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CARBON IN THE LABIL FRACTIONS OF SOIL ORGANIC MATTER IN SAVANNAH AREAS

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Abstract: This research aimed to evaluate the levels and stocks of carbon in the soil, as well as its physical fractions (COp and COam) in areas under different land uses in the Savannah in Bahia. The environments selected for the evaluations consisted of: area under native savannah vegetation *strict sensu* (ACN); area under conventional banana plantation (APB); area with agroforestry system with cocoa, mango and banana plantations (SAFs); and area under 7-year-old eucalyptus plantation (EUC). Soil samples were collected in layers of 0-10, 10-20, 20-30, 30-40 and 40-50 cm for the determination of total organic carbon (TOC) and particulate organic carbon (COp), mineral-associated organic carbon (COam) and BMI. The EUC treatment proved to be the most efficient use of soil in accumulating carbon in all the evaluated soil layers, as it presented the lowest losses in the carbon tors and higher stocks of this, in relation to the other treatments. The AEU and SAFs proved to be efficient in accumulating organic matter at a depth of up to 30 cm, as they presented BMI values higher than the equilibrium area (ACN).

Keywords: Particulate carbon, organic matter, carbon management index.

INTRODUCTION

With the increasing expansion of the agricultural sector, much has been discussed about the different uses of the soil for food production, and the conventional preparation practices that have been compromising the chemical, physical and biological properties, causing significant losses of soil organic matter, restricting soil organic carbon content, which, together with human action, has contributed to climate change with the emission of gases such as carbon dioxide (CO_2).

The soil tends to act as a carbon deposit, contributing to the sequestration of this from the atmosphere, or in the opposite direction. Since conventional planting is the most used management system in the country, excessive soil disturbance has influenced organic carbon stocks. as an alternative for sustainable production. Currently, the most effective way to store carbon in the soil is through the adoption of new technologies with less aggressive practices, capable of maintaining and/or increasing soil organic carbon, increasing and improving the quality of soil organic matter. (MOS) consequently contributing to the maintenance of the productive capacity of cultivated areas.

Due to its high sensitivity to management practices, organic matter is considered one of the main indicators of sustainability and environmental quality. Since its dynamics is influenced by the direct impact of the adopted systems, its contents in the soil can be altered with greater or lesser intensity. In this sense, the carbon management index (BMI) takes into consideration, the labile fractions of SOM, presenting itself as a measure for assessing the capacity of management to promote soil quality, comparing its alterations. Therefore, BMI takes into consideration, carbon stock and lability (BRAGA et. al., 2022).

Considering the need to obtain indices that can prove the ability of new agricultural practices to promote an increase in soil quality, as a way of evaluating the performance of a given soil use, this research aimed to evaluate the levels and stocks of carbon in the soil, as well as in their physical fractions (COp and COam) in areas under different land uses in the Savannah in Bahia.

MATERIAL AND METHODS

The research was conducted in the municipality of Barreiras, located in the extreme west of Bahia, between the coordinates 12° 08’00” South latitude and 44° 59’00” West longitude, with an altitude of 452 m. The climate, according to the Koppen classification, is BSh type, hot and dry with winter rains, with an average temperature that varies around 24.3° C. Annual precipitation averages 1,122mm, ranging from 900 at 1,500 mm/year and the average annual evapotranspiration of 1,575.4 mm, and the monthly average is around 131.3 mm. The rainy period occurs between October and March, and the dry period between April and September (BARREIRAS, 2010).

The following areas were studied: native savannah (ACN); banana plantation area (APB); area planted with agroforestry systems (SAFs) and eucalyptus planting area (EUC). The predominant pedological cover of the western region of Bahia consists of LATOSSOLOS with sandy and medium texture (REATTO et al., 2005).

In each area, 25 points were demarcated 25 m apart, and, through a raffle, 05 points were located for opening five profiles, with dimensions of 1 meter in length, 1 meter in width and 0.5 meters in depth. The five profiles in each area represented the 05 repetitions. After opening the profiles, deformed soil samples were collected at the following depths: 0-10 cm; 10-20cm; 20-30cm; 30-40 cm and; 40-50 cm, stored and identified for determination of carbon contents. Undisturbed soil samples were also collected at the same depths to assess soil bulk density (Ds).

After being duly identified, the samples were transported from the field to the Soil Chemistry and Physics Laboratories belonging to the Department of Human Sciences at ``Universidade Estadual da Bahia``, UNEB. The deformed samples were air-dried, crushed and passed through 2.0 mm mesh sieves to obtain the air-dried fine earth fraction (TFSA).

The chemical analyzes consisted of determining the total organic carbon (TOC) contents at different soil depths following the methodology suggested by Embrapa, (2017). The physical analysis consisted of determining the soil density (Ds), following Embrapa methodology, (2017).

The carbon stocks were obtained by correcting the soil mass using the layer and the soil equivalent mass through the reference soil mass (Ellert et al., 2001 *apud* Demessie et al., 2013), with the reference being ACN. To calculate the equivalent mass, the relative mass of the soil in the different forms of use was considered by the following expression:

$$\text{Msoil} = \text{ds} \times \text{E} \times \text{A} \qquad (\text{"Equation 01"})$$

being:

Msoil = soil mass, expressed in Mg ha^{-1};

ds = soil density, expressed in Mg m^{-3};

E = espessura, expresso em m;

A = area, 10,000 m2.

After defining the soil mass, the native savannah area (ACN) was considered as the reference area. Then, calculated the soil layers to be added or subtracted in order to match the soil masses of the treatments. To calculate the layers to be added or subtracted, the following expression was used:

$$\text{Ead/sub} = (\text{Mref-Marea}) \text{x} \frac{\text{fha}}{\text{ds}} \qquad (\text{Equation 02})$$

being:

Ead/sub = soil thickness of the layer to be added (+) or subtracted (-), expressed in m;

Mref = soil equivalent mass of the reference area, ACN, expressed in Mg ha^{-1};

Marea = soil equivalent mass of the area, expressed in Mg ha^{-1};

fha = conversion factor from ha to m^2 (0,0001 ha m^{-2});

ds = soil density, expressed in Mg m^{-3}.

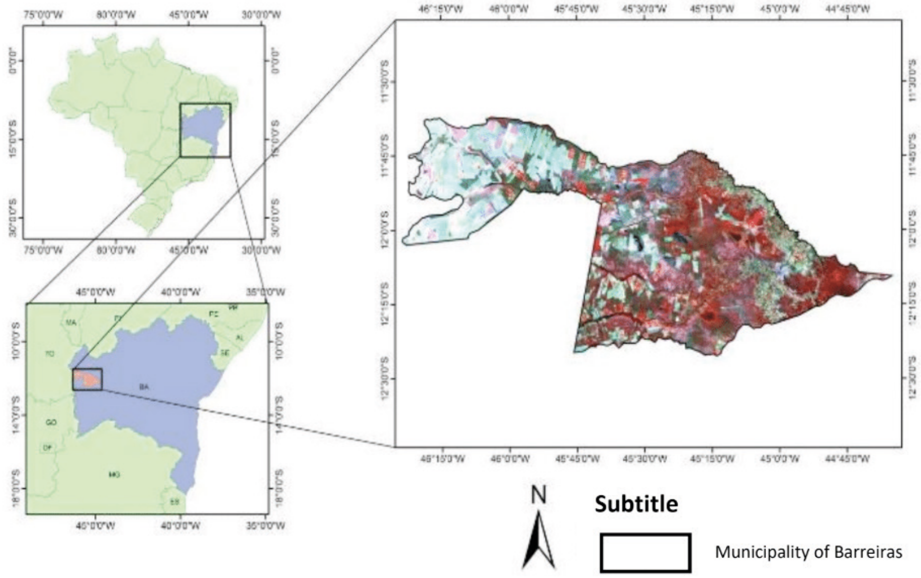


Figure 1: Location of the municipality of Barreiras.

Use of the soil	Symbol	Description
Native Savannah Area	ACN	Native Area without human intervention. Located at Fazenda São João in the city of Barreiras- BA. Latitude 11º 57’32” S and longitude 45º09’45” W.
Banana Planting Area	APB	Area located in Barreiras in the Barreiras Norte irrigated perimeter
Planting Area Systems Agroforestry	SAFs	Area located at Sítio Jacarandá, Barreiras Norte Irrigation District, at coordinates 12º 05’06” S and longitude 44º55’20” W.
Eucalyptus Planting Area	EUC	Area located at Fazenda São João, located in the municipality of Barreiras in the Western Region of Bahia, at coordinates 11º 58’15.8” S and 45º09’10.4” W, implemented in 2010.

Table 1. Characterization of the areas studied under different land uses in Western Bahia.

Total organite carbon stocks (EstCOT) in equivalent mass were obtained by the following expression:

$$\text{Est COT} = \text{cc x ds x} \left(\text{E} \pm \frac{\text{Ead}}{\text{sub}}\right) \text{x A x Fkg} \qquad \text{(Equation 03)}$$

being:

EstCOT = total organic carbon stock per unit area in equivalent layer, expressed in Mg ha^{-1};

cc = concentration of C, expressed in g kg^{-1};

ds = soil density, expressed in Mg m^{-3};

E = soil thickness of the studied layer, expressed in m;

Ead/sub = soil thickness of the layer to be added (+) or subtracted (-), expressed in m;

A = area, considering 1 ha, that is, 10,000 m^2;

Fkg = conversion factor from kg to Mg (0,001 Mg ha^{-1}).

The granulometric physical fractionation was determined according to the methodology of Cambardella and Elliot (1992). After weighing 20 g of TFSA, 60 mL of sodium hexametaphosphate solution (5 g. L^{-1}) was added. The samples were homogenized for 16 hours in a horizontal shaker and after this step, the samples were sieved using a sieve with a 53 μm mesh (0.053 mm – 270 swabs). The material retained on the sieve consisted of particulate organic carbon (COp), associated with the sand fraction, and what passed through the sieve corresponded to organic carbon associated with silt minerals + clay (COam). All material that was retained on the sieve was transferred to a petri dish and dried in an oven (50° C) for 24 hours. After this step, the material was ground in porcelain mortar and the organic carbon content was analyzed according to the Embrapa methodology (2017). The COam content was obtained by the difference between TOC and COp.

To estimate the carbon management index (BMI) (equation 04), the carbon stock index (CSI) was calculated, calculated through the relationship between the carbon stocks of the cultivated area in relation to the reference area (equation 05), and the lability index (IL) of the organic matter, which is determined by the lability of the treatment and the lability of the reference area (equation 06). The lability (L) was determined by the ratio between the stocks of particulate organic matter (EsCOp) and the stocks of organic matter associated with silt + clay (Est COam) (equation 07) (BLAIR et al., 1995).

$$\text{BMI} = \text{IEC x IL x 100} \qquad \text{(Equation 04)}$$

$$\text{ICE} = \frac{\text{EstCO}_{\text{tra}}}{\text{EstCO}_{\text{ref}}} \qquad \text{(Equation 05)}$$

$$\text{IL} = \frac{\text{L}_{\text{trat}}}{\text{L}_{\text{ref}}} \qquad \text{(Equation 06)}$$

$$\text{L} = \frac{\text{EstCOp}}{\text{EstCOam}} \qquad \text{(Equation 07)}$$

On what:

BMI = carbon management index;

IEC = carbon stock index;

IL = lability index;

$EstCO_p$ = COp stock in the evaluated treatment;

$EstCO_{ref}$ = organic carbon stock in the reference treatment;

L_{trat} = SOM lability in the evaluated treatment (cultivation area);

L_{ref} = SOM lability in the treatment of the reference area;

EstCOp = CO stock in the particulate

fraction;

EstCOam = CO stock in the silt + clay associated fraction of the SOM.

For data evaluation, a completely randomized design was considered. Data were submitted to analysis of variance (ANOVA), and when significant, they were compared by Tukey's test at 5% probability. The SISVAR statistical program was used.

RESULTS AND DISCUSSION

Table 2 presents the contents of total organic carbon (TOC), particulate organic carbon (COp) and associated mineral fraction (COam), as well as their relationships at different depths. It is observed that the average levels of TOC showed higher values for EUC, regardless of the evaluated layer. However, an increase of TOC in the EUC of approximately 60, 51 and 63% is observed in relation to ACN, SAFs and APB, respectively in the superficial layer of up to 10 cm. The lowest TOC contents were found in the APB, demonstrating a lower deposition of residues on the soil surface.

And also in the area with eucalyptus (EUC), it is verified that the levels varied from 9 g.kg-1 to 16.22 g.kg-1 along the depth of up to 50 cm. This effect may occur due to the accumulation of plant residues on the soil surface over time. In his study, Balin (2017) found that the higher TOC content in the EUC area is possibly due to the greater contribution of crop residues deposited on the surface. Similar results were found by Rosa et al. (2017) when carrying out studies with eucalyptus plantations at different ages and native savannah area, according to the authors, this fact is not related only to the deposition of organic material, but also to the age of cultivation. Among the areas, the APB presented higher TOC contents when compared to SAFs in the layer below 20 cm. This behavior may correspond to the accumulation of residues at these depths. Another important aspect is that changes in organic matter depend on the time of planting of crops and soil depth, being more likely to be detected when working with forest cover (DEAN, et. al., 2017).

As for the granulometric fractionation of organic matter (Table 3), the ACN, SAFs, APB and EUC treatments, in the particulate fraction (COp), in the 0-10 and 10-20 layers, did not show sensitivity to the adopted managements. The values of the particulate fraction differed statistically in the EUC area in the depths of 20 to 30 cm and 40 to 50 cm, an increase of up to 70 and 54% in the contents, respectively, in relation to the other land uses. The organic matter associated with the silt and clay fractions (COam), presents an advanced degree of humification (Bayer et al., 2004), and is normally less sensitive to changes in management. The 7-year-old EUC showed the highest associated carbon values at all depths, with values ranging from 8.37 g.kg-1 to 15.76 g.kg-1. The lower values of COam in the APB area compared to the surface layer of up to 10 cm may have been due to the soil turning before the installation of the crop, which, consequently, can accelerate the mineralization of the SOM by breaking the aggregates and exposing it to the action of microorganisms. Soil texture can influence the losses of organic matter associated with the fractions, as sandy soils reduce COam levels due to the lack of aggregates and, consequently, favor greater exposure of SOM to decomposing microorganisms.

Table 3 presents the values of total organic carbon stock (TOC) and particulate (COp) and complexed (COam) organic carbon, where it can be seen that the EstCOT of the soil increased in the EUC area at all depths. Similar results were found by Costa et. al., (2020a) who, working in Oxisols, found higher carbon stocks in eucalyptus plantations at depths of up to 60 cm.

There is still variation in EstCOT under land use in relation to the native reference area (ACN), however it appears that the SAFs balanced EstCOT in relation to ACN at depths of up to 30 cm.

The EstCOp did not show variations in the layers from 0.0 to 10.0 and 10.0 to 20.0 cm. The areas under Agroforestry System and Eucalyptus plantation did not differ only in the 20 to 30 cm layer, with increases in EstCOp of up to 44% and 52% respectively when compared to ACN. Between the EUC and APB areas, higher levels of EstCOp for the EUC were found at depths from 20 to 50 cm. These behaviors demonstrate that after 7 years the EUC is able to maintain and/or even increase the organic carbon content in the soil in the particulate fraction at depths.

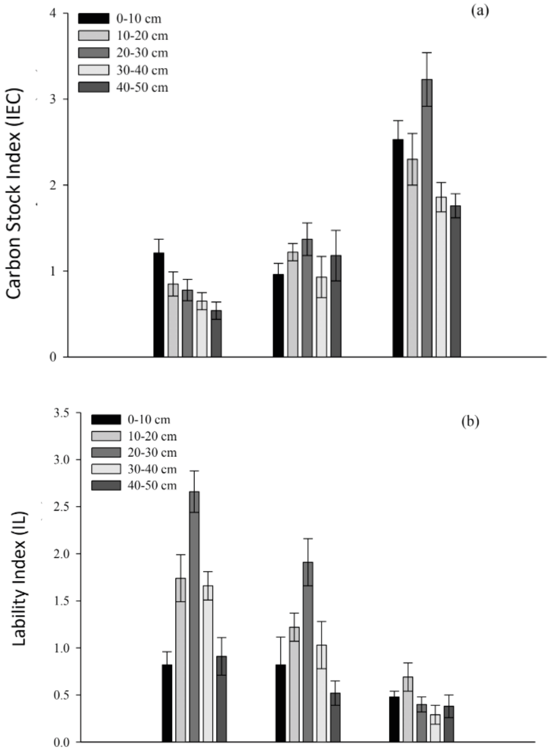
According to Bayer (2004), due to its high sensitivity, the particulate fraction can work as an efficient indicator to evaluate changes in land use. With the addition of plant residues in practices that favor the increase of organic matter in the soil, the formation of aggregates will occur, protecting the labile organic matter, and consequently, lower carbon losses.

When comparing mineral-associated carbon (COam) stocks in different land uses, it appears that EUC and SAFs increased COam by up to 64 and 28%, respectively, in relation to APB in the topsoil layer of up to 10 cm (Table 4). These differences may be associated with the maintenance of plant residues on the surface. For this variable, it is observed that the EUC presented higher values when compared to the other uses at all depths.

The figure 2 represents the carbon stock indices, IEC, (a), lability index, IL, (b) and carbon management index (c) in areas under different soil uses and depths in the Savannah.

In figure 2a, it is observed that the ECU obtained the highest carbon stock indexes in all depths analyzed (values greater than 1.00) when compared to the others, indicating that this use after 7 years is favoring the accumulation of carbon in the soil in depth. When observing the lability indexes, the EUC treatment presented lower values of IL (2b), showing greater potential for preservation and recovery of carbon and its compartments in the soil.

Regarding the carbon management index, it is observed that in the SAFs and EUC there was an increase in depths of up to 30 cm, demonstrating that agroforestry systems and 7-year-old eucalyptus plantations are capable of increasing soil organic matter. similar results were found by Costa et. al., (2020b) in eucalyptus plantations. With APB, however, there was a reduction in BMI in the superficial layer of up to 10 cm. In the deeper layers, the low BMI values can be attributed to the higher values of the IL indexes found in the area in these areas.



Use of the soil	COT	COp	COam	COp/COT	COam/COT
	-------------------g kg^{-1}-------------------			---------%---------	
Depth, 0-10cm					
ACN	6,55±0,97 bc	0,53±0,47 a	6,02±0,90 c	8,09	91,90
SAwFs	7,86±0,24 b	0,52±0,38 a	7,34±0,38 b	6,61	93,38
APB	5,97±0,41 c	0,36±0,28 a	5,61±0,50 c	6,03	93,96
EUC	16,22±1,02 a	0,46±0,46 a	15,76±0,93 a	2,83	97,16
DMS	1,33	0,33	1,10	-	-
Depth, 10-20cm					
ACN	5,86±0,68 b	0,27±0,36 a	5,59±0,68 b	4,61	95,39
SAFs	5,01±0,76 b	0,34±0,40 a	4,67±0,72 b	6,79	93,21
APB	7,24±0,90 b	0,34±0,28 a	6,90±0,93 b	4,70	95,30
EUC	13,56±0,16 a	0,26±0,40 a	13,30±1,66 a	1,92	98,08
DMS	2,79	0,25	2,72	-	-
Depth, 20-30cm					
ACN	4,67±0,54 c	0,28±0,58 b	4,39±0,52 c	5,99	94,00
SAFs	3,63±0,60 c	0,30±0,34 b	3,33±0,57 d	8,26	91,73
APB	6,38±0,80 b	0,19±0,31 b	6,19±0,80 b	2,98	97,02
EUC	14,13±1,02 a	0,65±0,91 a	13,48±1,04 a	4,60	95,40
DMS	1,22	0,33	0,99	-	-
Depth, 30-40cm					
ACN	4,95±0,61 b	0,38±0,58 a	4,57±0,59 b	7,68	92,32
SAFs	3,22±0,62 c	0,30±0,36 b	2,92±0,75 c	9,32	90,68
APB	4,61±0,97 b	0,18±0,12 b	4,43±0,97 b	3,90	96,09
EUC	9,23±0,91 a	0,65±0,24 a	8,58±0,91 a	7,04	92,95
DMS	1,25	0,34	1,29	-	-
Depth, 40-50cm					
ACN	5,11±0,43 c	0,38±0,54 b	4,73±0,63 c	7,43	92,56
SAF	2,78±0,64 d	0,36±0,34 b	2,42±0,63 d	12,94	87,05
APB	6,05±0,47 b	0,29±0,19 b	5,76±0,68 b	4,79	95,20
EUC	9,00±0,56 a	0,63±0,45 a	8,37±0,31 a	7,00	93,00
DMS	0,70	0,22	0,68	-	-

ACN = area under native savannah vegetation strict sensu; SAFs = agroforestry system (cocoa and banana); APB = area under conventional banana plantation; EUC = area under eucalyptus plantation. ± values refer to the standard error of the mean. DMS = least significant difference.

Table 2. Total organic carbon (TOC), organic carbon bound to particulate organic matter (COp) and associated with the mineral fraction (COam) and percentage of COp and COam subjected to different soil uses at depths of 0-10, 10-20, 20- 30, 30-40 and 40-50 cm in the Savannah of Bahia.

Use of the soil	EstCOT	EstCOp	EstCOam
--------------------Mg ha^{-1}---------------------			
Depth, 0-10cm			
ACN	9,66±1,26 bc	0,89±0,55 a	8,87±1,13 c
SAFs	11,57±0,59 b	0,81±0,50 a	11,43±0,52 b
APB	8,79±0,30 c	0,53±0,36 a	8,25±0,41 c
EUC	23,88±1,34 a	0,78±0,60 a	22,73±1,14 a
DMS	2,21	0,50	1,69
Depth, 10-20 cm			
ACN	8,67±0,77 b	0,55±0,47 a	8,28±0,80 b
SAFs	7,40±0,94 b	0,47±0,42 a	7,27±1,02 b
APB	10,70±0,99 b	0,39±0,50 a	10,19±1,06 b
EUC	20,13±2,14 a	0,50±0,34 a	19,93±1,84 a
	4,37	0,41	7,75
Depth, 20-30 cm			
ACN	7,13±0072 c	0,28±0,26 b	6,87±0,69 c
SAFs	5,55±0,74 c	0,50±0,44 a	5,41±0,71 c
APB	9,73±0,96 b	0,25±0,30 b	9,15±0,93 b
EUC	21,57±1,34 a	0,58±0,89 a	20,62±1,17 a
	1,97	0,19	1,63
Depth, 30-40 cm			
ACN	7,71±0,73 b	0,52±0,47 ab	6,96±0,77 b
SAFs	5,01±0,79 c	0,29±0,10 b	4,88±0,87 b
APB	7,21±1,27 b	0,27±0,30 b	6,61±1,26 b
EUC	14,39±1,19 a	1,01±0,72 a	13,73±1,23 a
	2,10	0,53	2,20
Depth, 40-50 cm			
ACN	7,89±0,80 c	0,57±0,27 b	6,92±0,76 c
SAFs	4,29±0,81 d	0,55±0,42 b	4,14±0,78 d
APB	9,34±0,86 b	0,49±0,24 b	8,55±0,81 b
EUC	13,88±0,31 a	0,97±0,57 a	13,43±0,50 a
	1,08	0,34	1,63

Table 3. Stock of total organic carbon (TOC) and particulate organic carbon (COp) and complexed (COam) submitted to different soil uses at depths of 0-10, 10-20, 20-30, 30-40 and 40-50 cm in the Savannah of Bahia.

ACN = area under native savannah vegetation strict sensu; SAFs = agroforestry system (banana and cocoa); APB = area under conventional banana plantation; EUC = area under eucalyptus plantation. ± values refer to the standard error of the mean. DMS = least significant difference.

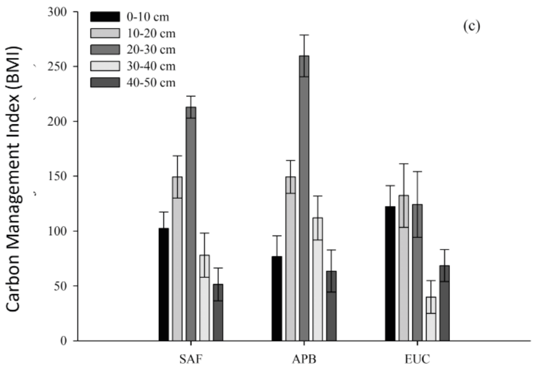


Figure 02. Carbon stock index, IEC, (a), lability index, IL, (b) and carbon management index (c) in soils under different uses in the Savannah.

CONCLUSIONS

1. Among land uses, the EUC increases the levels and consequently the total organic carbon stocks at depths of up to 50 cm, however, for COp fractionation only at depths below 20 cm. As for COam fractionation, there was an increase in SAF and EUC in the surface layer of up to 10 cm.

2. Regarding fractionation, changes in their stocks occur below 20 cm, with SAF and EUC having values greater than the other land uses, therefore, below 30 cm, APB and SAF balance their stocks in relation to ACN. In relation to COam all land uses balance or have increased their stocks in relation to ACN.

3. The BMI of the area under planting of ECU with 7 years and SAF, demonstrates the greater sustainability of the system in relation to the other areas evaluated in the layers of up to 30 cm.

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