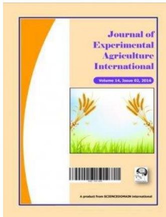

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Temporal Variability of Granulometric Fractions of the Organic Matter of an Ultisol in a Transition Area

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Authors' contributions

This work was carried out in collaboration with all authors. The authors FPMD and JCAN designed the study, wrote the protocol and wrote the first draft of the manuscript. The author ECP performed the statistical analysis and wrote part of the article. The authors SSM and LSR handled the analyzes and collections of the study. The author FTSS conducted the field experiment corrected and translated the entire article. All authors read and approved the final manuscript.

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ABSTRACT

The absence of vegetation cover associated with the increase of the intensity of use and soil management promotes the medium and long-term degradation of its chemical quality. The management practices adopted can determine if the soil will act in the environment as a source or drain of carbon to the atmosphere, determining the environmental impact of the agricultural activity. These contents, besides varying in the space, vary in the time, therefore the understanding of the variability of the organic carbon in the soil is essential for the improvement of the management practices in the organic systems of production. The objective of this study was to evaluate the

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behavior of the granulometric fractions of soil organic carbon and its total stocks over three years of cultivation in different systems of organic production management. The areas studied were: (SAF) agroforestry system, (MAR) passion fruit cultivation in monoculture, (ABA) pineapple cultivation in monoculture and (BAN) banana cultivation in a consortium. For comparison purposes, an area under native forest system (MN) was also evaluated. For each system of use, soil samples were collected at depths of 0.0-0.20 and 0.20-0.40 m in four replicates, two collections were done with an interval of three years. The TOC contents were significantly influenced by the isolated effect of the management systems and by the interaction between system and year of management, only in the depth of 0.0-0.20 m. In general, there was a reduction of EstS in all management systems, at a depth of 0.20-0.40 m, with the exception of the ABA system. This shows a higher susceptibility of the oxidation of organic matter in this soil layer. The levels of C-Am were shown to be more sensitive to changes in surface management only. The results showed that the absence of plant cover and the lack of species diversification promoted a decrease in the soil organic carbon stocks. And that the reestablishment of the carbon contents and stocks does not happen quickly and are influenced by the practices and time of handling.

Keywords: Organic carbon; organic systems; agroforestry systems; fruticulture.

1. INTRODUCTION

Earth's carbon is distributed in different reservoirs. Its largest share is present in the oceans with 38,000 Pg, followed by geological formations with 5000 Pg, and finally the soil carbon compartment (2500 Pg), which consists of mineral (1000 Pg) and organic carbon (1500 Pg) [1], the latter compartment being the most susceptible to modifications. The changes in carbon stocks in the organic compartment of the soil can be influenced by several factors, such as climatic, geographic and physiological [2]. In addition, anthropic activities, especially agriculture can significantly influence their changes.

Soils are the main responsible for maintaining the quality of the environment, however, with anthropic intervention, when improperly managed, they can favor the oxidation of organic matter, reducing their stocks in the soil and contributing to raising CO_2 levels for the environment [3]. On the other hand, when properly managed, agricultural practices can favor the increase of carbon stock in the soil.

In order to verify the changes occurring in soils, it is necessary to select good indicators that can measure such variations. Efficient indicators are sensitive to management changes and have an easy measurement [4], for example, soil organic matter, which is considered an indicator of quality, mainly due to its sensitivity in undergoing changes with the different management systems, besides influencing the other attributes, chemical, physical and biological, which are essential for the soil to perform its functions [5].

Because it is an indicator of great relevance in the determination of soil quality, it is essential to monitor the dynamics of soil organic carbon fractions over the cultivation time in order to verify if the management adopted in a given area is efficient in promoting improvements in soil quality or not, promoting losses in carbon stocks and consequently affecting the physical, chemical and biological properties of the soil. The objective of this work is to evaluate the behavior of soil organic carbon granulometric fractions and their total stocks over three years of cultivation in different systems of organic production management.

2. MATERIALS AND METHODS

The study was developed at the Organic Bocaiúva Farm, located in the district of Humildes, municipality of Feira de Santana, state of Bahia. Geographic coordinates are 12º16'00 "south latitude and 38º58'00" west longitude, and altitude is 234 meters. The climate of the region is classified as hot semi-arid with average annual rainfall of 848 mm, passing through long periods of drought. The rainfall and temperature data during the three-year evaluation of the experiment are presented in Fig. 1.

Five areas were selected for different uses: system with pineapple (ABA) monoculture cultivation with cover of spontaneous plants between the lines, system with passion fruit (MAR) under cultivation in monoculture in open soil, both in an area where Manihot esculenta had previously been cultivated, banana system (BAN) with cocoa and maintenance of the organic residue on the soil. The soil of all areas was deployed using harrowing and fertilization with organic compost in dryland agriculture. Agroforestry system (SAF) composed of citrus, coffee, banana, açaí and arboreal species, with implantation for about thirteen years under an area where there was previously pasture and native forest system (MT) for comparison purposes.

The collections were carried out in march 2015 and 2018, establishing transects in each selected area (Fig. 2). In each transect, four points were established for the collection of the samples, which were packed in plastic bags, then transported to the laboratory, where they were air dried and passed through a 2.0 mm sieve to obtain the TFSA.

For the determination of total organic carbon (TOC), the soil samples were ground in a mortar by quantifying the carbon by wet oxidation using $K_2Cr_2O_7$ 0.667 mol L^{-1} in sulfuric medium without external heating [6]. The carbon content was determined by colorimetry, using a maximum transmission filter of 650 nm, according to [7].

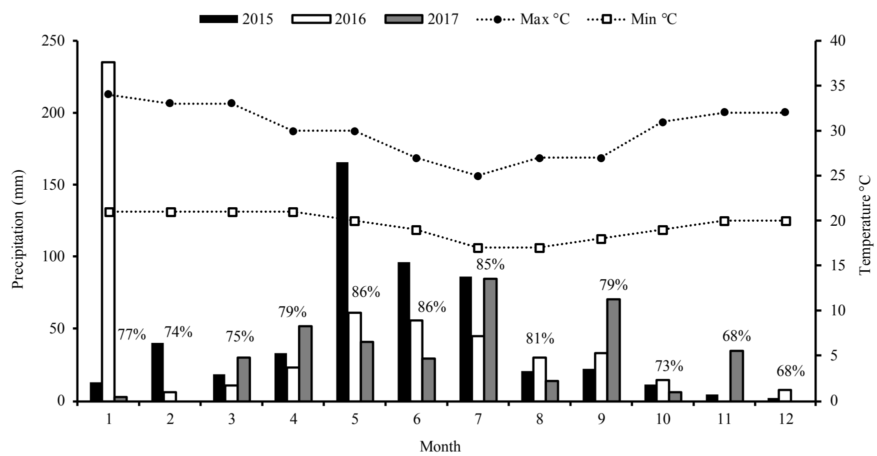

Fig. 1. Mean monthly values of temperature (ºC), precipitation (mm) and humidity (%) during the three consecutive years of the evaluation interval of the experimental area (2015 to 2017). Feira de Santana, Bahia

Fig. 2. Location of experimental areas in Feira de Santana, Bahia, highlighting the arrangement of organic management systems evaluated: (SAF) agroforestry system, (MAR) passion fruit cultivation in monoculture, (ABA) pineapple monoculture, (BAN) banana cultivation in consortium and native forest system (MN)

The particulate organic carbon (POC) was obtained through physical fractionation, according to a method adapted from [8]. To promote the dispersion of the particles, 10 g of soil samples were shaken in 30 ml of sodium hexametaphosphate solution (5 g L^{-1}) for 15 h on a horizontal shaker. Subsequently, the suspension was passed in a 0.053 mm sieve with the aid of water jet. The material retained in the sieve, consisting of the POC + sand fraction, was dried in an oven at approximately 60ºC for 24 hours, quantified in relation to its mass, ground and stored. The C content associated with the mineral fraction (silt + clay) after fractionation was not quantified, but the C content of the material in the sieve (POC + sand) was quantified by colorimetry. The organic C content associated with the mineral fraction (COAm) was calculated by difference between the TOC and POC levels.

The results obtained in the experiment were submitted to analysis of variance, in a factorial scheme to evaluate the effect of time on the variables and the averages compared by the Tukey test at the 5% probability level. The analyzes were carried out with the aid of the SISVAR Program [9].

3. RESULTS AND DISCUSSION

The total organic carbon (TOC), particulate organic carbon (POC) and the organic carbon associated with the mineral (C-AM) were subjected to ANOVA, where significant effects were observed between the systems use and management of soil and effects of the interaction (systems x time) only for COT (Fig. 3) and C-Am (Table 1) in the depth of 0.0-0.20 m.

No significant effects were observed between the systems in the depth of 0.20-0.40 m for none of the studied variables. However, when evaluating the overall mean of all systems over the years of management, was verified that there was an increase in all the fractions of the organic matter, with values of TOC, POC and C-Am in 2015 of 6,27; 0.05 and 6.22 g kg^{-1} increasing in 2018 to 9.77; 0.21 and 9.55 g kg^{-1}, respectively. This carbon increase in depth may indicate that the management practices adopted in the organic systems of use and management of the soil are favoring the sequestration of carbon with consequent increase of their stocks in depth. According to [10] the most important changes in the soil organic carbon dynamics, in terms of increment and loss of their contents, occur on the surface.

TOC levels were significantly influenced by the isolated effect of the management systems and by the interaction between system and year of management, only in the depth of 0.0-0.20 m (Fig. 3). For the TOC, when comparing the contents according to the temporal variability of management, only the native forest system showed a significant difference, demonstrating a reduction in the total contents. What possibly may be occurring, due to increased microbial activity in this system, and consequently, increased release of CO_2 lost to atmosphere. This occurs when there is a greater amount of surface material with less resistance to microbial degradation, that is, easily assimilable [11].

Statistically, the other managed systems did not show alterations in total TOC contents, although visually, it is possible to notice a slight trend of recovery of the contents, in all systems managed. This indicates that the management practices adopted in the different arrangements under organic system of production are favoring the maintenance of the organic carbon contents of the soil.

For the depth of 0.20-0.40 m, although there was no statistically significant difference can be observed that the SAF and BAN system, showed an increase in TOC contents in subsurface 4 and 2 times higher in year of 2018 than in the first year of evaluation, respectively (Fig. 3). What can be explained by the greater contribution of organic material in these systems, mainly coming from the greater density of roots in depth, which is due to the greater diversity of species in these systems. Significant differences were observed between management systems independent of temporal variability. In the first year of evaluation the ABA and BAN systems presented lower values than the others, in the second evaluation only MAR was statistically superior to BAN, not differing therefore, none of them from the native forest system.

[12] Evaluating the temporal variability of TOC during 10 years in pasture area, they concluded that, when properly managed and adopting strategic soil recovery practices, the TOC content presents temporal stability.

In Fig. 4, it is possible to observe better the behavior of the systems, through the data of the variation of the carbon stock (EstC), in relation to the reference system used (native forest), in the two depths studied. Agricultural soils can act as sources or drains of CO_2 emission into the atmosphere, appropriate management practices

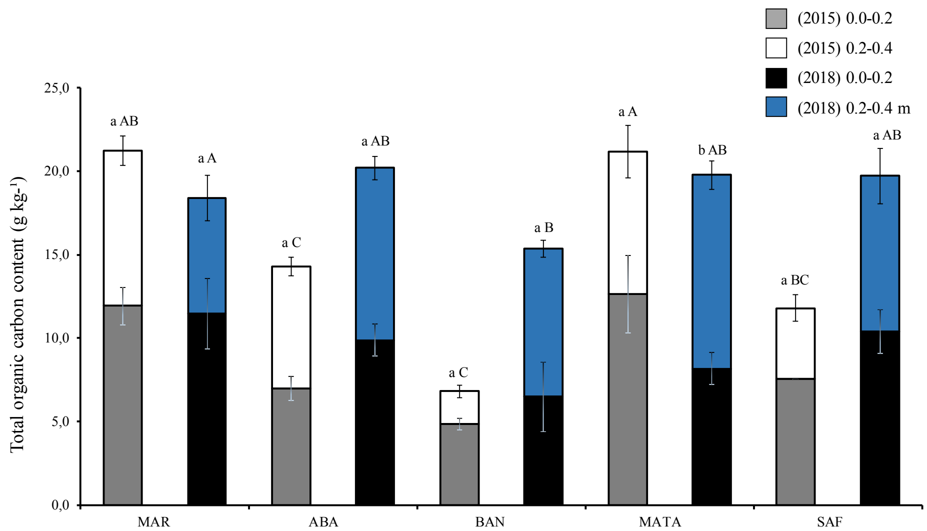

Fig. 3. Mean values of total organic carbon at depths of 0.0-0.20 and 0.20-0.40 m in areas under organic production system in the Bahian semi-arid under different uses: (SAF) agroforestry system, (MAR) cultivation of passion fruit in monoculture, (ABA) cultivation of pineapple in monoculture, (BAN) banana cultivation in a consortium and native forest system (MN). *Vertical lines represent the standard deviation and averages followed by equal lowercase letters do not differ the levels for years of handling within each system and capital letters do not differ between systems within each crop year. *Chart statistic referring to depth of 0.0-0.20 m

can favor carbon storage, contribute to environmental quality and maintain soil fertility. Organic production systems play an important role in mitigating the emission of gases, since they recommend an increase in organic matter in the soil, which tends to increase the carbon stocks in these systems.

In general, there was a reduction of the EstC in all the management systems, in the depth of 0.20-0.40 m, with the exception of the ABA system. This shows a higher susceptibility of the oxidation of organic matter in this soil layer. It should also be considered that the climatic conditions of the study region make it difficult to store carbon in the soil due to high temperatures and low humidity.

The negative variation is more accentuated in the MAR system, since it shows an increasing trend of reduction over the time of management, which can be justified by the absence of vegetation cover and the diversity of vegetal species in this system.

The opposite occurred in the BAN system, which showed recovery of the stocks with the management time in all the studied layers, which can be justified by the system being managed in consortium with other crops and by the continuous contribution of residues on surface resulting from the banana itself. However, for SAF there was a decrease with the time of management in both depths, this could have been due to management failures or even by greater microbial activity.

Although the literature points to POC as a fraction of high sensitivity to detect changes in management systems [13,14], in the present study, no significant differences were observed for the POC content at both depths studied, although numerically it is possible to observe that there is a tendency of maintenance or increase of the contents in all systems when evaluated over time (Table 1). The same was observed for the contents of C-Am, with the exception of the MT system that presented significant difference between the evaluation years, reducing the values over time.

[14], comparing no-tillage systems with native cerrado areas, in an Oxisol in different years of management, observed that there is a tendency to increase C-Am contents with the time of management, while the POC, present reverse behavior.

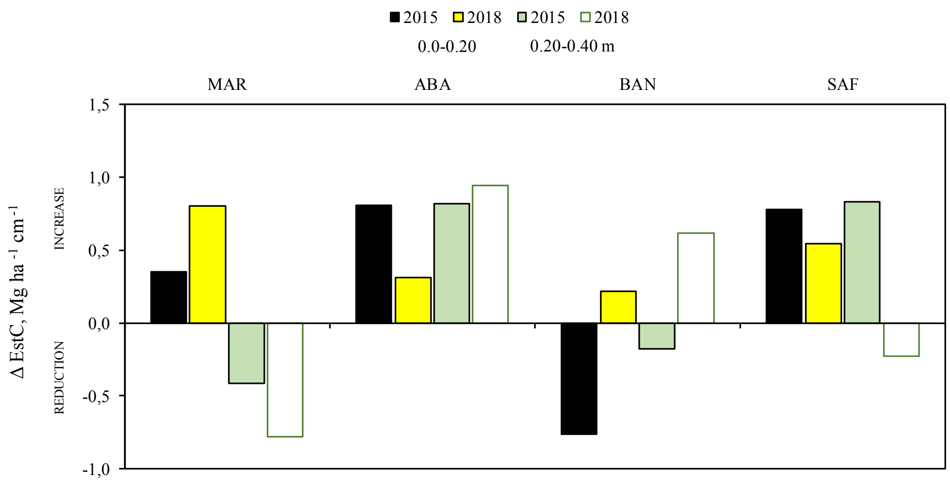

Fig. 4. Variation of organic carbon stocks (ΔEstC) at depths of 0.0-0.20 and 0.20-0.40 m in relation to the native forest system (MN) in areas of organic management in the semi-arid Bahia under different uses: (SAF) agroforestry system, (MAR) passion fruit cultivation in monoculture, (ABA) pineapple cultivation in monoculture, (BAN) banana cultivation in consortium. Positive values indicate an increase in the organic carbon stock in relation to the MN system

Table 1. Particulate organic carbon (POC) and carbon associated with the minerals (C-Am) at depths of 0.0-0.20 and 0.20-0.40 m in relation to the native forest system (MN) in areas of organic management in the Bahia semi-arid under different uses: (SAF) agroforestry system, (MAR) passion fruit cultivation in monoculture, (ABA) pineapple cultivation in monoculture, (BAN) banana cultivation in a consortium in the two years of evaluation

System	POC (gC/kg solo)[1]		C-Am (g/kg)	
	0.0-0.20 m			
	2015	2018	2015	2018
SAF	0.46 (±0.13)	0.78 (±0.17)	7.11 aBC (±0.54)	8.35 aAB (±1.10)
ABA	0.50 (±0.15)	1.35 (±0.37)	6.50 aC (±0.08)	8.54 aAB (±0.79)
MT	0.06 (±0.00)	0.36 (±0.19)	12.57 aA (±0.98)	7.85 bAB (±0.69)
BAN	0.62 (±0.19)	0.64 (±0.05)	4.22 aC (±0.37)	6.30 aB (±0.11)
MAR	0.30 (±0.08)	0.35 (±0.05)	11.63 aBA (±0.38)	11.38 aA (±1.10)
	0.20-0.40 m[1]			
SAF	0.05 (±0.00)	0.06 (±0.00)	4.18 (±0.57)	9.15 (±1.12)
ABA	0.05 (±0.00)	0.54 (±0.18)	7.25 (±0.41)	9.77 (±0.71)
MT	0.06 (±0.00)	0.06 (±0.00)	8.48 (±1.20)	11.34 (±0.84)
BAN	0.06 (±0.00)	0.06 (±0.00)	1.92 (±0.28)	10.16 (±1.49)
MAR	0.04 (±0.00)	0.35 (±0.12)	9.29 (±0.67)	7.36 (±1.91)

** Averages, followed by the same lowercase letter in the column and upper case in the row, do not differ from each other by the tukey test at 5% probability. [1]There was no significant difference. Values in parentheses represent the standard deviation of the mean.*

There is a negative correlation between the labile and humid fractions of the organic matter of the soil, when submitted to different systems of use and management, that is, these fractions go through inverse processes of formation. In the case of the POC, the fraction associated with recent contributions of organic matter, it ends up being lost by microbial oxidation, being later transformed into C-Am [15]. This means that, for C-Am levels to increase, it is necessary for degradation of the POC levels.

The levels of C-Am were shown to be more sensitive to changes in surface management only. In the comparison between the systems, regardless of the management time, only the MAR system did not differ from MT in the first year of evaluation, already in the second year of evaluation, all the systems showed to be in a continuous process of stabilization of the organic matter contents throughout of the time, reaching values statistically equal to MT. Can be verified that the levels of C-Am tend to increase in depth, when observed the values of the last year of evaluation. Similar values were observed by [16] evaluating SAF and passion fruit culture also under organic production systems.

4. CONCLUSIONS

The management of conservation practices adopted in the organic production system are efficient to maintain the total organic carbon contents of the soil under the conditions of the present study.

The continuous contributions of organic matter to the soil and the diversification of Species, through rotation and consortition practices in the organic systems, promoted positive variation in the carbon stocks over the years, evidenced by the banana system in consortium in the present study.

The absence of vegetation cover and the lack of species diversification promote a decrease in the soil organic carbon stocks.

The reestablishment of carbon stocks and carbon contents does not happen quickly and is influencers by management practices and time.

COMPETING INTEREST

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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