

Chemical Attributes and Carbon Fractions in Serra de Itabaiana National Park

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Abstract

This study aimed to assess soil chemical attributes, organic matter fractions and carbon stocks of forest in three different regeneration stages in the Serra de Itabaiana National Park, Sergipe. The study was conducted in three areas: open white sands, intermediate white sands, and closed white sands, with a history of differentiated degradation. Soil samples were collected at 0-20 cm depth for chemical characterization and for fractionation of soil organic matter and C stock. The open white sands obtained the best results regarding levels of macronutrients, total organic carbon, and total soil nitrogen, as well as higher carbon/nitrogen ratio compared with intermediate white sands and closed white sands, with such effects being attributed to recent exposure to fire. Carbon concentrations in humic fractions of organic matter were little influenced by different vegetation in regeneration, except the carbon fraction of humic acid, which is more sensitive to different management and soil usage.

Keywords: native vegetation, fertility, organic matter, sustainability.

1. INTRODUCTION AND OBJECTIVES

Soil organic matter (SOM) conservation has been used as an essential indicator of soil organic matter for its relationship with numerous chemical, physical and biological properties. Adequate levels of SOM in temperate and tropical ecosystems can benefit from increased soil fertility, as they minimize impacts on the environment through carbon (C) sequestration, reducing soil erosion and preserving biodiversity (Zhao et al., 2017).

Soil fertility is related to the molecular characteristics of the soluble alkaline fraction of organic carbon, the humic substances (HS). The fractions belonging to the humic substances are dynamic as they reflect changes in soil management. However, few studies on these substances do not confirm the influence of carbon on HS fractions regarding soil fertility (Rodrigues et al., 2017).

The presence of organic matter and its humid fraction may be compromised by specific anthropic actions such as

fire, influencing the soil fertility. In forest ecosystems, the occurrence of fire has a lasting effect, both in the microbial composition as well as in the soil organic matter. These changes may interfere with all soil carbon dynamics (Araya et al., 2017).

There are studies on soil organic matter characteristics in other regions of Brazil, such as the capoeira areas under burning (Pessoa et al., 2012), and the soil in different organic production systems (Loss et al., 2011). However, these studies are still incipient in native areas in the Northeast region of Brazil, although it is possible to find studies determining total organic carbon and SOM fractions in native and cultivated areas in coastal soils (Pedra et al., 2012), but these studies are scarce in native areas in the state of Sergipe.

Therefore, this type of soil survey and diagnosis under native vegetation at different regeneration stages is necessary, as only two studies with vegetation surveys have been carried out until today (Dantas & Ribeiro, 2010; White et al., 2013). This kind of research is an essential tool to evaluate soil quality

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in different soil-vegetation uses and the impact caused by this type of improper burning practice.

The vegetation in the Serra de Itabaiana National Park contains tree species considered typical of the Brazilian savannas, such as *Curatella americana* (Dilleniaceae), *Byrsonima coccolobifolia* (Malpighiaceae), *Vochysia lucida* (Vochysiaceae), *Tapirira guianensis* (Anacardiaceae), *Ouratea* sp. (Ochnaceae), and *Lafoensia* sp. (Lythraceae), but this characteristic is insufficient to classify the vegetation as cerrado, and conditions such as a humid climate, sandy quartz soil, hydrography and its distance from the central cerrado are sufficient to differentiate these species from a common cerrado vegetation. Sandy and yellowish white sedimentary soils can be found in the eastern side of the Itabaiana and Comprida mountain ranges. The areas where the white sands are exposed support vegetation ranging between shrub-herbaceous and shrub-tree, according to the regeneration history of the areas (Dantas & Ribeiro, 2010). The objective of this study was to evaluate the chemical attributes of the soil, as well as organic matter fractions and carbon stocks of forest in three different regeneration stages at the Serra de Itabaiana National Park, Sergipe.

2. 2. MATERIALS AND METHODS

2.1. Description of the study area

The Serra de Itabaiana National Park is located between the Areia Branca and Itabaiana municipalities in the state of Sergipe, Northeast Brazil. This park covers a total area of 7966 ha and comprises three units: Cajueiro, Comprida and finally the Itabaiana mountain range, which is the largest. Its geographic coordinates are between latitudes and approximate longitudes of 10° 40' S and 37° 25' W. The vegetation between the mouth of the Sergipe river and the northwest towards the three hills is composed of a narrow strip of open areas of the coastal *restingas* parallel to the coast, and fragmented forest remnants that cover the hills in the shape of an orange half, being characteristic of the morphoclimatic Atlantic forest domain (Dias et al., 2017).

The vegetation between the preservation area and the west is wild, with a mitigated *caatinga* that accompanies a complex of low mountain ranges, containing the three hills that compose the Park, until Bahia where the relief is flattened, and semi-arid vegetation becomes dominant (Ab'Saber, 1986; Vanzolini, 1986).

The region presents a tropical with dry summer climate and moderate surplus water in the winter, with a Thornthwaite (MI) rainfall index between -1.3 and 8.8. The region is characterized by an average annual precipitation between 1,100 and 1,300 mm and average annual evapotranspiration of 800 mm (Vicente, 1998).

The soil class present in the Serra de Itabaiana National Park white sand areas corresponds to Psamment, which is the nomenclature of ancient dystrophic quartz sands. This type of soil is considered well drained, ranging between moderate and extremely acidic and it presents low natural fertility (Embrapa, 2013).

Three areas of white sands with a history of differentiated degradation were selected to carry out the study. The first area was called open white sands (OWS) located in the Comprida mountain range, which was affected by the last great fire in the Serra de Itabaiana National Park in 2005. This fire occurred in the same year that the Comprida mountain range was included in the Conservation Unit (a Brazilian organization gathering many protected areas), in which shrub and grass vegetation predominate; the second area called intermediate white sands (IWS) is located in the Serra de Itabaiana and it has been protected since 1978, but periodic fires occurred up to 1994; the third and last area is located near the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) headquarters in the Serra de Itabaiana and it has not had considerable fire focuses for more than 30 years, including a more closed vegetation and greater size, and it is called closed white sands (CWS).

2.2. Design, collection of samples and chemical characterization of soil

Plots of 100 m × 20 m were demarcated, being divided into 20 continuous plots of 10 m × 10 m, totaling 2,000 m² in each of the three white sand sample areas outlined in the Serra de Itabaiana National Park. Soil samples were collected at a depth of 0-20 cm with the aid of a Dutch survey, following a transect of 100 m median to the plot.

Three samples were removed every 10 meters to compose a composite sample at 0-20 cm depth to form a repeat. The soil samples were dried in shade and air, then they were sieved in 2 mm mesh screens and homogenized, thus forming the air dry thin soil (ADTS) and the samples were prepared for determining the chemical attributes: pH (1:2.5), extractable P and K contents (Mehlich⁻¹ extractor), Ca, Mg, Al, Al + H, sum of bases (SB) (T), CEC at pH 7.0 (T), as well as the percentage of base saturation (V), total organic carbon (TOC), total soil nitrogen (TSN) by the Kjeldahl method, all determinations followed the methodology described by Donagema (2011).

2.3. Chemical fractionation of organic matter

The humic substances were separated for the chemical fractionation of the organic matter, according to the methodology adapted by Benites et al. (2003). The humic fractions were

extracted based on solubility in alkali or acid. The carbon of the humic fractions was determined by wet oxidation following the Walkley-Black method (1934). The organic carbon (C) of the fulvic acid fraction (C-FAF), humic acid fraction (C-HAF), and humin (C-HUM), as well as the C-HAF/C-FAF and C-EA/C-HUM, were calculated as (C-EA = C-FAF + C-HAF) (Benites et al., 2003). As the soil is treated with sandy soil, samples for soil density were collected, and soil density was determined using the methodology described by Donagema (2011), for soil with sandy granulometry.

The carbon stock in the sampled layer was estimated based on the expression: $TOC = (C \times Ds \times t)/10$, where TOC is the Total Organic Carbon stock in $g\ kg^{-1}$; Ds is the bulk density of the studied layer in $kg\ dm^{-3}$, and "t" is the layer thickness in cm (Cardoso et al., 2011).

2.4. Statistical analysis

The data were submitted to analysis of variance (ANOVA), and the means were compared by the Tukey's test at the 5% probability level. The statistical program SISVAR was used for both study of variance and mean test (Ferreira, 2011).

3. 3. RESULTS AND DISCUSSION

Regarding soil fertility, the open white sand area (OWS) presented higher values in absolute numbers of K^+ , Ca^{2+} and Al^{3+} (Table 1), as well as TOC and TSN (Table 2) compared with other areas. For the concentrations of potassium (K), magnesium (Mg), and percentage of saturation by bases (V), the significant superiority of the OWS and CWS areas was verified in relation to the IWS area (Table 1). The Ca^{2+} value in the OWS was higher in comparison with the CWS and IWS areas, differing significantly. According to some authors, the accumulation of ashes as a consequence of burning the vegetation increases the Ca^{2+} contents, mainly due to the rapid mineralization provoked by the fires (Rheinheimer et al., 2003).

The pH values in these areas (Table 1) ranged between 5.17 and 5.42, considered as medium acidity according to Costa et al. (2008) and Sobral et al. (2007). In the IWS area, which was susceptible to periodic fires, the 5.42 pH was higher than the other areas studied. According to Batista et al. (1997), many substances in the form of oxides are released after burning the organic matter of the soil, with remaining carbonates usually presenting alkaline reaction, thus, increasing the pH of the soil. The exchangeable aluminum values obtained were between 0.13 and 0.28, indicating low aluminum toxicity according to Larcher (2004). Based on these results, it is possible to establish a relationship between the pH and Al^{3+} values. We observed that the exchangeable aluminum values increased as the pH of the soil was more acidic. According to Slattery (1999), a higher concentration of Al occurs in acid soils, which is undesirable because of its toxicity to plants.

The potential acidity (H + Al) (Table 1) did not present a statistical difference between white sand areas. However, the H + Al values in the IWS area were 1.26, which is considered low, and presented values of 3.72 and 2.52 for the OWS and CWS, respectively, which are considered average according to Costa et al. (2008). Regarding SB, the highest values were found in the OWS area, which differed significantly from the IWS; similar behavior was obtained for the variables effective CEC (t) and CEC at pH 7.0 (T). OWS and CWS presented higher levels of organic carbon in the soil, increasing thus effective CEC (t) and CEC at pH 7.0 (T). This increase can also be observed by Briedis et al. (2012), in which the raise in soil TOC increases potential and effective cation exchange capacity. Thus, changes in TOC support the number of negative charges in the soil.

In relation to the levels of phosphorus (P) in the soil, the three different areas presented no significant variation (Table 2), so that the mineralized phosphorus probably moved quickly to non-labile forms when not absorbed by plants (Novais & Smyth, 1999).

Table 1. pH values, concentrations of potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), aluminium (Al^{3+}), potential acidity (H + Al), Sum of bases (SB), effective CEC (t), CEC pH 7.0 (T) and percentage of bases saturation (V) of Psamment under different stages of native vegetation in the Serra de Itabaiana National Park.

Vegetation Areas	pH	K	Ca	Mg	Al	H + Al	SB	t	T	V
	(H ₂ O)	$cmol\ c\ dm^{-3}$					%			
OWS ¹	5.17a ²	0.004a	2.58a	0.56a	0.28a	3.72a	3.15a	3.44a	6.87a	48.56a
IWS	5.42a	0.002b	0.38b	0.01b	0.13a	1.26a	0.38b	0.51b	1.64b	29.37b
CWS	5.37a	0.003a	1.15b	0.64a	0.22a	2.52a	1.79ab	2.02ab	4.32ab	47.59a
Average	5.32	0.003	1.37	0.40	0.21	2.50	1.77	1.99	4.28	41.84

¹ OWS: open white sands; IWS: intermediate white sands; CWS: closed white sands; ² Measures followed by the same letter in the columns do not differ by Tukey's test at the 5% probability level.

Table 2. Concentrations of extractable phosphorus (P), total organic carbon (TOC), total soil nitrogen (TSN) and the values of the C/N ratio and carbon stocks (CS) of Psamment under different stages of native vegetation in the Serra de Itabaiana National Park.

Vegetation areas	P	TOC	NT	C/N	CS
	mg kg ⁻¹	g kg ⁻¹		----	Mg ha ⁻¹
OWS ¹	24.47a ²	12.84a	0.35a	36.09a	36.60a
IWS	24.69a	2.92b	0.14b	19.20b	9.72b
CWS	36.27a	7.72ab	0.32ab	23.18b	23.28b
Average	28.48	7.83	0.27	26.16	24.20

¹ OWS: open white sands; IWS: intermediate white sands; CWS: closed white sands; ² Measures followed by the same letter in the columns do not differ by Tukey's test at the 5% probability level.

According to Sobral et al. (2007), these levels of P in soil are considered adequate in Table 2. According to Galang et al. (2010), an increase in P availability is generally observed after burning due to the accumulation of ashes in the soil, although no significant differences were found. However, according to Knicker (2007), these effects tend to disappear in the medium term due to rainfall leaching, resulting in concentrations that may even be lower as observed in this study, where the concentrations in OWS and IWS areas were lower than CWS.

For the total organic carbon (TOC) (Table 2), a significant difference was found between the OWS and IWS areas, since the CWS area did not differ in relation to the other areas. These values can be explained due to OWS having been burned in a more recent period than the IWS, and such increase may be associated with the raise in the leaf fall and vegetal remains caused by the burning, as evidenced by Pessoa et al. (2012).

TSN values (Table 2) followed the same trend as TOC, where the area of closed white sand did not show a significant difference in relation to the other sands. These data corroborate the observation made by Haridasan (2008), showing that the total raise of N decreases in relation to the total organic carbon content. Only OWS and IWS presented a significant difference between them, with the first being superior to the second. According to Rheinheimer et al. (2003), this difference generally occurs because the most recent burning of dead vegetation promotes catalysis in the mineralization process, thereby enriching the soil as observed in OWS; while the TSN in IWS was already susceptible to losses by percolation and volatilization in months posterior to the burning.

For the different areas, the C/N ratio (Table 2) varied between 9.72 and 36.60, being significantly higher in OWS compared to IWS and CWS areas. This high C/N ratio in OWS is possibly causing slow decomposition of soil organic residues, especially when compared to the IWS and CWS area, which explains the TOC accumulation in the OWS area.

Regarding the carbon stock values in the soil, one can note that the OWS area was statistically superior to the other areas, indicating that the burning action may have increased the C

stock in the soil, and possibly influencing the soil density. As a result, its relevance in the results is higher (Table 2). The predominance of grasses in OWS may have supported this higher C stock in the soil. Bernoux et al. (1999) observed that the replacement of native vegetation by pasture favored an increase in the soil C stock. This process is also related to the lower decomposition rate of grasses, favoring a greater contribution of carbon.

The carbon content in the different fractions of the soil humic substances (Table 3) in the white sand areas was also analyzed, being: fulvic acid fraction (C-FAF), the humic acid fraction (C-HAF) and humin (C-HUM).

These humic substances of the SOM showed changes in carbon content in the fulvic acid fraction (C-FAF) ranging between 0.244 and 0.721 g kg⁻¹. However, no statistical difference was found ($p < 0.05$) between the white sand areas (Table 3). Although no significant differences were observed, the CWS area presented higher values of this fraction, demonstrating the faster regeneration of this area since C-FAF are richer structures in carboxylic groups than C-FAH (Dick et al., 2009).

The OWS area differed statistically from the IWS in carbon humic acid fraction (C-HAF), with OWS being higher. According to Cunha et al. (2001), humic fractions tend to be sensitive to disturbances caused by land use and vegetation systems, which may explain the difference between the OWS and IWS areas.

The values corresponding to carbon in the humin fraction (C-HUM) were higher when compared to C-FAF and C-HAF in all areas. Pessoa et al. (2012) also found higher mean values for carbon in the humin fraction in their evaluation of the distribution of humic fractions in the Northeast region of Brazil. Higher carbon values in the humin fraction are often evidenced in research about humic substances in tropical soils (Araújo et al., 2011; Fontana et al., 2010). According to Knicker et al. (2007), wildland fires changes the distribution of humic compartments of soil organic matter, causing increases in C-HUM concentration in detriment to C-FAF and C-HAF.

Table 3. C concentration of humic fractions of soil organic matter under vegetation with different regeneration stages in the Serra de Itabaiana National Park, Sergipe.

Vegetation Areas	C-FAF ²	C-HAF	C-HUM	C-HAF / C-FAF	C-EA/ C-HUM
	g kg ⁻¹			----	----
OWS ¹	0.244a ³	0.520a	1.157a	3.60a	0.655a
IWS	0.023a	0.046b	0.450a	0.18a	0.203a
CWS	0.721a	0.265ab	1.017a	3.15a	0.526a
Average	0.329	0.277	0.875	2.31	0.461

¹OWS: open white sands; IWS: intermediate white sands; CWS: closed white sands; ²C-FAF: carbon in fulvic acid fraction; C-HAF: carbon in humic acid fraction; C-HUM: carbon in humin; C-EA: C-FAF+C-HAF; ³Measures followed by the same letter in the columns do not differ by Tukey's test at the 5% probability level.

The C-HUM levels did not differ between white sand areas. However, the highest concentrations of C-HUM were found in OWS and CWS. The OWS values can be explained because part of the humic acid fraction is transformed into humin in areas that have been burned, since the soil is composed of additional inputs of lignin-rich materials from the incomplete burning of the biomass (Araya et al., 2017).

The C-HAF/C-FAF ratio did not show significant effect among the different white sand areas (Table 3). The OWS and CWS presented values higher than 1 in absolute numbers, indicating a predominance of humic acid in the soil in relation to the fulvic acid fraction. The C-EA/C-HUM ratio presented values below 1 in all areas, indicating the superiority of the humin fraction in the soil in relation to other fractions. Furthermore, one can state that the more labile part of C, C-FAF, and C-HAF may have been depleted in depth or suffered a microbial attack; a possible fact since the sandy soil does not offer any protection to native organic matter. Corroborating with Guimarães et al. (2013), C-FAF and C-HAF/C-HUM increases information on the loss of SOM in the soil profile.

4. CONCLUSIONS

The OWS and CWS areas presented the highest concentrations of exchangeable bases, CEC, TOC and TN content in the soil.

The carbon concentrations in the humic acid fraction were more sensitive to different soil managements and uses.

In general, the possible presence of more recalcitrant plant material because of the presence of fire and low decomposition rate in the OWS area favored the higher carbon content in the soil.

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