

Litter dynamics in a seasonally dry forest fragment

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ABSTRACT: Litter decomposition makes possible the nutrient cycling and is a link between vegetation and soil, vital for a healthy forest ecosystem. Although several studies on litter decomposition have been carried out in different regions of Brazil, there are few studies for transitional zones between Cerrado and Caatinga, particularly in the state of Piauí. Therefore, the objective of this work was to evaluate the litterfall production, litter composition and decomposition rate in a tropical dry forest fragment located in the southeast region of Piauí, Brazil. Monthly litterfall dynamics were evaluated for one year, by placing litter traps in the center of six forest inventory permanent sample plots, and the decomposition rate was determined by the litterbag technique. Litterfall production was estimated at 4,401.7 kg ha⁻¹ year⁻¹, similar to Caatinga environment values, with the leaves fraction contributing with the highest percentage (64%). On the other hand, litter decomposition rate was estimated at 0.003 g day⁻¹, similar to rates found in Cerrado environments, highlighting the importance to better understand this ecozone litter dynamics. Wind speed had significant correlation with litterfall production. The number of species in the sample plot had highest correlation with the decomposition rate, and the diameter growth rate was the dendrometric variable most correlated to litterfall production.

Dinâmica da serapilheira em um fragmento de floresta estacional semidecidual

RESUMO: A decomposição da serapilheira torna possível a ciclagem de nutrientes, sendo uma ligação entre vegetação e solo, vital para um ecossistema florestal saudável. Embora diversos estudos sobre o tema tenham sido realizados em diferentes regiões do Brasil, há poucos registros de estudos para zonas transacionais entre Cerrado e Caatinga, particularmente no estado do Piauí. Logo, o objetivo deste trabalho foi avaliar a produção de serapilheira, sua composição e a taxa de decomposição em um fragmento de mata seca tropical localizado na região sudeste do Piauí. A dinâmica da serapilheira foi avaliada mensalmente durante um ano com uso de coletores instalados em seis parcelas amostrais, a taxa de decomposição foi determinada utilizando *litterbags*. A produção de serapilheira foi de 4.401,7 kg ha⁻¹ ano⁻¹, valor mais próximo para ambientes da Caatinga, com a fração de folhas contribuindo com o maior percentual (64%). Já para a taxa de decomposição o valor encontrado ($k=0,003$ g dia⁻¹) foi semelhante a ambientes de Cerrado, destacando a importância de entender melhor essa dinâmica nos ecótonos. A velocidade do vento teve correlação significativa com a produção de serapilheira. O número de espécies em cada parcela teve maior correlação com a taxa de decomposição e o incremento diamétrico foi a variável dendrométrica mais correlacionada com a produção de serapilheira.

Introduction

The Brazilian Cerrado and Caatinga biomes represents 33,8% of the country's land cover (Souza Júnior et al. 2020) and these seasonally dry tropical forests are water-limited biomes with a high number of endemic species and provides numerous ecosystem services (Stan and Sanchez-Azofeifa 2019, Siyum 2020). It is common sense that dry forests play a pivotal role in rural livelihoods, especially for forest-dependent communities (Albuquerque and Melo 2018, Siyum 2020), and the impacts of these anthropic actions must be considered in forest dynamics. Among the semiarid regions of the world, the Northeast of Brazil is considered one of the most populous, which causes intense anthropic activity, and, in some cases, these favor environmental degradation processes (Albuquerque and Melo 2018, Francisco et al. 2020).

In drylands, where soil fertility is typically low, plant litter accumulation and decomposition provide critical carbon and nitrogen inputs into soil (Chuckran et al. 2020) and have long been considered as complex and important factors in controlling both vegetation structure and ecosystem function (Xiong and Nilsson 1999, Holanda et al. 2017). Litterfall serves three main functions in the ecosystem: energy input for soil microflora and fauna, nutrient input for plant nutrition, and material input for soil organic matter development (Pitman 2013, Krishna and Mohan 2017, Chuckran et al. 2020).

The quantification of litterfall production and decomposition, and the effects of vegetation, soil and climate variables on litterfall dynamics, is important to understand given the impacts that climate change causes in forest dynamics (Souza et al. 2019). The process of forest litterfall depends on the tree species, the age of the stands and their development, and is influenced by environmental conditions, particularly water and nutrient availability (Goma-Tchimbakala and Bernhard-

Reversat 2006). Litter production presents a seasonal behavior, with peaks of material supply to the soil according to the conditions of the environment or the physiological and phenological patterns of the vegetation (Brasil et al. 2017, Oliveira et al. 2019).

Thus, this study characterizes litterfall dynamics through a time-series of litter collection in a seasonally dry forest fragment located in Piauí, Brazil. We assessed the litterfall production and decomposition, relating biodiversity metrics, stand structural attributes and climate variables with monthly litter production, aiming to address the role of indirect interactions mediated by plant litter inputs in a dry forest environment. We hypothesized that the number of species and tree growth rates have a positive effect on litter production. We also projected higher production of litter in the dry season and significant relationships with climatic variables. We expected the production values to be slightly like the ones we found for tropical dry forests, although lower when compared to preserved environments.

Material and Methods

Study area

This study was carried out in a forest fragment located in Bom Jesus, state of Piauí, Brazil. The area has 8 hectares, and it is located on the edge of the Federal University of Piauí campus, and is surrounded by residences and small agricultural farms that eventually use the vegetation to collect wood for energy and other purposes (Figure 1). The region climate, according to Köppen classification, is Aw (hot and humid tropical), with annual temperature average of 27°C and annual precipitation average of 984.8 mm (Alvares et al. 2013, Medeiros 2019). This region is characterized by a dry season in the winter, were around 90% of the total precipitation occurs from November to April (INMET 2018). The soil in the area is for the yellow latosol class with a sandy-loam texture.

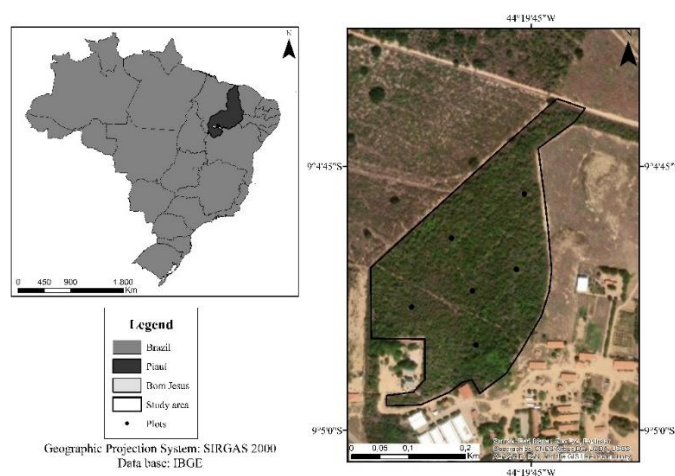


Figure 1. Location of the state of Piauí, the municipality of Bom Jesus, the study area, and distribution of the sample plots of the forest inventory.

In September of 2018 six circular permanent plots (400 m²) were allocated in the area. All trees \geq 5 cm of diameter at breast height (DBH at 1,30 m above the ground) had their height and diameter measured, as well their botanical identification. Remeasurement of the plots was done one year later,

in September 2019. The vegetation is a transition between the Caatinga and Cerrado biomes, characterized by small to medium-sized trees, with structural attributes similar for the two measurements (Table 1).

Table 1. Mean and standard deviation for the dendrometric variables for the two measurements in the study area (DBH in centimeters, H in meters, G in m² ha⁻¹ and N in trees per hectare).

Plot	DBH 2018	DBH 2019	H 2018	H 2019	G 2018	G 2019	N 2018	N 2019
1	7.4±3.1	7.7±3.3	6.4±2.1	6.0±2.6	6.27±0.12	6.78±0.13	1250	1225
2	7.9±3.7	7.9±4.0	5.8±1.4	6.1±1.7	5.35±0.18	5.53±0.19	900	875
3	7.7±3.0	8.1±2.9	5.7±1.4	6.1±1.8	4.54±0.12	4.90±0.11	850	850
4	7.2±2.8	7.6±4.2	7.0±1.4	7.0±1.9	4.78±0.12	6.09±0.21	1000	975
5	6.9±2.1	7.1±2.2	6.3±1.3	6.7±2.0	1.83±0.07	1.96±0.08	425	400
6	7.9±2.3	8.3±2.5	7.3±1.6	7.9±2.0	6.06±0.08	6.80±0.09	1150	1150
Mean	7.5±2.9	7.8±3.2	6.4±1.5	6.6±2.0	4.81±0.12	5.34±0.14	930	912

Litterfall sampling and in situ decomposition

To understand the litterfall dynamics we used a sampling design with months and plots as replicates. Litter samples were collected monthly from September 2018 to August 2019 in the plots, using one 0,25m² litter trap placed in the center of each plot, totaling 6 litter traps per month. The traps were made of a metal structure with 50 cm height off the ground, adapted from the methodology proposed by Valentini et al. (2014) to avoid the accumulation of water during rainy seasons, and consequential acceleration of the litter decomposition. The litterfall samples were collected monthly and sorted into leaves, twigs, reproductive parts, and debris. Litterfall fractions were then oven dried (at 65 ± 3 °C) until a constant weight was reached and were weighed using an analytical scale (0.0001 g).

The litterbag technique was used to determine the litterfall decomposition rate (decay). 72 bags (25 x 25 cm with 2 mm mesh) were aleatory placed in the ground of the plots. The litterbags contained 20 g of no sorted fresh litter were inserted into the litter layer of the soil. Data were gathered monthly (beginning in March of 2019 till February of 2020), in each litterbag the material was oven dried, weighted, and the remaining litter quantity was measured. After the determined dry weights, the percentage of the remaining mass was calculated for each period by the ratio between final and initial mass weight. For each plot, a decay constant (k) was determined using an exponential decay model (Olson 1963):

$$X_t = X_0 e^{-kt}$$

where X_t is the mass at time t , X_0 is the initial mass, and k is the decay constant.

Statistical analysis

To evaluate the influence of the climatic variables (mean monthly temperature, wind speed and total precipitation) on litterfall production, a

dataset was collected from the National Institute of Meteorology (INMET) weather stations located in Bom Jesus and Alvorada do Gurguéia (90 km away from the study area, used when missed values occurred from Bom Jesus). Pearson correlations at 5% significance were tested between monthly litterfall production and climatic variables. We also correlated the litter production and decomposition rate with the number of species (n_{sp}) and the dendrometric variables growth rate (mean annual increment - MAI).

Vegetation data (number of species and annual tree growth rates for DBH, H and G) were calculated for each plot, and the influence of these values in the plot's litterfall production and decomposition rate was tested using Pearson correlations at 5% significance.

We used an analysis of variance (ANOVA) to evaluate the annual variation in total litterfall, Tukey's test was used to investigate which month differed from each other in litter production ($p \geq 0.05$). All statistical analyses were carried out using the statistical environment R (R Core Team 2021).

Results and Discussion

The mean annual litter production was 4,401.7 kg ha⁻¹ year⁻¹, similar to the values presented by authors from different sites (Table 2). We found that the litterfall production in our study area presented greater similarity to Caatinga values than Cerrado, the last usually with larger values. It is important to point out that different values found in the literature may be due to different methodologies, typologies, and conservation status of forests, making it challenging to draw a parallel between the average values reported.

Table 2. Literature reported values of annual litter production in different Brazilian states for Caatinga and Cerrado biomes.

State/Biome	Annual litter production (kg ha ⁻¹ year ⁻¹)	Reference
CE/Caatinga	4,277.2 (Caatinga in regeneration process)	Brasil et al. (2017)
	2,248 (Caatinga with anthropic activity)	
	4,038.8	Moura et al. (2016)
	4,673.1	Salgado et al. (2015)
PB/Caatinga	3,335.6	Ferreira et al. (2019)
	3,785.7	Holanda et al. (2017)
	4,500 (preserved Caatinga)	Araújo et al. (2019)
	3,300 (Caatinga with anthropic activity)	
1,630.5	Silva et al. (2015)	
RN/Caatinga	2,068.6	Santana and Souto (2011)
	3,673	Lopes et al. (2015)
PI/Caatinga	8,410 (preserved Caatinga)	Lima et al. (2010)
	8,440 (preserved Caatinga)	Lima et al. (2015)
	3,266.8	Costa et al. (2015)
TO/Cerrado	1,349.01 (Cerrado <i>sensu stricto</i>)	Teixeira et al. (2016)
	6,042.5	Pedro et al. (2019)
DF/Cerrado	6,301.4	Ribeiro et al. (2017)
GO/Cerrado	10,291.2	Carvalho et al. (2019)
MG/Cerrado	7,545	Siqueira et al. (2016)
	2,500	Giácomo et al. (2012)
	4,400	Costa et al. (2020)
MT/Cerrado	11,886.84	Valentini et al. (2014)
	622 (Cerrado <i>sensu stricto</i>)	
	1,046 (Cerradão)	Silva et al. (2007)

The leaves fraction was the one that most contributed to the mean biomass production (63.7%), followed by twigs (31.3%), reproductive parts (3.6%) and debris (1.4%) (Figure 2). Leaf tissue can account for more than 70% of above ground litter fall in forests (Krishna and Mohan

2017). There was a statistical difference at 95% of significance level between the evaluated months by the Tukey’s test for months with the highest and lower litterfall production months (June, July, November and December, respectively, Figure 2).

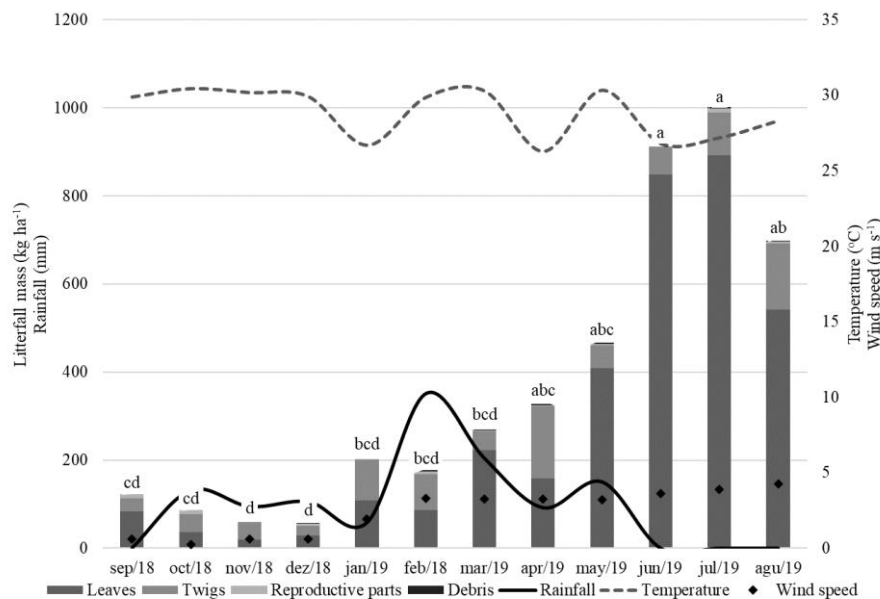


Figure 2. Litterfall dynamics and climate variables during the study period in a tropical dry forest area in Bom Jesus, PI. Means with the same letter were not significantly different (Tukey test, P ≥ 0.05).

It was verified that the months of greatest litterfall production (June, July, and August) correspond to the months with the lowest precipitation and higher wind speeds (Figure 2). In contrast, months with the highest precipitation were the months in which there was the lowest litterfall production. At least 50% of the seasonally dry tropical forests species exhibiting a deciduous nature (Stan and Sanchez-Azofeifa 2019), where under seasonal water deficit conditions, the plants either tolerate drought or avoid drought by dropping leaves and thus limit transpiration during the dry season to survive (Siyum 2020, Chuckran et al. 2020). This corroborates with our results, that showed the increase in litter production in the months with low precipitation, with elevated amount of leaves fraction (Figure 2). Araújo Filho (2013) reported that in the beginning of the wet season or the end of the dry season in an arboreal Caatinga, for a total of 2,287.2 kg ha⁻¹ of ground biomass, 92.2% is made up

of stubble or litter, and only 5.3% comes from herbaceous plants and 2.5% of woody species.

The decay constants (k) did not differ significantly between the plots (p -value = 0.66). The mean value found of $k=0.003\pm 0.0001$ g day⁻¹ is lower to the ones observed in tropical forests and plantations ($k=0.1$ – 4.8) (León and Osório 2014), although it is well known that environments with slow decomposition rates and low surface litter deposition have k values less than 1 (Krishna and Mohan 2017). When comparing our value with other related studies (Figure 3), such as Pedro et al. (2019) in an area of Cerrado in Tocantins, the reported value of k was also 0.003 g day⁻¹. Bauer et al. (2016) studying two areas of regenerated Caatinga in the state of Paraíba, reported values of $k=0.002$ and 0.001 g day⁻¹. In contrast to the litter production, the decomposition rate was more similar to Cerrado vegetation dynamics than Caatinga, highlighting the transitional zone in which the study area is located, presenting patterns from both biomes.

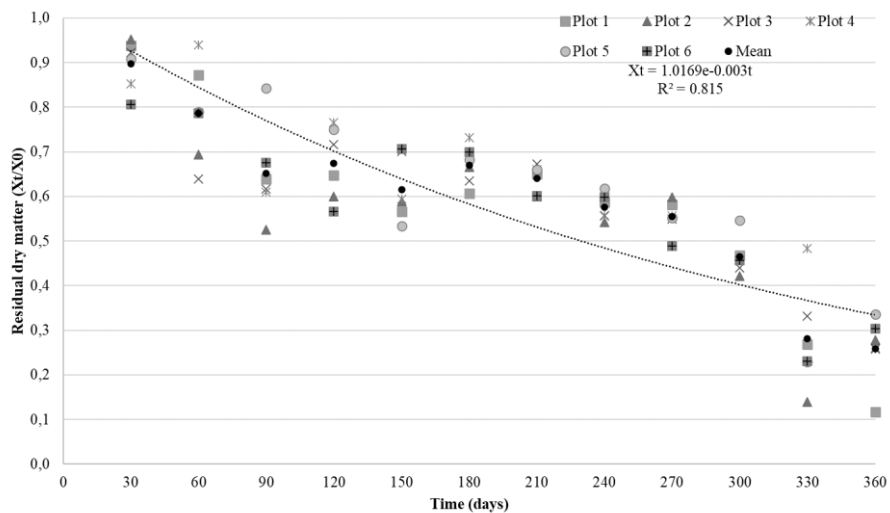


Figure 3. Residual dry matter (X_t/X_0) of litter and fitted model as a function of time for a tropical dry forest area located in Bom Jesus, Piauí.

When evaluating the correlation between the climatic variables and total litter production and decomposition (Table 3), it is perceived that the variable with the highest positive correlation is wind ($r=0.77$), while rainfall ($r=-0.48$) and temperature ($r=-0.58$) both have a negative correlation. Pedro et al. (2019), studying litterfall in a Cerrado area, also reported no significant correlation between litterfall production and temperature, and higher correlation between litter production and rainfall compared with our study ($r=-0.68$). The correlations of decomposition rate (Table 3) with wind and rainfall were negative ($r=-0.51$ and -0.49 , respectively) and positive with temperature ($r=0.11$). Our results did not show a significant correlation between decomposition and temperature, possibly because of the low temperature variation in the region ($\pm 1.6^\circ\text{C}$).

Krishna and Mohan (2017) argued that this variable can be considered as a prime factor in determining the rates of litter decomposition, since it may influence the existence of microbes and other soil fauna that significantly affect the rate of decomposition.

The species composition of the study area is similar to that reported by Ribeiro et al. (2021), with 81% of the trees found in area belonging to the species ($n=26$): *Pityrocarpa moniliformis* Benth. (24.4%), *Cenostigma macrophyllum* Tul. (24%), *Combretum glaucoparpum* Mart. (12%), *Hymenaea courbaril* L. var. *stilbocarpa* (Hayne) Lee et Lang. (8.9%) and *Mimosa verrucosa* Benth. (6.3%). The correlation between number of species and litter production was negative ($r=-0.24$) and positive for the decomposition rate ($r=0.59$), indicating that flora

composition may play an important role in litter dynamics (Souza et al. 2019, Chen et al. 2020). The MAI in diameter and basal area presented an opposite correlation behavior with litter production and decomposition, positive for the first and negative for the second. For MAI in height and number of

species, both presented positive correlation for litter production and for decomposition rate (Table 3). Although vegetation characteristics play an important role in litter dynamics, in our study we did not find a statistically significant correlation between these variables.

Table 3. Person's correlation matrix between litterfall production and decomposition rate (k) with climate variables and vegetation characteristics.

Climatic	Litterfall	k
Rainfall	-0.48	-0.49
Wind	0.77*	0.51
Temperature	-0.58*	0.11
Vegetation	Litterfall	k
Litterfall	-	-0.73
n_sp	-0.24	0.59
MAI_DBH	0.72	-0.29
MAI_H	0.06	0.35
MAI_G	0.35	-0.25

* Person's test significant ($p < 0.05$)

Conclusions

The litter production in our study area (4,401.7 kg ha⁻¹ year⁻¹) presented similar values found for the Caatinga biome, although the decomposition rate was more similar to the Cerrado biome.

Wind speed and temperature were the climate variables with significant correlation with litter production, and rainfall was significantly correlated to the decomposition rate. The months of greatest litterfall production (June, July, and August) correspond to the months with the lowest precipitation and higher wind speeds.

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