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SOIL CARBON STOCKS AT 3 AND 11 YEARS OF AN INTEGRATED CROP-LIVESTOCK-FORESTRY SYSTEM ON A CLAYEY FERRALSOL IN THE BRAZILIAN SAVANNA

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ABSTRACT

Integrated Crop-Livestock-Forestry systems (ICLF) are potential carbon sinks. Here we present soil organic carbon (SOC) stocks in an ICLF system at 3 and 11 years after implementation. The ICLF was implemented in 2008/2009 at Boa Vereda farm, in Cachoeira Dourada, Goiás state, Central-West region of Brazil, on a clay Ferralsol. SOC stocks were determined within rows of trees and between rows of trees, hereby called alley, in three soil layers (0.0-0.3, 0.3-1.0 and 0.0-1.0 m) in 2012 and 2020. A non-cultivated pasture was used as reference. Results show a trend for increased soil C stocks at 0.0-1.0 m under ICLF system from 3 to 11 years after implementation compared to the non-cultivated pasture. There was also a higher C accumulation rate under ILPF at this soil layer, compared to the same pasture. All treatments lost C at 0.3-1.0 m, but the non-cultivated pasture lost C the most rapidly. At 0.0-0.3 m all treatments gained C over time. These data only relate to the effect of the presence of trees in the ICLF, weighted COS stocks from tree-rows and alleys were not calculated in this paper.

Key words: soil C sequestration; eucalyptus trees; beef cattle

INTRODUCTION

Soil organic carbon (SOC) stocks depend on the interaction of soil with biosphere. Through photosynthesis performed by autotrophic organisms, C compounds are transformed into plant tissues which reach the soil through above and belowground biomass. Carbonaceous materials, root exudates and washing of soluble plant constituents by rainwater feeds soil microorganisms that in turn contribute to accumulation of soil C throughout time. Among terrestrial ecosystems, soil is the largest active C reservoir. About 1,500 Pg of C are stored as organic matter down to one meter of soil depth (IPCC 2013). SOC represents the C present in soil organic matter (SOM), which in turn comprises all living and dead organisms, in different stages of decomposition. For soil fertility management usually the non-living compartment of SOM is considered the main factor, represented by root and leaf litter, water soluble organic compounds, soil enzymes and very complex mixture of microbial and plant biopolymers and their degradation products (KELLEHER; SIMPSON, 2006; SIMPSON et al., 2007). The non-living SOM have a readily decomposable compartment, but also contains the largest pool of recalcitrant organic C in the terrestrial environment. The increment in SOM contributes to maintenance of soil C stocks and C removal from atmosphere. SOM management is, therefore, one key to manage the challenges of agriculture related to climate change (GELAW et al., 2014; ADHIKARI et al., 2017). This should also change the way we define soil fertility, including SOC as an attribute to define a fertile soil (LEHMANN; KLEBER, 2015). Production systems that are more biodiverse, such as the different variations of integrated crop-livestock-forestry systems, imply an ingenious dynamic in land use and management that can result in financial and environmental services (SANG et al., 2013, TORRES et al., 2014). In the Brazilian savannah, the integrated crop-livestock-forestry (ICLF) system is usually characterized by the association of trees, mainly eucalyptus, annual crops for grain production, soybean or corn, and livestock, for beef or dairy. The combination of these components of production generates positive synergy (VILELA et al., 2011). Franzluebbers et al. (2014) emphasize, for example, that increasing SOM and water infiltration are among soil attributes improved by the implementation of agricultural and livestock integration. The objective of this work was to investigate the potential of SOC accumulation under an ICLF system on a Ferralsol of the Brazilian savannah, central west region of Brazil. Here we show preliminary results.

MATERIAL AND METHODS

Location

This study was carried out at Boa Vereda farm, located in Cachoeira Dourada, Goiás (18° 27'43.19 "S, 49° 35'58.53" W), at 484 m a.s.l. The soil was classified as a typical clay Ferralsol (632 g kg^{-1} clay and 221 g kg^{-1} sand at 0-30 cm and 672 g kg^{-1} clay and 170 g kg^{-1} sand at 30-100 cm), with slope ranging from 0 to 15% (SANTOS et al., 2013). The Köppen-Geiger classification is Aw (tropical savanna climate with dry winters between May and October) (CARDOSO et al., 2014). The average annual precipitation is 1,315 mm with December being the rainiest and August the driest month. Maximum temperature is reached in September (± 32.00 °C) and minimum in July (± 15.53°C). The relative air humidity varies between 80% in January and 47% in August (INMET).

Area history and management of crop-livestock-forestry system

In the rainy summer season 2009/2010, the ICLF system was implemented on a 30-year-old pasture with rows of three lines of eucalyptus trees (*Eucalyptus urograndis*) in north-south direction. Each row of trees was spaced 3 m between lines, 2 m between trees along the lines and 20 m between rows, resulting in a total of 476 trees ha^{-1} in an area of 14.7 ha (Figure 1). At plantation establishment, eukalyptus was fertilized with 150 g $plant^{-1}$ of the formula 08-30-10 + Zn and boric acid (10 g $plant^{-1}$). In August 2008, the soil of the alley between the tree rows was heavy-harrowed to 13 cm depth, and in October 2008 limestone was applied followed by light harrowing. Soybean (*Glycine max*) was sown in the alleys and received 12 kg ha^{-1} N, 90 kg ha^{-1} K_2O and 30 kg ha^{-1} P_2O_5 at sowing time. In the summer of 2010/2011, soil tillage was done with heavy-harrow and several passes of light-harrow before sowing corn with palisade grass (*Urochloa brizantha*) according to the Santa Fé System (KLUTHCOUSKI; AIDAR, 2003). The soil was fertilized with 24 kg ha^{-1} N, 90 kg ha^{-1} K_2O and 30 kg ha^{-1} P_2O_5 for corn (*Zea mays*) and 40 kg ha^{-1} P_2O_5, 24 kg ha^{-1} S and 15 g boric acid for eukalyptus maintenance. Since 2011, the soil under continuous pasture has annually received 56 kg ha^{-1} N and 52 kg ha^{-1} P_2O_5. Beef cattle was introduced for feeding on the brachiaria at a stocking rate of 2.1 animals ha^{-1} (Pacheco et al., 2013). Cattle was introduced in the dry winter (2011), around 70 days after corn harvest, when eucalyptus trees were about 6 m height and 10 cm diameter at breast height. As a reference, an area under 30 years of continuous pasture mainly consisted of signal grass (*Urochloa decumbens* formerly *Brachiaria decumbens*) was selected. Between 2012 and 2020 small amounts of limestone and NPK fertilizer have been applied to the soil for plant nutrient replenishment.

Sampling and analysis of Soil Organic Carbon

Within the ICLF system, soil samples were collected in five sampling modules (replicates), using soil profiles of 150 x 150 x 120 cm. In the tree-rows soil pits were placed in the middle of the tree-rows and in the middle of the alley (Figure 1). In the continuous pasture five soil profiles were placed in line at 20 m distance from each other in an east-south direction. In each soil profile samples were taken at seven depths (0.0-0.1 m, 0.1-0.2 m, 0.2-0.3 m, 0.3-0.4 m, 0.4-0.6 m, 0.6-0.8 m, and 0.8-1.0 m) in the rainy seasons of 2011/2012 and 2019/2020. Soil density was determined using Kopecky volumetric rings. The samples were taken in the middle of each soil layer. Soil C was analyzed by dry combustion (950 °C) using a Vario Isotope Cube coupled in series with a mass spectrometer (Isoprime, Elementar Inc., Hanau, Germany). Five replicates were taken for each measurement. According to Sisti et al. (2004), estimates of SOC stocks expressed as Mg ha^{-1} were based on quantification in equivalent soil mass using the continuous pasture as reference. As soil density suffers seasonal changes, for samples collected in the wet season 2019/2020 we used soil density from the wet season 2011/2012 in order to normalize data. Values of SOC stocks were calculated for three soil layers (0.0-0.3 m, 0.3-1.0 m and 0.0-1.0 m). Finally, estimates of SOC accumulation rate were calculated as the difference in SOC stocks from the wet season 2011/2012 to the wet season 2019/2020 in Mg C ha^{-1} year^{-1}.

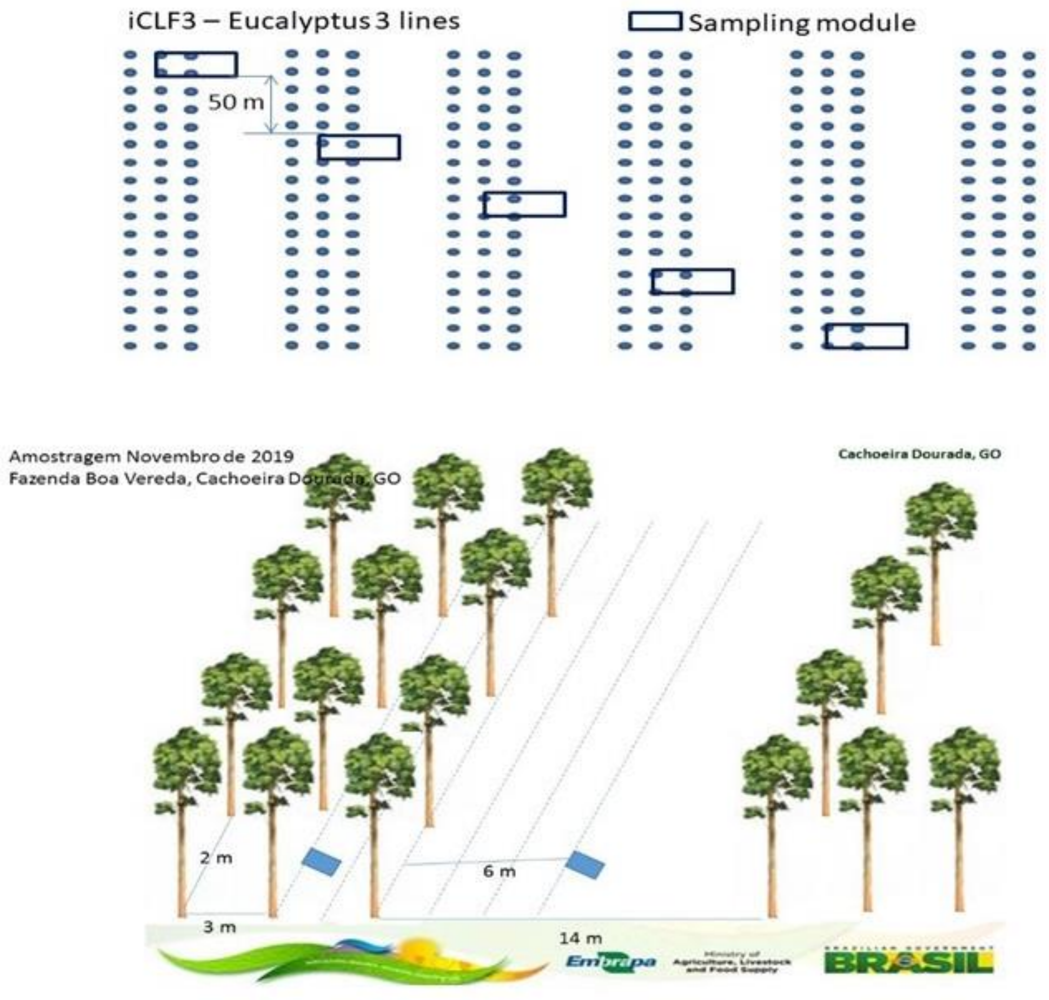

Figure 1. Location of soil profiles and sampling modules and display of trees on the area under integrated crop-livestock-forestry (ICLF) system at Boa Vereda Farm. Chachoeira Dourada, State of Goiás, Brazil.

Statistical analysis

Analyses were performed using the linear mixed model procedure (Proc Mixed) in SAS/STAT (SAS, 2008). Local of sampling (continuous pasture, ICLF-tree-rows and ICLF-alleys) were considered as fixed effects and repetition (modules) as random effect. F-test was applied to check for the interaction effect of year*place of sampling on SOC stocks and the effect of tree-row and alley on the rate of SOC accumulation within three soil layers (0.0-0.3, 0.3-1.0 and 0.0-1.0 m). Tukey’s test was applied to check for differences between years for each treatment (tree-row, alley and continuous pasture) within each soil layer.

RESULTS AND DISCUSSIONS

Adoption time of ICLF systems had a significant effect on SOC stock changes at all depths (F = 5.75; $p \leq 0.005$). Despite the effect of the interaction year*place of soil sampling was not significant, SOC stocks increased from 3 to 11 years after implementation of the ICLF system (under tree-rows and in alleys) at all soil depths (0.0-0.3, 0.3-1.0, 0.0-1.0 m; Figure 2).

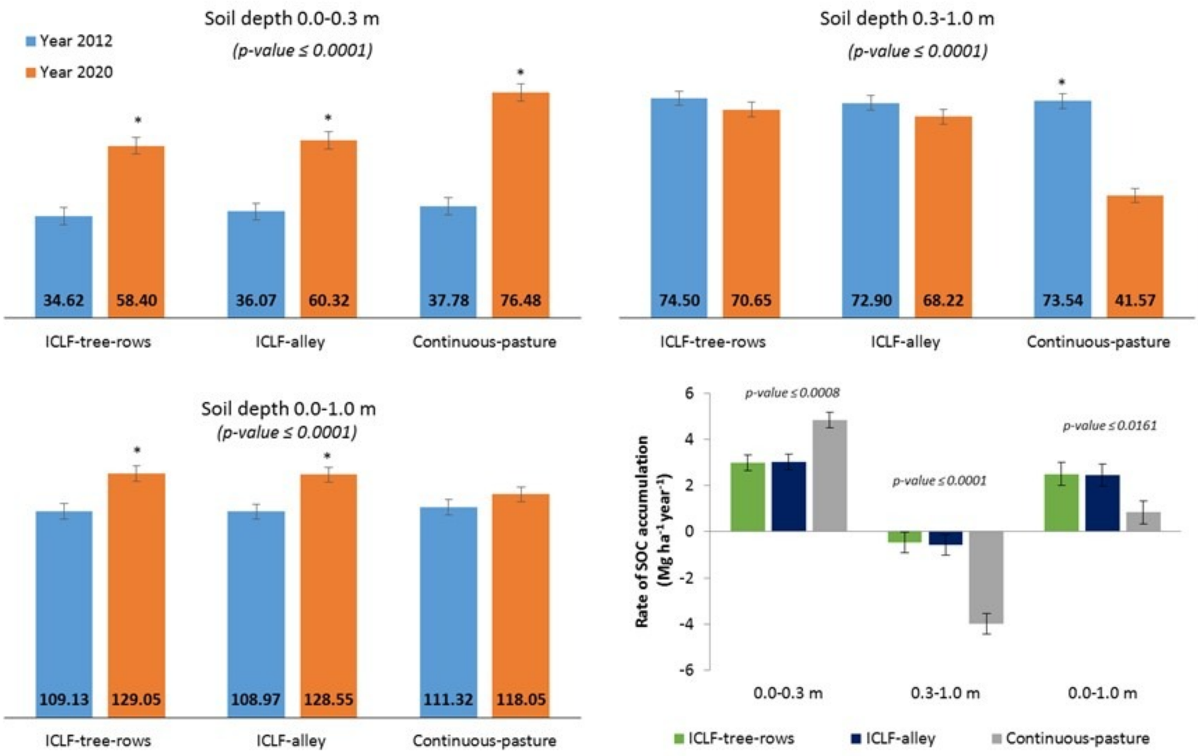

Figure 2. Effect of year (2012 and 2020) and place of sampling (ICLF-tree-rows, ILCF-alley and Pasture-non-cultivated) on soil organic carbon (SOC) stocks (Mg ha^{-1}) and local effect on SOC accumulation rate at 0.0-0.3, 0.3-1.0 and 0.0-1.0 m layers. In parenthesis are nominal significance levels (p-value) of F-tests for effects. Error bars represent standard error of means (n=5). *Means are significantly differet among years by Tukey's test (p-value).

The proportion of SOC stocks at 0.0-0.3 m to 0.0-0.1 m soil depth increased from 33% to 52%, average of 36.2 Mg ha^{-1} between 2012 and 2020. This increase could be attributed to the surface application of limestone (calcium or magnesium) and mineral fertilizers in all treatments. All treatments (sampling places at tree-rows, alley and continuous pasture) accumulated SOC during the last 8 years at 0.0-1.0 m, after the implementation of the ICLF. SOC accumulation occurred at 0.0-0.3 and SOC loss at 0.3-1.0 m at all treatments. The rate of SOC accumulation at 0.0-0.3 m was highest in continuous pasture (4.84 Mg SOC ha^{-1} $year^{-1}$), which also showed the highest rate of C loss at 0.3-1.0 m (-4.00 Mg SOC ha^{-1} $year^{-1}$) (Figure 2). At 0.0-1.0 m, the overall SOC accumulation rate was positive in all treatments, but ICLF-tree-rows (2.49 Mg SOC ha^{-1} $year^{-1}$) and ICLF-alley (2.45 Mg SOC ha^{-1} $year^{-1}$) outperformed the continuous pasture (0.84 Mg SOC ha^{-1} $year^{-1}$). The lower SOC accumulation in ICLF, either under tree-rows or in the alleys, at 0.0-0.3 m could be explained by the effect of the implementation of the ICLF that involved mechanical soil disturbance that likely resulted in initial SOC loss. Bieluczyk et al. (2020) found SOC accumulation rate (Mg ha^{-1} $year^{-1}$) of 1.68 for extensive grazing pasture; 1.96 for integrated crop livestock; and 1.74 between tree-rows of an ICLF system in 0.0-0.4 m soil layer of a sandy-clay-loam, between 2010 and 2016, in a 6-year period. SOC accumulation rates are expected to be higher in a shorter period of time than that we found in this study. However, SOC accumulation is influenced by various factors, from soil management to soil properties such as texture, mineralogy and original SOC content (ZINN et al., 2007; CARDINAEL et al., 2017). The Ferralsol in our study was clayey, which theoretically implies in high C sequestration potential, and the original SOC cc. in the Ferralsol in 2012 was moderate (1.06 to 1.09 % at 0.0-0.3 m). Considering this, the estimated SOC accumulation rate between 2.97 and 3.03 Mg SOC ha^{-1} $year^{-1}$ at 0.0-0.3 m and 2.49 and 2.45 Mg SOC ha^{-1} $year^{-1}$ at 0.0-1.0 m in the ICLF system found in this study is potentially at the higher end of SOC accumulation rate. Corbeels et al. (2016) calculated diachronic annual SOC accumulation rates at 0.0-0.4 m soil layer to be between 0.3 and 1.8 Mg ha^{-1} $year^{-1}$ in pasture and between 0.09 and 0.63 Mg ha^{-1} $year^{-1}$ in no-till fields, implemented on land under conventional tillage in a Ferralsol, located in southwest Goiás, within a biome in transition between savannah and Atlantic Forest. Additionally, Oliveira et al. (2019) calculated 1.47 Mg ha^{-1} $year^{-1}$ SOC accumulation rate in 0.0-1.0 soil layer 12 years after implementation of an ICLF system in a lighter textured soil compared to the soil in this study.

CONCLUSIONS

Results show higher increment in SOC stocks in the Ferralsol from 3 to 11 years after adoption of the ICLF system, compared to continuous pasture at 0.0-1.0 m. Pastureland had higher increase in SOC stock at the upper soil layer of 0.0-0.3 m than the ICLF tree-rows and alleys, but it also lost much more SOC at 0.3-1.0 m than the soil under ICLF. In this study only the effect of tree-rows and alley in the ICLF were compared to the reference pasture separately to verify the effect of the components of ICLF on SOC accumulation. Further analysis will have to be done to explore the overall effect of ICLF, calculating the weighted SOC stock under ICLF based on the proportion of the land area under trees and alley. Also, determination of losses in dissolved organic carbon is recommended.

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