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Artigos

Soil carbon stocks and labile fractions of organic matter under agroforestry system in breast of pernambucan altitude

Estoques de carbono do solo e nas frações lábeis da matéria orgânica sob sistema agroflorestal em brejo de altitude pernambucano

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ABSTRACT

Intense soil preparation and disturbance in crops, over time, reduces the quantity and quality of soil organic matter. Given this context, this work aimed to determine soil carbon stocks and labile fractions under agroforestry system (AFS) and toposequences in an altitude marsh, Taquaritinga do Norte, Pernambuco, Brazil. The study was carried out at the Yaguara farm, and the areas studied were native forest with 4.57 ha and coffee plantation in shade with native forest with 25.59 ha. Soil samples were collected in four trenches measuring 1.5 x 1.5 x 0.60 m, with a distance of 50 meters. Soils were collected at depths of 0–20, 20–40 and 40-60 cm, followed by chemical, physical and density analyzes to determine soil carbon stocks and labile fractions. The area with shaded coffee showed higher values of soil carbon stocks at depths of 0-20 cm and 20-40 cm. At a depth of 40-60 cm, the AFS top toposequence showed the highest carbon stock with 11.73 Mg ha^{-1}, followed by the area with native vegetation with 10.6 Mg ha^{-1}, slope with 9.23 Mg ha^{-1} and pediment with 7.00 Mg ha^{-1}. It was found that the top toposequence with shaded coffee exhibited a greater stock of labile carbon at depth 0-20 cm with a value of 1.06 Mg ha^{-1}, followed by the bedding areas (SAF) with 0.88 Mg ha^{-1}, native forest with 0.79 Mg ha^{-1} and slope with 0.67 g kg^{-1}. However, the area of native vegetation showed the highest value of labile carbon at a depth of 40-60 cm. It was concluded that the area with shaded coffee in the top toposequence showed great capacity to increase total carbon stocks and labile carbon stocks of soil organic matter.

Keywords: Soil organic matter; Labile carbon; Agroforestry systems

RESUMO

O intenso preparo e revolvimento do solo em cultivos, com o tempo, reduz a quantidade e a qualidade da matéria orgânica do solo. Diante desse contexto, este trabalho teve como objetivo determinar os estoques de carbono do solo e frações lábeis sob sistema agroflorestal (SAF) e topossequências em brejo de altitude, em Taquaritinga do Norte, Pernambuco, Brasil. O estudo foi desenvolvido na fazenda Yaguara, e as áreas estudadas foram mata nativa com 4,57 ha e plantio de café sombreado com mata nativa com 25,59 ha. As amostras de solos foram coletadas em quatro trincheiras 1,5 x 1,5 x 0,60 m, com distância de 50 metros. Foram coletados solos nas profundidades de 0–20, 20–40 e 40-60 cm, seguido de análises químicas, físicas e densidade para determinação dos estoques de carbono no solo e frações lábeis. A área com café sombreado apresentou maiores valores de estoques de carbono no solo nas profundidades de 0-20 cm e 20-40 cm. Na profundidade de 40-60 cm, a topossequência de topo do SAF apresentou maior estoque de carbono com 11,73 Mg ha^{-1}, seguido da área com vegetação nativa com 10,6 Mg ha^{-1}, encosta com 9,23 Mg ha^{-1} e pedimento com 7,00 Mg ha^{-1}. Verificou-se que a topossequência de topo com café sombreado exibiu maior estoque de carbono lábil na profundidade 0-20 cm com o valor de 1,06 Mg ha^{-1}, sucedido das áreas de pedimento (SAF) com 0,88 Mg ha^{-1}, mata nativa com 0,79 Mg ha^{-1}e encosta com 0,67 Mg ha^{-1}. No entanto, a área de vegetação nativa apresentou o maior valor de carbono lábil na profundidade de 40-60 cm. Concluiu-se que a área com café sombreado na topossequência topo mostrou grande capacidade para elevar os estoques de carbono total e estoques de carbono lábil da matéria orgânica do solo.

Palavras-chave: Matéria orgânica do solo; Carbono lábil; Sistemas agroflorestais

1 INTRODUCTION

The C (carbon) stored in the MOS (soil organic matter) is the largest natural reservoir within the global C cycle, being fundamental in climate regulation (GONG *et al*., 2021). According to Mackay *et al*. (2021) a 5% increase in C stored in the soil promotes a decrease of atmospheric CO2 by a percentage of 16%, thus being an alternative to mitigate GHG emissions (greenhouse gases) from different sources. The addition of C in the soil is related to the photosynthesis process carried out by plants, followed by the deposition of branches and leaves and the formation of roots under the layers (BAUMGARTNER *et al*., 2021). Soil C stabilization mechanisms are associated with physical protection of SOM, chemical protection directed at the formation of organomineral compounds and maintenance of soil organic matter (HANKE; DICK, 2020). It is worth emphasizing that organic carbon is stored in two distinct fractions in the MOS: labile and stable. These fractions are defined by their impact and preservation period in the soil (OLIVEIRA *et al*., 2018). Labile organic matter in the soil mainly originates from the degradation of plant and animal biomass, root distillates and dead microbial biomass. Labile carbon is an easily accessible form of C stock for microbial action and, for this reason, it is identified as a fundamental source of energy for microorganisms (BONGIORNO *et al*., 2019).

The variability of soil carbon stocks is mainly influenced by climatic, environmental and topographic factors (WANG *et al*., 2021). In addition, coverage changes actively participate in C stocks, as they can reduce or increase them depending on the applied management (SILVA SANTANA *et al*., 2019). Forests and grasslands generally exhibit the highest C stocks among ground cover and are used as indicators (CHEN *et al*., 2019). It should be noted that the change in soil cover is the second factor that most favors C emissions and has significant impacts on soil C stocks (OLORUNFEMI *et al*., 2020). Thus, SAFs (agroforestry systems) have substantial potential in the C cycle and stocks (NATH *et al*., 2021), as they promote favorable chances of capturing and storing C in the soil (CHATTERJEE *et al*., 2018) due to high incorporation of above and below ground biomass, through leaf litter, secondary xylem and root system biomass (RODRÍGUEZ *et al*., 2021). According to Assunção *et al* (2019), the form of management used for the crops needs to be evaluated, as it influences the entry and quality of SOM, since traditional cultivation methods reduce the physical protection condition of SOM, unprotecting the degradation factors, causing the decrease of C and evidencing erosive processes.

Therefore, it is of great importance to know the effects of changes in land use on carbon and labile carbon stocks, as they act as early indicators of changes in soil quality due to management practices. The sensitivity and dynamism of labile carbon induced a wide adoption of these techniques in soil science as indicators of change in the soil ecosystem (DUVAL *et al*., 2018) and the agroforestry system as a potential for stabilizing and retaining carbon in the soil. Thus, the study aimed to determine soil carbon stocks and labile fractions under an agroforestry system and toposequences in an altitude marsh, Taquaritinga do Norte, Pernambuco, Brazil.

2 MATERIAL AND METHODS

2.1 Study area

The research was carried out at the Yaguara farm, inserted in the municipality of Taquaritinga do Norte, belonging to the geoenvironmental unit of the Planalto da Borborema, State of Pernambuco, in the geographical coordinates 7°53‘17”South and 36°5‘33”West.

The area is inserted in the relief called Brejo de Altitude, and the soil classified as Ultisols (SOIL SURVEY STAFF, 2014). The climate of the region was classified as Aw according to KÖPPEN (1948), of tropical climate with dry winter, mountainous relief with deep and narrow valleys. The highest rainfall was recorded between February and August, with an annual average of 721 mm and an annual average temperature of 21°C and altitude between 736 m and 1,100 m. The areas studied were two, one with native vegetation as a control and the other with planting coffee with native vegetation called shaded coffee.

The area of native vegetation is more than 60 years old and with 4.57 ha,and has large species of swamps between 20 and 35 m in height. Through the floristic survey, the experiment site presented the following forest species: *Galezia gorazema* Moq., *Rosaceae Rubus* sp. *lnga subnuda* Salzm. ex Benth., *Caesalpinia leiostachya* Benth. Ducke, *Copaifera trapezifolia* Hayne, *Roupala cearaensis* Sleumer, *Cedrela* sp., *Terminalia* sp., *Oreopanax capitatum* Decne *et* Planch. var. multiflorum (DC.) E. March, *Manilkara rufula* (Miq.) Lam, *Aspidosperma pyricollum* Muell. Arg. – “pereiro brabo”. Bignoniaceae *Tabebuia avellanedae* Lorentz ex Griseb. - “Pau-d’arco roxo” (LIMA, 2007).

The shaded coffee plantation area features native vegetation with rustic cultivation, has more than 30 years of *Coffea arabica* L plantation and has 25.59 ha. The native vegetation species present in this area were the same as those found in the native vegetation area. The percentage of shade generated by the native vegetation for the coffee was in around 75%. Coffee seedlings were planted within an area of native vegetation, where pits were opened with dimensions 0.40 x 0.40 m in width and depth, with a distance of 2 m from one of the others. The cultural treatments used were organic fertilization with the use of manure and chicken litter, thinning with a manual brush cutter, tree pruning.

As recommended by Embrapa (2006), 10 liters of cattle manure were applied per hole. The manures were tanned for 45 days, and the application was carried out fifteen days before planting. The application of the poultry litter used in the work consisted of doses of topdressing fertilization, 6.5 t ha^{-1} of poultry litter, with 4 reapplications. The doses were established based on the supply of nutrients required by the crop, according to the productivity levels established by technical bulletin 100 (RAIJ *et al*., 1997) carried out in two growing seasons.

In each area, four trenches were opened, with a distance between them of 50 m, with dimensions of 1.5 x 1.5 m and a depth of 0.60 m, in three mountainous slopes (45% to 75%), undulating (8% 20%) and gently wavy (3% to 8%), according to EMBRAPA (1979). The collections were carried out in the dry period of July 2020 according to the methods of Marinho-Júnior *et al* (2021). In each trench, samples of deformed and undisturbed soil were collected, at depths of 0–20, 20–40 and 40-60 cm, with the aid of a volumetric ring and uhland auger, for physical and chemical analyses. The deformed soil samples were air-dried at room temperature and sieved at 2 mm. The undisturbed soil samples were submitted to soil density analysis, which was obtained by the volumetric ring method described by Grossman and Reinsch (2002).

The samples of soil and light organic matter - LOM obtained by the method adjusted by Fraga and Salcedo (2004), were macerated in a porcelain mortar and pistil until it formed a fine powder and passed through a 150 μm mesh sieve. The determination of carbon - C of the soil and light fraction was carried out through this fine powder, by the dry combustion method (CHNS / O) in an elementary analyzer (Model PE-2400 Series II Perkin Elmer). Labile carbon (C-labile) was determined by oxidation with 0.033 mol L^{-1} potassium permanganate ($KMnO_4$) solution (BLAIR *et al*., 1995).

The C concentrations were converted into soil carbon stock (SCS) in Mg ha^{-1} for each depth sampled as follows (ARAUJO FILHO *et al*., 2018) the Equation (1):

$$Stock\ C = (Cc \times Sd \times VSD) \times 1000 \quad (1)$$

Where, Stock C is the carbon stock in the soil layer, in (Mg ha^{-1}); Cc is the carbon concentration in the soil sample, in (kg Mg^{-1}); Sd is the soil density in the layer, in (Mg m^{-3}) and the VSD is the volume of sampled depth, in (m^3). The total stock of C at a depth of 0 to 50 cm was calculated by adding the values obtained in each sampled layer.

The parameters evaluated concentrations and stocks of C, light organic matter and labile fraction of the soil were subjected to normality tests Shapiro and Wilk, then performed the analysis of variance to assess the differences between the uses of the soil in the depths. The comparison of means was performed by the Tukey test at 5% significance and using the statistical software SISVAR (FERREIRA, 2011).

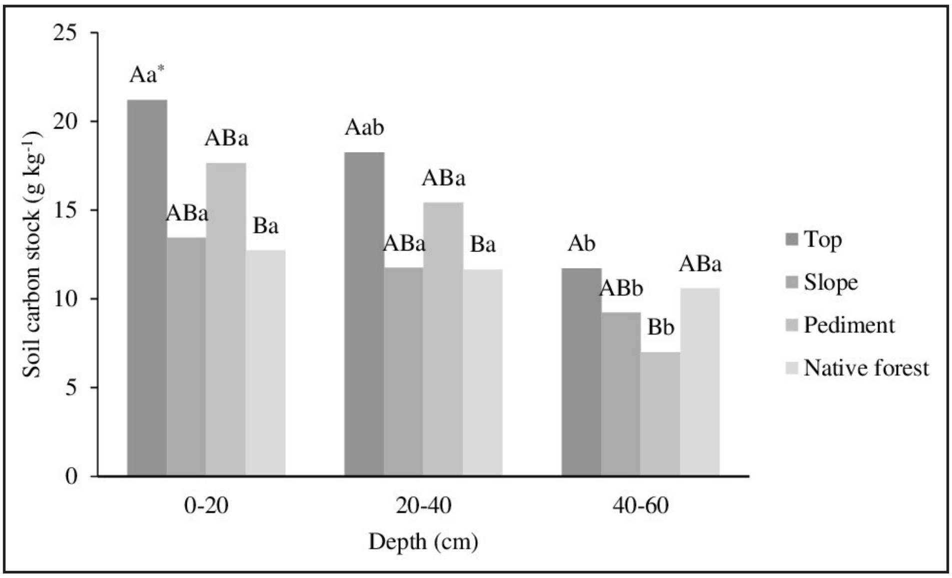
3 RESULTS AND DISCUSSION

Carbon stocks at different depths, toposequences and vegetation were shown in Figure 1.

There was a 5% probability of difference between the areas evaluated in this study. The areas evaluated for carbon stocks were toposesequences described by top, slope, pediment, both with shaded coffee, and native forest witness, which were differentiated by capital letters, and in depths of 0-20 cm, 20-40 cm and 40-60 cm, which were differentiated by lowercase letters.

It was found that the area with the highest carbon stock in the soil was the top with shaded coffee (SAF) at a depth of 0-20 cm with a value of 21.22 Mg ha^{-1}, followed by the bedding areas (SAF) with 17.66 Mg ha^{-1}, slope (SAF) with 13.45 Mg ha^{-1} and witness of native forest with 12.74 Mg ha^{-1}, all at the shallowest depth. The smallest stocks were seen at depth 40-60 cm in all areas evaluated. The top area with shaded coffee had the highest stocks at all depths. Carbon stocks can be influenced by several factors, among them are the biomass of leaves and roots, the density, texture and clay content of the soil and the entry of decomposed litter in the profile is one of the most prominent factors. In agroforestry systems, biological activity, root exudates, humus formation and decomposition activity is more favored, which facilitates litter decomposition (GUILLEMOT *et al*., 2018; ZHANG *et al*., 2021).

Figure 1 – Soil carbon stocks at different depths and toposequence under an agroforestry system in an altitude marsh, Taquaritinga do Norte, Pernambuco, Brazil



Source: Authors (2021)

In where: *Significant differences are indicated by different letters by the Tukey test at 5% significance level; Capital letters indicate differences between toposequence and lower letters indicate differences between soil layers.

As explained Seifu *et al*. (2021), topographic factors have a strong influence on soil carbon stocks and cause great variability. Therefore, the highest concentration of carbon stocks in the upper areas may be associated with milder temperatures, which limits the degradation of carbon stocks (SEIFU *et al*., 2021; TSOZUÉA *et al*., 2019). Recent researches demonstrate that topographic factors play a fundamental role in the stabilization and accumulation of soil carbon stocks. Wang *et al*. (2019) quantified the relative contribution of biotic and abiotic factors that affect the spatial variation of aboveground litter stock and concluded that the influence of environmental and topographic factors on litter percentage was very expressive, exceeding the value of 71%. Qiao *et al*. (2019) demonstrated that the effectiveness of carbon use could decrease in regions with milder temperatures compared to warm areas, for reasons that the rate of climate warming occurs faster in high latitudes than in low ones. Zhang *et al*. (2018) reported that the slope toposequence is more susceptible to erosion, as the slope is an important factor when dealing with erosive processes, especially those caused by water, which can mobilize carbon stocks. Thus, the top toposequence is more favored with carbon stocks due to its reduced surface water runoff, which allows stocks to become more immobilized. (SEIFU; ELIAS; GEBRESAMUEL, 2020).

Over time, topographic factors can also modify some soil properties that influence its biogeochemical processes, which allow the elements to interact with nature (SURIYAVIRUN *et al*., 2019). Nitzsche *et al*. (2017) showed that due to erosion or hydrological flux soluble carbon particles, transported from the slope toposequence, can accumulate in the pediment toposequence, increasing the carbon stocks deposited in this area, which may explain the fact that among the toposequences analyzed in the pediment area have shown the second highest values (MOGES *et al*., 2020). Poudel, Sasaki and Abe (2020) found similar results to this study in their work, related to toposequence, with average carbon stocks ranging from 78.6 Mg ha^{-1} in the lowest area to 251.1 Mg ha^{-1} in the highest area.

Based on the results obtained in this work, it should be noted nutrient cycling is a process that occurs in all forest ecosystems, but each one has a different dynamic of storing carbon in the compartments and different flows of these stocks. The reason why this occurs involves factors such as vegetation characteristics, climatic variables, microbiological action, among others that influence litter input, as well as influencing decomposition processes (BARBOSA *et al*., 2017).

In this way, agroforestry systems, when compared to native vegetation, have higher carbon stocks because there is greater deposition of organic matter with different C/N (carbon/nitrogen) ratios, that is, because there is a combination between perennial and agricultural, it favors a greater contribution of organic carbon, mainly in the upper layers of the soil, due to the action of the microbiota being more favored in the SAFs (ROSA; NETO, 2019). Furthermore, the addition of animal manure associated with the deposition of straw from planting is a favorable tool for increasing soil carbon levels (TROMBETTA *et al*., 2020).

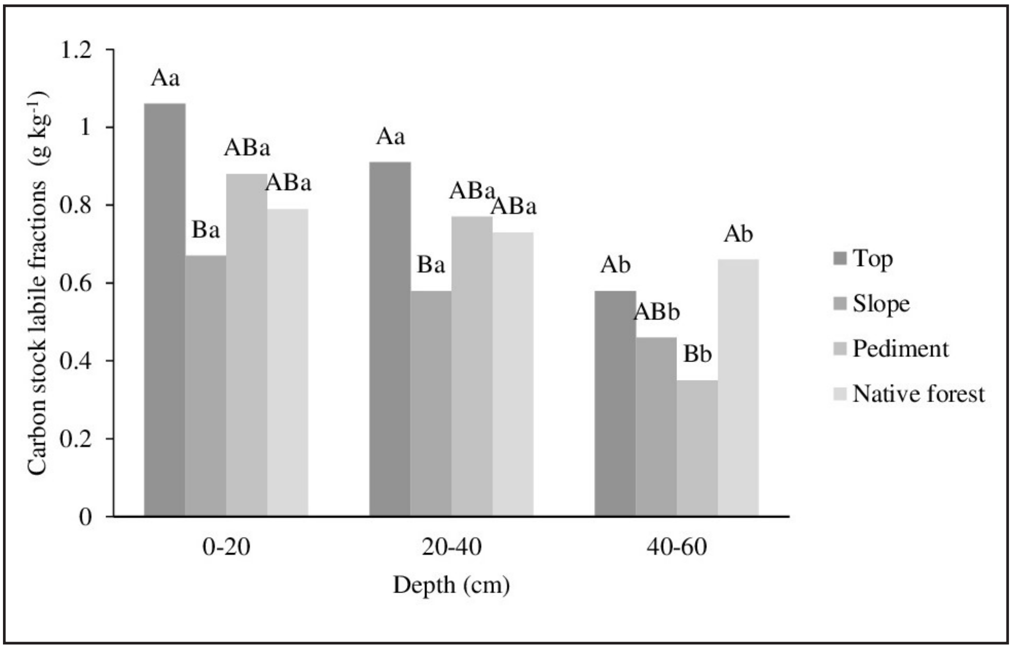
Rosa and Neto (2019), observed in their work comparing physical attributes and carbon stock in agroforestry systems, findings similar to those obtained in this study, where in the more superficial layers there was a predominance of carbon stocks in the areas of SAFs and already in the deeper layer evaluated (40-50 cm) the native vegetation exceeded the SAFs in carbon stocks (ROSA; NETO, 2019). This factor is mainly due to the crop residues that favor the entry of C at the most superficial depth (LIM *et al*., 2018).

In relation to the carbon stocks in the 40-60 cm layers of the soil, these have lower values. It was found that the pediment toposequence area had the lowest value among the other areas evaluated with 7.00 Mg ha^{-1} of carbon stock. This lower value in pediment toposequence area, which can be explained by the fact that the lower slope of the relief allows greater retention and vertical infiltration of water, which favors the mobilization of carbon stocks (CANELLAS *et al*., 2000). The second lowest value was found in the slope toposequence with the value of 9.23 Mg ha^{-1}. As explained by Canellas *et al*. (2000) in their work, the pedogenesis processes are accentuated in this area, as well as the slope contributes to the drag of particles, thus decreasing the carbon penetration along the profile.

For the 40-60 cm layer, the top area had the highest soil carbon stock value with 11.73 Mg ha^{-1}. This area allows an environment in which carbon stocks are more immobilized (SEIFU; ELIAS; GEBRESAMUEL, 2020). In relation to native forest, this had the second highest value of carbon stock in the 40-60 cm layer with 10.6 Mg ha^{-1}. This result is associated with the fact that soil disturbance is not very expressive in this area (MARINHO-JUNIOR *et al*., 2020). Isernhagen *et al*. (2017), Freitas *et al*. (2018) and Santos *et al.* (2019) demonstrate in their work this tendency of carbon stocks to decrease in depth and that they are more expressively present in the more superficial layers, which corroborates the results presented in this study.

Carbon stocks in the labile fractions at different depths, toposequences and vegetation were shown in Figure 2.

Figure 2 – Carbon stocks in labile fractions at different depths and toposequence under an agroforestry system in an altitude marsh, Taquaritinga do Norte, Pernambuco, Brazil



Source: Authors (2021)

In where: *Significant differences are indicated by different letters by the Tukey test at 5% significance level; Capital letters indicate differences between toposequence and lower letters indicate differences between soil layers.

There was a 5% probability of difference between the areas evaluated in this study. The areas evaluated for carbon stocks in the labile fractions were toposesequences described by top, slope, pediment, both with shaded coffee, and native forest witness, which were differentiated by capital letters, and at depths of 0-20 cm, 0 -40 cm and 0-60 cm, which were differentiated by lowercase letters. It was found that the area that exhibited the highest labile carbon stock was the top toposequence with shaded coffee (SAF) at depth 0-20 cm with the value of 1.06 Mg ha^{-1}, followed by the bedding areas (SAF) with 0.88 Mg ha^{-1}, witness of native forest with 0.79 Mg ha^{-1} and just after the slope area (SAF) with 0.67 Mg ha^{-1}, all at the most superficial depth. The smallest stocks were evidenced at depth 40-60 cm in all areas evaluated. According to Cui *et al*. (2021), it is essential to describe the dynamics of labile carbon stocks during crop development to understand the stabilization of soil organic matter. Labile carbon is the most reactive part of soil organic matter, which makes it very sensitive to environmental changes and that it also plays a key role in soil microbiota and, consequently, in nutrient cycling (CUI *et al*., 2021).

The top area is more favored in terms of labile carbon stocks and this is due to the fact that the altitudinal gradient influences the concentration of MOS, as well as the solar incidence, precipitation and deposition processes (SEIFU; ELIAS; GEBRESAMUEL, 2020). Other authors highlight the importance of topography in carbon stocks such as Patton *et al*. (2019) and Arunrat *et al*. (2020). The efficiency of the use of carbon stocks can vary depending on altitude, becoming more immobilized in colder regions and more reactive in warmer regions, so the rate of climate warming varies with altitude, being faster in higher and higher areas. slower in lower areas (QIAO *et al*., 2019).

Zhang *et al*. (2018) showed results in their study evaluating the effects of topography on carbon stocks that values were higher in the top and slope areas more inclined than the footing position, thus, the topography, a fundamental driving factor for the spatial distribution of labile carbon stocks.

The values of labile carbon stocks in the top area with a depth of 0-20 cm, in this study, corresponded to almost 5% of the total carbon stock values. Isernhagen *et al*. (2017) verified this same tendency of the labile carbon stock to be more notorious in the more superficial layers and to decrease in depth, related to the accumulation of biomass. According to Nitzsche *et al*. (2017) the slope area has the most facilitated erosion processes and that consequently may present reduced soil fertility and productivity due to leaching and, in parallel, soil fertility may increase in bedding areas due to the deposition of organic carbon from the slope (NITZSCHE *et al*., 2017).

4 CONCLUSION

Overall, the area with shaded coffee in the top toposequence showed great capacity to increase total carbon stocks and labile soil organic matter carbon stocks.

The agroforestry system proved to be important for the use of the land in a more appropriate way, increasing the carbon reservoirs.

The increase in soil C stocks was due to the lack of soil preparation, climatic conditions and topography in areas with shaded coffee.

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