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Carbon Management Index and Carbon Stock of a Cohesive Oxisol Under Different in the Region Northeast of Brazil

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Abstract

The objective of this study was to evaluate the soil organic carbon fractions and the carbon management index (CMI) in a cohesive oxisol under different uses. Conventional cassava planting (CC), pasture (PP), and 7- and 12-year agroforestry systems (AF7 and AF12, respectively), were tested against secondary forest (SF). Soil samples of these areas were physically fractionated in order to determine total organic matter (TOC) as well as the labile- (LOC) and non-labile (NOC) fractions of the soil organic matter, as well as carbon management index (CMI). Total organic C ranged from 14.17 to 27.20 g kg^{-1} of soil, showing no differences in the surface layer among the land uses as compared to the secondary forest. No differences were found in the surface layer for LOC as well, except for the AF12 where LOC was higher. This condition accounts for higher microbial activity and nutrient cycling in the soil. This system also showed higher CMI values, pointing to a better response of soil quality under long-term agroforestry system. This system improved soil organic matter, regardless of the depth. On the other hand, conventional cassava and planted pasture systems reduced carbon in soil. In conclusion, the agroforestry system is the best choice of farmers, when they seek for better soil quality.

Keywords: carbon, soil quality, soil management

1. Introduction

Cohesive Oxisols are widely found in the tablelands of northeast coast of Brazil which includes the Recôncavo of the state of Bahia (Araújo et al., 2018). In such a tropical region, the rate of turnover of organic matter is particularly high and the content is low. However, despite the low content, organic matter is still an important carbon reservoir and a source of energy for biological activity and nutrient cycling (Janzen, 2014; Lehmann & Kleber, 2015). In addition, it enhances soil structure, water holding capacity, mineralization and immobilization of nutrients. Therefore, it is important to define which kind of use farmers will put on these soils in order to prevent loss increase soil quality.

The intensity of soil management influences organic matter contents and fractions. Therefore, both, content and fraction of organic matter are considered important indicator of the quality and sustainability of agro-ecosystems (Trigalet et al., 2017). Among the conservationist management systems, agroforestry (AFS's) can be the most appropriated for small farmers in the region of Recôncavo/Bahia. As it put together agricultural crops and tree species, this system promotes greater coverage and protection, reducing soil, water and nutrient losses by erosion and/or leaching. The beneficial changes are especially related to the capacity of the soil to store and supply water to the plants, besides promoting a higher structural quality of the soil, mainly due to the input of organic matter (Chen et al., 2017). On the other hand, long-term-conventional management system is such an intensive land use of soil that decreases organic matter and disturb soil structure, increasing soil density and reducing water infiltration (Bertol et al., 2015), besides some other undesirable effects on physical, chemical and biological attributes of the soil (Araujo et al., 2012; Šimanský et al., 2013).

Due to the great importance of organic matter to chemical, physical and biological properties of weathered soils, such as the oxisols, in tropical ecosystems (Vasconcelos et al., 2010), many studies aimed to understand the impacts of land use and management at the cerrado region. However, more information about the impacts of land use and management on soil carbon is still needed for cohesive oxisols.

Dystrocohesive Yellow Oxisols, especially in the Coastal Tablelands in Brazil, are known to present strong agricultural limitations, such as low fertility. In addition, the high resistance subsurface horizon reduces the effectiveness of soil depth (Corrêa et al., 2008). This horizon has lower pore volume which reduces water infiltration and root growth. Land use and management alternatives that mechanically reduce the cohesiveness of these layers have ephemeral effects. Only increasing organic matter can positively affect the soil attributes in the long term.

The carbon management index (CMI) is highly sensitive to the changes caused by soil management systems (Loss et al., 2011a; Rossi et al., 2012). In this study we measured carbon stock and CMI, based on the carbon fractions in the soil, under conventional cassava planting, seven-year- and twelve-year-agroforestry system (AF7 and AF12, respectively) and planted pasture; all of them compared to a natural secondary forestry condition, as proposed by Schiavo et al. (2011). Therefore, this study aimed to indicate the lowest impact scenario for the farmers to appropriately use these soils.

2. Material and Methods

The study was done in the Recôncavo region, Bahia, at 39°5′28″W and at 12°41′50″S, 226 meters of altitude, in a flat to slightly hilly landscape in the Atlantic Forest biome. The climate is tropical and humid, according to Köppen, with 900- to 1300-mm annual precipitation. The rainy season goes from March to August and the annual mean temperature is 24.5 °C. The main soil classes in the Recôncavo region are dystrocohesive Yellow Oxisol and dystrocohesive Yellow Ultisol. The soil class in the whole experimental area is a sandy-clay-loam dystrocohesive typical Yellow Oxisol.

The experimental design consisted of conventional cassava cultivation (CC), planted pasture (PP), and 7- and 12-year agroforestry systems (AF7 and AF12, respectively), all of them compared to a secondary forest area (SF). In order to sample the soil, 1 ha was randomly selected in each of the experimental sets, and soil was sampled at 0-0.1-, 0.1-0.2-, and 0.2-0.4-m layers; five composite samples, made of five simple samples, were collected from each area.

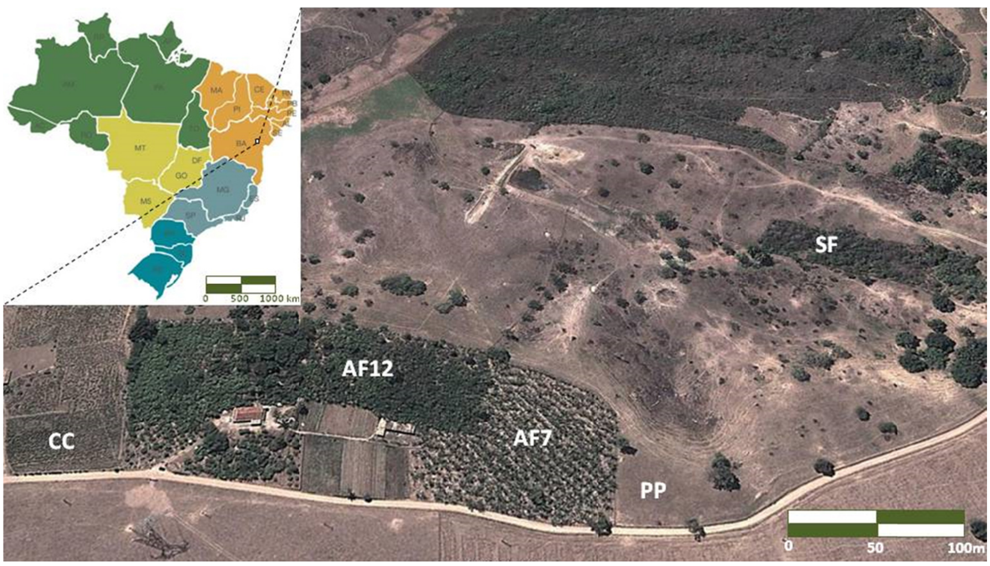

Figure 1. Experimental area of land use and management systems in the Recôncavo region, Bahia

Amount of total organic carbon (TOC) was quantified according to an adaptation of Walkley and Black (1934). The samples were physically fractionated in order to obtain the particulate organic carbon (POC) (Cambardella & Elliot, 1992) which was also measured according to an adaptation of Walkley and Black (1934). An aliquot of 20 g of soil was shaken with 60 mL of sodium hydroxide solution (5 g L^{-1}) for 15 hours on a horizontal shaker at 155 rpm. Then, the suspension was sieved to 0.053 mm. The retained material, that contains sand and particulate organic carbon, was oven dried at 50 ºC until constant weight. After drying, mass was quantified, the whole material was ground and the amount of carbon was measured using $K_2Cr_2O_7$ 0,667 mol L^{-1} in sulfuric acid, as an adaptation of the method of Walkley and Black (1934) (Cantarella et al., 2001).

The carbon management index (CMI) was calculated according to the expression: CMI = CPI × LI × 100, as described by Blair et al. (1995), where CPI represents the C Pool Index and LI represents the Lability Index. By comparing the CMI of a cropped area with the CMI of an uncropped/sustainable area (CMI = 100) one can have a fair estimation of how damageable is a given crop system to the soil. Therefore, in this study, the CMI of the cropped areas were compared to a secondary forest area where the soils are well preserved. The CMI was calculated based on the changes in TOC and LC between a reference system (secondary forest) and an under farm management system. To obtain the values of the carbon compartment index (CPI) and the lability index (LI) the following expressions were used: CPI = TOC at a given management system/TOC at the reference system and LI = L at a given management system/L at the reference system, where, L = LC/NLC: labile carbon (LC) and non-labile carbon (NLC).

In order to determine the stock of soil carbon, the following equation was used: EstC = (TOC × Ds × z)/10, where, EstC: soil carbon stock (Mg ha^{-1}), TOC: total organic carbon (g kg^{-1}), Ds: soil density (g dm^{-3}) and z: soil layer thickness (cm).

The results were compared using the Scott Knott test at 5% probability using the 5.6 version of Sisvar software (Ferreira, 2011).

Description of the experimental area (treatments):

Seccondary Forest (SF): it has been persevered for 30-year with native tree species such as mimosa-black (*Anadenanthera macrocarpa* Benth.), Brazilian pepper (*Schinus terebinthifolius* Radii), cedar (*Cedrela fissilis* Vell.), Jurema (*Mimosa hostilis* Benth.).

Agroforestry system (SAF7): Is has been mainly cropped for 7 years with cacao tree (*Theobroma cacao*) and the banana (*Musa spp*.). As secondary crops, there are other fruit species (*Theobroma grandiflorum, Spondias dulcis, Plinia cauliflora*) and native trees of the region. The former use was with orange (*Citrus sinensis* L. Osbeck). The system was manually implanted and, after three years, it was chemically fertilized (10:10:10) and amended with nine tons of chicken manure per hectare.

Agroforestry system (SAF12): This area was established 12 years ago, also with cacao tree (*Theobroma cacao*) and the banana (*Musa* spp.) as the main crops. As secondary crops, there are other fruit species (*Theobroma grandiflorum*, *Spondias dulcis*, *Plinia cauliflora*) and native trees. The former use was with orange *Citrus sinensis* L. Osbeck). The system was also manually implanted and it was limed and organically fertilized six years after implantation.

Planted pasture (PP): This area was implanted and has been grazed since 1987. The main specie is *Urochloa sp*. It was formerly composed of native vegetation, mainly Jurema (*Mimosa hostilis* Benth.). During implantation, the soil was plowed, limed and fertilized. It is in continuous grazing during most of the year. The soil in this land use system was never limed nor fertilized after the implementation of the system.

Conventional Cassava Crop (CC): This area has been cropped using conventional tillage for more than 50 years. It has been plowed and disked every year, as well as subsoiled as necessary, in order to cultivate cassava. Additionally, there is an alternation of crops in the area with yam (*Colasias esculenta*) and sweet potatoes (*Ipomoea batatas*). The soil was limed in 2001 and amended with castor bean cake every 10 years. There is no for the fertilization of system period of application.

3. Results and Discussion

Amounts of TOC ranged from 14.17 to 27.20 g kg^{-1} of soil (Table 1), with no difference ($p > 0.05$) in the 0-0.10-m layer among the treatments. On the other hand, TOC was higher in the 0.1-0.2-m layer of soil in the secondary forest, as compared to the other treatments, which is accounted for by the higher density of roots as well as the contribution of organic matter to the soil by the native vegetation. In the 0.2 to 0.4-m layer, the AF12 and AF7 systems, and the reference secondary forest also showed higher TOC, compared to the conventional cassava and planted pasture. In soils under pasture, the root system is closer to the surface, whereas the frequent tillage increases turnover in the soil of conventional tillage due to the breakdown of aggregates. Working with no-till in integrated crop-livestock system, the results of Loss et al. (2011a), showed the same trend as found here. In another work, Loss et al. (2011b) showed that when corn is cultivated under conventional till, it reduces organic carbon of soil. In a dystrophic Red Oxisol with native vegetation, in the region of Maracaju-MS, the TOC levels were higher, when compared to the no-tillage system and the agroforestry system (Silva et al., 2011).

Table 1. Total organic carbon (TOC), particulate organic carbon (POC), and carbon associated to minerals (CAM) of a Dystrocohesive Yellow Oxisol under different land use and management

MANN.	TOC	CAM	POC	CAM/TOC	POC/TOC
	---------------------------- g kg^{-1} ----------------------------			------------------- % -------------------	
0-0.1 m					
SF	25.06 a*	20.14 a	4.92 a	79.65 a	20.35 b
AF12	27.20 a	21.22 a	5.98 a	70.00 b	29.99 a
AF7	23.67 a	18.18 a	5.48 a	76.62 a	23.28 b
PP	25.52 a	20.57 a	5.95 a	77.66 a	22.33 b
CC	14.17 a	9.29 a	4.88 a	65.59 b	34.41 a
0.1-0.2 m					
SF	26.86 a	22.70 a	4.15 b	80.84 a	19.16 b
AF12	16.68 b	11.24 b	5.44 a	62.80 b	37.20 a
AF7	13.92 b	9.47 b	4.45 b	67.75 b	32.25 a
PP	19.32 b	15.09 b	4.22 b	77.36 a	22.64 b
CC	14.50 b	9.77 b	4.73 b	66.66 b	33.34 a
0.2-0.4 m					
AF	18.27 a	14.01 a	4.06 a	76.42 a	23.58 b
AF12	20.07 a	15.70 a	4.37 a	77.00 a	23.00 b
AF7	18.91 a	14.03 a	4.88 a	72.39 a	26.61 b
PP	15.66 b	11.60 a	4.06 a	73.99 a	26.01 b
CC	10.93 b	6.60 b	4.26 a	60.17 b	39.83 a

Note. * Means followed by the same letters do not differ from each other, according to the Scott-Knott test (5% probability).

Under the AF7 and AF12 systems, as well as in the secondary forest, the root system is deeper, mainly in the AF12. Changes in soil TOC contents, as a function of management practices, are better detected throughout the years of cultivation (Xavier et al., 2013).

Replacing native vegetation by annual crops, pastures and/or commercial forest may lead to a decrease in the organic carbon stocks in the soil, due to increasing erosive processes, decomposition of organic matter, and reduction of quality and quantity of the residues on the soil surface (Lima et al., 2008). Additionally, residues are removed or incorporated to the soil in order to enter with a new crop, as often happen in the conventional systems.

Amount of particulate organic carbon (POC) is often shown as a good indicator of the changes caused by different land uses and management of soils (Figueiredo et al., 2010). In the case of 0-0.1- and 0.2-0.4-m layers, no changes due to different land uses and management systems were detected (Table 1). This was also found elsewhere by Santos et al. (2017) that did not found any changes on POC of soil under native and cultivated pastures, compared to native area, at 0-0.1- and 0.1-0.3-m depth. Even incorporating green manure in soil did not affect the POC levels in the 0-0.1-m depth, as found by Xavier et al. (2016).

Amount of POC was higher in the AF12 (Table 1), showing the superiority of this system to microbial activity and nutrient cycling, since POC can be considered the labile fraction of soil organic matter (Xavier et al., 2016). Under crop-livestock system, soil has higher POC, even compared to no-till system, pasture or native forest, as shown by Gazolla et al. (2015). Here, the amounts of POC ranged from 6.6 to 22.7 g kg^{-1}. As expected, in the 0-0.1-m layer there were no differences among the treatments, since POC is barely affected by soil management. However, in the 0.1-0.2-m, POC was high only in the secondary forest, what is due to the higher humification of organic matter. As for the 0.2-0.4-m layer, the conventional cassava system showed the lowest amount of POC (Table 1). This is due to the intensive use of soil which reduces stabilization of organic matter.

In this study, the AF systems are composed mainly by banana e cocoa trees. The residues of such plants are more difficult to be decomposed. The residues of these plants have higher C/N ratio, as pointed elsewhere by Gazolla et al. (2015). This favors the increase of carbon which is bound to silt and clay particles as organo-mineral complexes.

Organo-mineral complexes favor soil micro aggregation, which positively affect structure, porosity, density and water infiltration (Loss et al., 2011b). Therefore, increasing POC is a good indicator of the physical quality of soil.

Six et al. (1998) observed that land use by agricultural practices strongly affected soil aggregation, mainly due to the reduction of intermicroaggregated organic carbon fractions that have the capacity to stabilize macroaggregates. Saha et al. (2011), studying the impact of soil use on organic carbon fractions and aggregate stability, found that in pasture and forest soils the stability of gravels was higher than agriculture and degraded areas.

Higher CAM/TOC ratios were observed in the pasture, secondary forest, and AF7 systems; about 80% in the 0-0.1-m layer (Table 1). The same was observed for the 0.1-0.2-m layer of the PP and SF. In the 0.2-0.4-m layer the conventional cassava system showed the lowest ratio.

The AF12 showed higher CMI (Figure 2), which means that this system is the one to give higher quality to the soil. The other treatments had higher CMI than the secondary forest only in the 0-0.1-m layer. In the northeast region, soils under agroforestry management systems show CMI values very close to the secondary forest (Souza et al., 2016).

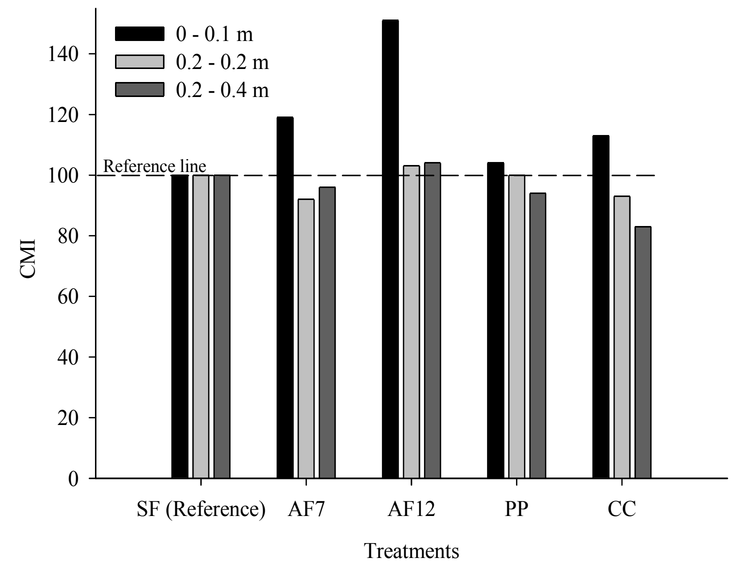

Figure 2. Carbon Management Index (CMI) in different systems of use and management, of a Dystrocohesive Yellow Oxisol in the Recôncavo region, Bahia. SF: secondary forest; AF7: 7-year agroforestry system; AF12: 12-year agroforestry system; PP: planted pasture; and CC: conventional cassava system

No differences were found for carbon stocks in the 0-0.1-m layer ($p < 0.05$) among the management systems (Figure 3). Under the secondary forest, carbon stock was higher than the other treatments in the 0.1-0.2-m layer, which represents the higher capacity of this system for carbon sequestration. On the other hand, the conventional cassava system had 54% less carbon than the secondary forest. Sacramento et al. (2013), comparing conservationist systems against conventional systems, verified that the forest-crop-livestock system caused less loss of C, compared to the conventional system, where losses were up to 58.87 Mg ha^{-1}.

Replacing native forest for other crop systems impact organic carbon and result in carbon emission to the atmosphere (Siqueira Neto et al., 2011). Therefore, it is essential to search for agricultural management systems that maintain or increase carbon in the soil.

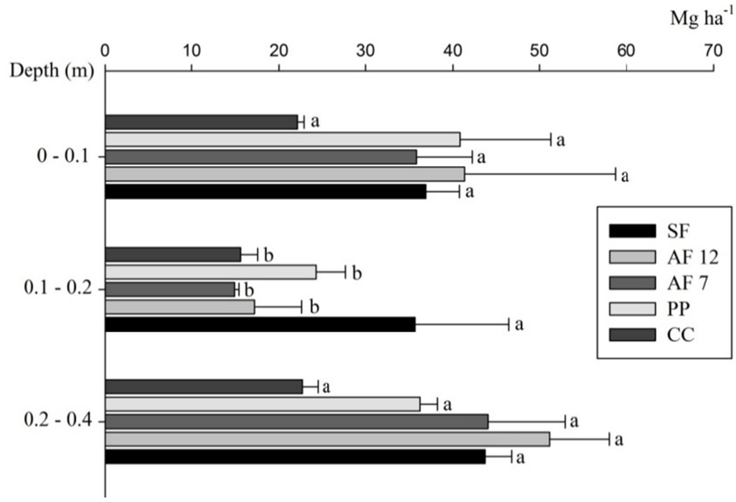

Figure 3. Soil carbon stock (EstC) in different systems of use and management of a Dystrocohesive Yellow Oxisol in the Recôncavo region, Bahia. CC: conventional cassava; PP: planted pasture; AF7: 7-yerar agroforestry system; AF12: 12-year agroforestry System; SF: Secondary forest. Bars with the same letter do not differ from one another within each treatment, by the Scott Knott test at 5% probability

In the present study, the results shows the possibility that the higher levels of each carbon parameters at 0.2-0.4m, provided by AF7 and AF12, contribute to the reduction of cohesive layer in the region of this soil in the Recôncavo region of Bahia.

4. Conclusions

Agroforestry systems were the best systems to maintain soil organic matter in a Dystrocohesive Yellow Oxisol of the Recôncavo Region, Bahia.

The Carbon Management Indexes of agroforestry systems were the most closer to the secondary forest area, especially in the more superficial layers of the soil, compared to planted pasture and conventional cassava system.

Conventional cassava and planted pasture caused the highest impacts on organic carbon in a Dystrocohesive Yellow Oxisol of the Recôncavo Region, Bahia.

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