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Seeding densities of the oat crop and the amount of grazing on the physical property and soil carbon

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Abstract

The objective of this study was to evaluate the effect of two sowing densities of oat crop, managed in an integrated crop-livestock system (ICLS), or the use of fallow during the winter period, on the soil physical properties, total carbon and soil carbon stock, in two years. A split-plot in a randomized block design, with additional treatment was used. It was found that the number of grazing in the year 2014 adversely affected the values of macroporosity and microporosity in the layer 0-0.05 m, besides the microporosity in the 0.1-0.2 m layer. The total porosity in the 0.1-0.2 m layer was positively influenced by the sowing density of oats only in the year 2014. The soil penetrometer resistance (SPR) had changes after winter 2015, at 0-0.05 m due to the number of grazing. During 2014, there were no changes in the total carbon and carbon storage of the soil. In 2015, the amount of grazing used, negatively affected the total carbon in layers 0-0.05 and 0.1-0.2 m. However, it positively affected the storage of carbon in soil in the layer 0.05-0.1 m. The adoption of the lower density of the oat crop with realization of a grazing tends to improve the physical properties, total carbon and soil carbon stocks.

Keywords: Soil porosity, penetrometer resistance, conservation management.
Abbreviations: ICLS_Integrated crop-livestock system, SPR_soil penetrometer resistance.

Introduction

The cultivation of oat, whether single or consortium in integrated crop-livestock system (ICLS), is a technically and economically viable alternative used by farmers in the winter period in the south of Brazil. This cultivation makes it possible to obtain high-quality forage for animal feed, as well as straw to cover the soil for sowing summer crops under no-tillage system with good quality (Castagnara et al., 2012). However, in areas where ICLS is used, inadequate oat crop management may result in lower straw production for soil protection and no-tillage of crops in succession (Demétrio et al., 2012) which may contribute to a decrease in productivity. Animal presence with or without high grazing intensity may reduce soil cover, and entry of animals with high soil humidity or even inadequate machine traffic may adversely affect the soil structure, causing, for example, soil compaction. Spatial variability of soil properties such as soil structure and soil penetrometer resistance (SPR) is relevant for identifying those zones with physical degradation (López de Herrera et al., 2016). In order to measure soil degradation, several indicators such as macroporosity, microporosity, total porosity (Castagnara et al., 2015), soil density (Collares et al., 2011) and penetrometer resistance are used (Fidalski and Alves, 2005), with inferences on soil structural stability throughout the years of cultivation (Foley et al., 2005). The high grazing intensity in ICLS can increase soil density and microporosity, as well as promote the reduction of macroporosity (Andreolla et al., 2014), as it promotes a structural rearrangement of soil particles (Reichert et al., 2010). Besides providing conditions that can increase the process of soil degradation (Tirloni et al., 2012), it could lead to changes in the functional quality of the agricultural system (Aziz et al., 2013). Changes in soil physical quality in ICLS can compromise grain and pasture productivity, especially under adverse climatic conditions (Moreira et al., 2012). Another important indicator of soil quality is the soil organic matter content (SOMC), because it is influenced by the soil cultivation system and it is positively related to soil physical attributes (Matias et al., 2012), leading to the formation and stabilization of the aggregates, providing better structuring of the soil (Gomes et al., 2015). Management systems that provide lower contributions of crop residues, besides directly affecting the SOMC, causing the decrease of carbon content (Silva et al., 2013) are not indicated. In addition, we must emphasize that the implantation of the oat crop, in ICLS is important to avoid the maintenance of the fallow in the winter period. The fallow tends to favor agricultural areas subject to solar radiation, wind erosion, infestation by spontaneous plants (Balbinot Júnior et al., 2008) and to lower straw deposition. Due to the possibility of soil changes, influenced by sowing density the amount of grazing, the objective was to evaluate variations in macroporosity, microporosity, total porosity, soil density and penetrometer resistance, as well as total carbon and stock of carbon, of a clayey Red Latosol of Paraná western region, managed under an integrated crop-livestock system or under the maintenance of fallow.

Results and Discussion

Physical attributes of soil

According to the results, at the end of the winter of 2014, the management of the animals (without grazing, one grazing and two grazing) influenced the values of macroporosity and microporosity in both, the 0-0.05 m layer and the 0.1-0.2 m layer. The seeding density (60 and 40 kg ha^{-1}) affected the total porosity in the layer of 0.05-0.1 m. Soil density was not influenced by any of the factors evaluated in any of the studied layers. After the winter of 2015, no significant differences were observed among the attributes studied, due to the influence of the treatments applied in the 0-0.05 m, 0.05-0.1 and 0.1-0.2 m layers. The evaluation performed after the winter of 2014 shows that the values found for the macroporosity in the 0-0.05 m layer for the treatment without grazed (0.21 m³ m^{-3}) were higher than one grazing and two grazing (0.11 m³ m^{-3}) (Table 1). The behavior of macroporosity is usually antagonistic to microporosity, that is, when the values of macroporosity increase, those of microporosity decrease, or vice versa. In the 0-0.05 m layer, the values of micropores found for the one grazing (0.46 m³ m^{-3}) or two grazing (0.47 m³ m^{-3}) presented a greater amount than the treatment without grazing (0.42 m³ m^{-3}). A similar result was found by Lanzanova et al. (2007), in which the frequency of oat grazing altered the macroporosity of the soil in the 0.1-0.15 m layer. Corroborating with the results Bertol et al., (2000) it is affirmed that the effects of soil management associated with animal trampling were concentrated in the soil surface layer (0-0.05 m). In addition, the consumption of oats by the animals reduces the amount of remaining residues on the soil surface, since the straw covering the soil attenuates the pressure applied instantaneously on the soil in the direct proportion of its quantity, dissipating part of the compaction energy (Braida et al., 2006). According to (Debiasi and Franchini, 2012) animal trampling can generate compaction zones in more superficial layers, hardly below 0.1 m from the soil surface. For the 0.05-0.1 m layer, seeding density influenced the total porosity, and the lowest sowing density (40 kg ha^{-1}) promoted higher total porosity (0.55 m³ m^{-3}), compared with the highest density (60 kg ha^{-1}) (0.54 m³ m^{-3}) (Table 1). This result may have been caused by the root system of oats, since, according to Bertol et al. (2000) in the ICLS the presence of roots of forage grasses improves the structure of the soil, mitigating the impact of trampling, through the root renovation (Castagnara et al., 2012). In addition, we have a dual purpose: crops are stimulated to develop the root system when grazed. However, in the 0.1-0.2 m layer, the values found for microporosity in the treatment without graze (0.46 m³ m^{-3}) were higher than treatments that suffered one grazing (0.43 m³ m^{-3}) (Table 1). For Conte et al. (2011) in areas managed under ICLS, no change in soil compaction is expected through animal trampling below 0.1 m soil layer, so in this work the change in microporosity is not attributed exclusively to the presence of the animal in the area. For the soil density values, there was no influence of the factors studied in any of the years. Vieira and Klein (2007) affirm that the soil under no-tillage system generally presents higher density and lower porosity than soils submitted to conventional tillage. The values found for soil density (Table 2) are all below the values considered critical (1.60 Mg m^{-3}) for crop development (Silva and Rosolem, 2001), or limiting (1.40 Mg m^{-3}) for clayey Red Latosol (Klein and Camara, 2007). Most of the values for macroporosity fluctuate between 0.05 and 0.10 m^{3} m^{-3} (Table 2), which are reported as restrictive for crop yield (Beutler and Centurion, 2004), as macroporosity directly affects soil aeration. In addition, soil microporosity values are above 0.33 m^{3} m^{-3} (Kiehl, 1979), which is considered ideal for plant development. This high value may be disfavoring the aeration and infiltration of water in the soil. Although the soil presents some compaction evidences, they may not always reflect the reduction in yield, since crops have different tolerances to compaction (Reichertet al., 2009). In addition, in these cases, an important factor is the presence of moisture in the soil, which means that there is a complex interaction between the climatic and edaphic conditions of the soil (Girardello et al., 2011). The results confirmed the small changes caused by animal trampling to the physical properties of the soil in the studied layers, as found by other authors (Spera et al., 2009; Castagnara et al., 2015). These changes do not reach critical levels for the root growth of the cultivated plants, since the pressure applied by the animal's feet to the soil is not stronger than the soil resistance to plastic deformation (Conte et al., 2011), besides that the entrance of the animals into the area was performed with a low soil moisture (Figure 1). Also changes caused by animal grazing become easily reversible by natural processes that occur in the soil, such as humidity, alternating drought cycles, the action of natural agents and sowing operations as the preparation located in the line (Conte et al., 2011) and the natural rearrangement of soil particles. In relation to the penetrometer resistance (PR) of the soil in the studied layers, there was no influence by the factors studied in the year 2014, and the lowest PR values were found in the soil superficial layer (Figure 2). The mean values of soil gravimetric moisture were 24% and 26% respectively for years 2014 and 2015. After the evaluation of year 2015, the amount of grazing influenced soil PR only in the first layer studied. The lowest values of soil PR were found when one grazing and no grazing were used and the highest values when oats were two grazed only in the first layer (0-0.1 m) (Figure 2). Different results from this study were found by Spera et al. (2010) who reported that there was no difference for soil penetrometer resistance, in the 0-0.05 m layer, with or without the presence of the animal in a clayey Red Latosol. Although the values for PR are in a range, in most of the layers, being below or slightly above 2.0 MPa that is considered limiting for the growth of the roots of the plants (Tormena et al., 1998), and those that are below the limit of 2.5 MPa impair plant growth (Caranache, 1990).

Table 1. Physical properties of a clayey Red Latosol in ICLS, with different management, after the winter crop of 2014.

Management	Macroporosity ($m^3\ m^{-3}$) (0-0.05 m)			Microporosity ($m^3\ m^{-3}$) (0-0.05 m)		
	A40	A60	Mean	A40	A60	Mean
Without grazing	0.19	0.23	0.21a	0.43	0.40	0.42b
One grazing	0.11	0.12	0.11b	0.47	0.45	0.46a
Two grazing	0.12	0.10	0.11b	0.47	0.47	0.47a
Mean	0.14	0.15		0.46	0.44	
	Microporosity ($m^3\ m^{-3}$) (0.1-0.2 m)			Total soil porosity ($m^3\ m^{-3}$) (0.05-0.1m)		
Without grazing	0.46	0.46	0.46a	0.55	0.56	0.56
One grazing	0.45	0.42	0.43b	0.55	0.53	0.54
Two grazing	0.45	0.44	0.44ab	0.56	0.52	0.54
Mean	0.45	0.44		0.55A	054B	

Values represented by the different lower case in the column and upper case letters in the lines, show significant differences (Tukey test, p<0.05). A40 and A60: sowing densities, 40 and 60 kg ha^{-1} of seeds.

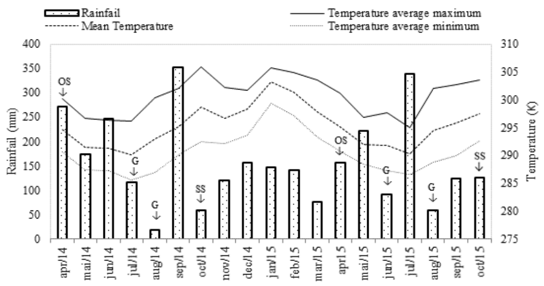

Fig 1. Monthly average of the maximum, minimum and average temperatures (K) and accumulated rainfall during the months of the experimental period. OS oat seeding, SS soybean sowing and G winter grazing, respectively.

Table 2. Physical properties of the soil in the 0-0.05 m, 0.05-0.1 m and 0.1-0.2 m layer in ICLS, with different management, after the winter crop of 2014 and 2015.

Year	Macroporosity ($m^3\ m^{-3}$)			Microporosity ($m^3\ m^{-3}$)		
	0-0.05	0.05-0.1	0.1-0.2	0-0.05	0.05-0.1	0.1-0.2
2014	0.15	0.10	0.10	0.45	0.45	0.45
2015	0.06	0.06	0.06	0.50	0.48	0.48
	Total soil porosity ($m^3\ m^{-3}$)			Soil bulk density ($Mg\ m^{-3}$)		
2014	0.60	0.55	0.54	1.10	1.28	1.29
2015	0.56	0.54	0.53	1.23	1.31	1.33

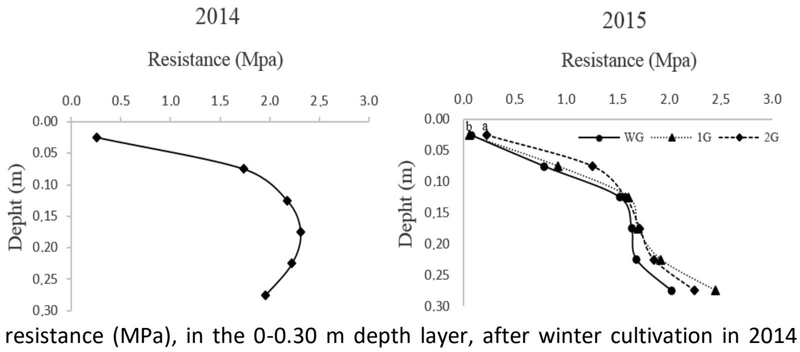

Fig 2. Soil penetrometer resistance (MPa), in the 0-0.30 m depth layer, after winter cultivation in 2014 and 2015. WG without grazing, 1G one grazing and 2G two grazing, respectively. Different measurements at each depth, show significant differences (Tukey test, p<0.05).

Table 3. Total carbon in ICLS, with different management, after the winter crop of 2015.

Management	Total carbon ($g\ dm^{-3}$) (0-0.05 m)			Total carbon ($g\ dm^{-3}$) (0.1-0.2 m)		
	A40	A60	Mean	A40	60	Mean
Without grazing	7.62	7.55	7.59a	7.55	7.44	7.49b
One grazing	7.43	7.44	7.43ab	7.60	7.84	7.72a
Two grazing	7.46	7.39	7.42b	7.40	7.26	7.33b
Mean	7.50	7.46		7.51	7.51	

Values represented by the different lower case in the column, show significant differences (Tukey test, p<0.05). A40 and A60: sowing densities, 40 and 60 kg ha^{-1} of seeds.

Table 4. Total carbon stock TCS (Mg ha^1), in the layer of 0.05-0.1m, after the winter of 2015.

Fallow	40			60		
	WG	1G	2G	WG	1G	2G
5.20	4.67^-	4.77^-	4.63^-	4.81^{ns}	5.14^{ns}	5.14^{ns}

$^-$: Significant and inferior to fallow (Dunnett test, $p<0.05$); ns: Not significant (Dunnett test, $p>0.05$). 1G: one grazing; 2G: 2 grazing; WG: Without grazing. A40 and A60: sowing densities, 40 and 60 kg ha^{-1} of seeds.

Table 5. Soil chemical and textural characteristics, before the implantation of the winter crop of 2014.

Depth	P	pH	H+Al	Al^{3+}	K^+	Ca^{2+}	Mg^{2+}	SB	CTC	V	Clay	Silt	Sand
m	mg	$CaCl_2$	------------------------cmol$_c$ dm^{-3}--------------------							%	---------g kg^{-1}----------		
0.0-0.1	30.3	4.4	6.6	0.4	0.5	3.0	1.8	5.3	12.0	44.7	681.0	266.5	52.5
0.1-0.2	20.2	4.4	6.8	0.3	0.5	2.7	1.4	4.6	11.4	40.1	751.5	199.1	49.4

P e K –MEHLICH-1; Al, Ca e Mg = KCl 1 mol L^{-1}; H+Al = pH SMP (7.5).

Bertol et al., (2004) suggest that the effects of no-tillage cropping systems involving winter crops should manifest themselves after several years of adoption. However, the presence of plants and their root system can minimize the possible impacts to be caused by trampling of animals (Castagnara et al., 2012), result evidenced in this work, since all plots contained plants, even spontaneous on the fallow plots.

Despite the low magnitude changes in the physical properties of the soil in 2014 and the non-alteration of properties during 2015, it cannot be said that these were solely due to the changes caused by the animals, since the control also had such behavior. Furthermore, in ICLS, the effects of machine traffic during summer cropping can cause structural changes in the soil and these can be observed in post-grazing data, so there is no way to separate the effects of trampling and machine traffic (Moreira et al., 2014).

Total carbon and soil carbon stocks

For the total carbon and soil carbon stock values evaluated at the end of the winter of 2014, the studied layers were not influenced by the management factors studied. However, the evaluation carried out in 2015 showed that the number of grazing influenced the TC in the layers of 0-0.05 and 0.1-0.2 m and the interaction of factors (additional factorial) on the carbon stock at the 0.05-0.1 m layer.

The highest TC contents were found in the 0-0.05 m layer, for the treatment without grazed, when compared to one grazed and two grazes (Table 3). A similar result was found by Sotiles, Savi, Tavares and Santos (2015) showing discrete variations in the TC content of the soil along the profile and that the variations are influenced by grazing and soil management. (Silva et al., 2011) such as the increase in TC caused by the use of plants (Pereira et al., 2010) or a decrease caused by non-conservationist management.

Increases in TC contents require time, using conservation systems such as the no-tillage system (Guareschi et al., 2012) or even the SILP, which sequester C from the atmosphere, contributing to the mitigation of the greenhouse effect. When managed correctly, integration/consortium systems can benefit C contends in the system, thereby increasing soil C levels (Bell and Moore, 2012) since the amount of straw that enter in the system influences the rate of C addition to soil (Johnston et al., 2009). The magnitude of this process also depends on the quantity and quality of the straw deposited on the soil surface (West and Post, 2002; Paul et al., 2013).

Campos et al., (2013) evaluating different management systems, found higher levels of TC in the layers 0.05-0.1 and 0.1-0.2 m when adopting no-tillage system for 5 and 9 years old. Similar carbon accumulations in conservation systems along the time were also found by Rosset et al. (2016) in the Paraná state.

For the TCS in the soil, in the 0.05-0.1 m layer, after the winter cycle of 2015, significant values were shown in the interaction of factors (seeding density x fallow). The fallow and the highest sowing density (60 kg ha^{-1}) provided a higher TCS, compared with the lowest sowing density (40 kg ha^{-1}) (Table 4). The highest levels of TCS in the fallow were due to the seed bank of winter crops, mainly ryegrass (Lolium multiflorum) and turnip (Brassica napus L.), as the area was kept in this management system by two years. For the higher sowing density of oats, probably the greatest amount of roots per area, contributed to this result.

It was expected that in the areas where the grazing was in the fallow, a lower deposition of dry mass occurred, which consequently would affect the carbon content, but this result was not observed. According to Souza et al. (2009) in areas with greater grazing intensity, there is a higher carbon output of the system, due to animal grazing and, consequently, there is a lower stock of this element in the soil. However, for Moreira et al. (2012), grazing treatments may have a balance between grazing and root system development with regrowth after grazing, however, reductions in organic carbon stock are common in cultivated areas where dry mass preservation does not occur Bayer et al. (2008).

Souza et al. (2009) studying ICLS with black oats and ryegrass and soybeans in Rio Grande do Sul, found that intensities of moderate grazing (0.2-0.4 m of residue height) increased C, from 3.9 and 2.8 Mg ha^{-1} to 8.2 and 7.4 Mg ha^{-1}, respectively. Matias et al. (2012), evaluating different management systems, observed that the largest stock of organic carbon was in the 0-0.05 m layer in no-tillage system. The equilibrium between the immobilization process and the mineralization of the organic matter in soil, which affects the carbon stock, occurs only five years after implantation (Sá et al., 2004), that is, the consolidation of effects, no-tillage on soil characteristics, takes time.

Materials and Methods

Location, climate and soil of the study area

The work was developed at the experimental station "Professor Antônio Carlos dos Santos Pessoa" (24º 31 '58''S and 54º 01' 10'' W, with an approximate elevation of 400 m), belonging to the Universidade Estadual do Oeste do Paraná - Campus Marechal Cândido Rondon, in a clayey Red Latosol

(Santos et al., 2013). The area was being managed under integrated crop-livestock system (summer soybean and double purpose cereals in the winter) for two years and had the following physicochemical characteristics described in table 5. Due to the saturation by bases present values below to 50%, surface liming with 3 t ha^{-1} of calcitic limestone was performed 30 days before seeding the 2014 oat crop. The objective was to raise the base saturation to 70% (Table 5).
The climate of the region, according to Koeppen's classification, is subtropical humid mesothermal type Cfa, with well-distributed rainfall during the year and hot summers. The average temperatures of the coldest quarter vary between 290.15 and 291.15 K, the one of the warmest quarter between 301.15 and 302.15 K and the annual temperature between 295.15 and 296.153 K. The climatic data regarding the experimental period were obtained from an automatic weather station distant about 50 m from the experimental area (Figure 1).

Experimental design

The experimental design was a randomized complete block design, in split-plot, with additional treatment (fallow, with natural ryegrass and turnip resemination), repeated four times, totaling 28 experimental plots. In the A bands (10 x 18 m), two sowing densities of the oat crop (40 and 60 kg ha-1 of commercial seeds) were allocated plus the fallow plot. In the B bands (5 x 20 m), transversal to the bands A, was allocated the management of the oats: without grazing, one grazing with a height of residue of 0.15-0.2 m and two grazing with a height of residue of 0.15-0.2 m. The plots for the oat crop were formed by the combination of bands A and B (5 x 10 m), having each block, an area of 540 m (18 x 30 m).

Implantation and management of oat crop

The experiment was started in April 2014, and in this area during two years a treatment was done before sowing, using Isopropylamine glyphosate-salt in the dose of 3.0 L ha^{-1}, commercial product, volume of 100 L ha^{-1} spray.
The oat crop was seed on 04/25/14 and 04/24/15 with a fertilizer-seeding machine, coupled to a tractor, in an integrated crop-livestock system on soybean straw, with a spacing between rows of 0.17 m. 60 and 40 kg ha^{-1} of commercial white oat seeds, cultivar IPR 126, were used. Fertilization was carried out based on soil chemical analysis using 250 kg ha^{-1} of a 10-15-15 (N, P_2O_5 and K_2O) for basic fertilization and, for cover fertilization, 120 kg ha^{-1} of N in the form of urea. The cover fertilization was done manually, divided in three times, at the beginning of the tillering of the oats and, immediately after each grazing, in the treatment that was grazed twice. However, for treatments that only was grazed and/or not grazed, the cover fertilization was divided in two times, in tillering and after grazing. No applications of agrochemicals were made during the oat development cycle.
The oat managements, B bands, were initiated when the plants reached between 0.3 and 0.35 m in height. Seventeen animals of the lactating Dutch breed with an average weight of 650 kg ± 50 kg were used for grazing. The animals remained in the bands for four hours daily (two in the morning and two in the afternoon) or until the height of the oat had reached 0.15-0.2 m, so that there was no damage to the growth meristem (Neres et al., 2012). A high animal load was used for rapid grazing of the bands. Grazes were started at 65 and 113 days after sowing (DAS) in 2014 and 96 and 127 DAS in 2015.

Performed analyzes

The soil physical characterization was performed by the volumetric ring method according to Donagema et al., (2011). The samples were collected in the useful area of each plot, in the 0-0.05 m, 0.05-0.1 m and 0.1-0.2 m layer. From the plots, undisturbed soil samples were taken with the help of metal rings with an internal volume of approximately 50 cm^3 introduced vertically in the profile. The physical analyzes were performed at the UNIOESTE Soil Physics Laboratory. The evaluation was carried out at 150 DAS in 2014 and at 157 DAS in 2015.
The penetrometer resistance (PR) measurements were performed with an electronic penetrograph (penetroLOG-Falker-PLG1020). Three random readings were taken, in the plot area, to compose an average of each plot, up to the layer of 0.3 m. On the day of the analysis, soil samples were also collected for the determination of gravimetric moisture.
The total carbon and soil carbon stocks were evaluated at the end of winter. Four samples per plot were taken from the 0-0.05 m, 0.05-0.1 and 0.1- 0.2 m depth in order to form a representative composite sample. After the collection, the samples were conditioned in plastic bags, identified and transported to the laboratory, dried in the air and passed in 2 mm sieves for analysis. Soil organic matter (SOM) was determined in muffle, following a method established by Goldin (1987), and modified by Rodella and Alcarde (1994). With the results of SOM, the total carbon contents (TC) in the soil were determined and estimated using the Bemmelen factor 1,724, based on the assumption that SOM contains 58% of organic carbon. For the total carbon stocks (TCS) the expression proposed by Freixo et al., (2002) was used:

$$TCS\ (mg\ ha^{-1})\text{:}\ \frac{content\ of\ C\ (g\ kg^{-1})\ .\ Sd\ (Soil\ density\text{: } Mg\ m^{-3}).\ e\ (layer\ thickness\text{: } cm)}{10}$$

Statistical analysis

The data were submitted to analysis of variance and, according to the result of the F test, with significance the Tukey test was applied at the 5% probability level for comparisons between averages, or the Dunnet test at the level of 5% when the additional factorial was significant.

Conclusion

The number of grazing used in the oat crop adversely affects the physical attributes of the soil (macroporosity and soil microporosity), in the 0-0.05 m layer, as well as microporosity, in the 0.1-0.2 m layer. The lower sowing density of oats promoted a higher total porosity in the 0.05-0.1 m layer after the winter of 2014. Oat crop in a system of integrating livestock farming with two grazing, promoted a greater soil penetrometer resistance, in the year 2015. During 2014, there was no influence on the total carbon and carbon stock of the soil. In 2015, the total carbon was influenced by the amount of grazing, layers 0-0.05 and 0.1-0.2 m, and the use of grazing promoted the best results.

The interaction of the additional factorial promoted alterations on the carbon stock in the layer of 0.05-0.1 m, and the fallow had a carbon stock equal to the higher sowing density of oats. The realization of a grazing tends to improve the overall carbon and carbon stock in the ground, regardless of the seeding density.

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