The effects of rainfall and vegetation on litterfall production in the semiarid region of northeastern Brazil

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(With 1 figure)

Abstract

Litterfall has a strong influence on biodiversity and on the chemical and physical characteristics of the soil. Its production can be quite variable over time and space, and can be influenced by both natural and anthropogenic factors. We evaluated litterfall production and its relationship with rainfall, species richness, and the densities of the arboreal vegetation. Thirty litter traps were constructed with 1.0 m^2 nylon mesh (1.0 mm) and randomly installed within a 2000 m × 500 m area of arboreal/shrub Caatinga (dryland) vegetation. Litter samples were collected monthly from November/2010 to June/2012, and the collected material was classified, dried, and weighted. Species richness and tree densities were determined by conducting phytosociological surveys in 20 m × 20 m plots surrounding each of the litter traps. The litterfall accumulation rate was 3.673 Mgha^{-1}yr^{-1}, similar to values from other seasonally dry tropical forests. Litterfall production was continuous, and principally accompanied the rainfall rate, but with a time interval of 2 to 3 months, with the greatest accumulation at the beginning of the dry season and the least during the rainy season. The different fractions of materials demonstrated distinct accumulation rates, with leaves being the principal category. Litterfall production was found to be related to tree density, but no link was found to species richness. The observed temporal heterogeneity of litterfall production demonstrated a strong link between rainfall and the dynamics of nutrient cycling in the semiarid region of Brazil.

Keywords: Caatinga, spatial variability, temporal variability, necromass, neotropical region.

Efeitos da precipitação e da vegetação sobre a produção de serapilheira em uma área do semiárido do nordeste brasileiro

Resumo

A serapilheira exerce forte influência sobre a biodiversidade e as características físicas e químicas do solo. Sua produção pode ser bastante variável no tempo e no espaço e pode ser influenciada por fatores naturais e antropogênicos. Este estudo buscou avaliar a taxa de produção de serapilheira e a sua relação com a precipitação, riqueza de espécies e densidade da vegetação arbórea. No interior de uma área de 2000 m × 500 m foram sorteados aleatoriamente 30 pontos amostrais e em cada um deles instalado um coletor de aço de 1,0 m^2. As coletas ocorreram mensalmente de novembro de 2010 a junho de 2012. O material coletado foi triado, secado e pesado. A riqueza de espécies e a densidade de árvores foram obtidas através de estudo fitossociológico em 30 parcelas de 20 m × 20 m. Foi registrada uma produção de serapilheira de 3,673 Mgha^{-1}yr^{-1}, taxa condizente com os valores encontrados para florestas tropicais sazonalmente secas. A produção de serapilheira foi contínua entre os meses, acompanhando principalmente o efeito tardio da precipitação (dois a três meses anteriores) e apresentou maior deposição no período do início da estação seca e menor no chuvoso. As frações do material apresentaram taxas de contribuição distintas, sendo a de folha a maior contribuinte. A produção de serapilheira também foi relacionada com a densidade de árvores, porém não houve relação com a riqueza de espécies. A heterogeneidade temporal da produção de serapilheira evidencia a forte ligação entre as chuvas e a dinâmica de ciclagem de nutrientes na região semiárida do Brasil.

Palavras-chave: Caatinga, variabilidade espacial, variabilidade temporal, necromassa, região neotropical.

1. Introduction

Litterfall constitutes the most superficial layer of the soil and it is composed of leaves, stems, branches, fruits, flowers, and other plant parts, as well as animal remains and fecal material – constituting a reserve of mineral elements and organic material that strongly influences the dynamics of ecosystem nutrient cycling

(Coleman et al., 2004). Litterfall provides shading and helps retain humidity, creating micro-climatic conditions that can promote seed germination and seedling establishment (Moraes et al., 1998). The importance of litterfall goes beyond protecting and fertilizing the soil, as it directly affects local biodiversity conservation (Coleman et al., 2004). As such, studies focusing on the dynamics of litterfall are important to our understanding of nutrient cycling, forest growth, successional patterns, carbon cycling, ecological disturbances, and the interactions of environmental variables (Vasconcelos and Luizão, 2004; Zhou et al., 2007; González-Rodríguez et al., 2011).

Various biotic and abiotic factors (both environmental and spatial) affect litterfall production, such as the type of vegetation, altitude, latitude, temperature, light regime, moisture availability, and the physical and chemical characteristics of the soil (Bray and Gorham, 1964; Vitousek, 1984), with seasonal variations in the production and decomposition of litterfall being mainly related to climatic factors (Spain, 1984). In arid and semiarid ecosystems such as the Caatinga, litterfall has an important role in protecting the soil (Souto, 2006). The superficial leaf litter layer not only attenuate the intense solar radiation, but also aids in retaining moisture – as Caatinga soils have low infiltration capacities and therefore high rates of surface runoff (Souto, 2006; Moraes et al., 1998).

The Caatinga biome is one of the largest examples of semiarid savanna in the neotropical region, covering approximately 735,000 km^2 in northeastern Brazil (Andrade-Lima, 1981; Leal et al., 2005). The regional landscape is dominated by a mosaic of different phytophysionomies, including arboreal, shrub, and thorny vegetations that are well-adapted to dry conditions (Coimbra-Filho and Câmara, 1996). The Caatinga environment is characterized by high levels of solar radiation during at least part of the year and sparse vegetation cover (Sampaio, 1995), with high evapotranspiration rates during the entire year (1500-2000 mmy^{-1}) and low rainfall rates (300-1000 mmy^{-1}); precipitation is normally concentrated into from 3 to 5 months – although rainfall patterns can be extremely erratic (Sampaio, 1995).

In light of the importance of litterfall to the dynamics of tropical ecosystems, especially semiarid regions, the present study sought to evaluate litterfall production rates in an area of Caatinga vegetation and examine their relationships with rainfall and vegetation structure (species richness and the density of individuals).

2. Material and Methods

The present study was undertaken on the Cauaçu Farm (05° 34' 0.8'' S and 35° 55' 3.1'' W) that occupies approximately 700 ha in an area of Caatinga (dryland) vegetation in the municipality of João Câmara, Rio Grande do Norte State, in northeastern Brazil. The regional climate is semiarid, with a mean annual temperature of 24.7 °C (minimum 21 °C and maximum 32 °C), a mean annual rainfall rate of 648.6 mm, and mean annual humidity of 70%. The rainy season normally extends between March and June (Brasil, 2005). The study site was situated at 100 to 200 m a.s.l.in an area of open to dense arboreal-shrub vegetation with scattered rock outcrops (the latter with its own low and very sparse vegetation).

The litterfall was collected on a monthly basis from November/2010 to June/2012 in a 2000 m x 500 m area. Thirty sampling points were randomly designated, and 20 m × 20 m plots were established around them. At the center of each plot a 1.0 m^2 collector was assembled, composed of a galvanized steel frame holding a nylon mesh (1.0 mm) suspended approximately 20 cm above the ground. The nylon mesh served to collect the falling litterfall without accumulating water (thus avoiding decomposition during the rainy season) (Costa et al., 2007).

The litterfall accumulated in the collector was harvested every month and manually sorted into different fractions: leaves (including leaflets and petioles), branches (including bark and other woody parts), reproductive structures (flowers, fruits and seeds), and miscellaneous material (which could not be precisely identified). After sorting, the different fractions were dried in a forced-air oven at 70 °C for 72 h and then weighed to four decimal-place accuracy using a precision balance. Rainfall data was provided by EMPARN (Agricultural Research Company of Rio Grande do Norte).

The species richness and densities in the plots were determined through phytosociological surveys (Mueller-Dombois and Ellenberg, 1974) that sampled all of the live individuals with stem diameters at soil level greater than or equal to 3.0 cm (DSL ≥ 3.0 cm) and with total heights ≥ 1.0 m (Rodal, 1992).

One-way ANOVA testing was utilized to analyze the temporal variations in litterfall production, after confirming the homogeneity of the variances of the data. In order to conform to the requirements of normality, the litterfall production data was *log* (x+1) transformed before analysis. Spearman's Correlation coefficient was used to evaluate the relationships between litterfall production and rainfall and the vegetation parameters (species richness and vegetation density). We evaluated the time lag influence of rainfall by considering precipitation levels during the second and third months previous to the collection of the litterfall material. Statistical calculations were performed using STATISTIC 5.0 software (Statsoft, 1995).

3. Results

The study area had a mean total litterfall production of 3.673 $Mgha^{-1}yr^{-1}$, with a mean monthly production rate of (± standard error) 0.306 ± 0.03 $Mgha^{-1}$. There were significant variations in monthly total litterfall production rates ($F_{19,580} = 56.617$, $P<0.001$), with the greatest deposition rates in August (0.914 $Mgha^{-1}$) and September/2011 (0.922 $Mgha^{-1}$), while the smallest productions were observed in November (0.039 $Mgha^{-1}$) and December/2010 (0.021 $Mgha^{-1}$) (Table 1). Leaves constituted the predominant fraction of the litterfall,

Table 1. Monthly values of litterfall production at the Cauaçu farm located in the municipality of João Câmara, Rio Grande do Norte State, Brazil, during the period between November/ 2010 and June/ 2012. The values presented are the means ± SE.

Date		Litterfall									
Year	Month	Leaves		Branches		Flowers		Miscellaneous		Total	
		$Mgha^{-1}$	SE	$Mgha^{-1}$	SE	$Mgha^{-1}$	SE	$Mgha^{-1}$	SE	$Mgha^{-1}$	SE
2010	Nov	0.010	(± 0.002)	0.021	(± 0.006)	0.006	(± 0.002)	0.002	(± 0.000)	0.039	(± 0.068)
	Dec	0.005	(± 0.001)	0.007	(± 0.002)	0.004	(± 0.001)	0.006	(± 0.001)	0.021	(± 0.038)
2011	Jan	0.046	(± 0.011)	0.027	(± 0.003)	0.004	(± 0.001)	0.012	(± 0.002)	0.089	(± 0.133)
	Feb	0.048	(± 0.007)	0.041	(± 0.009)	0.009	(± 0.003)	0.007	(± 0.001)	0.105	(± 0.161)
	Mar	0.148	(± 0.019)	0.071	(± 0.013)	0.021	(± 0.008)	0.008	(± 0.002)	0.249	(± 0.349)
	Apr	0.166	(± 0.018)	0.072	(± 0.011)	0.005	(± 0.001)	0.012	(± 0.002)	0.254	(± 0.342)
	May	0.151	(± 0.016)	0.051	(± 0.008)	0.004	(± 0.001)	0.008	(± 0.001)	0.214	(± 0.277)
	Jun	0.142	(± 0.017)	0.033	(± 0.005)	0.003	(± 0.001)	0.005	(± 0.001)	0.182	(± 0.222)
	Jul	0.315	(± 0.038)	0.058	(± 0.009)	0.005	(± 0.001)	0.009	(± 0.002)	0.386	(± 0.457)
	Aug*	0.713	(± 0.069)	0.115	(± 0.016)	0.081	(± 0.021)	0.005	(± 0.002)	0.914	(± 1.115)
	Sep*	0.699	(± 0.072)	0.162	(± 0.047)	0.060	(± 0.009)	0.000	(± 0.000)	0.922	(± 1.144)
	Oct	0.224	(± 0.025)	0.036	(± 0.005)	0.037	(± 0.011)	0.002	(± 0.001)	0.299	(± 0.374)
	Nov	0.032	(± 0.008)	0.035	(± 0.009)	0.014	(± 0.002)	0.001	(± 0.000)	0.082	(± 0.132)
	Dec	0.012	(± 0.003)	0.032	(± 0.009)	0.008	(± 0.002)	0.001	(± 0.000)	0.053	(± 0.095)
2012	Jan	0.006	(± 0.002)	0.050	(± 0.036)	0.017	(± 0.004)	0.003	(± 0.001)	0.075	(± 0.145)
	Feb	0.022	(± 0.003)	0.029	(± 0.008)	0.006	(± 0.001)	0.003	(± 0.001)	0.060	(± 0.098)
	Mar	0.044	(± 0.006)	0.045	(± 0.011)	0.016	(± 0.008)	0.002	(± 0.001)	0.107	(± 0.169)
	Apr	0.286	(± 0.052)	0.038	(± 0.007)	0.008	(± 0.005)	0.005	(± 0.001)	0.337	(± 0.388)
	May	0.337	(± 0.049)	0.023	(± 0.007)	0.005	(± 0.003)	0.002	(± 0.001)	0.366	(± 0.395)
	Jun	0.132	(± 0.013)	0.016	(± 0.002)	0.002	(± 0.001)	0.000	(± 0.000)	0.150	(± 0.168)
Total (in 20 months)		3.537		0.962		0.312		0.093		4.904	

*Months with the highest production.

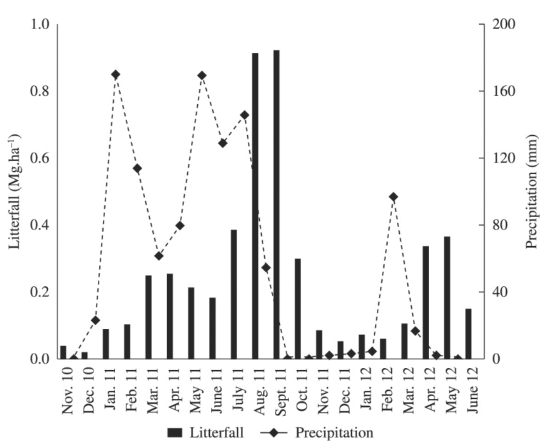

Figure 1. Temporal variations in litterfall production and precipitation during the period between November/ 2010 and June/ 2012 at the Cauaçu farm located in the municipality of João Câmara, Rio Grande do Norte State, Brazil.

generating approximately 72% of the total dry weight; branches represented approximately 20%, with reproductive structures and miscellaneous materials representing approximately 6% and 2% respectively.

In the first year (November/2010 to October/2011), the total rainfall was approximately 950 mm, with a monthly average of 56.81 ± 14.48 mm. Litterfall production was most highly correlated with the precipitation in the second and third months preceding the samplings ($r_{s\,60\,days} = 0.821$; n=20; P<0.001; $r_{s\,90\,days} = 0.748$; n=20; P<0.001); no significant relationship was observed between litterfall production and rainfall in the 30 days immediately preceding the samplings ($r_{s\,30\,days} = 0.439$; n=20; P>0.05) (Figure 1).

Species richness and vegetation densities varied from 3 to 15 species and from 130 to 920 individuals ha^{-1} respectively. Litterfall production was significantly correlated with vegetation density ($r_s = 0.504$; n=27; P = 0.007) but not with species richness ($r_s = 0.088$; n=27; P = 0.66).

4. Discussion

The total litterfall production recorded in the present study was within the range observed for seasonally dry tropical forests in Latin America, which varies between 2.8 and 8.5 $Mgha^{-1}yr^{-1}$ (Jaramillo et al., 2011), but greater than litterfall values reported for other Caatinga areas (Alves et al., 2006; Souto, 2006; Costa et al., 2007; Santana and Souto 2011). Costa et al. (2010) and Santana (2005), for example, reported the deposition of 2.9 $Mgha^{-1}yr^{-1}$ and

2.1 $Mgha^{-1}yr^{-1}$ in two areas of Caatinga in Rio Grande do Norte State, while Lopes et al. (2009) reported the production of 2.8 $Mgha^{-1}yr^{-1}$ in a Caatinga site in Ceará State.

The different litterfall fractions all provided distinct contributions, with leaves dominating the total production (~72%), followed by branches, reproductive structures, and miscellaneous materials. According to Bray and Gorham (1964), leaves are consistently responsible for between 58% and 79% of all deciduous material, independent of the ecological zone considered. In areas of Caatinga vegetation, the leaf fraction has been observed to vary from 56.2% to 80.6% (Santana, 2005; Alves et al., 2006; Costa et al., 2007; Andrade et al., 2008; Lopes et al., 2009; Costa et al., 2010).

Martínez-Yrízar and Sarukhán (1990) reported a 17% contribution of the branch fraction in a deciduous forest in Mexico, a value very similar to that seen in the present study (20%), although the percentages reported from other regions around the world vary greatly. The reproductive structure fraction is directly related to the type of climate and to the phenologies of the dominant species (Lampe et al., 1992; Diniz and Pagano, 1997; Martínez-Yrízar et al., 1999; Alvarez et al., 2009). According to Amorim et al. (2009), wide variations in the flowering patterns of caatinga species have been noted, influencing the spatial patterns of reproductive structure productions.

The monthly production of litterfall demonstrated a marked seasonality accompanying the dry and rainy periods, with the greatest litter depositions in August and September/2011 (at the beginning of the dry season) and the lowest deposition in November and December/2010 (at the beginning of the rainy season). According to Delitti (1995), litterfall productions will have distinct relationships with rainfall patterns depending on the ecosystems in question. In Atlantic Forest and restinga (coastal, sandy soil vegetation) areas the greatest deposition of organic material occurs during the rainy season, while the greatest deposition in Cerrado and Caatinga areas occurs during the dry season (Delitti, 1995; Valenti et al., 2008).

The low litterfall production rates observed in Caatinga sites during the rainy season are due to the growth of new foliage, with the plants taking advantage of readily available water resources to produce new leaves and then accumulate nutrient reserves with their increased photosynthetic capacities (Souto, 2006). The peak of litterfall production at the beginning of the dry season is considered a preventative strategy to avoid water losses through transpiration during the following months of water stress (Meguro et al., 1979; Silva et al., 2004; Santana, 2005; Alves et al., 2006; Souto, 2006; Costa et al., 2007).

The variations in litterfall production among the sample plots were the result, at least in part, of differences in the densities of their plant species. Litterfall production rates reflect edaphic (Vitousek, 1984) and biological factors such as the structure of the vegetation (Schlittler et al., 1993; Werneck et al., 2001), its age (Leitão-Filho et al., 1993), and floristic composition (Sundarapandian and Swamy, 1999). The intensity with which each factor affects leaf litter accumulation is determined by the particular characteristics of each plant communities (Pires et al., 2006). The litterfall quantities in the sampling areas appeared to be the consequence of the particular characteristics of each habitat, and this spatial heterogeneity was observed in terms of total litterfall production as well as in relation to each of its component fractions (leaves, branches, reproductive structures, and miscellaneous).

In conclusion, the present study demonstrated that not only rainfall rates but also tree densities influence litterfall production in the Caatinga dryland region, and that the effects of rainfall are most evident after 60 to 90 days. In addition, our results corroborated that leaf fraction is the main component of litter in tropical communities (Bray and Gorham, 1964). As there are at least eight different ecoregions in the semiarid region of Brazil (Velloso et al., 2002), each with distinct characteristics in terms of their soils, vegetations and climates, litterfall production values would be expected to accompany these variations and accumulations will demonstrate strong spatial components.

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