3.2.5. | SUB-SURFACE SOIL ORGANIC CARBON STOCK AFFECTED BY TREE LINES IN AN OXISOL UNDER INTEGRATED CROP-LIVESTOCK-FORESTRY IN THE SOUTHERN AMAZON[A]

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ABSTRACT

The carbon (C) removed from the atmosphere through photosynthesis may be finally transferred into the soil. Soil organic C storage (SOC), therefore, is an important indicator of the capacity of a production system to sequester SOC. Integrated agriculture production systems (IS) are one of the main strategies of the Brazilian government to reduce or compensate for C emissions from agriculture. Besides, IS are also important means of intensifying and diversifying production and at the same time propitiate benefits to the environment. Our goal was to see whether IS in the form of crop-livestock-forestry (ICLF) could stock more SOC than continuous Pasture without soil management and to contribute to the elucidation of the role of trees in SOC accumulation. The study was carried out in the north of Mato Grosso State, Brazil. Intensive land use was represented by two sites recently under ICLF implemented 3 years before the study. Carbon stocks were analyzed for the 0.0-0.3 and 0.0-1.0 m layers. Around 50% of all C was stored below the 0.3 m. The high C storage places in ICLF were identified in the tree lines at 0.3-1.0 m where N deficiency was not present.

Keywords: Integrated systems (IS); Total soil C; Total soil N; $\delta^{13}C$*; Pasture; Eucalyptus spp*

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Lower emission of greenhouse gases (GHG) and atmospheric carbon (C) sequestration are among the environmental services that can be provided by farming. Integrated farming systems (IS), became a widely cited concept, as they seek to achieve enhanced production with reduced impacts on the environment. Integrated systems is a production strategy that combines crop, livestock and forestry activities in the same area (Gil *et al.* 2015).

A great diversity of IS exists worldwide, evidencing the need for and adaptability of the concept to various ecoregions and production purposes (Sulc and Franzluebbers 2014; Peyraud *et al.* 2014). These are common in being able to capture ecological interactions between different land use systems, providing opportunities for more efficient agriculture ecosystems in the cycling of nutrients, preserving the natural and environmental resources, improving soil quality and increasing biodiversity (Lemaire *et al.* 2014).

Large C accumulation capacity is associated to integrated crop-livestock-forestry (ICLF) due to the assimilation of additional atmospheric C in the biomass compared to conventional agriculture, some forestry (monocultures) systems and to other IS without trees. To achieve C sequestration in the soil, besides the biomass, is relevant, since part of the soil C may actually be immobilized and stored in the soil from days to decades or even hundreds of years, depending on the mechanism of immobilization and the processes of soil organic matter transformation.

The aim of this study was to assess soil C stocks under two intensively used agriculture areas, under ICLF, in comparison to a continuous pasture without soil management, in the southern part of the Amazon ecosystem, in real farm conditions. Besides, we hope to contribute to the elucidation of the role of the trees to the accumulation of C in the soil.

[a] Based on Oliveira *et al.* Integrated farming systems for improving soil carbon balance in the southern Amazon of Brazil - a case study. Regional Environmental Change (in press)

METHODOLOGY

Data were collected at a private property near Nova Canaã do Norte in Mato Grosso State of Brazil (10°38’13” S, 55°42’32” W). The farm was originally covered by Rain Forest which was partly preserved. The soil was kaolinitic Oxisol, throughout the farm, in a slightly rolling topography. The climate was tropical with dry winter (May-August), the average annual rainfall being around 1,954 mm of which about 95% was concentrated between September and April. The mean annual temperature was 26°C.

A continuously grazed pasture (Pasture), and two ICLFs were studied. The ICLF sites had *E. urograndis* as the tree component. *E. urograndis* is one of the most cultivated species in forestry in Brazil due to its high productivity, ecological adaptability and merchantability. In the ICLFs the trees were arranged in lines within the sites. In one of the sites, each tree line was composed of one tree row (ICLF1), in the other, of three tree rows (ICLF3). The Pasture (*Urochloa brizantha*), around 5 ha, was considered degraded because of the low forage production, presence of patches not covered by grass and its soil physical properties. The Pasture as well as the site where the ICLFs were installed had been under native forest which was removed from the area in 1998. The Pasture remained under continuous grazing after 1998, and since then, the area had no soil management and received no fertilizer or lime. The deforested area where the ICLFs were implemented was used and managed similarly between 1998 and 2009, alternating grazing and annual crops. January 2009, ICLF1 and ICLF3 were implemented in 4.7 ha each, within a larger, 42,7 ha area. For comparison between the ICLFs and Pasture the period of 2000-2012 was considered. We evaluated how much more SOC was present in the soil where more and more intensive land use was introduced on the deforested area, first by alternating and then combining different land uses and agriculture activities in ICLF, instead of continuous low-intensity Pasture. We called it SOC stock diferentiation.The Pasture was taken as reference for the SOC accumulation study in the ICLFs.

Soil samples were taken in February 2012, collecting 5 replicates for each measurement. Horizontally, soil and plant sampling was done in a manner to respect the structure of the sites in terms of the disposition of the tree lines to be able to infer on tree line effects. Vertically, the soil was sampled to 1 m depth, devided in 8 sampling layers to be able to study the vertical stratification of soil properties.

Total soil and plant C, N and isotope ratio (δ ‰) was analyzed by dry combustion (950 °C) using Vario Isotope Cube coupled in series with a mass spectrometer (Isoprime, Elementar Inc. Hanau, Germany) (Elementar Inc., Hanau, Germany). Total SOC and N stocks were calculated for equivalent soil mass per soil sampling layer, for each sampling position in each ICLF site, using Pasture as reference. SOC and N stocks were analyzed for the 0.0-0.3, 0.3-1.0 and 0.0-1.0 m layers. The sampling positions in the ICLFs were compared individually to the Pasture to evaluate the role of each ICLF position in the C dynamics of the site. Then, the average SOC and N stocks of each ICLF were calculated, obtained as the weighted average of all sampling positions within. In this calculus each sampling position was represented in the proportion in which it covered the sampled area.

To analyse the data we used linear mixed models that allowed us to account for potential spatial correlation among sets of sampling positions (soil profiles). Dunnett tests indicated if there were significant effects for the ICLF treatments compared to the Pasture. Analyses were performed using the linear mixed model procedure (Proc MIXED) of the statistical software SAS/STAT® (SAS Institute Inc. 2008).

RESULTS

Soil organic carbon (SOC) stocks

Considering a 1 m deep soil layer, the top 0.3 m stored about 49% of SOC and, correspondingly, the underlying 0.7 m contained 51%. In the top 0.3 m soil layer soil C stocks varied between 55.05 (Pasture) and 66.74 (ICLF1-5) Mg ha^{-1} and no significant differences were observed among the ICLFs and the Pasture (Fig. 1).

Higher SOC stocks than in Pasture (55.61 Mg C ha^{-1}) were observed, however, at 0.3-0-1.0 m, for the central and external tree rows of ICLF3 (71.66 and 72.92 Mg C ha^{-1}, respectively). At ICLF3-CR there was 16.05 and at ICLF3-ER 17.31 Mg ha^{-1} more SOC than under the Pasture that corresponds to 1.33 and 1.44 Mg ha^{-1} annual positive differentiation, respectively, in SOC stock beneath the top 0.3 m soil layer under the tree lines, considering 12 years of soil management. No significant SOC accumulation was observed in the other sampling positions. Considering the 0.0-1.0 m soil layer, the SOC stock differentiation rate under the tree line in ICLF3 (ICLF3-CR and ICLF3-ER), was an annual 1.91 Mg ha^{-1}.

To evaluate the overall potential of the ICLFs to accumulate or preserve SOC, we calculated the average weighted SOC and N stocks. The ICLF3 had a positive overall SOC balance (128.34 Mg C ha^{-1}), compared to the continuous pasture (110.66 Mg C ha^{-1}), while the ICLF1 (110.21 Mg C ha^{-1}) did not differ from that. The additional 17.68 Mg SOC ha^{-1} in the ICLF3 means an annual 1.47 Mg SOC ha^{-1} differentiation rate between the Pasture and the ICLF system.

The isotopic signature ($\delta^{13}C$) of the soil

The soil under Pasture had greater abundance of ^{13}C than the areas under ICLF down to 0.4 m, except ICLF3-9 (-23,32) that was similar to the Pasture at 0.3-0.4 m. The stronger C3 signal in the ICLFs at 0.0 to 0.4 m can be attributed to the C3 annual crops, which dominated the first two years (2008-2010) of ICLF, such as rice and soybean, and to eucalyptus. In the 0.4-0.6 m layer only the ICLF1 was different from the Pasture (-22.02). In the 0.6-1.0 m soil layer the effect of agriculture management systems was not detected with the stable carbon isotope technique (Fig. 1). Below 0.6 m the isotope signature of the soils (-20.32-21.99) of the evaluated areas was comparable to the native Forest soil and indicated a mixture of C3 and C4 plants, representing earlier geological times (Pessenda *et al.* 1998).

DISCUSSION

While in ICLF3 our results indicated that the system affected SOC stocks in the subsurface layer under the tree line, the same was not observed for the ICLF1. The annual SOC differentiation rates between the Pasture and the ICLFs were, however, positive at all sampling positions and at all soil layers (Table 1). In ICLF3 in the 0.3-1.0 and 0.0-1.0 m layers a decline in the SOC differentiation rate from the central tree row (ICLF3-CR) to the middle of the ally pasture (ICLF3-9) could be observed. Similar trend did not exist neither in the 0.0-0.3 m soil layer in the same area (ICLF3) nor in the ICLF1. In the area under ICLF3, therefore, we found strong indication that the trees had important role in subsurface C accumulation or preservation.

We suspect that the different behavior of the two areas in C dynamics could lay in the great heterogeneity of the studied area that extended, considering the Pasture and the ICLFs, over 42.7 ha. It is known that the nutrient balance influences C accumulation in tropical and subtropical agricultural and grassland soils and that N has an important role in it (Kirkby *et al.* 2014). We measured that the ICLF1 had generally lower N content than the area under continuous Pasture, especially at the ICLF1-2.5, 5 and 10 sampling positions, where it was significantly lower. Under the ICLF3 two sampling positions (ICLF3-ER at 0.3-1.0 m and ICLF3-CR at 0.0-1.0 m) had more N than the Pasture (data not shown).

The interdependence between N and SOC in the soil could also be observed by the correlation between their concentrations in the ICLFs (R^2=0.96 at 0.0-0.3 m and R^2=0.97 at 0.0-1.0 m), supporting the idea that N deficit in the soil may be limiting to the accumulation of SOC. It was therefore clear that the sites under ICLF1 and ICLF3, had different conditions for SOC accumulation in the soil.

CONCLUSIONS

The variation in the isotopic composition (δ^{13}C) of the soil was strongly affected by the change in land use, showing evidence that vegetation change affected soil organic matter in short term down to 0.6 meters in the soil profile. In quantitative terms, however, evaluating only the top 0.3 m, the effect of the agricultural management systems on SOC stocks was not detectable. Difference in the SOC stocks was identified, however, below 0.3 m, in the tree lines of the ICLF site with three tree rows in the tree lines (ICLF3). This ICLF resulted in overall higher SOC stock, considering a one-meter deep soil layer, when compared to a site under continuous pasture. SOC dynamics was closely related to soil N. While the ICLF3 site had more SOC, another, ICLF1, which had been implemented on a site that showed N deficiency, did not accumulate SOC compared to the pasture site. Adopted sampling pattern to the functional heterogeneity of the ICLF was necessary to evaluate its effect on SOC stocks. Our results indicated that, in the edaphic-climatic conditions of the study site, agriculture systems that include forest component can represent viable solutions for SOC accumulation even in the short term if soil fertility constraints are not present. As land use and management can directly influence soil conditions, including the nutritional status of soils, it is important that adequate and, if necessary, corrective soil management be coupled to the implementation of ICLF, or any IS, to bring out or enhance their potential. Nevertheless, more investigation is necessary on the driving forces and impediments of SOC accumulation in IS, including detailed research on soil organic matter stability.

REFERENCES

Gil, J., Siebold, M. & Berger, T. 2015. Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso, Brazil. *Agric Ecosyst Environ.,* 199: 394-406. doi: 10.1016/j.agee.2014.10.008

Sulc, R.M. & Franzluebbers, A.J. 2014. Exploring integrated crop-livestock systems in different ecoregions ofthe United States. *Eur J Agron*., 57: 21-30. doi: 10.1016/j.eja.2013.10.007

Peyraud, J-L., Taboada, M. & Delaby, L. 2014. Integrated crop and livestock systems in Western Europe and South America: A review. *Eur J Agron*. 57: 31-42. doi: 10.1016/j.eja.2014.02.005

Lemaire, G., Franzluebbers, A., Carvalho, P.C.D.F. & Dedieu, B. 2014. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agric Ecosyst Environ*, 190: 4-8. doi: 10.1016/j.agee.2013.08.009

Sas - SAS Institute Inc. 2008. SAS/STAT ® 9.2: User’s Guide. SAS Institute Inc., Cary-NC

Pessenda, L.C.R., Gomes, B.M., Aravena, R., Ribeiro, A.S., Boulet, R. & Gouveia, S.E.M. 1998. The carbon isotope record in soils along a forest–cerrado ecosystem transect: implications for vegetation changes in the Rondonia state, southwestern Brazilian Amazon region. *The Holocene*, 8: 599-603. doi: 10.1191/095968398673187182

Kirkby, C.A., Richardson, A.E., Wade, L.J., Passioura, J.B., BG, D., Blanchard, C. & Kirkegaard, J.A. 2014. Nutrient availability limits carbon sequestration in arable soils. *Soil Biol Biochem*, 68: 402–409. doi: 10.1016/j.soilbio.2013.01.011