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Litter production in a natural stand of Brazil nut trees (*Bertholletia excelsa* Bonpl.)

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This research estimated litter production and analyzed its relation to environmental variables such as maximum temperature, insolation, and rainfall. The study was conducted on a 300 × 300 m experiment as part of the project titled mapping of native Brazil nut stands and socio-environmental and economic characterization of Brazil nut production systems (MapCast), in the Tapajós National Forest (FLONA Tapajós). Every 30 days for one full year (August 2015 to July 2016), litterfall was collected and stored in a laboratory. After drying, the material was separated into leaves, wood, flowers and fruits, and miscellaneous and weighed. Statistical tests conducted were Shapiro-Wilk (5%), Principal coordinate analysis, t-test, Pearson's linear correlation, cross-correlation, and canonical redundancy analysis. Rainfall and temperature data were inferior and superior, respectively, to normal climate conditions in the region, and data for solar insolation had an abnormal pattern compared to normal climate conditions. Leaf production varied between 169.9 and 965.6 kg ha^{-1} month^{-1}, and that of wood between 26.7 and 501.3 kg ha^{-1} month^{-1}, while that for flowers and fruit varied from 0.6 to 19.6 kg ha^{-1} month^{-1}. The greatest leaf production was measured during the months with the lowest amount of rainfall and highest temperatures, and variation in leaf production and total litterfall was partially explained by temperature and insolation.

Key words: Litter, *Bertholletia excelsa*, Amazon, El Niño, FLONA Tapajós.

INTRODUCTION

Forest litter is considered the most dynamic portion of the litter-soil system (Scoriza et al., 2012), being composed of leaves, stems, flowers and fruits, and detritus (Golley, 1978). Giácomo et al. (2012) relate that litter has the function of reducing water loss through evaporation and temperature fluctuation at the soil surface, and protecting soils from erosion, excessive solar radiation, compaction, and nutrient leaching. In tropical regions it is considered the principal source of nutrients entering the soil due to its decomposition and subsequent reabsorption of nutrients by the vegetation, a process that supports ecosystem sustainability (Calvi et al., 2009).

There are currently a lot of studies on the effect of soil compaction on limiting root growth of plants. Plants are the source of life in the living world. They perform many ecological functions in their environment, and they shape the life of living things in the environment where they live. The life of living things in the world is directly or indirectly dependent on plants (Sevik and Cetin, 2015; Cetin, 2016). The ability of plants to fulfil their functions primarily depends on the availability of appropriate climatic and edaphic conditions (Cetin, 2015). Therefore, soil is one of the absolutely necessary conditions for plant existence, which is essential for the life of living things.

Some studies shows that it examined the change of the soil structure in the forests according to the tree species. An attempt to determine some soil characteristics based on tree species and depth of soil was made within the scope of the study. Soil is important for forest and landscape. Enzymes in the soil structure ensure that they are alive in forest areas (Sevik and Cetin, 2015; Cetin, 2016; Cetin, 2015).

Processes related to litter production are of great importance in forests that grow on soils of naturally low fertility, such as those in a large part of the Amazon basin (Quesada et al., 2011). Almeida et al. (2015) detailed the need for more research to elucidate the factors that influence litter production in the Amazon biome due to the fact that existing studies are limited in geographical scope and therefore insufficient with respect to the scale and heterogeneity of the Amazon system.

In productive forest ecosystems, such as in natural stands of Brazil nut trees (*Bertholletia excelsa* Bonpl.), a species native to the Amazon and of great importance to economic sustainability of the region (Salomão, 2014), the study of litter production can help to understand the nutrient dynamics in these stands (Lima et al., 2015; Proctor, 1983) and direct management techniques. Godinho et al. (2014) also emphasize the importance of quantifying litter production in pristine ecosystems that are threatened by human activities, such as the case of stands of native Brazil nut trees along the BR 163 (Santarém-Cuiabá) highway (Scoles et al., 2016).

Besides human disturbance, litter production can be influenced by meteorological variables, soil fertility, plant genetic factors, and forest successional stage and species composition (Almeida et al., 2015).

Meteorological factors are frequently included in research on litterfall, principally air temperature and precipitation (Bianchin et al., 2016; Chave et al., 2010; Ferreira et al., 2015; Santos Neto et al., 2015; Zhang et al., 2014) and also evapotranspiration (Wagner et al., 2016). Borchert et al. (2015) related that insolation is also a relevant climatic factor for litter production. The degree of influence of these environmental factors can vary depending on the region studied (Godinho et al., 2015; Wagner et al., 2016).

In order to understand the functioning of tropical forests in relation to climatic variables it is necessary to understand how these will respond to climate change (Bi et al., 2015). Meir et al. (2009) and Malhi et al. (2009) emphasize that knowledge of Amazonian forest ecosystems during the dry season should be a central focus of research due to the risks of forest integrity posed by regional climate change predictions. Godinho et al. (2015) explain that there should be more attention paid to forests in countries that are in the process of development, such as Brazil, because they suffer from intense human activities, principally due to the use of fire, clear cutting, and over-exploitation of forest resources. In the Tapajós region, Pyle et al. (2008) found elevated values for woody materials in forest litter and attributed this result to a change in forest environmental equilibrium that could be happening in the study region. Furthermore, the variability in Amazonian precipitation can be partially explained, principally during the dry season, by the ENSO (El Niño Southern Oscillation) (Yoon and Zeng, 2010).

The aim of this study was estimate litter production and analyzed its relation to environmental variables such as maximum temperature, insolation, and rainfall in a *B. excelsa* stand used by the local population for Brazil nut harvesting.

MATERIALS AND METHODS

Study area

This study was developed in an area that is part of the larger study area of the project titled Mapping of native Brazil nut stands and socio-environmental and economic characterization of Brazil nut production systems (MapCast), at km 84 in the Tapajós National Forest (FLONA).

The study site was 300 m × 300 m and was installed in an area that had a natural stand of *B. excelsa* (Figure 1). In 2015, there were 92 Brazil nut stems with DBH (Diameter at Breast Height) above 10 cm (Figure 1), and the density of these stems on the study site was 10 stems/ha. According to Mori and Prance (1990), this density is considered high for humid tropical forests. Precipitation data (mm), maximum temperature (°C), and insolation (hours) corresponding to the litter sampling period were obtained from a conventional weather station in Belterra-Pará.

The FLONA Tapajós has several classes of soil; however, Yellow Oxisols are predominant (Carvalho, 1992) throughout the FLONA.

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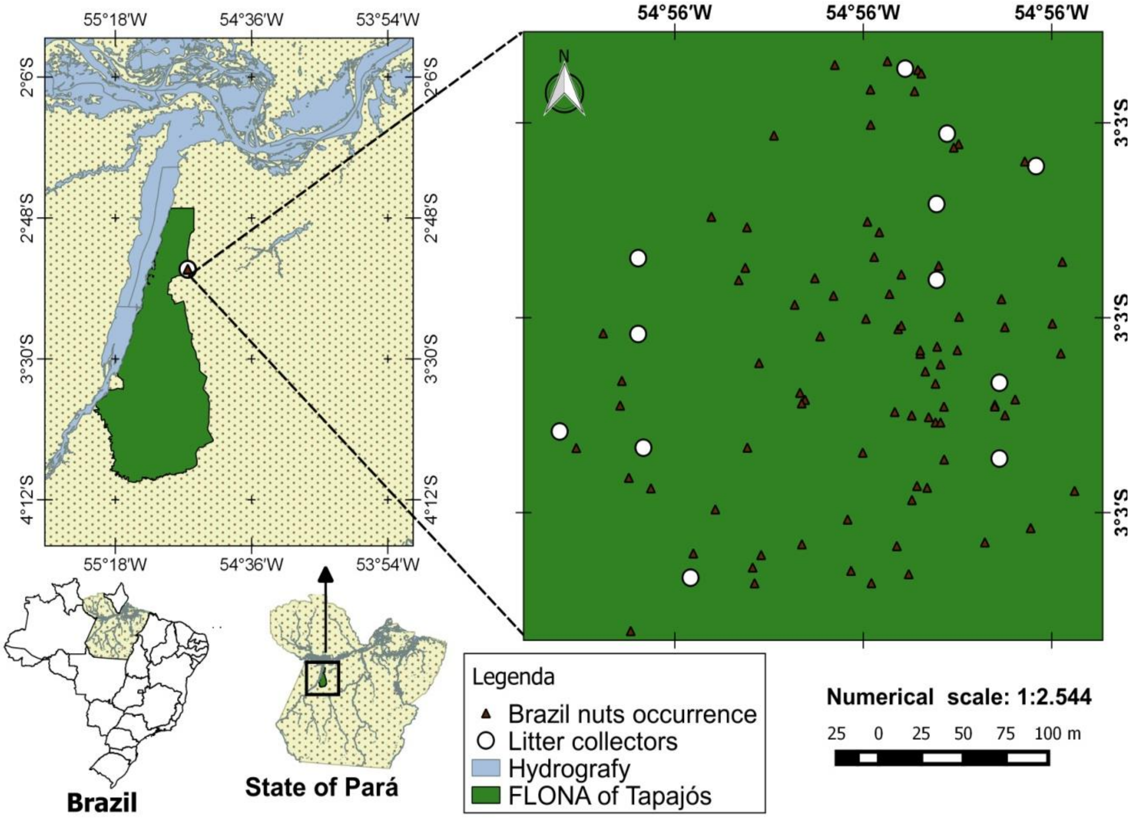

Figure 1. Location of the Tapajós National Forest, the MapCast project study site, the *Bertholletia excelsa* stems, and the litter collection points.

Guerreiro et al. (2017) present the principal physico-chemical characteristics of the MapCast project study site using a geostatistical analysis. The majority of the vegetation of the FLONA is characterized dense ombrophilous forest with emergent trees reaching 50 m in height (Pinho et al., 2004). The canopy is dense, closed, and compact, and is about 25 to 30 m in height (Veloso et al., 1991).

According to Radambrasil (1976) and Espírito-Santo et al. (2005), the FLONA Tapajós was subdivided into 16 classes divided in two great phytophysiognomy groups: Dense Tropical Forest, and Open Tropical Forest. The first has a subcategory lowland dense tropical forest, which occurs in lowland areas with clay soil and has as dominant species: *Diplotropis* species, *Minquartia guianensis*, *B. excelsa*, and *Goupia glabra*. The second subcategory is submontane dense tropical forest and is formed by trees of smaller stature such as *Mouriri brevipes*, *Mezilaurus itauba*, *Qualea* species, and *Manilkara huberi*.

The second of the great phytophysiognomy groups occurs on the intensely dissected plateus with erosion prevalent on the slopes, narrow valleys, and soils with a medium texture where forests with lianas and various palm species are found. The works of Loureiro et al. (1979), Maués (2002), Locatelli et al. (2005), Salman et al. (2008), and Scoles (2010) describe the principal characteristics of the species *B. excelsa* found on the MapCast study site.

The altitude of the FLONA is approximately 175 m above sea level and the relief is strongly undulating (Ibama, 2004). The climate is rainy with average annual rainfall of 2,300 mm (Pinho et al., 2004). The average annual temperature is 25°C, with an average minimum of 18.4°C and maximum of 32.6°C, and average air relative humidity is 86% (Carvalho, 2001).

Litter collection and processing

Litterfall collection was conducted using 12 circular nylon collectors (1 m^2) with a 2 mm mesh. Collectors were installed 50 cm above the soil surface and randomly distributed in the study area (Figure 1). Every 30 days during one full year from September 1st, 2015 to August 1st, 2016 litterfall was collected and stored in properly identified Kraft paper bags. In the laboratory, the material was dried in an oven at 40°C for 24 h.

The litter was separated into four classes: (1) leaves, including leaflets and petiole; (2) wood, including bark, small pieces of branches and twigs of all sizes, including those larger than 2 cm; (3) flowers and fruits (reproductive structures); and (4) miscellaneous unidentifiable vegetation material. The material was dried at 80°C for 48 h until reaching constant weight. The material was weighed on an analytical balance with three digits and was conducted for each collector, by material class and month. Using the dry weight values, the monthly production for each class and for total production was calculated in $kg.ha^{-1}$. The procedures used for drying, separation, and weighing followed those used by the soils laboratory at Embrapa-Amazônia Oriental in Santarém, Pará.

Meteorological data

Data for precipitation (mm), maximum temperature (°C), and insolation (hours) corresponding to the litter sampling period were obtained from a conventional weather station in Belterra-Pará, located at 38 km from the study site. Data for precipitation and insolation were summed individually for each month and daily maximum temperature values were presented as monthly averages.

Statistical analysis

Data for litter and meteorological variables were tested for normality using the Shapiro-Wilk test at a 5% level of significance (Zar, 1999). In order to describe the similarity and the ordination of the litter production data, principal coordinate analysis (PCO) was employed, using the Euclidian distance. The outliers found by this test were discarded before further analysis.

In order to determine if there was a significant difference at a probability level $\alpha \leq 0.05$ between production of leaves, woody material, flowers and fruits, and total litterfall (sum of the four classes) during the periods determined by the PCO analysis, a t-test was applied to data that were transformed using the Neperian logarithm (ln) (Valentin, 2012).

Verification of relationships between meteorological variables and litter production was conducted using the Pearson's Linear Correlation test, and to test for time lags between litter production and meteorological variables, a cross-correlation test was used (Davis, 1986). Each of these tests used non-transformed data.

The canonical redundancy analysis (CRA) test was used to quantify the influence (%) of the meteorological variables on the production of litter in each class using the "Forward selection" method with the Monte Carlo permutation test using the ranging standardization to indicate which variables were significant. The Shapiro-Wilk, PCO, t-test, and the correlations were conducted using the Past statistical program, version 3.14 (Veloso et al., 1991), and the CRA was done using the program Canoco, version 4.5 (Ter Braak and Smilauer, 2002). The choice of these statistical tests is supported by the analyses done in Valentin (2012), Vasconcellos et al. (2013) and Wagner et al. (2016).

RESULTS

Meteorological data

Rainfall data (Figure 2A), temperature (Figure 2B) and insolation (Figure 2C) are presented together with litter production data for each class. The rainfall data for the study period from August 2015 to July 2016 were below the normal rate for the region, except for September wherein one rainfall event was responsible for the rainfall registered for the entire month, thus conferring to the month of September a rainfall total above the historical average for this month (Figure 2A).

Average maximum temperatures were above normal during the entire study period with December 2015 and January 2016 at 3.1 and 3.6°C above the average for the last 45 years, respectively, (Figure 2B).

Insolation data for August 2015 to July 2016 also did not follow the normal pattern for the region, alternating between a greater number of hours (August and September, 2015; December 2015 to May 2016; and July 2016) and a lower number of hours of insolation (October to November, 2015 and June 2016) (Figure 2C).

Litter production

Leaf production as litterfall varied between 169.9 (in May 2016) and 965.6 kg ha^{-1} $month^{-1}$ (in September 2015), woody material from 26.7 (in December 2015) to 501.3 kg ha^{-1} $month^{-1}$ (in September/2015), and for flowers and fruits between 0.6 (in January 2016) and 19.6 kg ha^{-1} $month^{-1}$ (in April 2016) (Figure 2A). During the months with the lowest rainfall (Figure 2A) and highest temperatures (Figure 2B) leaf litter fall production was the highest.

Wood production had the largest peaks in the rainy season, except for September. The litter class flowers and fruits had its largest production in the months of September (18.3 kg ha^{-1} $month^{-1}$), October 2015 (15.8 kg ha^{-1} $month^{-1}$) and April 2016 (19.6 kg ha^{-1} $month^{-1}$). Leaf production was always greater than production in the other classes for all 12 months (Table 1).

Statistical analysis

The PCO analysis yielded two groups, with the first group composed of the months of February, March, April, May, June, and July, 2016, and the second group formed by the months of August, October, November, and December, 2015, and January, 2016 (Figure 3). These groups were designated as the rainy and dry periods, respectively, and the month of September was considered and outlier by the PCO analysis.

After litter data transformation normality was corrected and then a t-test was conducted to test for significant variation between the rainy and dry periods for total leaf production ($t=5.49$; $p<0.01$) (Figure 4A) and for total litter production ($t=4.28$; $p<0.01$) (Figure 4D).

The litter classes wood and flowers and fruits showed no significant variance ($p>0.05$) (Figure 4B and C) and no significant correlation with any meteorological variable (Table 2).

Leaf production had a time lag of one month for the variable rainfall (Lag: 1, $r = -0.65$) and insolation (Lag: 1, $r = 0.80$), and total litterfall showed a time lag of one month (Lag: 1, $r = 0.78$) for insolation (Table 2). There was no time lag for production of wood and flowers and fruits, and the vegetation showed no response, at a monthly scale, to temperature variation.

The three meteorological variables analyzed explain 38.24% of the temporal variation in litterfall production (Figure 5). The first axis explains 32.4% of production of leaves and total production of litter, related to temperature and insolation, forming a gradient from the dry to the rainy period. Rainfall comprises the second axis which had a lower value for percentage of explanation of the variation in production data. Wood production had no relation with any meteorological variable, result that is in agreement with that from the Pearson linear correlation test and the t-test. The Monte Carlo permutation test using the "Forward selection" method indicated that temperature explained 26.5% of the variation in production data, with this being the only meteorological variable considered significant ($p \leq 0.05$).

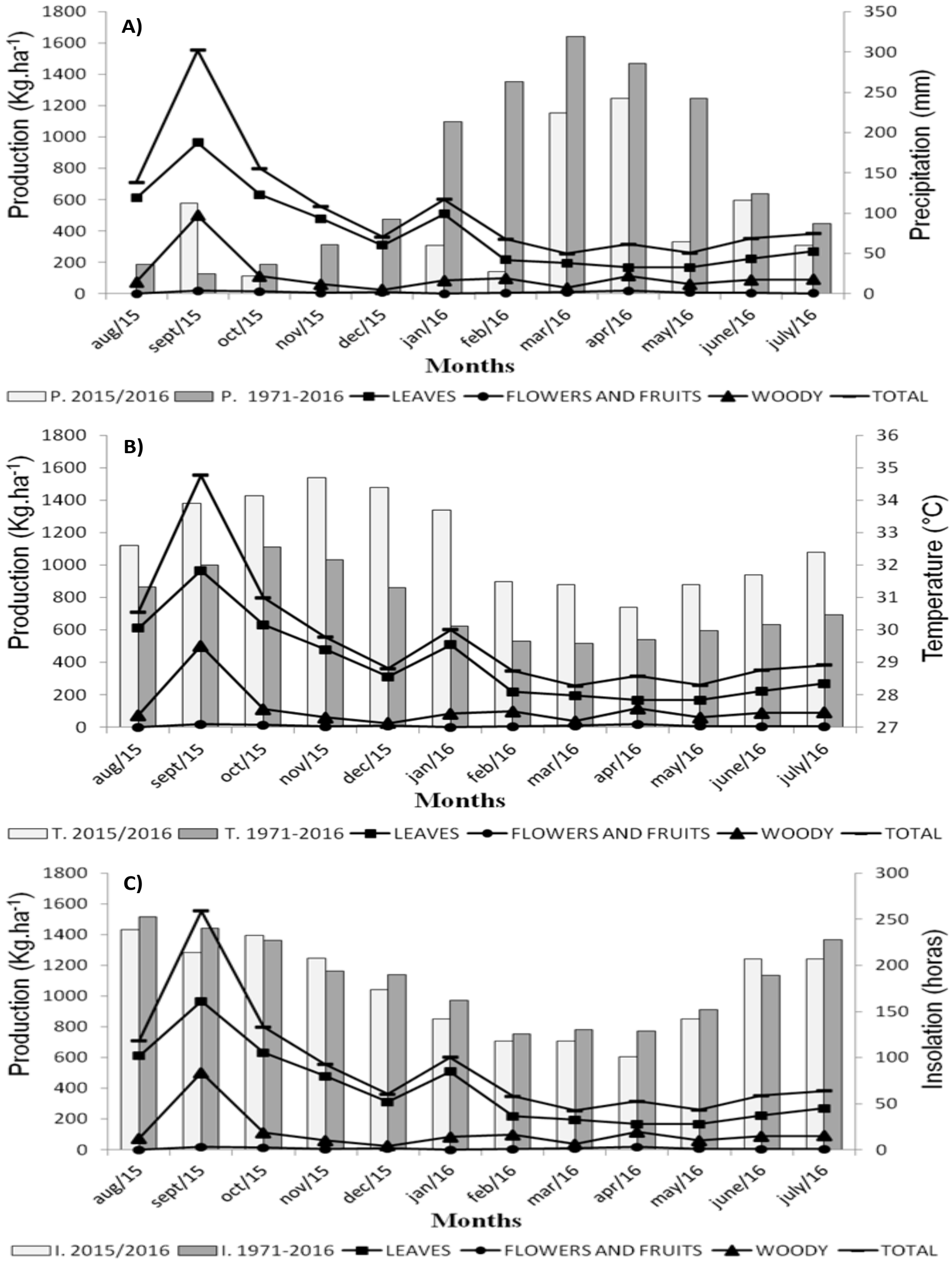

Figure 2. Monthly values for litter production for leaves, woody material, and flowers and fruits, and data for rainfall (A), temperature (B) and insolation (C), in a natural Brazil nut tree stand in the FLONA Tapajós, Pará. Continuous lines represent production data for the four classes of litterfall; bars represent meteorological variables P.: precipitation, T.: temperature, I.: insolation. The average historic values for climatic variables are identified as “1971-2016”.

Table 1. Contribution of each litterfall class in relation to total monthly production deform August 2015 to July 2016.

Parameter	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
			2015						2016			
Leaf (%)	85.8	62.1	79.1	86.1	85.7	84.6	62.5	75.8	53.5	65.2	63.5	70.3
Wood (%)	10.5	32.2	14.1	11.2	7.4	13.9	28.6	14.8	36.5	23.2	25.6	23.9
Flowers and fruits (%)	0.2	1.2	2.0	1.0	3.2	0.1	1.7	4.0	6.2	3.1	1.3	1.1
Miscellaneous (%)	3.5	4.5	4.8	1.7	3.8	1.5	7.3	5.3	3.9	8.4	9.6	4.7

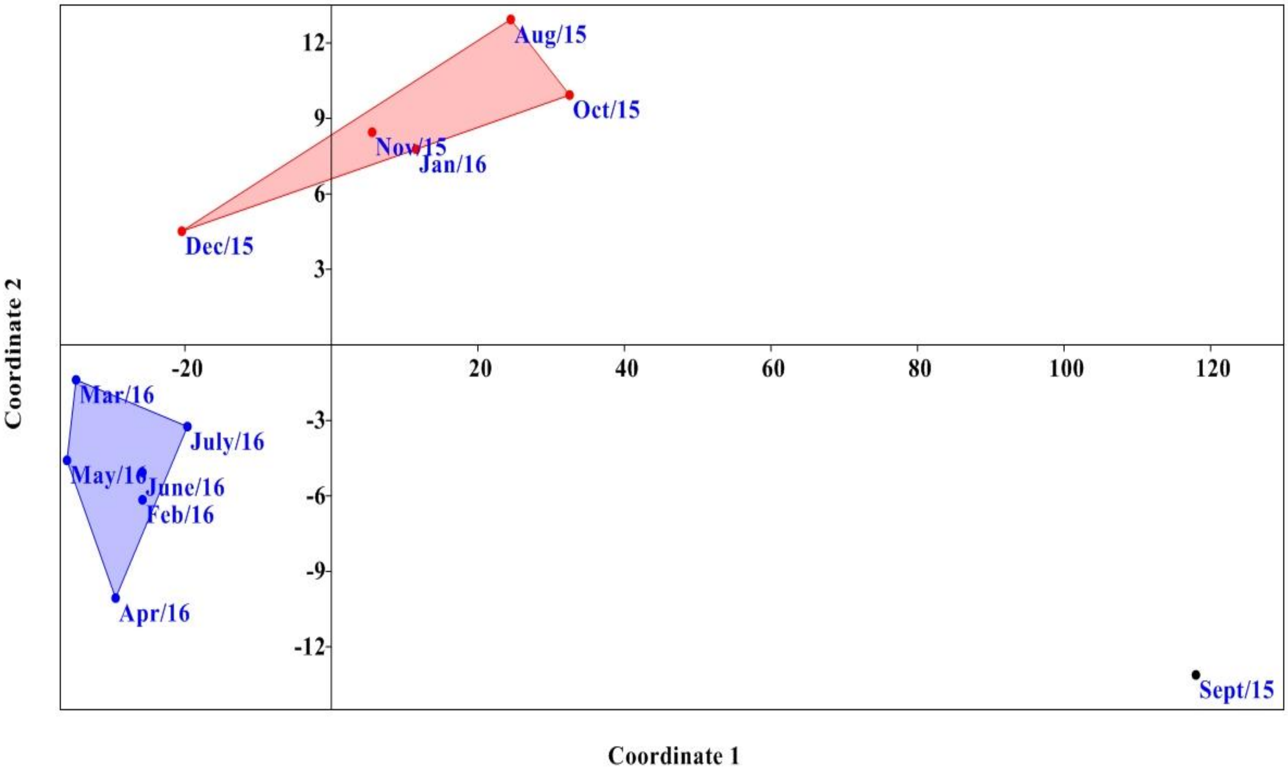

Figure 3. Similarity groups yielded by the PCO analysis using litter production data from a native Brazil nut tree stand in the FLONA Tapajós, Pará. The group in red is formed by the months of July 2016 (July/16), August (Aug/15), October (Oct/15), November (Nov/15) and December (Dec/15) 2015 and represents the dry period. The group in blue is formed by the months of January (Jan/16), February (Feb/16), March (Mar/16), April (Apr/16), May (May/16) and June (June/16) 2016 and represents the rainy period. September (Sept/15) had no similarity with the two groups.

DISCUSSION

Temporal variation of the meteorological data and litter production

The sampling period for litter production (August 2015 to July 2016) coincided with a very intense El Niño event according to the Oceanic Niño Index (ONI) (Golden, 2016). The comparison between the historical climate averages for rainfall and temperature for the past 40 years and the data from this study shows a strong anomaly caused by this event in the FLONA Tapajós.

The average monthly production of the leaf and wood classes was higher than that reported by Silva and Oliveira Júnior (2010) in 2007 and by Silva (2014) in 2002 and 2003, in dense ombrophilous forest on terra firme at km 67 in the FLONA Tapajós wherein flowers and fruits showed inferior values to those in the current study, principally for months with less rainfall. The results from the current study are greater than those reported by Ferreira et al. (2015) in humid tropical forest in the FLONA Caxiuanã in the eastern Amazon.

The high values for leaf and wood production could be due to influence of the temperature and rainfall anomalies related to the El Niño event that occurred during 2015 and 2016. For example, in 2007 the temperature of the eastern portion of the Pacific ocean, which is a variable that influences the precipitation rate in the Amazon, was stable, and therefore there was no El Niño event in this year, but in years 2002 and 2003 there was a moderate and weak El Niño, respectively (INMET, 2010). Costa et al. (2014), studying litter production in 2009 and 2010 in the FLONA Caxiuanã, reported a significant increase in litter production coinciding with an El Niño event.

The low value for flower and fruit production in El Niño years was also reported by Silva (2014). The high temperatures (Figure 2B) and the subsequent reduction or absence of water in the system in the current study could have altered reproduction processes of the vegetation in the study area. Chagas et al. (2012) related, about the National Forest of Caxiuanã, also in Pará State, that a reduction in rainfall significantly affected all the parameters of vegetation development, and Guerreiro (2017) conducted a socioeconomic study with extrativists of *B. excelsa* who collected Brazil nuts in the area around km 84 of the FLONA Tapajós, and these local people related that production of Brazil nuts and other fruits in 2016 was extremely low compared to preceding years. They associated this reduction to the intense dry period and frequent fires that occurred in the forest in the

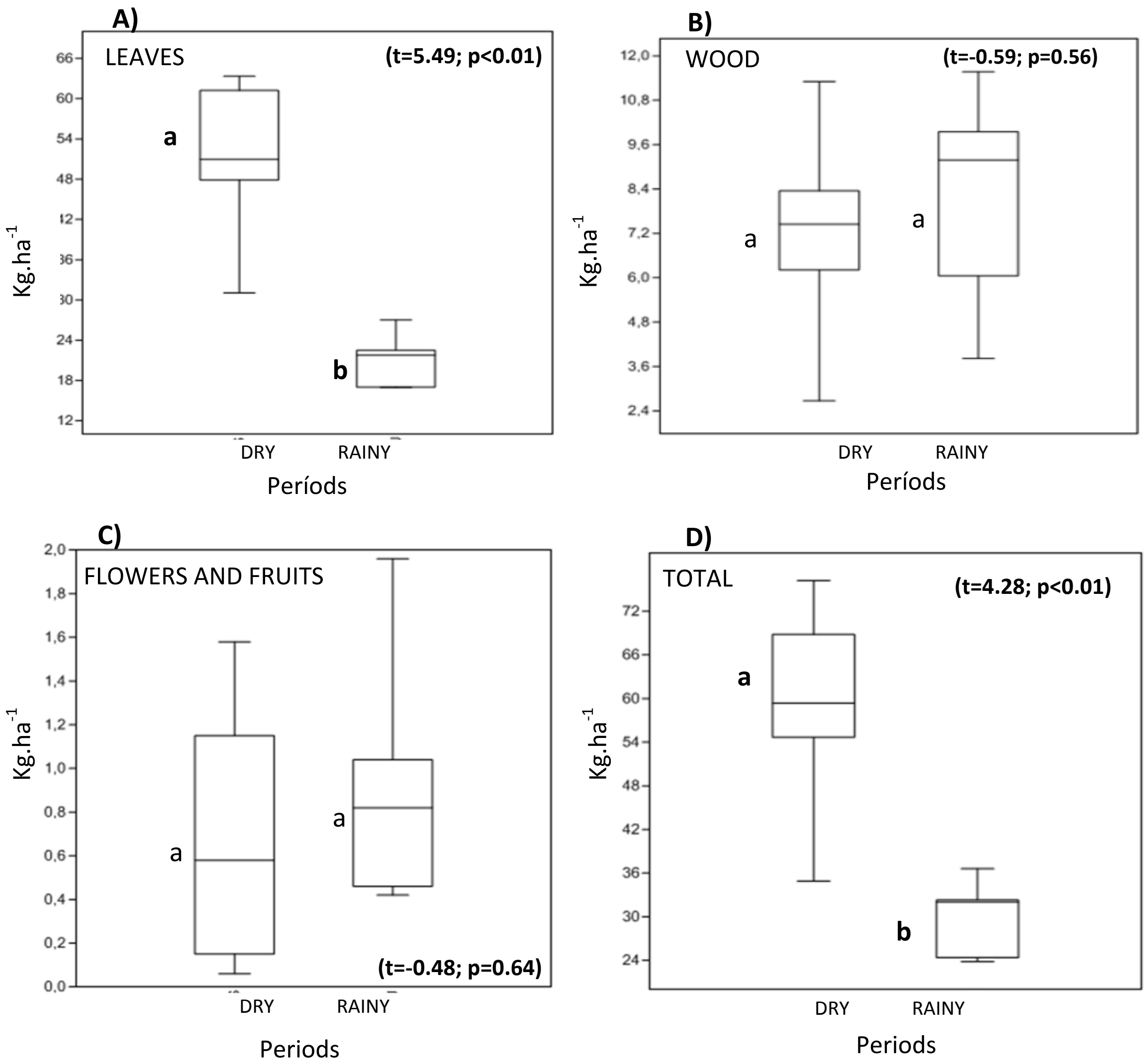

Figure 4. Variation in the production of leaves, wood, flowers and fruits, and total litter (sum of all four classes) in relation to the rainy and dry periods in a native Brazil nut tree stand in the FLONA Tapajós, Pará. Periods with the same letter are not significantly different by the *t-test* at a 5% significance level. Error bars represent standard deviation.

Table 2. Results from the Pearson Linear Correlation and cross correlation tests conducted using litter production data and meteorological variables in the study area in the FLONA Tapajós, Pará.

Parameter	Pearson's correlation			Cross correlation	
	Precipitation	**Temperature**	**Insolation**	**Precipitation**	**Insolation**
Leaves				**Lag: 1**	**Lag: 1**
	r = -0.60	*r* = 0.73	*r* = 0.69	*r* = -0.65	*r* = 0.80
	p = 0.05	p = 0.01	p = 0.02		p<0.01
Total production					**Lag: 1**
	ns	*r* = 0.67	*r* = 0.67	p = 0.04	*r* = 0.78
	-	p = 0.03	p = 0.02	sd	p<0.01

r: Correlation coefficient; p: probability level of significance; ns: insignificant (p > 0.05); sd: no time lag (p > 0.05); Lag: time lag (time lag for the response of litter production in relation to environmental variables, in months).

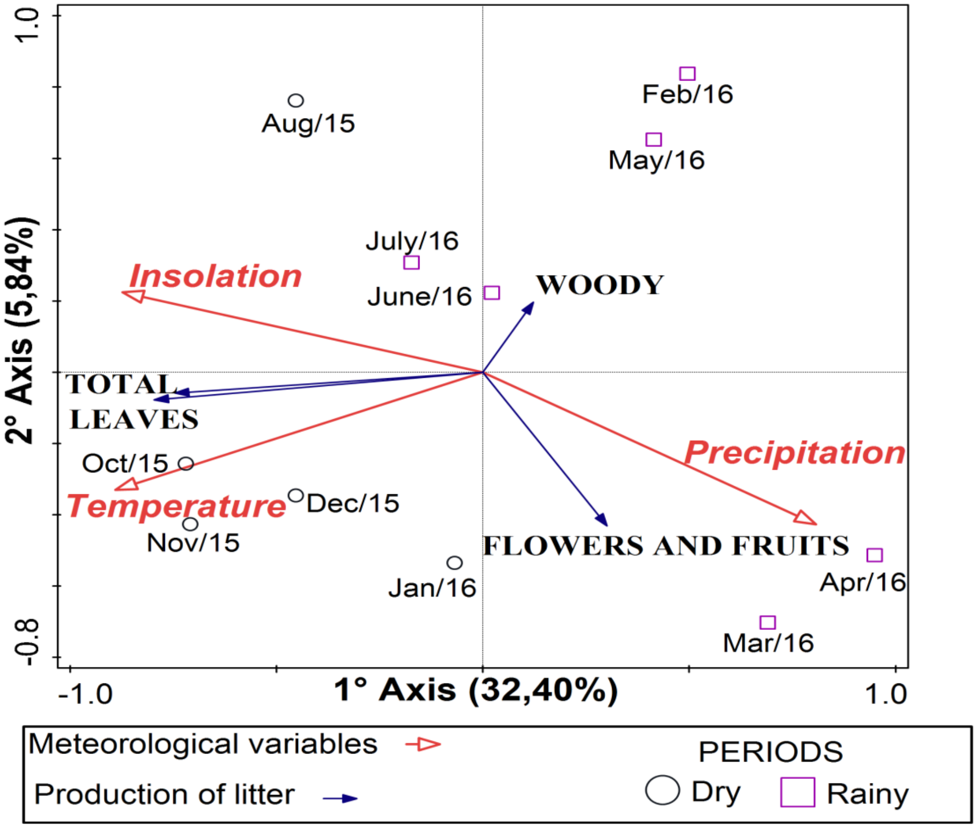

Figure 5. Diagram of the RDA ordination with meteorological variables and litter production data from the study area in the FLONA Tapajós, Pará. The response variables (Precipitation, Temperature and Insolation) are represented by the red arrows, the dependent variables (estimated production for the classes leaves, wood, flowers and fruit, and total production) are represented by the blue arrows. Circled months represent samples from the dry period, and squares represent samples from the rainy period.

second half of 2015.

The peak of litter production occurred in September 2015 and coincided with a single rainfall event that exceeded the historic average rainfall amount for that month. Frequent torrential rainfall and strong winds that occur in the Amazon region cause a larger production of litter (Godinho et al., 2015). Wood production in this month was also high and Moraes (2002) related that the first strong rains after a prolonged dry period stimulates the fall of dry branches that are still attached to the tree and this might have occurred in the current study since the preceding month of August registered no rainfall.

The larger contribution of leaves to total litter production in all collection months has been reported in other studies in tropical forests (Almeida et al., 2015; Ferreira, 2014; Ferreira et al., 2015; Silva et al., 2009; Silva and Oliveira Júnior, 2010; Silva, 2014).

Litter production and meteorological variables

The significant variation between the rainy and dry periods for leaf and total litter production agrees with the results from the correlations done between these classes and precipitation, temperature, and insolation. Silva (2014) also showed a correlation between litter production and temperature, and Santos Júnior (2008) related that environmental forcing factors present a well-defined pattern during the entire year with larger values for temperature and insolation and a smaller volume of water during the dry period compared to the rainy period, and this is also reflected in the dynamics of the vegetation.

The association of water stress and high temperatures with the greater number of hours of sunlight without interference of clouds during the dry period could have caused a large pulse of litter production due to physiological stimulation, dispersion of older materials, or natural breakage of parts of the trees (Silva, 2013). The falling of leaves during the period of reduced rainfall is considered a defense mechanism in order to reduce water loss due to evapotranspiration (Parolin et al., 2010; Ourique et al., 2016).

Flower and fruit production in areas of high plant diversity, such as the FLONA Tapajós (Andrade et al., 2015; Gonçalves and Santos, 2008), often present a well-defined seasonality of litter production because different species possess different phenological aspects (O'brien et al., 2008). The peaks in production registered for woody materials in both the rainy and dry periods increased the standard deviation and impeded a significant result for the t-test in spite of the fact that wood production was much larger during the dry period. Malhi et al. (2009), analyzing data from three experimental areas located on terra firme forests under deep Oxisols, highly leached and under high plains, all located in the eastern region of the Amazon, also identified an abnormal production of woody litter and suggested that possible alteration of environmental variables influenced this biological variable.

The time lag indicates the time that the vegetation took to respond to changes in environmental factors. Studies by Restrepo-Coupe et al. (2013) and Borchert et al. (2015) explain that in tropical forests light interacts with adaptive mechanisms to indirectly determine photosynthetic capacity through leaf production and seasonality of litterfall. The phenology of many tropical trees is highly correlated with seasonal variation in insolation (Rivera et al., 2002).

In contrast to the studies by Silva (2014), Ourique et al. (2016) and Mochiutti et al. (2006), conducted in the Amazon region, the current study did not identify a relationship between rainfall and litter production through the redundancy analysis. The results from the Pearson's correlation also support this result since the correlation was weak only for leaf production. Hayashi (2006) also did not register a correlation between litter production and rainfall in a primary forest in the Amazon. The greater influence of temperature on total litter production and leaf production is explained by Kapos et al. (1997) as being an adaptation of tree species to low levels of variation of the abiotic factors wherein leaf loss is increased when trees experience abnormal or brusque changes in these factors. In the present study, the temperature data were substantially higher than the historical climatic average for the region.

Conclusion

Litter production varied during the year-long sampling period and the highest litter production by class was leaves in the dry period and wood in the rainy period.

The variation of leaf and total litter production is partially explained by temperature variation and insolation. The meteorological variables examined in this study do not explain the variation in production of reproductive material or wood that occurred between August 2015 and July 2016. The El Niño event 2015/2016 was responsible for the anomalies in rainfall and temperature data with respect to the historical climatic averages for these variables.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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