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Aggregation, carbon, and total soil nitrogen in crop-livestock-forest integration in the Eastern Amazon

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Key words:

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ABSTRACT

Sustainable agricultural production systems can improve physical attributes of soil as well as increase carbon and nitrogen stocks in soils. The objective of this study was to evaluate changes in the stability of soil aggregates and contents and stocks of carbon and nitrogen after the conversion of native forest to crop-livestock-forest integration systems in the region of Western Pará. Soil samples from five management systems (including a control) were collected at three depths in a randomized block design, with five replications. The stability of the aggregates, soil density, particle density, and total soil porosity, as well as total carbon and nitrogen and their respective stocks were evaluated. The native forest had the highest percentages of macroaggregates, followed by the integration system with African mahogany. At a depth of 0-0.10 m, the contents and stocks of carbon were higher in the agricultural area and in the integration system with cumaru, whereas nitrogen contents and stocks were higher in the native forest, followed by the integration systems with mahogany and cumaru. Compared to the other systems, the pasture area stored more carbon at depths of 0-0.10 and 0.10-0.20 m.

Palavras-chave:

carbono orgânico
física do solo
sustentabilidade
Amazônia brasileira

Agregação, carbono e nitrogênio total do solo em integração lavoura-pecuária-floresta na Amazônia Oriental

RESUMO

Os sistemas sustentáveis de produção agropecuária podem melhorar os atributos físicos do solo, além de aumentar os estoques de carbono e nitrogênio nos solos. Objetivou-se nesse trabalho avaliar as alterações na estabilidade de agregados, teores e estoques de carbono e nitrogênio após a conversão da floresta nativa para implantação de sistemas de integração lavoura-pecuária-floresta, região Oeste do Pará. As coletas de solo de cinco sistemas de manejo foram realizadas em três profundidades, com delineamento experimental em blocos ao acaso, com cinco repetições. Foi avaliada a estabilidade dos agregados, densidade do solo, densidade da partícula e porosidade total do solo, além do carbono e nitrogênio total e seus respectivos estoques. A mata nativa apresentou os maiores percentuais de macroagregados, seguida do sistema de integração com mogno africano. Na profundidade de 0-0,10 m os teores e estoques de carbono foram maiores na área de agricultura e no sistema de integração com cumaru. Na profundidade de 0-0,10 m os teores e estoques de nitrogênio foram maiores na mata nativa, seguida pelos sistemas de integração com mogno africano e cumaru. A área de pastagem estoca mais carbono ao longo das profundidades 0-0,10 a 0,10-0,20 m, quando comparada aos demais sistemas.



INTRODUCTION

The crop-livestock-forest integration systems (ILPF) are alternative systems that combine agricultural, livestock, and forestry activities in the same area, performing consortia, successions, and crop rotations (Balbino et al., 2012). In this model of management, it is possible to verify an exponential increase in the storage of organic carbon (C) in the soils incorporated due to agroforestry systems (Panettieri et al., 2017), as well as the increase in the relative stoichiometric ratios of carbon and nitrogen (C:N), thus improving the stability of the aggregates (Wu et al., 2016).

Soil structure is an important property in this context, since it regulates several processes, such as water movement, oxygenation, and soil temperature (Salton et al., 2008; Rozane et al., 2010; Loss et al., 2015), which are important for the development of different species. Soil aggregates can store four times as much C as biomass and three times as much C as the atmosphere; therefore, study of C and N is the key to assessing the stability of soil aggregates (Neira et al., 2015).

Soil aggregation contributes to the increase in aggregate diameter, and C and N stocks in the soil; and minimizes the changes in the carbon cycle that are influenced by the availability of nitrogen from soil (Zhu et al., 2017), because the greater the aggregation, the lower the flow of CO₂ from the soil (Abdalla et al., 2016).

Alternative systems such as the ILPF in the Amazon region are recent, and the first results of the systems implemented by the Eastern Amazon Embrapa are still incipient and require scientific work for proper validation.

Studies in already established systems serve to prove the efficiency of the management systems in altering the attributes of the soils positively, a result that is very important for the producers of the studied region, since this information can trigger new practices of degraded areas management and favor the recovery of disturbed areas (Balbino et al., 2012).

The objective of this work was to evaluate the stability of soil aggregates using aggregation index and aggregate distribution by diameter classes, in addition to total organic carbon (TOC), total nitrogen (TN), total organic carbon stock (ECOT), and total nitrogen stock (ENT) of the soils of four different soil management systems, compared to the native forest after six years of the experiment.

MATERIAL AND METHODS

The experiment was conducted at Fazenda Nossa Senhora Aparecida, in the municipality of Belterra, State of Pará. The municipality is located in the mesoregion of Baixo Amazonas, approximately 45 km from the metropolitan region of Santarém, at an altitude of 175.74 m at 2° 38' 11" S latitude and 54° 56' 13" W longitude. The municipality of Belterra stands out, as it has most of the field experiments of the eastern Amazonian Embrapa, corresponding to the Lower Amazon region.

The climate of the region is classified as Am (Tropical monsoon climate), according to Koppen classification, with annual temperature and precipitation of 26.2 °C and 1743 mm respectively (INMET, 2018). The soil is classified as Yellow

Latosol (oxisol) with loamy texture, and a predominant vegetation of dense ombrophilous type of terra firme (Rodrigues et al., 2001).

The experiment was installed in an area that previously had pasture, and was approximately eight hectares in area. In the year of 2010, before the implementation of ILPF, some soil preparation operations, such as plowing, sorting, sub-soiling, and soil correction with dolomitic limestone, were carried out; soil was analyzed to characterize the area. The soil was characterized to have the following parameters: pH = 5.26, MO = 30.66 g kg⁻¹, Al³⁺ = 0.43 cmol_c dm⁻³, Ca²⁺ = 2.96 cmol_c dm⁻³, Mg⁺ = 0.93 cmol_c dm⁻³, SB = 4.08, CEC = 4.51, and V% = 37, according to the methodology described by EMBRAPA (2011).

After the preparation of the area, the experiment was installed with the following plants: African mahogany (MA; *Khaya ivorensis* A chev.) and cumaru (CU; *Dipteryx odorata* (Aublet.), Willd.), for forest vegetation; crop rotation soybean, maize, and rice for crop rotation and *Brachiaria* for pasture area.

A spacing of 7 × 5 m was used for 280 plants of each forest species on 0.92 hectares. Both areas had grasses for soil cover, which were used for grazing small animals.

The first crop planted in the agriculture area (AA) was corn cultivar BRS 1030, in 2010; in 2011, corn RS 1055 was planted. However, in the year 2012, BRS 326 soybean was implanted; and in 2015, soybeans and maize were cultivated for the production of straw. Fertilization for corn, rice, and soybean was carried out twice a year, respectively with NPK (10-28-20) at an application rate of 350 kg ha⁻¹, NPK (5-25-25) and NPK (04 -25-20) at an application rate of 400 kg ha⁻¹, over a total area of 2.78 hectares.

In the Pasture area (PA), the first crop to be implanted in 2010 was BRS Tracajá soy; in the following years (2011/2012) BRS sertaneja rice was planted, followed by rotation with corn cultivar BRS 1055 in the year 2013, and maize again in 2014; in 2015 *Brachiaria* grass was introduced. The intensity of grazing in the area is low, with two to three animals in an area of 2.78 ha.

The native forest area used as control of the experiment was characterized as a typical vegetation of Amazonian forest, classified as dense arborous, with 15-30 m tall arboreal flora. The area was traditionally logged in the year 1996. It is in a state of natural regeneration, with lianas and partially closed canopies. The total area of the native forest is approximately 18 hectares, located at a distance of approximately 20 m from the experimental site.

The study was carried out from June 2015 to August 2016, i.e., soil samples were collected and analyzed 6 years after ILPF implantation. The experimental design was in randomized blocks, with split plots and five replications. The treatments were composed of five areas (plots) and three depths (subplots), where samples of deformed and undisturbed soil samples (clods) were prepared by opening trenches (0.50 × 0.50 × 0.50 m) of three different depths: 0-0.10, 0.10-0.20, and 0.20-0.40 m, with five replicates. For soil samples, collection areas of 5,000 m² (100 × 50 m) were delimited for all the areas of the experiment.

Soil samples were analyzed for TOC and TN content in the soil laboratory of Embrapa Amazônia Oriental, Belém, Pará.

The physical analyses were carried out in the soil laboratory at the Federal University of the West of Pará, Santarém, Pará. TOC was determined according to Yeomans & Bremner, (1988). NT was quantified by sulfur digestion, followed by Kjeldahl distillation and titration with 0.02 mol L⁻¹ hydrochloric acid (HCl), according to Bremner (1996). Soil TOC and TN stocks were calculated by multiplying the soil density, thickness of the sampled layer and soil TOC or TN content (Carvalho et al., 2009).

Density of the soil (Ds) was determined by waterproofed clod method and particle density (Dp) was determined by volumetric balloon method, while total porosity (Pt) was calculated based on soil density ratio of the particle, following the method compiled and described by EMBRAPA (2011).

Determination of percentage of the aggregates and their respective stabilities was performed according to the method described by Yoder (1936) e Kemper & Rosenau, (1986), where the aggregate mass was determined using wet sieving method. The weighted average diameter (WAD) and geometric mean diameter (GMD) were calculated from the mass of the aggregates.

Distribution of the aggregates in diameter classes was evaluated, where it is possible to classify them into macroaggregates with $\varnothing \geq 2.0$ mm; mesoaggregates with $2.0 > \varnothing \geq 0.25$ mm; and microaggregates with $\varnothing < 0.25$ mm. The sensitivity index of soil aggregates for both DMP and DMG was calculated using Eq. 1:

$$\text{ISMD} = \frac{\text{DMt}}{\text{DMo}} \quad (1)$$

where:

ISMD - index of sensitivity of the mean diameter;

DMt - value of DMG/DMP of soil in each treatment; and,

DMo - value of DMG/DMP of the soil in the original cover (native forest).

The results were analyzed for normality and homogeneity of the data using Lilliefors test and Cochran test, respectively. The data of TOC, TN, ECOT, and ENT as well as that of soil physical attributes were subjected to analysis of variance (ANOVA) to verify, at each depth, the effects of soil management systems. The averages were compared by Tukey test at 5% probability using the software Assisat version 7.7 (Silva & Azevedo, 2016).

RESULTS AND DISCUSSION

The percentage of stable aggregates in water per diameter class, for each management area in the three depths ranging from 0-0.40 m can be observed in Figure 1. NF obtained the best results with reference to the quantity of macroaggregates ($\varnothing \geq 2.0$ mm) at all depths evaluated, as well as the lowest percentage of microaggregates ($\varnothing < 0.25$ mm) (Figure 1).

The higher stability of the aggregates in natural systems such as NF may be due to higher moisture and microbial biomass accumulation. Such factors have positive effects on the distribution of soil-aggregate diameters (Linsler et al., 2015), because microorganisms play an important role in the maintenance of levels of microbial biomass that provides mechanisms for better soil-particles fixation, aggregation, and number of macroaggregates (Wang et al., 2017).

The highest percentage of mesoaggregates was observed in AA at the depths of 0-0.10 and 0.20-0.40 m, while at the depth of 0.10-0.20 m, CU showed the highest value. The highest percentage of microaggregates was observed in CU and PA, in the 0-0.10 m layer, and in CU, MA and PA in the other layers evaluated (Figure 1).

Presence of aggregates of smaller diameter is closely linked to soil management practices. Such practices may reduce the number of stable aggregates in water (Trivedi et al., 2015) by, promoting changes in the mechanical stability of soils, breaking the aggregates into smaller particles, exposing TOC, and increasing the compaction of the areas, with the loss of physical quality of the soils (Dec et al., 2012).

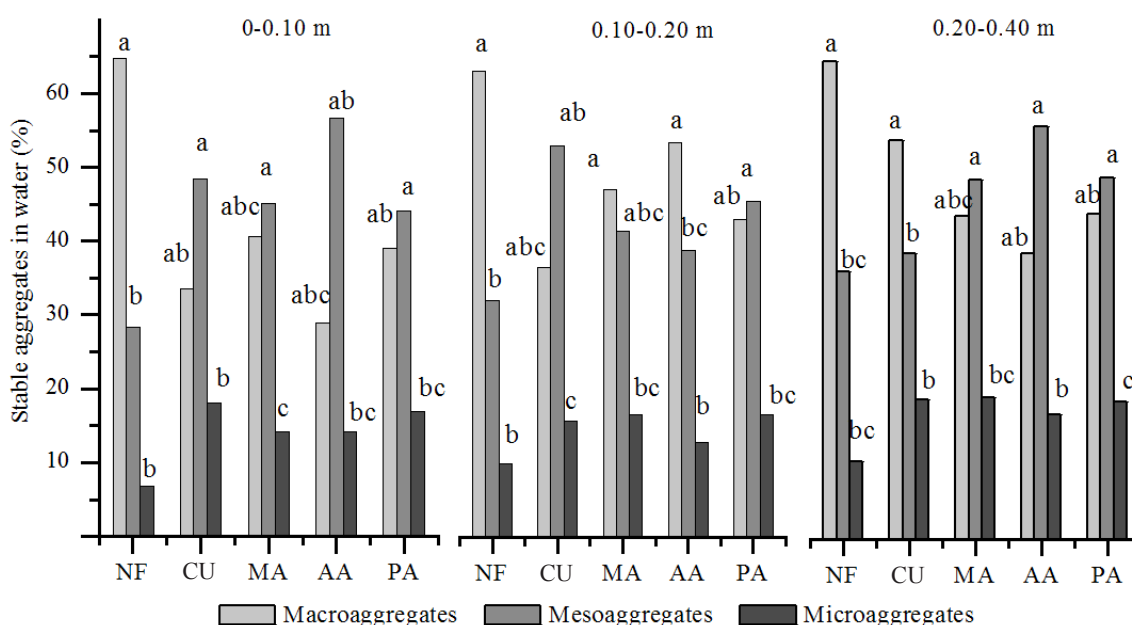


Figure 1. Percentage distribution of stable aggregates in water at the depths of 0-0.10; 0.10-0.20; and 0.20-0.40 m in Yellow Latosol (oxisol), under native forest (NF), cumaru area (CU), African mahogany (MA) area, agriculture area (AA) and pasture area (PA), after six years of land use in Belterra-Pará

When evaluating the values of D_p and D_s , NF area showed the lowest D_p values in the three depths evaluated (Table 1). When analyzing the values of variable D_s , it is possible to verify that the 0-0.10 m layer of NF showed the lowest density, followed by 0.10-0.20 layer of AA and 0.20-0.40 m layer of CU area in the. The lowest values of D_s in AA may be related to crop rotation in the area (Tormena et al., 2002).

The TOC and TN contents at the three depths evaluated can be seen in Table 2. AA and CU have the highest values in the first and third layers, and PA and AA in the second layer. The TN contents were higher in the first and second layers of NF and the third of AA.

These contents can be due to trees favoring the nutrient cycle, along deeper layers of the soil, as well as the presence of residual fertilizers of the cultures previously implanted in the area. It is known that forest species have the capacity to capture and transport nutrients for long distances in the soil profile, favoring the accumulation of TOC at the surface and in deeper layers (Matias et al., 2012).

The decrease in TOC values along the three depths analyzed (Table 2), may be due to the longer time periods required for the stabilization of organic matter in the soil of the different management systems, and the greater increase in organic matter in the superficial layer may be due to the plant material originating from leaves and branches, as observed by Ayoubi et al. (2012) e Dortzbach et al. (2015).

The decrease in TN content with the increase in depth and concentration of contents in the most superficial layer of the soil (0-0.10 m) was similar to those found in a study carried out by Souza et al. (2009). This can be attributed to the fact that nitrogen constitutes 3.3 to 7% of the soil organic matter (Dick et al., 2009). Another probable explanation for higher concentration of TN in the superficial layers would be the contribution through mineral fertilization, preparation, and conducting of the field experiment in AA.

The ECOT and ENT values at the three depths evaluated can be seen in Table 3. At the depths of 0-0.10 and 0.20-0.40 m, AA and CU showed the highest values; however, at the depth of 0.10-0.20 m, PA has the highest ECOT. Regarding the ENT values, the NF area stands out, as it stores more of this nutrient in the first two depths evaluated, than the third.

The higher ECOT levels in the soil may reflect the size of the vegetation, because in areas with larger vegetation, there is an increase in the carbon stock of the system (Giacomo et al., 2015). It may also be related to the storage capacity of C by pastures, when adopting alternative management systems. These levels may be higher than those found in native forest, according to a study carried out by Dortzbach et al. (2015).

The observed results may indicate that crop-livestock-forest integration (ILPF) has the ability to provide important nutrients for soil fertility, thus increasing TN levels along soil depths, according to studies carried out by Balbino et al. (2012).

Table 1. Densities of particles (D_p) and soil (D_s) at the depths of 0-0.10, 0.10-0.20, and 0.20-0.40 m for different land use systems

Systems of use	D_p (kg dm ³)			D_s (kg dm ³)		
	Depth (m)					
	0-0.10	0.10-0.20	0.20-0.40	0-0.10	0.10-0.20	0.20-0.40
Native forest (NF)	2.04 ± 0.08	2.14 ± 0.19	2.07 ± 0.06	1.23 ± 0.16	1.38 ± 0.14	1.36 ± 0.09
Cumaru (CU)	2.59 ± 0.33	2.15 ± 0.20	2.31 ± 0.06	1.36 ± 0.07	1.41 ± 0.09	1.27 ± 0.14
Mogno (MA)	2.48 ± 0.24	2.66 ± 0.18	2.53 ± 0.11	1.48 ± 0.28	1.37 ± 0.09	1.30 ± 0.12
Agriculture (AA)	2.45 ± 0.20	2.47 ± 0.06	2.74 ± 0.15	1.65 ± 0.18	1.36 ± 0.13	1.50 ± 0.19
Pasture (PA)	2.66 ± 0.15	2.63 ± 0.09	2.67 ± 0.16	1.49 ± 0.13	1.57 ± 0.17	1.78 ± 0.14
CV %	8.20	6.23	4.46	11.69	8.90	9.78

Table 2. Total organic carbon (TOC) and total nitrogen (TN) contents at the depths of 0-0.10, 0.10-0.20, and 0.20-0.40 m for different land use systems

Systems of use	TOC (g kg ⁻¹)			TN (g kg ⁻¹)		
	Depth (m)					
	0-0.10	0.10-0.20	0.20-0.40	0-0.10	0.10-0.20	0.20-0.40
Native forest (NF)	19.09 ± 1.53	19.09 ± 1.26	11.17 ± 2.56	1.55 ± 0.11	1.45 ± 0.11	0.90 ± 0.00
Cumaru (CU)	21.38 ± 2.82	18.73 ± 2.81	14.07 ± 3.79	1.53 ± 0.04	1.35 ± 0.09	1.08 ± 0.08
Mogno (MA)	19.56 ± 2.58	17.64 ± 2.63	10.26 ± 1.92	1.53 ± 0.04	1.34 ± 0.08	0.93 ± 0.04
Agriculture (AA)	22.48 ± 0.49	20.52 ± 5.92	15.73 ± 6.26	1.48 ± 0.08	1.25 ± 0.26	1.18 ± 0.31
Pasture (PA)	16.81 ± 3.16	26.02 ± 17.95	10.08 ± 4.43	1.33 ± 0.11	1.20 ± 0.19	1.00 ± 0.22
CV %	11.00	26.87	30.45	5.35	11.38	12.25

Table 3. ECOT and ENT stocks for depths of 0-0.10, 0.10-0.20, and 0.20-0.40 m of different land use systems

Systems of use	ECOT (t ha ⁻¹)			ENT (t ha ⁻¹)		
	Depth (m)					
	0-0.10	0.10-0.20	0.20-0.40	0-0.10	0.10-0.20	0.20-0.40
Native forest (NF)	24.44 ± 3.33	26.49 ± 4.06	30.23 ± 6.68	1.90 ± 0.27	2.01 ± 0.33	2.45 ± 0.16
Cumaru (CU)	26.74 ± 7.17	25.90 ± 4.92	38.74 ± 12.77	1.88 ± 0.25	1.86 ± 0.18	2.93 ± 0.40
Mogno (MA)	23.65 ± 0.80	24.43 ± 4.94	28.02 ± 6.36	1.87 ± 0.22	1.86 ± 0.21	2.52 ± 0.20
Agriculture (AA)	27.62 ± 3.49	27.93 ± 7.77	42.51 ± 16.72	1.81 ± 0.24	1.71 ± 0.34	3.19 ± 0.85
Pasture (PA)	20.36 ± 3.02	35.96 ± 24.90	28.02 ± 12.80	1.62 ± 0.18	1.64 ± 0.16	2.74 ± 0.71
CV %	14.25	30.33	32.55	12.69	13.46	16.16

CONCLUSIONS

1. The native forest had the highest percentage of macroaggregates, followed by the integration system with African mahogany.

2. At the depth of 0-0.10 m, the contents, and stocks of carbon were higher in the area of agriculture and in the integration system with cumaru. At the depth of 0-0.10 m, the contents, and stocks of nitrogen were higher in the native forest, followed by integration systems with cumaru and African mahogany.

3. The pasture area stores more carbon along the depths of 0-0.10 and 0.10-0.20 m, when compared to the other systems.

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