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Litterfall: A Bio-indicator for Edge Effect in a Semi-deciduous Seasonal Forest

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ABSTRACT

This study aimed to evaluate the use of litterfall as an indicator of fragmentation in a Semi-deciduous Seasonal Forest in Além Paraíba, MG, Brazil. Litterfall was collected monthly for one year in conical collectors (0.25 m^2 of surface), located at seven distances from the forest edge: 10, 30, 60, 100, 160, 250 and 350 m. The litterfall was dried in an oven and separated (leaves, branches, reproductive structures, miscellaneous). Litterfall was greater near the forest edge, probably due to a predominance of species with high leaf deposition (pioneers and deciduous). Litterfall had peaks at the beginning of the rainy season for the average obtained from the seven distances from the forest edge. The edge effect did not clearly influence the contribution of the fractions or the seasonality of total litterfall.

Keywords: forest fragmentation, atlantic forest, deciduous material.

1. INTRODUCTION

Litterfall is fundamental to nutrient cycling dynamics, as it constitutes a source of input of organic matter and return of mineral elements to the soil in tropical forest ecosystems (Moraes et al., 2008), where soils are generally acidic and have low natural fertility (Bernardi et al., 2002). Litter production depends on the primary productivity of forest ecosystems (Luizão, 2007). This in turn varies according to the latitude, altitude, temperature, wind incidence, precipitation, herbivory, and availability of water and soil nutrients, in addition to successional stage and degree of environmental disturbance (Figueiredo et al., 2003).

Therefore, litterfall can be considered a bio-indicating tool for the nutrient cycling dynamics of an ecosystem, since changes in the environment may modify the deposition of deciduous material (Machado et al., 2008). Such changes may be due to an edge effect, which occurs when large continuous areas of forest are deforested to realize different anthropic activities such as creation of pastures and planting of agricultural crops. As a result, forest fragments disconnected from one another and of different sizes appear, with their edges in contact with anthropic matrices. Therefore, air and soil temperatures are higher while relative air humidity is lower at the edge in comparison with the interior of the forest fragments (Lima-Ribeiro, 2008).

As such, pioneering (Lima-Ribeiro, 2008) and deciduous species (Holanda et al., 2010) predominate on the edge compared to the interior of forest fragments. This modifies the dynamics of nutrient cycling, since total litterfall may be higher at the forest edge, as found in the Amazon Forest (Vasconcelos & Luizão, 2004) and in the Atlantic Forest (Portela & Santos, 2007). However, in this latter biome, lower litterfall at the edge (Vidal et al., 2007) and the absence of differences between the edge and interior of forest fragments (Gomes et al., 2010) have also been reported. These divergences are probably due to variations between studies in terms of the classification criteria for forest fragments as to their size (small or large), successional stage (more or less advanced), history of disturbance (more or less recent anthropic impacts), connectivity between them (degree of isolation between forest fragments) and distances from the interior to the forest edge.

This study aims to evaluate the use of litterfall as an indicator of forest fragmentation through observing litterfall patterns at different distances from the edge in a semi-deciduous seasonal forest fragment. The tested hypothesis was that litterfall at the edge is higher than that at the interior of an Atlantic Forest fragment.

2. MATERIAL AND METHODS

The study area is located on a rural property found at the geographical coordinates latitude 21°56’53.52 “S and longitude 42°53’40.42 “W, in the municipality of Além Paraíba, state of Minas Gerais, Brazil. The municipality is part of the *Zona da Mata Mineira* and it borders the state of Rio de Janeiro. The region presents strong undulating and mountainous relief and an average altitude of 390 m (Cunha et al., 2012), with a predominance of Haplic Cambisols (Cunha et al., 2013). The climate is subtropical, Köppen classification type Cwa (Alvares et al., 2013). The average annual temperature is 22.3 °C and the average annual rainfall is 1390 mm, with a dry period between the months of June to September (Cunha et al., 2013) and higher rainfall in December and January.

The study was carried out in a semi-deciduous seasonal forest fragment (IBGE, 2012) of approximately 372 ha, which is located in an agricultural matrix. The canopy reaches approximately 13 m, and *Miconia* sp. (Melastomataceae), *Apuleia leiocarpa* (Vogel) J. F. Macbr. (Fabaceae) and *Anadenanthera peregrina* (L.) Speg. (Fabaceae) predominate. The sub-canopy has an average height of 6 m with a predominance of *Siparuna guianensis* Aublet. (Siparunaceae). The understorey is abundantly colonized by *Psychotria* sp. (Rubiaceae). Vines are the highest arboreal individuals near the edge of the forest fragment, which is in contact with approximately 9 hectares of corn crop.

The litterfall evaluation was conducted in an area with a mean slope of 30°, installing conical collectors with a 0.25 m^2 surface made with a nylon screen with a 1 mm mesh. These collectors were arranged approximately 1.30 m from the ground in 75 m lines parallel to the edge of the forest fragment, at seven distances (m) moving from the edge towards the interior of the forest fragment: 10, 30, 60, 100, 160, 250 and 350 m. Four collectors (replicates) were installed for each of these distances and spaced 25 m apart.

The material deposited in the collectors was collected monthly from February 2005 to January 2006, and placed in identified plastic bags. The litterfall was then dried in a forced ventilation oven at 65 °C in the laboratory for approximately 72 h. Leaves, branches (up to 2 cm in diameter), reproductive structures (flowers, fruits and seeds) and miscellaneous (unidentifiable material) were separated by hand using a magnifying glass and tweezers. After drying, the fractions were weighed on an analytical scale to a precision of two decimal places to obtain the dry matter mass. Litterfall was estimated by Equation 1 (Lopes et al., 2002):

$$ALP = (LP \times 10{,}000) / Ac \quad (1)$$

where: ALP is the average annual litterfall (Mg ha^{-1} year^{-1}), LP is the average monthly litterfall (Mg ha^{-1} month^{-1}), and Ac is the collection area (m^2).

After performing analysis of variance, the mean annual litterfall (total and fractions) for each distance from the edge was compared using the t-test (LSD: least significant difference; $P < 0.05$) using BioEstat software version 5.3. Using the same software, Spearman's correlation analysis ($P < 0.05$) between monthly litterfall (total and fractions) and mean temperature and total precipitation data was performed for the same collection month, and from one to six months prior to litterfall.

For this, the average litterfall value for the distances from the edge (g m^{-2} day^{-1}) was considered. Climatic data were obtained from the Center for Weather Forecasting and Climate Studies (*CPTEC*) homepage of the National Institute of Space Research (*INPE*).

In order to distinguish the treatments from one another, a multivariate hierarchical cluster analysis was performed using Ward's single-link method and PAST software version 2.17c. For this, average values of dry matter mass from the litterfall fractions produced during the study period (Mg ha^{-1}) for each treatment were considered. In order to evaluate the association between litterfall dry matter mass (dependent variable) and distances from the edge or litterfall fraction triad (independent variables), a generalized linear model was analyzed using STATISTICA software version 8.0.

3. RESULTS

A significant effect of the forest edge was observed for leaf litterfall ($F = 5.3127$, $P = 0.0021$), miscellaneous ($F = 5.5862$, $P = 0.0016$) and total litterfall ($F = 3.2574$, $P = 0.0200$). In general, leaves and miscellaneous fraction values, as well as total litterfall, were significantly higher at distances closer to the edge of the forest fragment (10, 30, 60 and 100 m), but presented no difference in relation to the areas more distant from the edge (160, 250 and 350 m), and also with no significant differences between them (Table 1). No edge effect on branch production ($F = 1.7460$, $P = 0.1593$) or

Table 1. Annual litterfall at different distances from the edge of a semi-deciduous seasonal forest fragment, Além Paraíba, MG*.

Distance from the edge (m)	Leaves	Branches	Reproductive structures	Miscellaneous	Total
	Mg ha^{-1} year^{-1}				
10	6.41 a (1.21)	2.83 a (1.38)	0.23 a (0.13)	0.33 a (0.14)	9.79 ab (2.65)
30	6.24 ab (1.67)	1.80 a (1.39)	0.31 a (0.18)	0.67 a (0.90)	9.01 abc (3.94)
60	7.27 a (1.78)	3.54 a (1.97)	0.25 a (0.20)	0.28 a (0.13)	11.35 a (3.01)
100	4.32 c (0.95)	1.19 a (1.51)	0.53 a (0.52)	0.16 ab (0.05)	6.20 bc (2.06)
160	4.51 bc (0.95)	1.12 a (1.04)	0.26 a (0.07)	0.06 c (0.03)	5.96 c (1.53)
250	3.79 c (0.80)	1.67 a (1.24)	0.55 a (0.16)	0.08 bc (0.03)	6.08 c (2.00)
350	4.06 c (0.34)	1.66 a (0.37)	0.38 a (0.20)	0.07 bc (0.03)	6.16 c (0.49)
Average	5.23 (1.67)	1.97 (1.46)	0.36 (0.25)	0.24 (0.37)	7.79 (3.02)

*Means of four replicates followed by standard deviation in parentheses; Values followed by different letters in the comparison between different distances from the edge and within the same fraction indicate significant differences ($P < 0.05$) by the t-test (LSD: least significant difference).

reproductive structures was found (F = 1.1617, P = 0.3632).

No clear pattern was observed for the edge effect influence on the percentage contribution of leaf and branch fractions in the total produced (Figure 1). The average percentage contribution of the leaf fraction in the total litterfall was 73%, in which the lowest and highest values were observed at distances of 250 m (62%) and 160 m (76%) from the edge, respectively. Regarding branch fraction, which presented the second highest average percentage contribution (27%), the values varied between 19% (for both distances of 100 and 160 m) and 31% (60 m).

The greater the distance from the edge, the higher the percentage contribution of the reproductive structures, while the miscellaneous contribution decreased (Figure 1). The mean contribution of the reproductive structures was 5%, and the values varied from 2% (for distances of 10 and 60 m) to 9% (for distances of 100 and 250 m). The miscellaneous items presented the lowest average participation (3%) in comparing the fractions, and the values varied from 1% (for distances of 160, 250 and 350 m) to 7% (for 30 m).

Total litterfall was determined throughout the study period (Figure 2). The highest total litterfall values occurred at the end of the rainy season (February) at distances of 100 and 250 m from the edge (4.11 and 4.28 g m^{-2} day^{-1}, respectively). For the distance of 30 m, the highest litterfall (5.13 g m^{-2} day^{-1}) took place at the end of the dry season (September). The highest litterfall values at the other distances from the edge occurred at the beginning of the rainy season, between October (160 m: 3.17 g m^{-2} day^{-1}) and November (10, 60 and 350 m: 6.79, 7.52 and 3.17 g m^{-2} day^{-1}, respectively).

For the average calculated between the distances from the edge, the highest average values of total litterfall produced were found in October and November (3.36 and 3.70 g m^{-2} day^{-1}, respectively), corresponding to the beginning of the rainy season. On the other

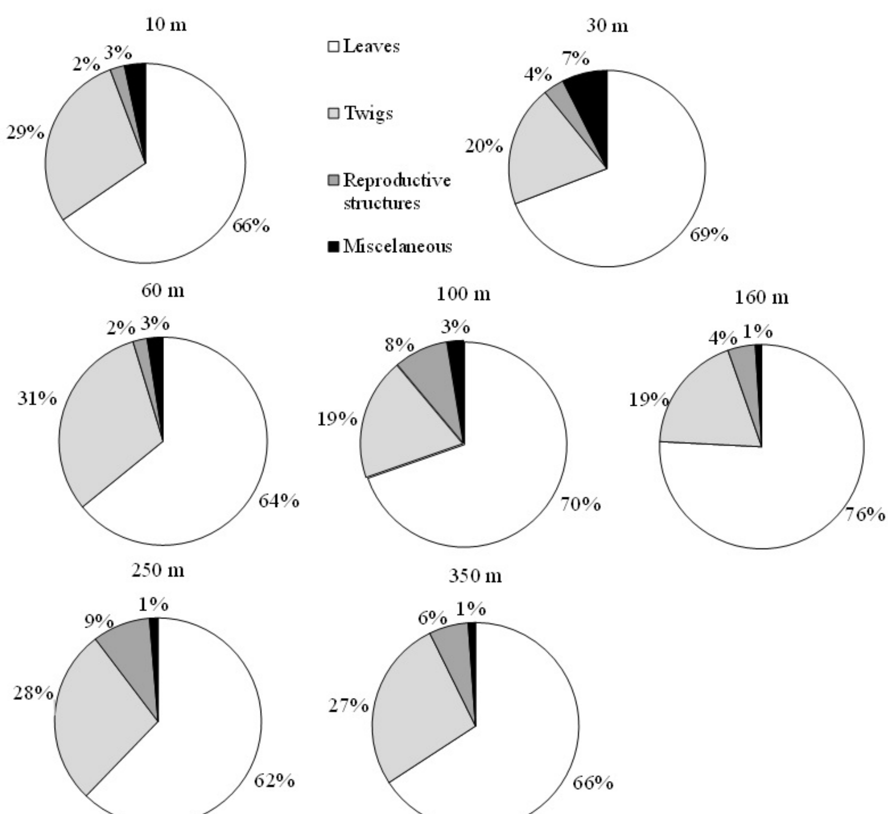

Figure 1. Percentage contribution of the fractions in the total annual litterfall produced at different distances from the edge of a semi-deciduous seasonal forest fragment, Além Paraíba, MG, Brazil.

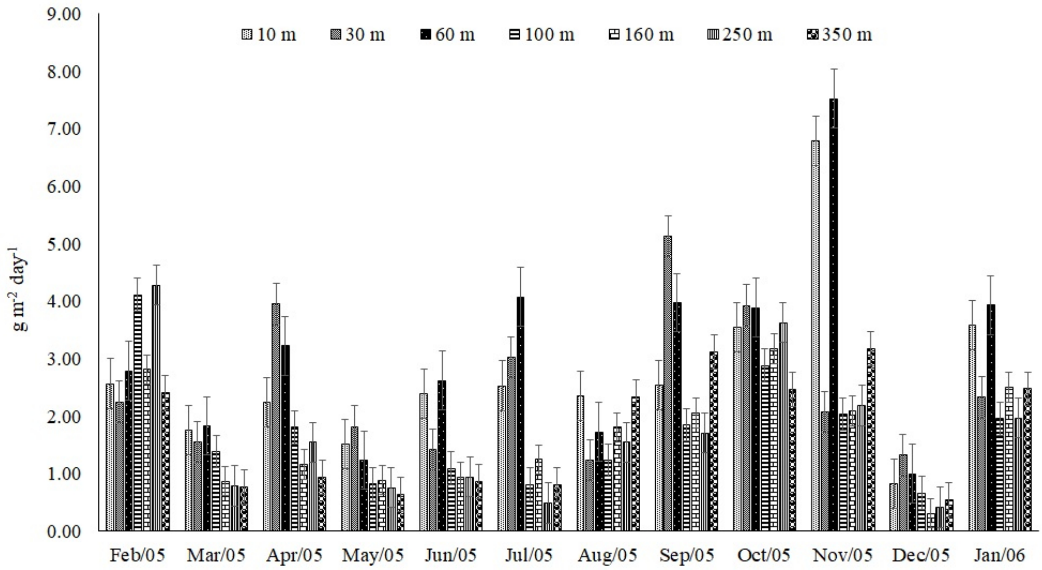

Figure 2. Seasonal variation (with standard error bars) of the total litterfall at different distances from the edge of a semi-deciduous seasonal forest fragment, Além Paraíba, MG, Brazil.

hand, the lowest total litterfall value was observed in December (0.73 g m^{-2} day^{-1}), which is a month that corresponds to the middle of the rainy season.

A significant correlation ($P < 0.05$) was observed between total precipitation and miscellaneous for the same month of production ($P = 0.0058$, $r = -0.7413$), four months earlier ($P = 0.0240$, $r = 0.6434$), five months earlier ($P = 0.0073$, $r = 0.7273$) and six months earlier ($P = 0.0168$; $r = 0.6713$). This significant correlation pattern also occurred between mean temperature and miscellaneous, for the same month of production ($P = 0.0051$; $r = 0.7483$) and five months prior ($P = 0.0011$; $r = 0.8182$).

Significant correlations were also found between total precipitation and reproductive material production six months after production ($P = 0.0385$; $r = -0.6014$); average temperature and reproductive material in the same month ($P = 0.0283$; $r = 0.6294$); and average temperature and total litterfall four months later ($P = 0.0512$; $r = -0.5734$). No significant correlation was found between the other litterfall fractions and the climatic variables analyzed.

Multivariate hierarchical cluster analysis indicated strong similarity between the three distances closest to the edge (10, 30 and 60 m), forming the first group, and between the distances further from the edge (100, 160, 250 and 350 m) which were gathered in a second group (Figure 3). On the other hand, the relatively

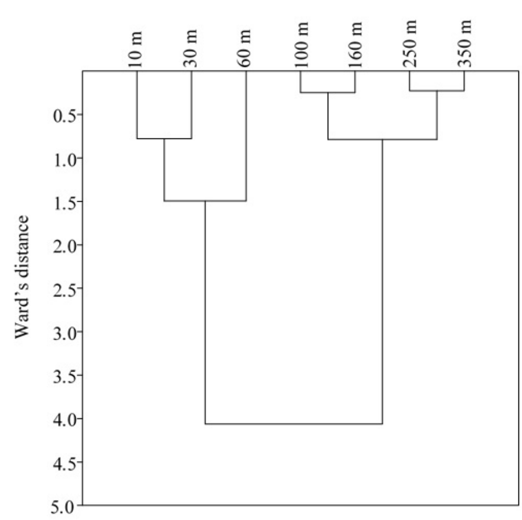

Figure 3. Dendrogram of multivariate cluster analysis for litterfall (Mg ha^{-1}) at different distances from the edge of a semi-deciduous seasonal forest fragment, Além Paraíba, MG, Brazil.

large distance between the values observed for these two groups highlighted the significant dissimilarity between them.

The generalized linear model analysis showed a significant association ($P < 0.05$) of total litterfall with edge distance and collection month (Table 2). This model also indicated the absence of a significant effect

Table 2. Analysis of the generalized linear model to evaluate the association between total litterfall (Mg ha^{-1}) with edge distance from a semi-deciduous seasonal forest fragment and the collection month, in Além Paraíba, MG, Brazil.

Edge effect on total litterfall	SS	Degrees of freedom	MS	F	P
Intercept	1,574.607	1	1,574.607	506.415	0.000000
Distance from the forest edge	109.713	6	18.285	5.881	0.000009
Month	282.811	11	25.710	8.269	0.000000
Distance x Month	209.796	66	3.179	1.022	0.439958
Error	783.549	252	3.109		

SS: sum of squares; MS: mean square; F: ratio between the model and its error; P: probability of significance.

from the interaction between independent variables (edge distance, collection month) in association with total litterfall; however, it suggested a significant association between edge distance and total litterfall, as well as between the collection month and total litterfall. This model explained 43% of the data variance (R^2 = 0.434), which reinforces the results shown in Table 1 and Figures 1 and 2.

4. DISCUSSION

Plant dehydration at the edges of forest fragments occurs due to their greater exposure to wind, direct solar radiation, higher temperatures and lower air humidity, thus leading to higher litterfall (Vasconcelos & Luizão, 2004). Higher solar radiation at the edges also leads to greater presence of pioneer species than in the forest fragment interior (Lima-Ribeiro, 2008). These species produce more leaf litterfall due to high rates of growth and leaf exchange when compared to non-pioneer species (Dickow et al., 2012).

Another aspect which highlights species composition as affecting higher litterfall is the predominance of deciduous species on the edges, presenting greater foliar deposition in drier periods, which is a strategy to minimize water loss due to high evapotranspiration (Holanda et al., 2010). The hierarchical clustering dendrogram obtained from the multivariate analysis considering average litter fraction production clearly demonstrates this pattern.

This occurred because there was a clustering of distances closer to the edge (between 10 and 60 m) which presented a higher production of leaf litter and miscellaneous fractions, and which were distant from the group of distances greater than 100 m from the edge.

Similar to the present study with a corroborated hypothesis, Portela & Santos (2007) also found that total litterfall was significantly higher at the edge (5 m distance) in comparison with the interior (100 m distance). This study was conducted in a 30 ha forest fragment in the transition region between the Atlantic Coastal Forest and a semi-deciduous seasonal forest located in the municipality of Cotia, São Paulo state. On the other hand, these authors did not separate the litterfall into fractions, and found no differences between the edge and interior in relation to the data for total litterfall produced in smaller sized forest fragments (14 and 18 ha) with the same typology as the reported region.

This result suggests that the edge effect affected the whole extension of these smaller fragments due to the shorter distance between the interior and the edge. In the Atlantic Forest in the municipality of Ibiúna, São Paulo, Vidal et al. (2007) found that the nuclear area (118 ha) of a large fragment (175.1 ha) was proportionally larger (67% of the total area) than the nuclear area (≤ 1 ha) of two small fragments (5 ha), which only represented 20% of their total area.

In an area of Amazon Forest located 80 km north of Manaus, Amazonas, Vasconcelos & Luizão (2004) found higher total litterfall, as well as leaf and miscellaneous fractions (called fine residues) at the edge (distance <100 m from the edge) when compared to the interior (> 250 m of the edge), regardless of soil texture (clay or sandy). However, these same authors found no differences between edge and forest interior in terms of the production of branch fractions and reproductive structures. This set of results is corroborated by the present study.

However, in the Dense Montana Ombrophilous Forest in the municipality of Teresópolis, Rio de Janeiro state, Gomes et al. (2010) found no difference between the total litterfall and fractions (leaves, branches, reproductive structures and residues) when comparing different distances from the edge to the interior (0-10 m, 30-40 m, 60-70 m and 160-170 m). This pattern was also observed in forest fragments of different sizes (3.2, 8, 23, 62 ha), and according to the authors, this fact was probably influenced by the non-occurrence of relevant anthropic impacts around 90 to 100 years ago. Therefore, the structure of the plant community may have presented a certain similarity between the edge and the interior of the fragments considered.

In the Dense Montana Ombrophilous Forest, total litterfall was lower at the edge (10 m distance) of the small fragment 2 (4.75 ha) for the period of lower material production (March 2001 to July 2001), as well as for the larger fragment 3 (175.10 ha) for both the lower and higher litterfall production periods (August 2001 to January 2002) (Vidal et al., 2007). On the other hand, the same authors found no significant differences between the edge and the interior when comparing both periods (higher/lower material yield) in the isolated small fragment 1 (5.48 ha), and in the period of greatest production in fragment 2.

The occurrence of different litterfall responses in relation to the edge effect in forests is a reflection of the complex interaction of a wide range of factors, which vary when comparing different studies. These factors include forest typology; size, time and the degree of fragment isolation; fragmentation history; type of matrix in which forest remnants are located (Portela & Santos, 2007); species composition; successional stage (Dickow et al., 2012); soil textural composition; presence of new or old glades/clearings; season of the year and height relative to the ground at which the temperature and humidity of the air variables are measured (Camargo & Kapos, 1995); in addition to the litterfall fractions considered; and the distance from the edge in relation to the interior of the forest.

For this reason, the results do not always correspond to the forest edge-interior distance gradient (Camargo & Kapos, 1995). Thus, significant differences in microclimatic conditions in tropical forest fragments cannot be observed for comparison between the edge and the interior (Lima-Ribeiro, 2008). However, this author found a general pattern of lower air and soil temperature values, and higher relative air humidity values in these areas in relation to the anthropogenic matrix.

Compared to other studies conducted in semi-deciduous seasonal forests, and considering the average between the different distances from the edge evaluated in this study, litterfall was lower and closer to an early stage forest area (Table 3). Therefore, it is believed that lower litterfall was a result of the less developed tree community structure (Vidal et al., 2007; Pinto et al., 2008). In the present study, the canopy reached 13 m in height, while Meguro et al. (1979), Vital et al. (2004) and Nunes & Pinto (2007) reported greater canopy height values (20, 22 and 15 m, respectively).

Among the different litterfall fractions, the highest contribution of leaves (generally between 60 and 70% of total litterfall) was a result frequently found in different phytophysiognomies of forest ecosystems. This pattern was verified in the Amazon Forest (Vasconcelos & Luizão, 2004), in the transition between coastal Atlantic forest and semi-deciduous seasonal forest (Portela & Santos, 2007), in semi-deciduous seasonal forests (Pimenta et al., 2011) or in deciduous forests (Marafiga et al., 2012), in addition to Dense Ombrophylous Forest (Vidal et al.,

Table 3. Litterfall in semi-deciduous seasonal forests.

Site	Total litterfall (Mg ha^{-1} $year^{-1}$)	Reference
Além Paraíba, MG	5.2	This study
São Paulo, SP	9.4	Meguro et al. (1979)
Botucatu, SP	10.7	Vital et al. (2004)
Lagoa da Prata, MG	15.1	Nunes & Pinto (2007)
Viçosa, MG		Pinto et al. (2008)
FI	6.3	
FM	8.8	
Londrina, PR	8.2	Pimenta et al. (2011)

FI: initial forest; FM: mature forest.

2007; Pereira et al., 2008; Espig et al., 2009; Gomes et al., 2010; Dickow et al., 2012).

No clear pattern of edge effect influencing seasonality of total litterfall was observed. This was reinforced by considering the monthly total litterfall, as calculated by the average between the distances from the edge. Production peaks occurred in both drier and wetter months, which influenced the absence of seasonality in litterfall. This can be verified in forest ecosystems subjected to well-defined periods of rainfall restriction (Santos et al., 2011).

In this case, it is likely that similarities in the magnitude of severe weather events influencing litterfall deposition occurred, such as low rainfall during the drier season and torrential rains and strong winds during the rainy season. However, in forests located in areas with a marked dry season, highest total litterfall and leaf fraction production generally occur during this period (Valenti et al., 2008). This is a mechanism to minimize the need for vegetation during rainy months (Barbosa & Faria, 2006).

In the present study, a significant correlation was mainly observed between mean temperature, total precipitation and miscellaneous fraction production, followed by reproductive material production, as well as total litterfall to a lesser degree. This fact occurred not only for the climatic variable data regarding the litterfall month, but also for the climate data from the previous four, five and six months. Thus, environmental variations did not present an immediate response in litterfall in the forest ecosystem analyzed (Scoriza & Piña-Rodrigues, 2014).

However, the frequency with which significant correlations between precipitation and temperature were found was considered low. This result suggests the importance of including other climatic variables such as relative humidity and wind speed and direction in this type of analysis, in addition to conducting the research for a period of two consecutive years or longer (Scoriza & Piña-Rodrigues, 2014) in order to identify possible climate influence patterns on litterfall.

5. CONCLUSION

The greater litterfall at smaller distances from the forest edge probably occurred due to the presence of a microclimate (higher solar incidence and temperature, in addition to lower relative humidity) which favors the predominance of species with high leaf deposition, such as pioneers and deciduous species in comparison with the forest interior.

Litterfall took place throughout the sampling period. However, there was a significant association between the total litterfall and the collection month, with production peaks at the beginning of the rainy season, considering the average between the different distances from the forest edge.

No clear seasonal patterns were identified for total litterfall, or for the percentage contribution of the fractions, where the major contribution was leaf fraction as a response to the edge effect.

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