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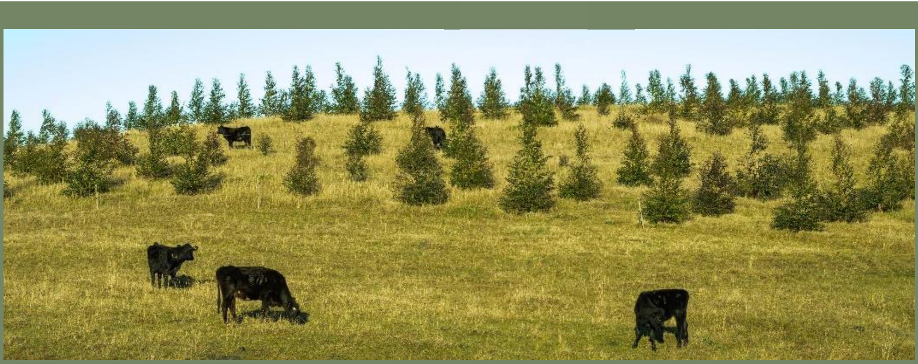
Sistemas Silvopastoriles

Hacia una diversificación sostenible



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II Congreso de la Red Global de Sistemas Silvopastoriles
IV Seminario Seminario Nacional de Sistemas Silvopastoriles
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CIPAV

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Editores

Julián E. Rivera
Carolina Viñoles
Jean Fedrigo
Adriana Bussoni
Pablo Peri
Luis Colcombet
Enrique Murgueitio
Andrea Quadrelli
Julián Chará

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Soil organic carbon in crop-livestock-forestry in a case study from the central-west region of Brazil

Carbono orgánico del suelo en cultivos-ganadería-silvicultura en un estudio de caso de la región centro-oeste de Brasil

B.E. Madari; P.S. Matos; J.M. Oliveira; M.T.M. Carvalho;*
A.L.R. Silveira, P.L.O.A. Machado; W A. Araujo; M.M.B. Siqueira;
T.M. Ferraresi; F.M.C. Freitas; P.V. Rizzo; R.R. Silva; A. Pacheco

*Brazilian Agricultural Research Corporation (Embrapa Arroz e Feijão), Rodovia GO-462, Km 12, Santo Antônio de Goiás, GO, CEP 75375-000, Brazil beata.madari@embrapa.br

Abstract

Crop-livestock-forestry (CLF) has been recommended as a strategy for soil carbon sequestration, reducing greenhouse gas (GHG) emissions of livestock as well as for sustainable soil management for improving soil organic carbon (SOC) and soil health. In this study we quantified SOC accruals in a very clayey Rhodic Ferralsol during the evolution of a 11-year-old crop-livestock-forestry system in the municipality of Cachoeira Dourada, Central West region of Brazil. CLF was implemented in 2009 in a conventional Pasture area, and soil samples were collected in 2012 and 2020 under two land uses, CLF, and the conventional Pasture as time-zero reference. The soil in CLF was evaluated within the tree lines (CLF-WL) and in the alley pasture between the tree lines (CLF-BL) having palisade grass. SOC dynamics were different in the upper 30 cm and in the underlying 70 cm layer. In the 0.0-0.3 m layer, after an initial decline in SOC stocks due to soil preparation for the implementation of CLF, SOC accumulation rates were positive in CLF (0.46-0.28 Mg ha^{-1} yr^{-1}), but negative in the reference Pasture (-0.26). At 0.3-1.0 m SOC stocks were higher (both in 2012 and 2020) in the CLF-WL (86.70 and 83.74) than in the Pasture (71.81 and 74.96), however, CLF SOC was declining. Total soil N under CLF, compared to the reference Pasture, was lower and declining. These findings confirm that in general CLF is a valid strategy to increase SOC stocks compared to conventional Pasture, but adequate soil fertility management is necessary to potentialize SOC.

Keywords: *Savanna, Soil Carbon Sequestration, Total Soil Nitrogen, Particulate Organic Carbon, Mineral Associated Organic Carbon.*

Resumen

Se ha recomendado a la agricultura-ganadería-silvicultura (AGS) como estrategia para el secuestro de carbono del suelo, la reducción de las emisiones de gases de efecto invernadero (GEI) del ganado, así como para el manejo sostenible del suelo para mejorar el carbono orgánico del suelo (COS) y la salud del suelo. En este estudio cuantificamos la acumulación de COS en un Ferralsol Ródico muy arcilloso durante la evolución de un sistema agrícola-ganadero-forestal de 11 años de antigüedad en el municipio de Cachoeira Dourada, región Centro Oeste de Brasil. AGS se implementó en 2009 en un área de pastos convencionales, y se recolectaron muestras de suelo en 2012 y 2020 bajo dos usos de tierra, AGS y pastos convencionales como referencia de tiempo cero. El suelo en AGS se evaluó dentro de las líneas de árboles (AGS-DL) y en el pasto en callejón entre las líneas de árboles (AGS-EL) que tenía pasto en empalizada. La dinámica del COS fue diferente en los 30 cm superiores y en la capa subyacente de 70 cm. En la capa de 0,0-0,3 m, después de una disminución inicial en las existencias de COS debido a la preparación del suelo para la implementación de AGS, las tasas de acumulación de COS fueron positivas en AGS (0,46-0,28 Mg ha-1 año-1), pero negativas en la capa de referencia. Pasto (-0,26). A 0,3-1,0 m, las existencias de COS fueron mayores (tanto en 2012 como 2020) en AGS-DL (86,70 y 83,74) que en Pastizales (71,81 y 74,96), sin embargo, AGS SOC estaba disminuyendo. El N total del suelo bajo AGS, en comparación con el pasto de referencia, fue menor y disminuyó. Estos hallazgos confirman que, en general, la AGS es una estrategia válida para aumentar las reservas de COS en comparación con los pastos convencionales, pero es necesario un manejo adecuado de la fertilidad del suelo para potencializar el COS.

Palabras clave: *Sabana, Secuestro de Carbono en el Suelo, Nitrógeno Total en el Suelo, Carbono Orgánico Partículado, Carbono Orgánico Asociado a Minerales.*

I. Introduction

Soil is the largest active terrestrial carbon pool and likely the one that consists of the most heterogeneous mixture of organic C compounds. It is an important component of the global C cycle, which is while land use change and soil management greatly affect the emission of greenhouse gases, above all, of CO_2. Agricultural activities are considered responsible for major C emissions. However, since the launch of the Paris Agreement in 2015 agriculture and agricultural soils have attracted considerable attention due to their C sequestration potential, and have become part of the global C agenda

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for climate change mitigation and adaptation. The C sequestration capacity of agricultural soils is due to the historical C loss under conventional soil management. Adopting sustainable soil and agrosystem management practices on degraded soils, however, can increase C stocks in these soils. Due to the importance of soil organic carbon (SOC) for soil functions, including fertility, especially in soils of tropical regions, an important co-benefit of C sequestration is an increase in the resilience and adaptation capacity of agrosystems. Soil carbon accumulation rate strongly depends on agroecological conditions, such as climate and soil type, land use and soil management. Therefore, it is important to identify agricultural management systems that can increase resource use efficiency, contribute to the mitigation of greenhouse gas (GHG) emissions, to promote adaptation to the consequences of global warming and regional climate balance.

Despite livestock activity being highly versatile, feeding hundreds of millions of people who are surviving in marginal areas, it is also the activity that occupies a major part of agricultural land worldwide, driving heavy impacts on natural resources and contributing significantly to climate change via GHG emissions (FAO, 2022). Livestock activity though can also contribute to biodiversity conservation and ecosystem services via nutrient cycling, SOC accumulation, and maintenance of agricultural landscapes. For example, crop-livestock-forestry (CLF) systems are an option of management in which production is diversified and intensified in space and time, usually resulting in economic and ecological improvements when implemented, in order to face mitigation and promote adaptation to global warming (Silva *et. al.,* 2011; Sá *et. al.,* 2017; Oliveira *et. al.,* 2018).

In Brazil, CLF is included in the national public policy (ABC+ Program) for low-carbon emission agriculture (MAPA, 2021). CLF stands as a strategy to lower or compensate GHG emissions from livestock and soil management via increments in land use efficiency and productivity (Lemaire *et. al.,* 2014; Reis *et. al.,* 2016). As estimated by the World Bank, the adoption of low C emission practices will contribute to capturing 7.4 million tons of CO_2 equivalent from the atmosphere in the next ten years. According to the Global Soil Organic Carbon Sequestration Potential Map, Brazil is the country with the highest total additional annual SOC sequestration potential in three Sustainable Soil Management (SSM) scenarios (SSM1: +5%; SSM2: +10%; and SSM3: + 20% of the increase in annual C returns to soils) (ITPS 2022).

Many studies use SOC concentrations or stocks as a sole indicator to assess SOC dynamics and evaluate C accumulation (Oliveira *et. al.,* 2018). However, SOC accumulation under different management practices depends on SOC heterogeneity. It consists of fractions, which vary in their physical and chemical properties, structural stability and vulnerability to decomposition with variable turnover rates (Simpson and Simpson, 2012). Fractionation of soil organic matter can be used to better understand SOC dynamics (Cotrufo *et. al.,* 2019). The applied soil fractionation method depends on the objective of the study. The most common method used to assess SOC sequestration and the permanence of SOC separates two SOC pools: (i) particulate organic C (POC) or organic matter associated with soil particles larger than 53 µm; (ii) mineral-associated organic C (MAOC), which is associated with clay and silt particles (diameters ≤ 4 to 64 µm) (Cotrufo *et. al.,* 2019). The POC fraction is a mixture of compounds formed by plant residues and microbial decomposition containing many structural C compounds and low nitrogen (N) (Six *et. al.,* 2002). The C components in POC are characterised by short turnover rates (Nandan *et. al.,* 2019). The MAOC fraction mainly consists of microbial-transformed C compounds and has higher N levels (Christensen, 2001). MAOC is considered a stable fraction which has potentially longer permanence in the soil and serves as a long-term nutrient storage reservoir with a relatively slow turnover rate (Li *et. al.,* 2018).

Generally, total SOC concentrations and stocks change slowly and are difficult to evaluate due to high background levels (Beare *et. al.,* 1997). For this reason, it is important to monitor SOC throughout a longer period of time, usually over 3 or 5 years, depending on the soil, climate and agrosystem. Therefore, the objective of this study was to determine SOC accumulation in a clayey Rhodic Ferralsol in a 11-years old crop-livestock-forestry system in southern Goiás State. Specifically, this study aimed (1) to quantify C and N stocks within 1 m soil depth to calculate C accumulation rate through time after implementation in an area under degraded pasture (in years 2012 and 2020); (2) to analyse the distribution of SOC in POC and MAOC to assess stability and potential permanence.

II. Material and Methods

II.1 Site Description, history and management

The study was developed at Boa Vereda farm in the municipality of Cachoeira Dourada, Central-West Brazil (-18°27'43.19 "S and 49°35'58.53" W, 484 m.a.s.l.) (Figure 1), with slope ranging from 0 to 15%. The climate is tropical savanna with well-defined rainy summer and dry winter, classified as Aw according to Köppen-Geiger criterion. The annual average precipitation is 1,315 mm, and the annual average temperature is 24º C. The soil where the crop-livestock-forestry (CLF) system was established is a clayey (662 g kg^{-1}) Rhodic Ferralsol.

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The CLF system was implemented in October 2009, on a Pasture in degradation process. This Pasture was our reference to evaluate the CLF. The location of field trial and sampling points within each area, CLF and Pasture, is shown in Figure 1. The eucalyptus trees (*Eucalyptus urograndis*) were fertilised with 150 g plant^{-1} of NPK (08-30-10) + Zn and boric acid (10 g plant^{-1}) at planting. In August 2010, the soil in the alley between the tree rows (CLF-BL) was prepared to 25 cm depth using a heavy harrow. In this operation 2000 kg ha^{-1} of calcium sulphate ($CaSO_4$. $2H_2O$) was incorporated. Following, in October 2010, a levelling harrow was used before planting soybean (*Glycine max*). The fertilisation of soybean, variety BRS GO 8360, was done with 300 kg ha^{-1} NPK (04-30-10) + Zn. In the summer of 2010/2011, soil preparation in the alley was done with harrow and levelling harrow, then corn (*Zea mays*) was sown, intercropped with palisade grass (*Urochloa brizantha*), according to the orientation for crop-livestock systems in the Cerrado by Kluthcouski and Aidar (2003), applying 300 kg ha^{-1} NPK (08-30-10) + Zn. Around 70 days after harvesting corn, that is 18 months after CLF implementation, cattle were introduced to feed in the alley pasture. At this point the trees of eucalyptus were about 6 m height with 10 cm in diameter. From this moment on CLF was used as pasture for feeding cattle at a livestock rate of 2.1 heads ha^{-1}. The eucalyptus trees received 200 kg ha^{-1} of superphosphate and 15 g ha^{-1} of boric acid; and the palisade grass in the alley 100 kg ha^{-1} of urea and 100 kg ha^{-1} of Mono-Ammonium-Phosphate (MAP). No further fertilisation was done.

The reference Pasture was not cultivated and received no fertilisation. Quichium (*Pennisetum clandestinum*) and signal grass (*Urochloa decumbens*) have been covering the soil under this area of pasture for at least 30 years. This area is being used as a nursery, a place where sick cattle are treated, for example.

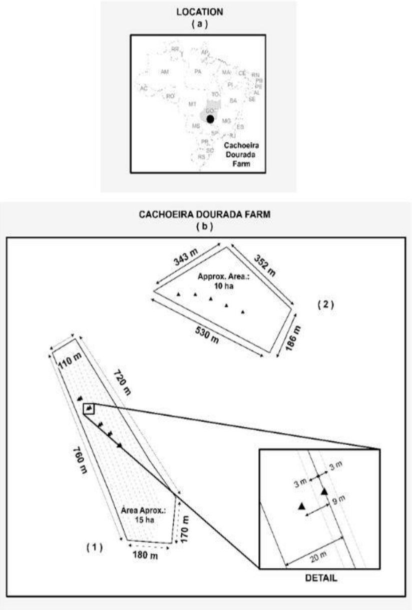

Figure 1. Location of Boa Vereda farm in Cachoeira Dourada, Central West region of Brazil (a) and sampled areas with sampling structure (b): a Crop-Livestock-Forestry (CLF) system consisting of tree rows, each containing three lines of trees paced 3 m between the tree lines, the distance between two rows was 20 m measuring between the central tree lines; and alley pasture between the tree rows (1); a non-cultivated Pasture, the reference area (2).

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II.2 Sample collection

Soil samples were collected in 1-m deep pits. Each sampling position, at the central tree line in the tree row (CLF-WL) and at the centre of the alley pasture (CLF-BL), had 5 repetitions (Figure 1-b1). In reference, Pasture 5 soil pits were sampled in a line, east-south direction, at 20 m distance between them (Figure 1-b2).

Soil sampling was done in 2012 and 2020 at the beginning of the summer rainy season (November). Samples were taken in seven soil layers: 0.0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 m. In each layer undisturbed soil samples were collected at the middle of the layer with a cylinder to measure soil bulk density. Simultaneously, other soil samples were collected to determine total soil C and N.

II.3 Soil organic carbon (SOC) and total N analyses and SOC and total N stocks

The concentration of total C and N (g kg^{-1}) of the fine earth fraction was determined from air-dried samples milled to pass through a 180µ sieve. Samples of around 8.5 mg were analysed in a Perkin Elmer 2400 Series II CHNS/O Elemental Analyser (Nelson and Sommers, 1996). The samples did not contain inorganic C, therefore total soil C was considered soil organic carbon (SOC). SOC stocks per layer were calculated using Equation 1.

SOC_i stock = OC_i x $BDfine_i$ x t_i x 0.1 (Equation 1),

where SOC_i stock the SOC stock of layer i (Mg ha^{-1}); OC_i is SOC concentration of layer i (g kg^{-1}); $BDfine_i$ is soil bulk density of layer i (g cm^{-3}); and t_i is the depth of layer i (cm). The soil did not contain gravel. Total N stocks were calculated similarly.

To eliminate the effect of soil compaction and to allow comparability among different areas and years, compaction was corrected by calculating the equivalent soil mass (Ellert and Bettany, 1995) using as reference the lowest average bulk density of the non-cultivated Pasture, for each soil depth in 2012.

SOC and total N stocks were calculated and evaluated for each sampling position (CLT-WL, CLF-BL and Pasture separately) and also considering the overall stocks of CLF, weighted by the proportional soil area under CLF-WL and CLF-BL. For that in the CLF the influence area of the trees and the alley pasture were estimated. Equation 2 was used to determine the overall SOC and N stocks (Mg ha^{-1}) in the CLF system:

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$$SOC_{CLF} = \frac{[(SOC_{WLS} x3.75)+(SOC_{BLS} x5.25)]}{9.0} \qquad \text{(Equation 2),}$$

where SOC_{CLF} is the overall SOC stock of CLF (Mg ha^{-1}); SOC_{WLS} is the SOC stock under the influence of the tree lines (Mg ha^{-1}); and SOC_{BLS} is the SOC stock under the influence of the alley pasture (Mg ha^{-1}); and 9.0 is the distance between the central tree line and the centre of the alley pasture.

II.4 Soil organic matter fractionation and C:N ratios

To proceed with the physical fractionation of soil organic matter (SOM), we adapted a procedure based on the works of Cambardella and Elliot (1992) and Cotrufo *et. al.,* (2019). Five grams of the fine earth fraction of the soil (≤ 2.00 mm) was shaken in dilute sodium hexametaphosphate (0.5%) and left for 18h to completely disperse the soil. The dispersed soil was then rinsed onto a 53-µm sieve and the fraction remaining on the sieve contained the particulate organic carbon (POC). The material that passed through the 53-µm sieve contained mineral-associated organic carbon (MAOC). After drying to a constant weight in a 60°C oven, each fraction was analysed for total C and N concentration (g kg^{-1}) using the before-mentioned elemental analyser. Stocks (Mg ha^{-1}) of particulate (POC) and mineral (MAOC) fractions of SOC and total N were calculated as described above. To obtain the C:N ratio of SOM and the fractions, a mass balance approach was used according to Cotrufo *et. al.,* (2019) (Equation 3):

$$C{:}N_{SOM} = C{:}N_{MAOM}\, x\, f_{MAOM} + C{:}N_{POM}\, x\, (1 - f_{MAOM}) \qquad \text{(Equation 3)}$$

where $C{:}N_{SOM}$, $C{:}N_{POM}$ and $C{:}N_{MAOM}$ are the C:N ratios of the total SOM, POM and MAOM, respectively, and f_{MAOM} is the MAOM proportion of the total SOM.

Cotrufo *et. al.,* (2019) postulated that the variation in the soil C:N ratio and the ability of soils to sequester C is related to f_{MAOM}, $C{:}N_{POM}$, and $C{:}N_{MAOM}$. Elucidating their causes and impact on soil carbon storage can guide soil carbon sequestration strategies.

II.5 Statistical analysis

A linear mixed model (Proc MIXED of SAS/STAT®; SAS Institute Inc. 2008) was used for the variance analysis of SOC and total N stocks and SOC fractions in the 0.0-0.3, 0.3-1.0 and 0.0-1.0 m layers in years 2012 and 2020. To control a small variation in clay content, co-variables were included in the statistical

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model. Two groups were created according to the clay content of each sample: clay content < 70% (1) and clay content ≥ 70% (2).

III. Results and Discussion

The increment in the overall SOC between 2012 and 2020 in the 0.0-0.3 m layer was 3.5% in the CLF, and 0.5% in the reference Pasture. In the case of the CLF, it is approximately 0.44% annual increase, while in the Pasture only 0.06%.

In the first year of measurement (2012), SOC stocks (Mg ha^{-1}; Figure 2-a) in the tree rows (CLF-WL) and alley pasture (CLF-BL) as well as the overall SOC in CLF (Figure 2-c) were lower than in the non-cultivated Pasture in the 0.0-0.3 m layer. On the other hand, the SOC stocks were higher in the CLF system than in the Pasture in the 0.3-1.0 m layer. Eight years later, in 2020, SOC stocks in CLF were higher than in Pasture only in the 0.3-1.0 m layer under the tree lines (CLF-WL) and in overall SOC. Considering the 0.0-1.0 m layer, there was no difference between the CLF, its components and the reference Pasture.

SOC loss during the first 3 years after implementing CLF (2009-2012) is likely due to soil preparation with heavy and levelling harrow down to 0.25 m of soil depth. Due to this event the physically protected SOC was exposed to decomposition, resulting in loss of SOC stocks in 2012 in the 0.0-0.3 m layer compared to the reference Pasture. On the other hand, at 0.3-1.0 m, not exposed to mechanisation, SOC stocks were higher in CLF than in the Pasture (Figure 2 a,c,e,g), representing 4.27 Mg ha^{-1} yr^{-1} accumulation rate during the first 3 years after CLF implementation.

Regarding total N stocks, in 2012 there was no difference between the treatments, except for the 0.0-0.3 m layer, where both CLF-WL and CLF-BL contained less N than the reference Pasture (Figures 2-b, d). In 2020, the total N stocks were generally lower in CLF compared to the reference Pasture, in all soil layers, despite the application of N and other nutrients at the implementation of the system (Figure 2-f, h). The reduction in N stocks was 3.16 Mg ha^{-1} for CLF-BL, 2.79 Mg ha^{-1} for CLF-WL and 1.86 Mg ha^{-1} for the reference Pasture in the 0.0-1.0 m layer between 2012 and 2020.

The lower soil N stocks measured in 2012 in the CLF might be related to the consumption of N by microorganisms for SOC degradation because of soil disturbance. In 2020, the lower N stocks, especially the overall stocks, occurred likely due to the exportation of nutrients by harvesting soybeans, corn, and wood. By 2020, 50% of the trees were removed through selective cutting. Another possibility would be that under shade, grasses can accumulate more N in their tissues (Anjos and Chaves, 2020), consequently extracting more N from the soil. Nitrogen is known to affect SOC dynamics, and the relative N loss from CLF compared to the reference Pasture may be an important factor hampering SOC accumulation rates, notably in the 0.3-1.0 m layer.

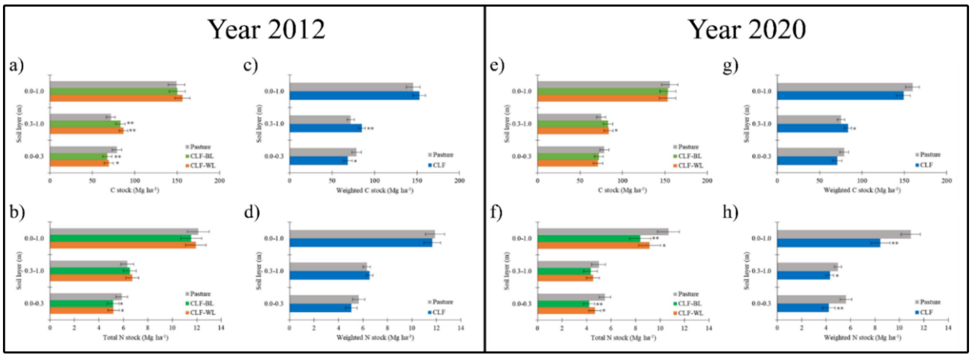

Figure 2. SOC and total N stocks (Mg ha^{-1}) in the components of a crop-livestock forestry system: under the tree lines (CLF-WL) and the alley pasture (CLF-BL) and overall CLF area (weighted) and under a non-cultivated reference Pasture in soil three layers (0.0-0.3 m, 0.3-1.0 m and 0.0-1.0 m) of a clayey Rhodic Ferralsol, 3 years (2012) and 11 years (2020) after CLF implementation in the Cerrado (savanna) biome in Central-West Brazil. Error bar represents the standard error (n=5). Differences between Pasture and CLF system and its components within each year and soil layer given by the Dunnett-Hsu test. Level of nominal significance for differences from pasture: *p-value ≤ 0.10; **p-value ≤ 0.05.

The SOC accumulation rate between 2012 and 2020 (Mg ha^{-1} yr^{-1}) in the 0.0-0.3 m layer was positive for CLF-BL (0.46) and CLF-WL (0.28), however negative for the reference Pasture (-0.26), which means that under the Pasture SOC was lost from soil to the atmosphere. On the other hand, in the 0.3-1.0 m layer, SOC accumulation was negative for CLF-WL (-0.37) and CLF-BL (-0.02), whereas positive for pasture (0.41). The negative rate in CLF-WL in this layer might be due the fact that intensification in soil management generates stress in microbiota, increases metabolic and enzymatic activity in soil, shifting rates of organic matter decomposition (Trasar-Cepeda *et. al.*, 2008).

Finally, considering the whole soil layer down to 1 m, the highest SOC accumulation rate occurred in CLF-BL (0.44) followed by the reference Pasture (0.15) whereas negative or null for CLF-WL (-0.09). Considering the overall SOC accumulation rate in CLF, it was positive (0.37) and negative for Pasture (-0.26) in the 0.0-0.3 m layer; negative for CLF (-0.19) and positive for Pasture (0.41) in the 0.3-1.0 m layer; and positive for both CLF (0.18) and

Pasture (0.15) within the entire soil layer 0.0-1.0 m.

The small accumulation rate in the non-cultivated reference Pasture may be related to the robustness of the root system of signal grass. According to Gichangi *et. al.,* (2017), the root system of *Urochloa* species can substantially increase SOC storage by producing massive root biomass compared to other species.

Particulate organic carbon (POC) represented about 4% of all SOC, and, consequently, 96% of SOC was in the MAOC fraction, regardless of the treatment. This is likely related to the texture of these soils; clayey textured soils, with high contents of Fe and Al oxides and hydroxides, contribute to organic carbon bonding in the form of organomineral complexes (Roscoe and Buurman, 2003). There were no significant differences in POC stocks between treatments (Figure 3-a). However, in the 0.3-1.0 m layer, stocks of MAOC (Mg ha^{-1}) were higher in CLF-WL (80.77) than in the non-cultivated Pasture (73.73) (Figure 3-b).

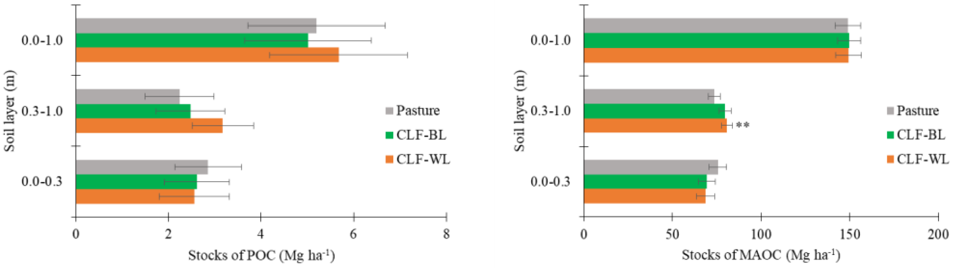

Figure 3. Stocks (Mg ha^{-1}) of (a) particulate organic carbon (POC) and (b) mineral-associated organic carbon (MAOC) in three layers (0.0-0.3 m, 0.3-1.0 m and 0.0-1.0 m) of a clayey Rhodic Ferralsol under an 11-year old crop-livestock-forest system (within and between tree lines: CLF-WL and CLF-BL) and a non-cultivated reference Pasture and in the Cerrado (savanna) biome in Central-West Brazil. Error bar represents the standard error (n=5). Differences between Pasture and CLF system and its components within each year and soil layer given by the Dunnett-Hsu test. Level of nominal significance for differences from pasture: *p-value ≤ 0.10; **p-value ≤ 0.05.

We expected that the POC stocks in the CLF system would be higher than in the Pasture since plant litter inputs rich in complex forms of C, like residues from thinning and selective cutting of eucalyptus, lignin, have a high energy cost associated with their breakdown and low microbial use efficiency. The microbial use efficiency matrix stabilisation concept suggests that this restricts C flow to the MAOC fraction and tends to increase POC content (Samson *et. al.,* 2020; Cotrufo *et. al.,* 2013). However, the mechanical disturbance of the soil at the implementation of CLF, together with the interventions for the planting and harvest of annual crops and the beginning and the selective cutting of eucalyptus, may have contributed to disrupting protective aggregates, increasing soil oxygen levels, and changing soil drainage, thereby increasing POC decomposition rates; by contrast, MAOC decomposition rates are much less sensitive to these changes (Lavallee *et. al.,* 2020). From a climate change perspective, the CLF system proved to be efficient in storing SOC in the most stable, however finite, fraction (MAOC), in the long-term. On the other hand, POC is less protected but can accumulate indefinitely, depending on soil management (Chen *et. al.,* 2021). This suggests that the management of CLF systems should be adjusted to incorporate more organic matter to increase POC. According to (Janzen 2006), a careful balance must be kept between locking away C and allowing SOC turnover to release nutrients and fuel plant productivity.

Regarding C:N ratio among SOM fractions, the C:N-POM ratio was lower in the CLF-WL (17.22; 14.72; 15.98) than in pasture (30.32; 24.71; 26.86) in all soil layers 0.0-0.3, 0.3-1.0 and 0.0-1.0 m, respectively. On the other hand, the C:N-MAOM ratio was higher for the CLF-BL (17.64) than in Pasture (14.49) at the soil surface layer 0.0-0.3 m. Significant differences were not observed for the C:N-SOM ratio, which ranged from 19.41 (CLF-WL) to 21.64 (Pasture) (Table 1).

According to Deng *et. al.,* (2013) the greatest organic matter mineralization would occur for a substrate at a C:N ratio of 25. If the C:N ratio is lower than 20, mineral N is released earlier along the decomposition process. The shifting point from N immobilisation to N release is around a C:N ratio of 20:1. Consequently, the lower C:N ratio in the POM of CLF-WL and CLF-BL, could favour the loss of N from CLF, while the slightly higher C:N ratio in the MAOM of CLF-WL and CLF-BL lead to higher SOC stabilisation.

Table 1. Total (C:N-SOM), particulate (C:N-POM) and mineral-associated (C:N-MAOM) ratios in three layers (0.0-0.3 m, 0.3-1.0 m and 0.0-1.0 m) of a clayey Rhodic Ferralsol under an 11-year old crop-livestock-forest system (within and between tree lines: CLF-WL and CLF-BL and a non-cultivated reference Pasture and in the Cerrado (savanna) biome in Central-West Brazil.

Area	C:N-SOM	C:N-POM	C:N-MAOM	f
	-------------------------------------- 0.0-0.3 m --------------------------------------			
Pasture	21.64 (1.29)	30.32 (5.31)	14.49 (1.28)	0.96
CLF-WL	19.41 (1.36)	17.22 (5.60)**	15.31 (1.35)	0.96
CLF-BL	19.76 (1.25)	20.02 (5.16)*	17.64 (1.24)**	0.97
	-------------------------------------- 0.3-1.0 m --------------------------------------			
Pasture	10.66 (0.63)	24.71 (3.53)	17.56 (4.51)	0.97
CLF-WL	11.21 (0.57)	14.72 (3.17)**	21.59 (4.05)	0.96
CLF-BL	11.10 (0.63)	19.70 (3.53)	17.75 (4.51)	0.97
	-------------------------------------- 0.0-1.0 m --------------------------------------			

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Pasture	15.35 (0.78)	26.86 (1.82)	15.20 (3.62)	0.97
CLF-WL	14.68 (0.78)	15.98 (1.82)**	18.02 (3.62)	0.96
CLF-BL	14.84 (0.72)	20.03 (1.68)**	18.96 (3.06)	0.97

Differences between Pasture and CLF system within each soil layer given by Dunnett-Hsu test. Standard error between parenthesis (n=5). Level of nominal significance for differences from Pasture: *p-value ≤ 0.10; **p-value ≤ 0.05. f is the MAOM proportion of the total SOM.

IV. Conclusions

Soil organic carbon dynamics was different in the upper 30 cm and in the underlying 70 cm layer. At 0.0-0.3 m, after an initial loss of SOC due to physical soil disturbance during soil preparation for the implementation of the CLF. After this initial period, however, the SOC stock change rates were positive both under the tree lines and in the alley pasture, while the reference Pasture lost C.

In the underlying layer, at 0.3-1.0 m, SOC stock was still higher compared to the reference Pasture, however, the accumulation rates were negative both under the tree lines and in the alley pasture and were positive in the reference Pasture. Despite the negative rates, in this layer the higher amount of MAOC under the tree lines, 11 years after implementing the CLF, suggests that the system favours SOC accumulation in organomineral complexes, which may contribute to enhancing C permanence in deeper soil layers. The general relative decline of total soil N under CLF, compared to the reference Pasture, calls attention to the importance of N, and in general, soil fertility management. In the medium to long term, declining N can hamper the SOC accumulation potential of the production system.

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