best management practices for fertilizer use**, Piracicaba: IPNI, 2010, p. 272-347.

CAIRES, E. F. *et al.* Lime and gypsum application on the wheat crop. **Scientia Agricola**, v. 59, n. 2, p. 357-364, 2002.

CANTARELLA, H.; TRIVELIN, P. C. O. Determination of total nitrogen in soil. *In:* RAIJ, B. V. *et al.*, eds. **Chemical analysis for evaluation of fertility of tropical soils.** Campinas: Instituto Agronômico, 2001. p. 262-276.

CARVALHO, P. C. F.. The grassland management to create suitable grazing environments for animal production. *In*: PROCEEDINGS OF THE PASTURE MANAGEMENT SYMPOSIUM, 22., 2005, Piracicaba: FEALQ, 2005. p. 7-32.

CERRI, C. C. *et al.* Review: Greenhouse gas mitigation options in Brazil for land-use chance, livestock and agriculture. **Scientia Agrícola,** v. 67, n. 1, p. 102-116, 2010.

COSTA, K. A. P. *et al.* Nitrogen doses and sources in Marandu pasture. I - Changes in soil chemical properties. **Revista Brasileira de Ciência do Solo,** v. 32, n. 4, p. 1591-1599, 2008.

DANIELSON, R. E.; SUTHERLAND, P. L. Porosity. In: KLUTE, A., ed. **Methods of soil analysis**. 2.ed. Madison, USA: American Society of Agronomy, 1986, p. 443-461.

EMBRAPA/FUNDAÇÃO ABC. **Large-scale soil survey - Municipality of Castro**. (Intern Bulletin). EMBRAPA/SOLOS/ EMBRAPA/FLORESTAS/FUNDAÇÃO ABC: Castro, PR, 2001.

FONSECA, A. F.; CAIRES, E. F.; BARTH, G. Extraction methods and availability of micronutrients for wheat under a no-till system with a surface application of lime. **Scientia Agricola,** v. 67, n.1, p. 60-70, 2010.

FONTANELI, R. S.; SANTOS, H. P.; MORI, C. Profitability and risk of production systems with pasture under no-tillage system. **Ciência Rural,** v. 36, n.1, p. 51-57, 2006.

GROHMANN, F. Pore size-distribution in three types of soil of the state of São Paulo. **Bragantia**, v. 19, n. 1, p. 319-328, 1960.

GUPPY, C. N. *et al.* Competitive sorption reactions between phosphorus and organic matter in soil: a review. **Australian Journal of Soil Research**, v. 43, n. 2, p. 189-202, 2005.

HAVLIN, J. L. *et al.* **Soil fertility and fertilizers**. 7.ed. Upper Saddle River: Pearson Prentice Hall, 2005.

INSTITUTO AGRONOMICO DO PARANÁ –IAPAR. **Climatic letters of Paraná State**. Instituto Agronômico do Paraná, Londrina, PR (IAPAR, Bulletin, 18), 1994, 49 p.

LANDERS, J. N. **Tropical crop-livestock systems in conservation agriculture. The Brazilian experience**. Rome, Italy: Food and Agriculture Organization of the United Nations, 2007. 92 p.

LANZANOVA, M. E. *et al.* Soil physical attributes in integrated cattle raisin-crop production system under no-tillage. **Revista Brasileira de Ciência do Solo,** v. 31, n. 5, p. 1131-1140, 2007.

LINDSAY, W. L.; NORVELL, W. A. Development of a DTPA soil test for zinc, iron, manganese, and copper. **Soil Science Society of America Journal**, v. 42, n. 3, p. 421-428, 1978.

MALAVOLTA, E. **Plant nutrition manual**. São Paulo: Editora Agronômica Ceres, 2006. 638 p.

MIYAZAWA, M.; PAVAN, M.A.; CALEGARI, A. The effect of plant material on soil acidity. **Revista Brasileira de Ciência do Solo,** v. 17, p. 411-416, 1993.

MORAES, A.; BANDEIRA, A.; SILVA, H. A. Introduction and justify. *In:* MORAES, A. *et al.*, eds. **Milk production in integrated crop-livestock systems.** Curitiba, PR: Instituto Paranaense de Assistência Técnica e Extensão Rural - EMATER, 2008. p. 7-12.

MOOT, G. O.; LUCAS, H. L. The design, conduct and interpretation of grazing trials on cultivated and improved pastures. In: INTERNATIONAL GRASSLAND CONGRESS, 6., 1952, Pennsylvania**. Proceedings**… Pennsylvania, USA: State College, 1952. p. 1380-1385.

NICOLOSO, R. S. *et al.* Soil organic carbon budget under crop-livestock integration in southern Brazil. **Revista Brasileira da Ciência do Solo**, v. 32, n. 6, p. 2425-2433, 2008.

PAULETTI, V. **Nutrients: concentrations and interpretations**. Castro, PR: Fundação ABC, 2004. 86 p.

PAVAN, M. A. *et al.* **Manual of the chemical analysis of soil and quality control.** Londrina, PR: Instituto Agronômico do Paraná: Londrina, PR. (Bulletin, 76), 1992, 40 p.

REINERT, D. J. *et al*. Bulk density critical limits for normal root growth of cover crops. **Revista Brasileira de Ciência do Solo**, v. 32, n.5, p. 1805-1816, 2008.

RUSSELLE, M. P.; FRANZLUEBBERS, A. J. Introduction to «Symposium: Integrated Crop-Livestock Systems for Profit and Sustainability». **Agronomy Journal,** v. 99, p. 323-324, 2007.

SÁ, J. C. M. *et al.* Soil organic carbon and fertility interactions affected by a tillage chronosequence in a Brazilian Oxisol. **Soil & Tillage Research**, v. 104, p. 56-64, 2009.

SAS SYSTEM. SAS Institute Inc. SAS Online Doc® 9.1.2. SAS Institute: Cary, NC, 2004.

SILVA, H. A. *et al*. Dairy heifers' performance in winter annual pastures under integrated crop-livestock system. **Pesquisa Agropecuária Brasileira**, v. 46, n. 10, p. 1372-1378, 2011.

SPERA, S. T. *et al*. Effect of crop-livestock under no-tillage on some soil physical attributes after ten years. **Bragantia**, v. 69, n. 4, p. 695-704, 2010.

SPERA, S. T. *et al.* Soil tillage and crop rotation systems on the soil physical attributes. **Bragantia,** v. 68, n. 6, p. 1079-1093, 2009.

SOUZA, E. D. *et al.* Soil organic carbon and nitrogen stocks in an untilled crop-livestock integration system under different grazing intensities. **Revista Brasileira de Ciência do Solo**, v. 33, n. 6, p. 1829-1836, 2009.

SOUZA, E. D. *et al.* Soil microbial biomass in a no-tillage integrated crop-livestock system under different grazing intensities. **Revista Brasileira de Ciência do Solo**, v. 34, n. 1, p. 79-88, 2010.

SPARKS, D. L. **Environmental soil chemistry.** 2.ed. Academic Press: San Diego, USA, 2003.

VITTI, G. C.; SUZUKI, J. A. **The sulfur determination - sulfate by turbidimetric method.** Jabotical, SP: Universidade Estadual de São Paulo, 1978.