

Soil Structural Attributes And Oxidizable Carbon Fractions After Turkey Litter Applications

Atributos estruturais e frações oxidáveis do carbono do solo após aplicações de resíduo de peru

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ABSTRACT - The residues generated on rural properties are used in pastures and croplands and can alter some soil attributes. Therefore, the objective of this study was to evaluate the effects of a chronosequence of turkey litter application rates on the structural attributes and oxidizable carbon fractions of a Red Latosol under rotational grazing. The experimental design was a randomized block design, consisting of the following treatments: 0 Mg ha⁻¹ of turkey litter (T0); 38.29 Mg ha⁻¹ of turkey litter (T1); 54.79 Mg ha⁻¹ of turkey litter (T2); and 69.24 Mg ha⁻¹ of turkey litter (T3), corresponding respectively to 0, 6, 8, and 9 years of turkey litter use as fertilizer, with four replications. After several years of turkey litter application, soil bulk density was reduced from the control treatment to treatments T1 and T3. The use of turkey litter also increased macroporosity in treatment T2 compared to T0. Regardless of the treatments with turkey litter use, the proportion of macroaggregates increased, reaching increments of up to 53% in T3 relative to T0. The oxidizable fractions F1 and F2 were more sensitive, while fractions F3 and F4 were less sensitive to the management with poultry residue.

RESUMO - Os resíduos gerados em propriedades rurais são utilizados em pastagens e lavouras e podem alterar alguns atributos do solo. Desta forma, objetivou-se avaliar os efeitos de uma cronossequência de aplicações de doses de cama de peru sobre os atributos estruturais e das frações oxidáveis do carbono de um Latossolo Vermelho, sob pastejo rotacionado. O delineamento experimental foi em blocos casualizados, constando dos seguintes tratamentos: 0 Mg ha⁻¹ de cama de peru (T0); 38,29 Mg ha⁻¹ de cama de peru (T1); 54,79 Mg ha⁻¹ de cama de peru (T2); e 69,24 Mg ha⁻¹ de cama de peru (T3), correspondendo, respectivamente, a 0, 6, 8 e 9 anos de uso da cama de peru como fertilizante, com quatro repetições. Após vários anos de aplicação de cama de peru, a densidade do solo foi reduzida no tratamento controle para os tratamentos T1 e T3. A utilização do resíduo aviário também aumentou a macroporosidade no tratamento T2 em relação ao tratamento T0. Independentemente dos tratamentos com o uso de cama de peru, a proporção de macroagregados foi aumentada, alcançando incrementos de até 53% no T3 em relação ao T0. As frações oxidáveis F1 e F2 foram mais sensíveis e as frações F3 e F4 menos sensíveis ao manejo adotado com o resíduo aviário.

Keywords: Carbon chemical fractionation. Poultry waste. Soil aggregation. Soil bulk density.

Palavras-chave: Fracionamento químico do carbono. Resíduo aviário. Agregação do solo. Densidade do solo.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

INTRODUCTION

The state of Goiás presents itself as a major Brazilian agricultural producer and, among the agricultural activities, cattle production occupies a large area. Pastures correspond to more than 14 million hectares, representing more than 50% of cropped areas in the state of Goiás (IBGE, 2017). In addition to cattle production, Goiás also stands out as a producer of poultry meat. In 2023, the state of Goiás accounted for 4.7% and 2.4% of Brazilian exports of chicken and turkey meat, respectively (ABPA, 2024).

The production of grains and animals, such as cattle and poultry, demands high investments, and a considerable portion of this is for the addition of chemical fertilizers. The animal production chain generates wastes, such as poultry waste, which, on the one hand, can be considered a problem for the agricultural sector (GRŽINIĆ et al., 2023). However, on the other hand, it has great potential to be used as fertilizers (KYAKUWAIRE et al., 2019) and soil conditioners, increasing soil physical quality (RIBEIRO et al., 2019a).

Distinct effects on soil aggregation can also be observed with the use of organic residues (COSTA et al., 2009; RIBEIRO et al., 2019b; TROLEIS et al., 2017). Positive effects can be observed with the use of turkey litter on micro porosity and total pore volume (RIBEIRO et al., 2019b). In a clayey Latosol (Oxisol) under different forms of pasture fertilization using organic and mineral residues, after 33 months there was no influence on soil aggregation (TROLEIS et al., 2017). On the other hand, in a clayey Latosol (Oxisol) cultivated with soybean in on-season and maize in off-season, the annual addition of 4 and 6 Mg ha⁻¹ of



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Received for publication in: January 1, 2025.
Accepted in: November 10, 2025.

Editor in Chief: Aurélio Paes Barros Júnior
Section Editor: Renisson Neponuceno de Araújo Filho

Data Availability: The data that support the findings of this study can be made available, upon reasonable request, from the corresponding author.

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poultry litter plus mineral fertilization after 6 years caused reduction in the mean weight diameter of aggregates (MWD). Additionally, there were changes in the distribution of macroaggregate size and increase of total porosity (RIBEIRO et al., 2019b). These changes in structure, particularly in soil pore spaces, can be fundamental for the dynamics of soil water infiltration and reduction of erosion (BONETTI et al., 2019; DIDONÉ et al., 2014).

The poultry waste fertilizer applied with mineral fertilizers can also increase the organic matter and oxidizable fractions of carbon in the soil (ADEYEMO; AKINGBOLA; OJENIYI, 2019; WANG et al., 2016), excellent indicators of soil quality (OLIVEIRA et al., 2023). The F1 and F2 fractions are considered more labile and more sensitive in demonstrating the effect of different management and fertilization sources. However, the F3 and F4 fractions are considered more recalcitrant, representing the physical and chemical protection of carbon and being less sensitive to the management adopted for the soil (BENBI et al., 2015; RIBEIRO et al., 2023). In the rice and wheat crops, poultry waste fertilization and crop residues led to increase in C stocks in the F1 fraction and reduction in the F4 fraction (BENBI et al., 2015).

Studies evaluating the cumulative effect of successive applications of turkey litter are still essential, especially for residues from turkey rearing. This study was based on the hypothesis that longer application periods provide positive effects on soil structural attributes and on the F1 and F2 carbon fractions in the soil. Our objective was to investigate the effects of different doses of turkey litter on structural

attributes and oxidizable carbon fractions in an Oxisol, cultivated in rotational grazing.

MATERIAL AND METHODS

The experiment was carried out at Fazenda Alvorada, located in Portelândia - GO, Brazil (17°17' 36" S, 52° 38' 59" W). The annual temperature is 24.2 °C and rainfall is 1.700 mm. The climate is semi-humid, classified as "Aw", according to Köppen (1928) classification.

The soil was characterized as Dystrophic Ferric Red Latosol (Oxisol Dystric Rhodic Haplustox apud US Soil Taxonomy) (MOTHCI, 1983), and its 0-20 cm layer contains 136 g kg⁻¹ of sand, 125 g kg⁻¹ of silt and 739 g kg⁻¹ of clay (very clayey textural classification). The experimental area was cultivated with *Urochloa decumbens* pasture, for dairy cattle, in a rotational grazing system since 1995.

The experiment started in 2008, in a randomized block design (16 plots of 0.5 ha), with four replicates and treatments of turkey litter doses: 0 Mg ha⁻¹ of turkey litter (T0); 38.29 Mg ha⁻¹ of turkey litter (applied for 6 years; T1); 54.79 Mg ha⁻¹ of turkey litter (applied for 8 years; T2); and 69.24 Mg ha⁻¹ of turkey litter (applied for 9 years; T3). The turkey litter doses were always applied between September and October (beginning of the rainy season). The history of turkey litter applications is described in Table 1. The turkey litter used in each of the applications was obtained from the same farm, had shavings as the base material, and its average chemical composition is presented in Table 2.

Table 1. Turkey litter application in the experimental area and total quantity of carbon supplied.

Treatments	Years of turkey litter application									Organic C Mg ha ⁻¹
	2008	2009	2010	2011	2012	2013	2014	2015	2017	
	Applied doses (Mg ha ⁻¹)									
T0	0	0	0	0	0	0	0	0	0	0
T1	0	0	0	7.89	7.34	5.71	5.71	8.64	3	8.64
T2	0	7.81	8.69	7.89	7.34	5.71	5.71	8.64	3	12.36
T3	14.45	7.81	8.69	7.89	7.34	5.71	5.71	8.64	3	15.63

T0: no application of turkey litter; T1: turkey litter dose of 38.29 Mg ha⁻¹; T2: turkey litter dose of 54.79 Mg ha⁻¹; T3: turkey litter dose of 69.24 Mg ha⁻¹.

Table 2. Chemical composition of turkey litter over the nine years of fertilization.

N	P ₂ O ₅	K ₂ O	Ca	Mg	Organic C	Dry matter	pH _(H2O)	C:N
%								
4.0	5.0	3.5	4.0	0.9	30.8	73.3	7.7	10:1

*Analysis: Tedesco et al. (1995).

For chemical characterization of each treatment, samples were taken in the 0-0.05, 0.05-0.1 and 0.1-0.2 m layers, at four points per treatment, forming a composite sample (Table 3), and the chemical analyses were performed according to Teixeira et al. (2017).

The continuous animal grazing started in 2008, every

45 days after the turkey litter application. The stocking rate was the same for experimental unit, with 20-25 animals of the Girolando breed, with live weight of 550-600 kg (3.1 to 4 AU ha⁻¹, considering the AU as 450 kg live weight). Grazing occurred in the rainy season (October-May) and at night during the dry season (June-September).

Table 3. Basic chemical characterization of the experimental area, in the 0-0.05, 0.05-0.1 and 0.1-0.2 m layers.

Accumulated Doses	pH CaCl ₂	TOC	P	K	Mg	Al	H +Al	SB	T	V%	
Mg ha ⁻¹		g kg ⁻¹	mg dm ⁻³								
0-0.05 m											
T0	4.5	22	2	0.18	1.5	0.7	0.4	5.2	2.38	7.58	31.44
T1	5.1	21	2	0.14	3.6	0.9	0.1	4.7	4.64	9.34	49.67
T2	5.2	23	4	0.16	4.5	0.5	0.1	3.4	5.16	8.56	60.30
T3	5.0	26	4	0.18	3.7	0.6	0.1	4.2	4.48	8.68	51.64
0.05-0.1 m											
T0	4.7	21	1	0.14	1.1	0.5	0.3	5.2	1.74	6.94	25.06
T1	4.9	20	2.2	0.22	2.5	1	0.1	5.2	3.72	8.92	41.74
T2	5.3	20	3	0.16	3.7	0.6	0.1	3.8	4.46	8.26	54.02
T3	4.8	21	2	0.18	2.5	1	0.1	4.2	3.68	7.88	46.76
0.1-0.2 m											
T0	4.4	18	1	0.12	1.2	0.6	0.3	4.7	1.92	6.62	29.05
T1	4.8	20	1	0.14	2.2	0.7	0.1	5.8	3.04	8.84	34.38
T2	5.0	19	1	0.16	2.0	0.7	0.1	4.2	2.86	7.06	40.55
T3	4.9	20	1	0.14	2.7	0.8	0.1	5.2	3.64	8.84	41.17

The soil samples were collected in November 2017 and in April 2018. A total of 96 undisturbed soil samples were collected in the layers of 0-0.05, 0.05-0.1 and 0.1-0.2 m at two points per plot, using steel rings with 5 x 5 cm in height and diameter, respectively, with a volume of 98 cm³ cm⁻³. Macro porosity was determined on a tension table (-6 kPa), and soil bulk density was determined as described by Teixeira et al. (2017).

To determine water-stable aggregates, small pits were opened in each plot and soil samples were collected at depths of 0-0.5, 0.05-0.1 and 0.1-0.2 m, at two points per plot. Undisturbed soil samples were wrapped in PVC films and placed in plastic containers. In the laboratory, the samples were manually broken at their points of weakness, passed through 4- to 2-mm-mesh sieves and, subsequently, 50 g of soil retained between the sieves (duplicate) were weighed. After that, the samples with soil were put into a set of sieves with mesh openings of 2, 1, 0.5, 0.25 and 0.125 mm and shaken in vertical shaker for 4 minutes (TEIXEIRA et al., 2017). The soil retained on each sieve was dried at 105 °C for 48 hours and weighed. To evaluate the aggregate mass, the aggregates were separated into three classes: micro aggregates (< 0.25 mm), meso aggregates (0.25-2.00 mm) and macro aggregates (> 2.00 mm), in addition to determining the mean weight diameter (MWD).

In the second collection season (April 2018), soil sampling was also performed for total organic carbon (TOC) determination and chemical fractionation. Eight soil samples were collected in each experimental unit, at 0.0-0.05 m, 0.05-0.10 m and 0.10-0.20 m depths, forming one composite sample. For TOC determination, 0.5 grams of soil were weighed and put into an Erlenmeyer flask with 10.00 mL of a solution of 0.0667 mol L⁻¹ K₂Cr₂O₇. After, distilled water was added to the solution, titrated with 0.1 mol L⁻¹ ammoniac ferrous sulfate (TEIXEIRA et al., 2017). For the chemical fractionation, the soil was passed through a 0.2-mm-mesh

sieve, where approximately 0.5 grams were weighed. For each soil sample, four analyses of the oxidizable fractions were performed using increasing amounts of H₂SO₄, corresponding respectively to the oxidizable fractions F1, F2, F3 and F4. To determine the respective fractions, ferroin was used as an indicator and the excess dichromate was titrated with 0.5 mol L⁻¹ ammoniac ferrous sulfate (MENDONÇA; MATOS, 2005).

The data were subjected to analysis of variance and the Tukey test was used at a 5% probability level, and a biplot chart was constructed to verify the overall variability of the experiment and the multivariate trends. For the statistical analysis, the model used was $y_{ij} = \mu + b_j + t_i + e_{ij}$, in which the observed value (y_{ij}) is decomposed into a general mean (μ), the block effect (b_j), the treatment effect (t_i), and the random error (e_{ij}). The analyses were carried out using the Rbio program with the R software interface (BHERING, 2017).

RESULTS AND DISCUSSION

Soil physical properties

Soil bulk density was lower in the treatments T1 and T2 (38.29 and 54.79 Mg ha⁻¹, respectively) compared to the T0 treatment without turkey litter application, in the surface layer of 0-5 cm, in both seasons (Figures 1a and 1b). The dose of 69.24 Mg ha⁻¹ (T3) was similar to T0, indicating a negative effect of turkey litter on soil bulk density. The management adopted in the experimental area was carried out according to the forage availability. Probably, the increase in this availability in the T3 treatment, due to the higher soil fertility, led the animals to staying for longer periods in the paddocks with greater forage availability, which may have contributed to obtaining similar soil densities between the T1 and T3

treatments. At the beginning of the rainy season, no changes in macro pores were observed in any of the evaluated layers (Figure 1c). On the other hand, after rainy season the

treatments with turkey litter application (T1, T2 and T3) had higher soil macro porosity at 0-0.05 m, compared to the T0 treatment (Figure 1d).

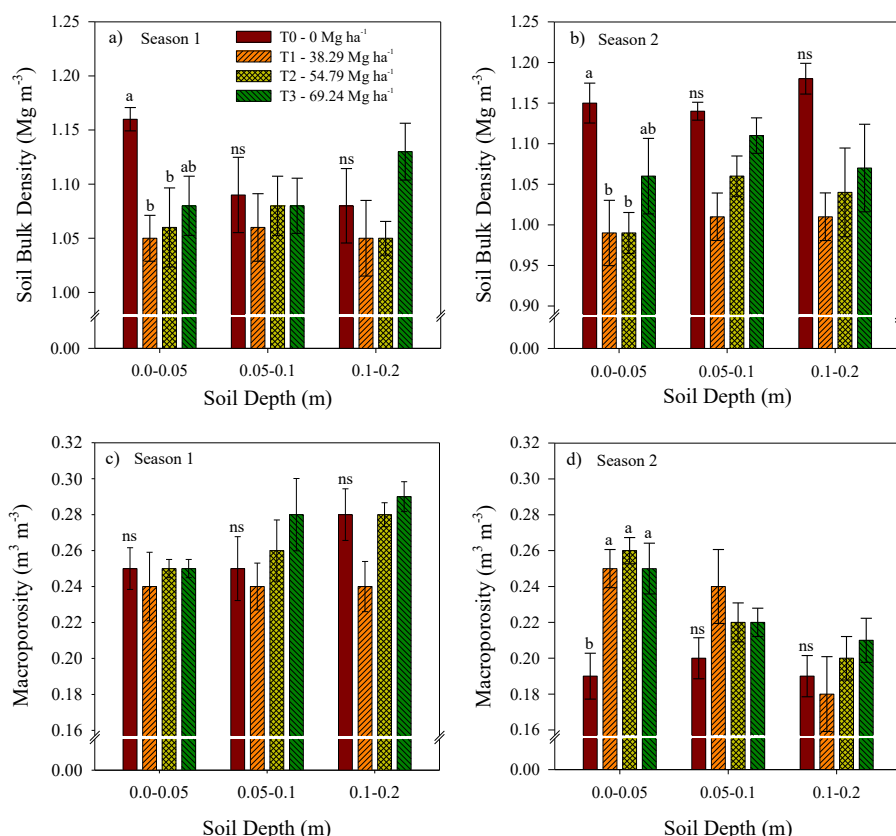


Figure 1. Soil bulk density at the beginning of the rainy season (season 1; a) and end of the rainy season (season 2; b) and soil macro porosity at the beginning of the rainy season (season 1; c) and end of the rainy season (season 2; d) under different doses of turkey litter in the long term. T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

In the treatments T1 and T2, the reduction in soil bulk density was equal to 9.5 and 8.6%, respectively, at the beginning of the rainy season, and to 14% after the rainy season, both in comparison to the T0 treatment. The reduction in soil bulk density occurs due to the low density of the turkey litter, which results in lower soil bulk density (ADEYEMO; AKINGBOLA; OJENIYI, 2019), increasing the structural quality, biological quality and root growth of plants (ARE et al., 2017; HOOVER et al., 2019; LIN; VAN SANTEN; WATTS, 2016). Lower soil bulk density in areas with poultry manure application was also observed in a degraded clayey soil of Nigeria (Typic Kandhaplustalf), where the use of manure (5 t ha⁻¹) reduced soil bulk density and increased soil physical quality (ARE et al., 2017).

In the 0.0-0.05 layer after the rainy season of 2018, macro porosity was higher under application of doses of turkey litter, being approximately 32 to 37% higher than in the control treatment (Figure 1). The highest soil bulk density was observed in the T0 treatment, which did not receive turkey litter doses. ARE et al. (2017) found a 6% increase in soil bulk density in the control treatment (without poultry litter application), compared to the initial soil bulk density (1.51 Mg m⁻³), whereas the treatment with poultry litter

application (5 t ha⁻¹) led to a 2.5% reduction in soil bulk density. In addition, the application of poultry waste (5 t ha⁻¹) is accompanied by an increase of soil organic carbon, and it is evident that the continuous application of poultry fertilizers led to improvement of soil physical quality of the degraded soil and subsequently increased the production of maize grains (ARE et al., 2017). The higher soil bulk density in the control treatment (T0) may be related to the lower production of *Urochloa decumbens*, which shows signs of degradation due to the non-fertilization of this treatment, which may lead to degradation of soil physical properties.

In addition to these factors, the increase in soil fertility, evidenced by the rise in pH and base saturation (V%) values and by the reduction in aluminum content in the treatments that received poultry residue application, may have favored the root and shoot development of *Urochloa decumbens*. As shown in Table 3, base saturation in the 0.0–0.05 m layer was 31.44% in treatment T0, reaching 60 and 51.4% in treatments T2 and T3, respectively. These improvements in soil chemical conditions in treatments T2 and T3 likely promoted higher productivity of *Urochloa decumbens* and indirectly contributed to the enhancement of the physical attributes evaluated in the experimental area.

Even in the control treatment, which showed reduction in macro porosity, this reduction did not reach the level considered limiting for plant development, $0.10 \text{ m}^3 \text{ m}^{-3}$ (TORMENA; SIVA; LIBARDI, 1998). The greater macro porosity in areas with turkey litter application is directly related to the increase in TOC and the improvement of soil structure. Greater macro porosity is fundamental for increasing water infiltration in the soil, especially in areas with animal trampling (BONETTI et al., 2019). The presence of turkey litter increases microbial activity, which combined with the presence of animal waste and *Urochloa decumbens* roots can increase biological macro pores and increase water infiltration (ADEYEMO; AKINGBOLA; OJENIYI, 2019).

The accumulated doses of turkey litter had an effect on the classes of aggregates at the beginning and end of the rainy season in the 0.0-0.05 m layer and on the classes of 0.25 - 2.0 mm and > 2.0 mm at the end of the rainy season in the 0.05-0.1 m layer (Tables 4 and 5). In the layer up to 0.05 m, at the beginning and end of the rainy season, the smaller aggregates (0.25-2 mm) were observed in the T0 treatment and the larger aggregates (> 2 mm) were observed in the treatments with turkey litter (T1, T2 and T3). After the rainy season, the differences in the 0.05-0.1 m layer (0.25 - 2.0 mm aggregates) were higher in T3 (Table 5). On the other hand, there were higher proportions of macro aggregates (> 2.0 mm) in the T0 treatment.

Table 4. Aggregate stability (%) of a Dystrophic Ferric Red Latosol after rotational grazing system fertilized with turkey litter at the beginning of the rainy season of 2017 (November).

Aggregate size classes	Treatments			
	T0	T1	T2	T3
0.0 – 0.05 m				
< 0.25 mm	10.2 a	7.0 b	5.2 b	7.3 b
0.25 - 2.0 mm	40.45 a	33.0 ab	29.1 b	29.2 b
> 2 mm	49.3 b	60.0 a	65.6 a	63.5 a
0.05 – 0.1 m				
< 0.25 mm	9.0 ^{NS}	7.7	9.3	8.3
0.25 - 2.0 mm	44.7 ^{NS}	36.2	44.0	40.7
> 2 mm	46.4 ^{NS}	56.0	46.7	51.0
0.1 – 0.2 m				
< 0.25 mm	8.4 ^{NS}	11.8	11.7	9.3
0.25 - 2.0 mm	44.3 ^{NS}	47.9	46.9	46.3
> 2 mm	47.3 ^{NS}	40.3	41.4	44.4

^{NS} Not significant. Lowercase letters compare treatments of turkey litter doses by Tukey test ($p < 0.05$). T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

Table 5. Distribution of water-stable aggregates (%), in the layers of the Dystrophic Ferric Red Latosol after rotational grazing system fertilized with turkey litter at the end of the rainy season of 2018 (April).

Aggregate size classes	Treatments			
	T0	T1	T2	T3
0.0 – 0.05 m				
< 0.25 mm	25.4 a	5.4 b	8.6 b	4.8 b
0.25 - 2.0 mm	39.7 a	6.32 b	32.2 ab	6.9 b
> 2 mm	35.0 c	88.4 a	59.2 b	88.3 a
0.05 – 0.1 m				
< 0.25 mm	5.1 ^{NS}	14.2	7.6	10.1
0.25 - 2.0 mm	12.7 b	12.9 b	31.3 ab	43.6 a
> 2 mm	82.2 a	72.9 ab	61.1 ab	46.3 b
0.1 – 0.2 m				
< 0.25 mm	3.9 ^{NS}	3.9	8.1	8.2
0.25 - 2.0 mm	17.2 ^{NS}	12.1	21.7	20.9
> 2 mm	78.9 ^{NS}	84.0	70.2	70.9

^{NS} Not significant. Lowercase letters compare treatments of turkey litter doses by Tukey test ($p < 0.05$). T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

The percentage of macro aggregates with the use of turkey litter ranged from 60 to 66% and was lower at the dose 0, which led to 49% distribution of aggregates in the macro aggregate classes at the beginning of the rainy season (Table 4). Thus, the accumulated turkey litter doses positively contributed to the aggregate size class, in the first data collection season in November 2017. The distribution of aggregates in the classes of meso aggregates and micro aggregates was higher in the treatment T0.

Similar results were observed in Red Latosols under pasture fertilized with turkey litter, where there were increment in the proportion of aggregates larger than 2 mm and reduction in the proportion of aggregates smaller than 0.25 mm (COSTA et al., 2009). On the other hand, the use of poultry litter doses of 4 and 6 Mg ha⁻¹ plus mineral fertilization in Latosol cultivated with soybean and maize reduced the proportion of aggregates larger than 2 mm in diameter and increased the proportion of aggregates smaller than 0.25 mm (RIBEIRO et al., 2019a).

After the rainy season, in April 2018, in the 0.0-0.05 m layer, the highest amount of macro aggregates (> 2 mm) was obtained using turkey litter at the accumulated doses T1 and T3, followed by the accumulated dose T2 and the T0 treatment (Table 5). As in the first evaluation season, the amounts of meso aggregates and micro aggregates were higher in the control treatment and lower in treatments with turkey litter.

The larger macro aggregates after accumulated doses of turkey litter may be related to the supply of organic

material, as well as to the root system and possibly shoot residues left by *Urochloa decumbens*. In the 0.1-0.2 m layer, the non-differentiation between treatments in the two evaluation seasons may be related to the root development of the grass because, even in soils that are not fertilized, there may be increases in aggregation with the use of grasses (COSTA et al., 2009). On the other hand, the organic matter and aggregate stability under *Urochloa brizantha* after application of turkey litter, alone or associated with limestone and gypsum, were not influenced by use, differing from the results obtained in the present study (TROLEIS et al., 2017). This positive effect of pastures on the aggregation of soil particles is linked to the root system of these grasses (COSTA et al., 2009; TROLEIS et al., 2017).

The mean weight diameter of aggregates (MWD) was influenced by accumulated turkey litter doses only in the 0.0-0.05 m soil layer (Figure 2). In the two evaluation seasons, the results showed similar behavior where the highest doses were able to increase MWD compared to the control treatment. At the beginning of the rainy season, the MWD results obtained with accumulated doses of turkey litter T2 and T3 (54.79 and 69.24 Mg ha⁻¹, respectively) were 22 and 17% higher than those of the control treatment, respectively (Figure 2a). The T1 dose was similar to the T0 dose and to the T2 and T3 doses. In the second evaluation season, the lowest and highest accumulated doses of turkey litter increased MWD by approximately 81% compared to the control treatment, and these doses were superior to the turkey litter dose T2 (Figure 2b).

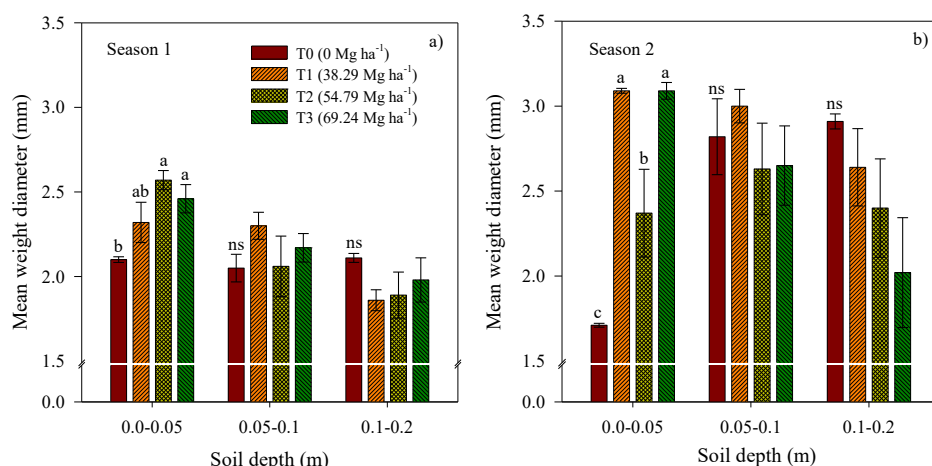


Figure 2. Mean weight diameter of aggregates (MWD) at different depths, in Dystrophic Ferric Red Latosol after rotational grazing system and application of accumulated turkey litter doses, collected at the end of the rainy season of 2018 (April). ^{ns} Not significant. *Equal letters in the column do not differ statistically - Tukey test at 5%. T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

There was a positive correlation between carbon stocks and MWD in the 0-0.05 m layer ($r=0.43^*$), where the highest carbon contents promoted greater increases in aggregate size. A positive correlation between carbon stocks and MWD was also observed in a chronosequence of no-tillage in the Cerrado, corroborating the results of the present study (SOUZA et al. 2016). Treatments with the use of accumulated doses of turkey litter may be related to higher carbon stocks in these treatments. Therefore, the use of turkey litter may have favored the higher proportion of macro aggregates and MWD,

due to the direct increment of carbon to the soil and even indirectly, for possibly increasing soil fertility, favoring the increase of root and shoot biomass and contributing to the increase in soil aggregation attributes. These results reinforce the role of labile carbon in promoting microbial binding agents and root-derived exudates, which enhance aggregate cohesion and contribute to the increase in mean weight diameter (TOPA et al., 2025).

High organic matter content with the use of poultry litter doses of 22.5 Mg ha⁻¹ associated with chemical

fertilization in maize crop was reported by Wang et al. (2016), similar to the finding of the present study. In this study, higher carbon contents were observed at 0.0-0.05 m and 0.05-0.1 m, which may be related to the absence of soil turning and application of waste on surface. Waste deposition on the soil and an increase in the amount of organic matter present on the surface have a number of beneficial effects, including the cycling of nutrients, aggregation, microbial activity, water storage, and gas exchange with the atmosphere. These factors may promote soil sustainability and, as a result, increase crop yield (COSTA et al., 2004).

Chemical fractionation of total organic carbon (TOC)

In the 0.0-0.05 m layer, the treatments T2 and T3 (54.79 and 69.24 Mg ha⁻¹ of turkey litter) led to the highest TOC contents, being superior to T1 and T0 (38.29 Mg ha⁻¹ of turkey litter and no application), resulting in increments of 18 and 23%, respectively, compared to the treatment T0 (Table 6). In the 0.10-0.20 m layer, the use of turkey litter regardless of treatment increased TOC by approximately 18% in comparison to T0.

Table 6. Total organic carbon (TOC) and oxidizable carbon fractions for different doses and layers of Dystrophic Ferric Red Latosol after rotational grazing system and turkey litter fertilization at the end of the rainy season of 2018 (April).

Treatments	TOC	F1	F2	F3	F4
g kg ⁻¹					
0 – 0.05 m					
T0	22 b	0.93 c	0.37 b	0.59 ^{ns}	0.27 ^{ns}
T1	22 b	0.95 c	0.55 a	0.83	0.37
T2	26 a	1.07 b	0.62 a	0.83	0.24
T3	27 a	1.19 a	0.59 a	0.85	0.16
0.05 – 0.10 m					
T0	21 ^{ns}	0.88 ^{ns}	0.47 ^{ns}	0.76 a	0.21 ^{ns}
T1	22	0.93	0.54	0.39 b	0.45
T2	22	0.96	0.55	0.53 ab	0.57
T3	23	0.96	0.58	0.7 ab	0.24
0.10 – 0.20 m					
T0	18 b	0.73 b	0.62 ^{ns}	0.39 b	0.20 ^{ns}
T1	21 a	0.96 ab	0.58	0.53 ab	0.29
T2	21 a	1.06 a	0.52	0.63 a	0.31
T3	21 a	0.99 ab	0.54	0.57 ab	0.32

T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

Regarding the oxidizable carbon, the F1 fraction had the highest contents, ranging from 7.3 to 11.9 g kg⁻¹, while the F4 fraction had lower contents, which ranged from 1.6 to 5.7 among the evaluated layers (Table 6). The F1 fraction was not influenced by the treatments in the 0.05-0.10 m layer; the F2 fraction was influenced only in the 0.0-0.05 m layer; and the F3 fraction was influenced in the layers of 0.05-0.10 and 0.10-0.20 m (Table 6).

Higher carbon stock (F1) and lower carbon stock (F4) in rice-wheat cropping system with the use of poultry waste and crop residues were also reported by Benbi et al. (2015), as found in the present study. F1 and F2 fractions have greater lability, while F3 and F4 fractions are considered more resistant to decomposition (BENBI et al., 2015; LOSS et al., 2010). Therefore, it is important to maintain a balance between these fractions so that there is a balance between the functions of each fraction, with F1 and F2 fractions being responsible for the availability of nutrients and F3 and F4 fractions representing chemical and physical protection (LOSS et al., 2010).

In the 0.0-0.05 m layer, the highest contents in the F1 fraction were obtained by the treatments T3 and T2, and the lowest ones in the treatments T1 and T0. In the 0.1-0.2 m

layer, F1 and F3 fractions showed similar behavior, with the highest contents of these fractions observed in T2 and the lowest one in T0, with the treatments T1 and T3 being intermediate between the highest and lowest applications of turkey litter. The F3 and F4 fractions were little affected by the use of accumulated doses of turkey litter in rotational grazing area rotated with *Urochloa decumbens*.

The treatments T3 and T2 increased the F1 and F2 fractions in the 0.0-0.05 m layer, in comparison to the T0 treatment, varying respectively between 28 and 15% and between 59 and 68%. The increments in these fractions in the surface layer may be related to the application of waste on the soil surface and also to the possible increments of crop residues left on the soil surface after grazing and to the growth of *Urochloa decumbens* roots, which may have been favored by the increase in fertility with the use of higher doses over time. Because of their strong correlations with microbial biomass and mineralizable carbon, increases in the F1 and F2 fractions are significant because they represent the fractions of easily oxidizable carbon and active organic carbon (BENBI et al., 2015). Therefore, the increments in these fractions of oxidizable carbon, as occurred in the treatments T2 and T3, are important for a higher biological activity of the soil.

To confirm each variable's contribution, canonical variable analysis was done (Figure 3). This method is comparable to principal component analysis, but it should only be applied in situations where the work at hand consists of an experimental design that repeats (BAIO et al., 2018).

The accumulation of variances in the first two variables corresponded to 99%, being higher than the recommended one, which is at least 80%. Therefore, an accurate interpretation can be obtained by using the canonical variables in this study.

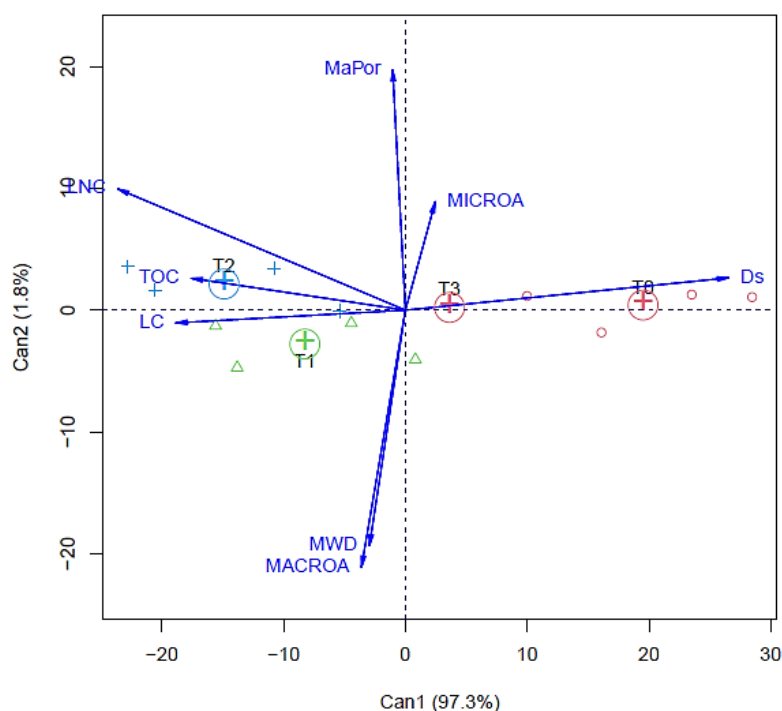


Figure 3. Canonical variables analysis between total organic carbon (TOC); labile carbon (LC), obtained by the oxidizable F1 and F2 fractions; non-labile carbon (NLC), obtained by the oxidizable F3 and F4 fractions; macro porosity (MaPor); soil bulk density (Ds); micro aggregates (MICROA); macro aggregates (MACROA); mean weight diameter of aggregates (MWD). T0: no application of turkey litter; T1: 38.29 Mg ha⁻¹ of turkey litter; T2: 54.79 Mg ha⁻¹ of turkey litter; T3: 69.24 Mg ha⁻¹ of turkey litter.

The eigenvectors (Figure 3) show that soil bulk density was the variable closest to the T0 treatment. This behavior is probably related to greater animal trampling in T0, as well as the lower biomass production of plant material due to lower soil fertility (Table 3). The proximity of Ds with the T0 treatment may be related to the negative correlation with the contents of TOC, LC, and NLC. This behavior is similar to that observed in studies by Are et al. (2017), in which a reduction in soil bulk density was reported following the application of 5 Mg ha⁻¹ of poultry litter. That is, the lower the contents of TOC, LC, and NLC, the higher the Ds. The variables TOC and LC are strongly correlated and are close to NLC. These three variables (TOC, LC, and NLC) are close to the T2 treatment. In T2 and T3, the highest applications of poultry residue were made. Similarly, in studies conducted by Benbi et al. (2015), the addition of poultry manure was found to contribute to the increase in the more labile carbon fractions, thus showing a behavior similar to that observed in our study. On the other hand, MWD and MACROA are highly correlated but are not close to any of the treatments in this study. The variables MAPOR and MICROA were isolated.

The reduction in soil bulk density observed in the T1 and T2 treatments, together with the increase in macro porosity and mean weight diameter of aggregates, highlights the positive effects of turkey litter application compared to the treatment T0. These results may be associated with the

increase in total organic carbon content, as well as with the higher concentrations of carbon in the F1 and F2 fractions, which represent easily oxidizable carbon and active organic carbon, respectively, due to their close relationship with microbial biomass and mineralizable carbon (BENBI et al., 2015). Thus, the increases observed in these carbon fractions, especially in treatments T2 and T3, are fundamental for maintaining greater soil biological activity, indirectly contributing to the improvement of the physical attributes evaluated in this study. Additionally, the improvements in pH and base saturation under turkey litter application stimulate root growth and microbial processes, enhancing the production of binding agents and biopores that reinforce macro aggregate formation and further reduce soil bulk density (TOPA et al., 2025).

CONCLUSION

The long-term use of turkey litter under rotational cattle grazing promoted improvements in soil structure, as shown by reduced soil bulk density and greater formation and stability of macro aggregates in the surface layer (0.0–0.05 m) of an Oxisol.

These physical gains were associated with increases in the more labile oxidizable carbon fractions, indicating positive effects on organic matter dynamics and greater sensitivity of

the carbon pool to management.

The beneficial effects were sustained at moderate doses, without negative impacts on soil quality, although responses tended to stabilize at higher rates.

Overall, turkey litter represents a viable strategy for improving soil structure and enhancing organic matter dynamics in pasture systems, contributing to more sustainable nutrient and residue management.

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