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Does the Caatinga Dry-Forest Management Change the Litter Composition and Nutrient Stocks?

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Abstract

Sustainable forest management (SFM) is a rational exploitation practice adopted in the Caatinga. This study aimed to evaluate the stock and the nutritional and organic composition of litter in Caatinga subjected to different forest management practices: shallow cutting (SC), selective thinning by minimum diameter (STMD), and selective thinning by species (STS), and using unmanaged Caatinga (control) as a reference, in dry and rainy seasons. There were a significant increase in total litter in STS and a decrease in stocks of STMD, shallow cutting and unmanaged forest. Forest management reduced leaves in the accumulated litter in both seasons and increased contribution from branches. The STS management promoted maintenance of the stock and nutritional and organic quality of the litter, bringing it closer to the condition of unmanaged natural forest in both climatic seasons. So, should be encouraged for a more sustainable management of the Brazilian phyto-physiognomy Caatinga.

Keywords: Caatinga, Forest management, Accumulated litter, Nutrient cycling.

1. INTRODUCTION

The Caatinga is a typical Brazilian biome which has characteristics of vegetation heterogeneity and a predominance of deciduous species (Marengo et al., 2017). It is located in the semi-arid region of the country, which is marked by the absence, scarcity and poor distribution of rainfall, associated with high temperatures and low relative humidity (Oliveira and Bernard, 2017).

These resources are rationally exploited through SFM, whose main objective is to organize production in management units within a cutting cycle compatible with forest regeneration (Hosokawa et al., 2013). Therefore, SFM is a viable perspective for regional development, as it guarantees timber production in a legal and conservationist way, with required socio-ecological observances (Meunier et al., 2018).

STMD and STS in Caatinga forest management has been used, however, the predominant practice is still SC. The latter corresponds to the total suppression of woody phytomass in the all of the designated area, being responsible for reducing thousands of hectares of Caatinga (Calixto Júnior and Drumond, 2011). STMD maintains a significant number of individuals, and provides the constant regeneration of the forest in a natural way, among other benefits (Barreto-Garcia et al., 2020). In the STS the selection of forest species to be removed is according to the wood properties and its usefulness, i.e., based on sustainability criteria of the vegetation, with the advantage of obtaining wood with greater timber-value and better conservation of the forest ecosystem characteristics (Barreto-Garcia et al., 2020).

It should be taken into account that the removal of woody vegetation can reduce or interrupt the supply of litter-forming plant material, altering the quality and quantity of soil organic matter, which in turn can make the forest sites to be unproductive through an imbalance in nutrient cycling (Lucena et al., 2017). This situation becomes more critical in tropical dry-forests, such as the Caatinga, where the climate and vegetation conditions provide low inputs of plant residues, high litter decomposition rates and low soil organic matter levels (Salcedo and Sampaio, 2008).

Furthermore, the analysis of nutrients in the litter can generate relevant information on the effects of disturbances on vegetation, such as those provided by Caatinga forest management. In this sense, the present study intends to answer the following question: (1) How do the composition and nutrient stocks of the litter respond to Caatinga forest management in two well-defined seasons (dry and rainy)?

2. MATERIAL AND METHODS

2.1. Study area

We performed this study at the "Floresta Nacional (FLONA) Contendas do Sincorá", which is located in the Chapada Diamantina region of the municipality of Contendas do Sincorá (13°45'46"S; 41°02'27"W) in the south-central part of the state of Bahia, Brazil (Figure 1). The region's climate is *BSwh* according to the Köppen classification. The mean annual temperature is 24.3°C, with annual rainfall between 20 and 140 mm, and the climate characterized as warm semi-arid. The soil is classified as Argissolo Vermelho-Amarelo according to the Brazilian System of Soil Classification (Embrapa, 2018), and equivalent to Ultisols in USDA Soil Taxonomy (Soil Survey Staff, 2014). Forest management was carried out in May 2015 with the removal of all woody-material and maintenance of harvest residues (thin branches, leaves and barks) in the managed areas. Before management, the studied area was in a late successional stage, considering that it has not undergone anthropic intervention since 1997 (year of the last woody-exploration) (Brasil, 2008). The selected experimental area consists of four management practices sites, which correspond to a reference site (unmanaged Caatinga forest) and three types of sustainable forest management in the Caatinga ecosystem:

(1) Unmanaged forest (control) – native Caatinga forest without anthropic interference; (2) Selective thinning by species (STS) – suppression of greatest occurrence tree species (*Commiphora leptophloeos* (Mart.) J.B. Gillett, *Jatropha molissima* (Pohl) Baill and *Pseudobombax simplicifolium* A. Robyns) (15% basal area reduction); (3) Selective thinning by minimum diameter (STMD) – suppression of all trees with diameter at breast height (DBH) greater than or equal to 5 cm (60% basal area reduction); (4) Shallow cutting (SC) – suppression of all trees, regardless of size or species (100% basal area reduction).

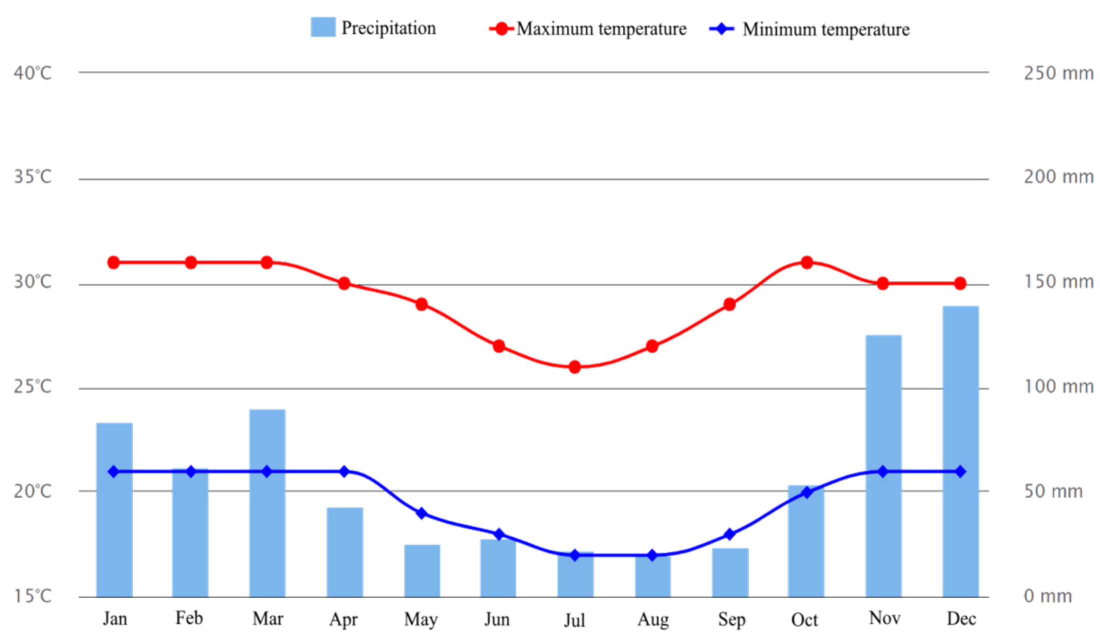

Figure 1. Maximum and minimum precipitation and temperature in the Chapada Diamantina region of the municipality of Contendas do Sincorá (13°45'46"S, 41°02'27"O) in the southern part of the state of Bahia, Brazil. Climatological averages are values calculated from a 30-year data series.

2.2. Litter collection

The choice of the most appropriate area for installing the experiment took place according to the criteria established by the Caatinga Forest Management Network, where the *Myracrodruon urundeuva* (Engl.) Fr. All., *Schinopsis brasiliensis* (Engl.), *Tabebuia* sp., *Aspidosperma pyrifolium* (Mart.) and *Cereus jamacarus* Mill species are frequent (Lima and Lima, 1998). Next, 16 units were delimited with 20 x 20 m (400 m^2) and designed for four treatments randomly distributed with four repetitions each for the case study. Litter samples accumulated on the soil surface were collected in 0.25 m^2 wooden traps at random distances in two well-defined seasons: the first campaign in December 2017 (rainy period) and the second in September 2018 (dry period).

The collected litter was separated into three fractions: senescent leaves (with leaflets and petioles), twigs (plant barks and branches fragments with diameter ≤ 1.0 cm) and amorphous material (unknown material with a higher degree of transformation). The selected material was dried at 60°C for 72 h to a constant weight, fine grounded and homogenized separately. Triplicate samples were obtained from composed samples (mixture of the simple samples collected in the four field replicates). The average litter stock accumulated on the soil was calculated according to the equation:

$$LS = [DW \times 10{,}000] \div Ca$$

In which: *Ls* stands for litter stock (kg ha^{-1}); *Dw* is average dry weight (kg) of litter; and *Ca* refers to the collector area (m^2).

2.3. Litter chemical analysis

An inductively coupled plasma optical emission spectrometer (ICP OES; Model ICPE-9000; *Shimadzu*, Japan) was used for calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P). The Kjeldahl method (INCT-CA method N-001/1) was performed to determine the total nitrogen (N). Polyphenols were extracted using the Anderson and Ingram (1996) method. Lignin and cellulose contents (%) were determined by the Fiber in Acid Detergent method (van Soest and Wine, 1968).

2.4. Statistical analysis

The litter accumulation and different fractions in each period and N, P, K, Ca, Mg, polyphenols, lignin, and cellulose content were tested for normality by the Shapiro-Wilk test, normal distribution residues and homoscedasticity by Cochran. Data were subjected to analysis of variance (ANOVA) and Tukey's test at 5% probability was used to compare means, in a completely randomized experimental design, using the ActionStat® software.

Data from N, P, K, Ca, Mg, lignin, polyphenols and cellulose contents (average of all litter fractions in dry and rainy season) were used in Principal Component Analysis (PCA) to verify the dissimilarity between the different sustainable forest management in Caatinga ecosystem. The PCA attempts to explain as much variation in few components as possible. Only the frst two components were used in this study, as they are considered suficient to explain the data and also because it facilitates interpretation of the graph in two dimensions (Lima et al.2023). The PCA was performed using the XLSTAT program (Statistical Software for Excel, 2018).

3. RESULTS AND DISCUSSION

The forest litter-biomass stocks in the sustainable forest management in the Caatinga ecosystem ranged from 4.29 to 7.75 Mg ha^{-1} in the dry season and from 5.17 to 6.92 Mg ha^{-1} in the rainy season (Figure 2). Lima et al. (2010) and Almeida et al. (2020) found higher litter stocks (8.4 Mg ha^{-1} and 14.5 Mg ha^{-1}, respectively) in similar unmanaged Caatinga sites. When compared with different Brazilian phyto-physiognomies, the Caatinga litter stocks presented lower values than those reported for the Cerrado *stricto sensu* (on average 6.08 Mg ha^{-1}) (Matos et al., 2021), and for a semi-deciduous Atlantic Forest biome (on average 8.2 Mg ha^{-1}) (Caldeira et al., 2013).

The management effect on litter accumulation was evidenced in the three fractions. The forest managements caused a greater entry of vegetable residues: a reduction of leaves and increased the contribution from twigs in the accumulated litter (compared to the control) in both seasons. In addition, the results also suggest that the STS favors the continuous and more diversified deposition of plant residues when compared to the STMD, SC and control (Figure 2). Although studies on forest litter production with a semi-arid climate, such as the Caatinga, indicate the leaf fraction as the most representative in litter formation (Lopes et al., 2015; Santana and Souto, 2011), the contribution of this fraction may decrease proportionally with maturity of plant species in managed forest systems, mainly caused by the high deposition of twigs and reproductive organs (i.e. fruits) (Vargas et al., 2019), and also from the greater susceptibility of leaves to decomposition, constituting a rapid source of nutrients during the cycling process at the soil surface (Laughlin et al., 2015). Barreto-Garcia (2020) in the same areas of the present study also observed that management provided a reduction of leaves in the litter and an increase in twigs, which caused a 42% reduction in soil microbial biomass.

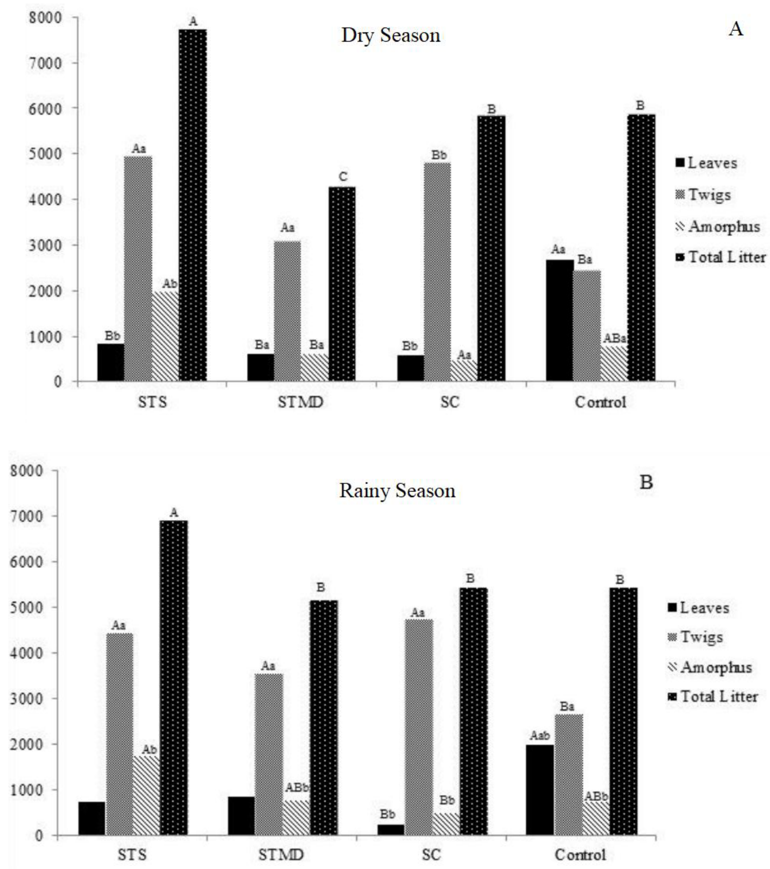

Figure 2. Average total litter deposition (kg ha^{-1}) and different fractions in sustainable forest management areas in the Caatinga ecosystem in Bahia, Brazil. (A) Dry seasin; (B) Rainy season. Means followed by the same letter do not differ statistically by *Tukey* test ($p \leq 0.05$). Capital case letters compare sustainable forest management to each other when there is statistical difference. Lowercase letters compare litter fractions to each other when there is statistical difference. [1]STS: Selective thinning by species, STMD: Selective thinning by minimum diameter, SC: Shallow cut, and Control: Unmanaged forest. Leaves: with leaflets and petioles, Twigs: plant barks and branches fragments whit diameter ≤ 1.0 cm, and Amorphous: unknown material with a higher degree of transformation.

The Principal Component Analysis (PCA) from N, P, K, Ca, Mg, lignin, polyphenols and cellulose contents (average of all litter fractions in dry and rainy season) explained 65.24 % of the variation through two principal components (30.63% PC_1 and 34,61% PC_2), and indicated dissimilarity between management systems and the Caatinga unmanaged forest in dry and rainy season (Figure 3). In general, the rainy season was distributed on the right and the dry season on the left of the diagram.STMD and SC were distributed in the lower quadrants and STS snd control in the upper quadrants. The organic compounds most closely associated with PC_1 were lignin and cellulose; while K, Mg and polyphenols were associated with PC_2 (Figure 3, Table 1).

The approximation of STS in relation to Control, and STMD in relation to SC in both seasons (Figure 3) shows that the intensity of the physical environment alteration (total or most of the vertical structure removal of the vegetation) has a direct effect on the litter dynamics, which corroborates the results previously discussed in the forest litter-biomass stocks. The similarity of STS and unmanaged Caatinga may be an indication that the selective thinning by species showed a lower negative impact on the litter (chemical composition) as a result of less interference from management and greater vegetation structure conservation. Likewise, the similarity of STMD and SC meaning that the selective thinning by diameter has a similar effect to the total removal of vegetation cover in the Caatinga biome. Therefore, conserved (i.e. rational use of forest resources) and/or preserved areas (i.e. absence of forest management) tend to promote the formation of a more diverse litter and continuous supply of plant residues, which can favor the decomposition process and nutrient cycling (Jewell et al., 2016).

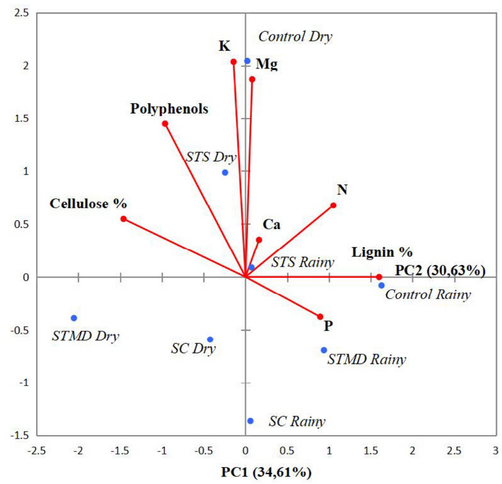

Figure 3. Ordination diagram produced by principal component analysis (PCA) of the nutrients stocks in litter at different sustainable forest management in Caatinga ecosystem in Bahia, Brazil. STS: Selective thinning by species, STMD: Selective thinning by minimum diameter, SC: Shallow cut, and Control: Unmanaged forest.

Table 1. Factor analysis by PCA of nutrients stocks in litter at different sustainable forest management in Caatinga ecosystem in Bahia, Brazil.

Variables	CP1	CP2
N	**0.99**	-0.02
P	**0.86**	-0.47
K	0.28	**0.81**
Mg	0.68	0.65
Ca	**0.85**	-0.02
Polyphenols	-0.02	**0.94**
Lignin	0.89	-0.15
Cellulose	-0.08	**0.89**
Variability (%)	46.96	37.47
Accumulated (%)	46.96	84.43

Our results showed the average contents of the organic compounds which compose the litter accumulated followed the trend *lignin > cellulose > polyphenols* in both seasons (Tables 2 and 3). These results are in line with the higher proportion of the twig fraction (~66.2%, Fig. 1), which is indicative of low decomposition rates by the biota, especially when compared to other fractions also deposited by plants on the topsoil. The nutrient amounts in the accumulated biomass followed the average trend *N > Ca > P > Mg > K* common between the treatments in the two seasons, while the order of the fractions with the highest nutrient stocks, in general, was *twigs > amorphous > leaves* (Tables 2 and 3). Despite the specific characteristics of the studied managements, the order of the total nutrient stocks analyzed was similar to those found by Souto et al. (2009) in a Caatinga ecosystem, although the biomass accumulation in the form of litter has been different from other studies (Lima et al., 2010; Almeida et al., 2020).

Nutrient concentrations generally vary according to the chemically functional characteristics of each nutrient, and the foliar (re)translocation strategies of plant species during the senescence process of each litter fraction: twig fraction has higher Ca contents in relation to the leaf fraction which contain higher N, P and Mg concentrations. Besides, the high N stocks in the litter may be directly linked to greater demand for this element by plants or a low rate of (re)translocation during the senescence process of plant material. The high Ca stock may be related to the low mobility of this element in plants, since it plays a structural role in forming the cell wall (Hawkesford et al., 2012). The K nutrient showed a low concentration in all evaluated sites, which was expected due to its high solubility in the intercellular space since it is not a structural element in plants, and thus contributing to its easy leaching from senescent plant biomass (Chapin, 2002) (Tables 2 and 3).

Table 2. Nutrients stocks (kg ha^{-1}) and polyphenols, lignin and cellulose concentration (%) in different fractions deposited during the dry season in sustainable forest management areas in the Caatinga ecosystem in Bahia, Brazil.

Management[1]	Fractions[2]	N	P	K	Mg	Ca	Polyphenols	Lignin	Cellulose
STS	Leaves	10.6	1.5	0.7	1.1	6.5	1.22	43.92	15.12
	Twigs	34.4	4.9	1.1	2.6	29.7	1.95	40.20	29.64
	Amorphous	25.6	4.7	1.5	2.5	17.8	0.37	61.68	11.92
STMD	Leaves	7.4	1.3	0.9	1.0	7.7	1.63	30.16	18.60
	Twigs	24.8	3.8	0.7	2.7	22.1	0.50	34.28	35.20
	Amorphous	11.6	1.7	0.6	1.0	11.6	0.62	38.40	18.48

Table 2. Continued...

Management[1]	Fractions[2]	N	P	K	Mg	Ca	Polyphenols	Lignin	Cellulose
SC	Leaves	7.4	1.2	0.5	0.8	6.9	0.93	41.20	19.16
	Twigs	35.7	4.3	0.9	2.4	31.8	0.49	39.40	30.32
	Amorphous	5.2	0.9	0.3	0.5	3.8	0.49	62.44	9.44
Control	Leaves	34.5	4.7	3.9	4.7	23.5	1.34	43.92	16.68
	Twigs	23.1	2.8	0.8	1.7	17.2	0.76	45.24	27.12
	Amorphous	11.5	1.6	0.9	1.3	6.6	1.13	49.84	12.24

[1]STS: Selective thinning by species, STMD: Selective thinning by minimum diameter, SC: Shallow cut, and Control: Unmanaged forest. [2]Leaves: with leaflets and petioles, Twigs: plant barks and branches fragments whit diameter ≤ 1.0 cm, and Amorphous: unknown material with a higher degree of transformation.

Table 3. Nutrients stocks (kg ha^{-1}) and polyphenols, lignin and cellulose concentration (%) in different fractions deposited during the rainy season in sustainable forest management areas in the Caatinga ecosystem in Bahia, Brazil.

Management[1]	Fractions[2]	N	P	K	Mg	Ca	Polyphenols	Lignin	Cellulose
STS	Leaves	4.5	0.9	0.1	0.2	3.2	0.14	55.44	4.60
	Twigs	45.0	11.5	0.7	2.4	34.4	0.26	42.68	21.76
	Amorphous	10.0	3.8	0.2	0.6	6.1	0.24	55.44	13.84
STMD	Leaves	13.2	2.9	0.3	0.7	10.3	0.10	62.04	1.04
	Twigs	42.4	9.9	1.0	2.8	34.8	0.19	44.44	24.64
	Amorphous	12.9	2.6	0.2	0.7	4.7	0.29	55.64	10.76
SC	Leaves	12.4	3.3	0.4	0.9	11.1	0.12	39.52	15.48
	Twigs	54.0	13.3	1.5	4.2	52.9	0.27	52.68	17.72
	Amorphous	27.0	9.1	0.7	1.9	22.9	0.16	47.28	9.12
Control	Leaves	35.0	5.4	0.8	2.1	14.4	0.12	63.72	9.88
	Twigs	31.3	9.5	0.9	2.4	23.2	0.40	53.44	18.88
	Amorphous	4.5	0.9	0.1	0.2	3.2	0.11	60.48	9.52

[1]STS: Selective thinning by species, STMD: Selective thinning by minimum diameter, SC: Shallow cut, and Control: Unmanaged forest. [2]Leaves: with leaflets and petioles, Twigs: plant barks and branches fragments whit diameter ≤ 1.0 cm, and Amorphous: unknown material with a higher degree of transformation.

4. CONCLUSIONS

The different forest management practices in the Caatinga showed short-term changes in litter accumulation and in its nutrients and organic compounds, with variation between dry and rainy seasons. STS most favored the maintenance of the litter stocks and nutritional and organic quality, bringing it closer to the condition of unmanaged forest at both times of the year. On the other hand, STMD and SC led to more expressive changes in the composition and nutrient cycling in the litter. As STS are more favorable to the maintenance or improvement of nutrient cycling, should be encouraged for a more sustainable management of the Brazilian phyto-physiognomy Caatinga.

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