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Litterfall Dynamics and Nutrient Cycling in an Experimental Plantation of Peach Palm (*Bactris gasipaes* Kunth)

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Abstract

This study aimed to evaluate litterfall and nutrient dynamics in an experimental plantation of peach palm (*Bactris gasipaes* Kunth) in Taubaté, São Paulo, Brazil. Litterfall was collected monthly between March 2010 and May 2011, and the plant material was separated into leaflets and rachises. During the 15-month study period, the plantation produced 9.2 Mg ha^{-1} of litter (4.8 Mg ha^{-1} of leaflets and 4.4 Mg ha^{-1} of rachises). Seasonal variations were observed in litter production and nutrient concentration. Litter deposition was the highest at the end of the dry season and at the beginning of the rainy season, that is, in months with low rainfall and lower minimum temperatures. Macronutrient return to the soil was estimated at 141.5 kg N ha^{-1}, 24.8 kg P ha^{-1}, 78.2 kg K ha^{-1}, 55.1 kg Ca ha^{-1}, and 37.8 kg Mg ha^{-1}.

Keywords: palm plantation, plant nutrition, macronutrient content, seasonal effect.

1. INTRODUCTION AND OBJECTIVES

The peach palm (*Bactris gasipaes* Kunth, Arecaceae) is native to Central America and the Amazon region (Kalil Filho et al., 2010) and widely cultivated in Latin America, Hawaii, Indonesia, and Malaysia (Steinmacher et al., 2011). In Brazil, peach palm cultivation has high socio-economic importance in several regions (Sousa et al., 2011) and it has attracted growing interest because of the market potential of the heart of palm and fruits for human consumption and of the leaves and other parts of the plant as animal feed (Lorenzi, 2010). The fruits contain considerable amounts of protein, oil, fiber, β-carotene (pro-vitamin A), vitamins B and C, and iron (Carvalho et al., 2009; Yuyama et al., 2005).

The tree grows in tuffs of one to 13 stems that can reach 20 m in height and 15–25 cm in diameter (Clement, Rival et al., 2009; Lorenzi, 2010). Stems are supported by a fibrous root system, with 75% of the roots extending 40 cm from the central stem to a depth of 20 cm. The rachis ranges from 1.5 to 2.5 m in length. Leaves may grow to 3 m and are composed of up to 240 leaflets originating at different angles (Lorenzi, 2010). Inflorescence development occurs between August and October and is followed by fruiting from December to March. Edaphoclimatic conditions may affect growth and development, inducing off-season fruiting (Yuyama et al., 2005).

Because peach palm grows in tuffs, it is an economically and environmentally attractive species for heart of palm extraction. Different from other palm species, such as juçara (*Euterpe edulis*) and açaí (*Euterpe oleracea*) (Fernandes et al., 2013; Kalil Filho et al., 2010), peach palm yields several harvests of heart of palm per year and has high production and adaptation capacity. In large-scale production systems, trees are planted at a density of 5,000 to 10,000 ha^{-1}, and the first harvest is made 18 and 24 months after planting (Kalil Filho et al., 2010; Steinmacher et al., 2011). The average yield is 0.8–1.2 stems per plant (Penteado et al., 2010).

Peach palm cultivation can be carried out under diverse climatic conditions. Optimal development is observed in hot

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and humid climate with average annual temperature of 21 °C, relative humidity of 80–90%, and 2,000 mm of well-distributed rainfall (Neves et al., 2007). Trees require plenty of water to grow, but do not tolerate waterlogging. Supplemental irrigation may be necessary in water-deficient areas. Management of soil's physicochemical properties is needed to achieve high productivity. Palms prefer deep, well-drained, loamy to clayey soils rich in organic matter (Leandro et al., 2014; Neves et al., 2008). Soils deficient in P, N, K, or Mg result in decreased growth (Viégas et al., 2009).

Proper crop residue management can improve the physicochemical characteristics of the soil, provide protection against erosion, and increase soil fertility (Souza & Piña-Rodrigues, 2013). Litterfall is the main pathway for nutrient transfer to the soil. Thus, knowledge of litter production and decomposition provides a basis for comprehending how an ecosystem functions (Herrera, 1989). The leaf fraction of litterfall has the highest nutrient density and is responsible for a faster transfer of macronutrients than the other fractions (Bianchin et al., 2016; Godinho et al., 2013; Machado et al., 2015; Marafiga et al., 2012; Pinto et al., 2016; Ribeiro et al., 2017). Litterfall decomposition and nutrient accumulation rates depend on several factors: climatic conditions, type of substrate, macronutrient content, and C/N/P ratios (Arco-Verde et al., 2009). In hot and humid climates or irrigated plantations, litterfall and crop residues usually decompose in 3 to 4 months (Malavolta et al., 1997).

This study aimed to determine litterfall and nutrient dynamics and seasonality in an experimental plantation of peach palm.

2. MATERIALS AND METHODS

Litterfall was collected between March 2010 and May 2011 on the experimental farm of the Department of Agricultural Sciences of the Universidade de Taubaté, Taubaté, SP, Brazil (23°01′51″S 45°30′34″W, 565 m altitude). The region is included in the Atlantic Forest domain in an area originally covered with seasonal semideciduous forest (IBGE, 2012). The average annual rainfall is 1,350 mm; the average annual temperature, 21.9 °C (Folhes & Fisch, 2006).

Peach palm seedlings were planted in 1998 at a 2 × 1 m spacing in red-yellow latosol previously cultivated with *Urochloa decumbens* (Stapf) R.D. Webster. The land was plowed and harrowed. Seedlings were fertilized at planting with 100 kg N ha^{-1} as calcium ammonium nitrate, 35 kg P_2O_5 ha^{-1} as simple superphosphate, and 30 kg K_2O ha^{-1} as potassium chloride. Mowing was regularly performed where necessary, and residues were left on the soil surface. Fertilization with Borax at 2 kg ha^{-1} was performed every three years.

Rainfall and temperature data were collected at a meteorological station close to the experimental site. These data are presented in Figure 1.

The total rainfall during the 15-month study period was 1,092.5 mm. However, rainfall had an irregular distribution. In the study area, the dry season lasts from April to August. In 2010, 51.4 mm of rainfall were recorded in April and 0 mm in August. The rainy season began in September 2010, when rainfall increased considerably, and extended through March 2011. The highest rainfall amounts were recorded in January (214.0 mm) and March 2011 (206.8 mm) (Figure 1).

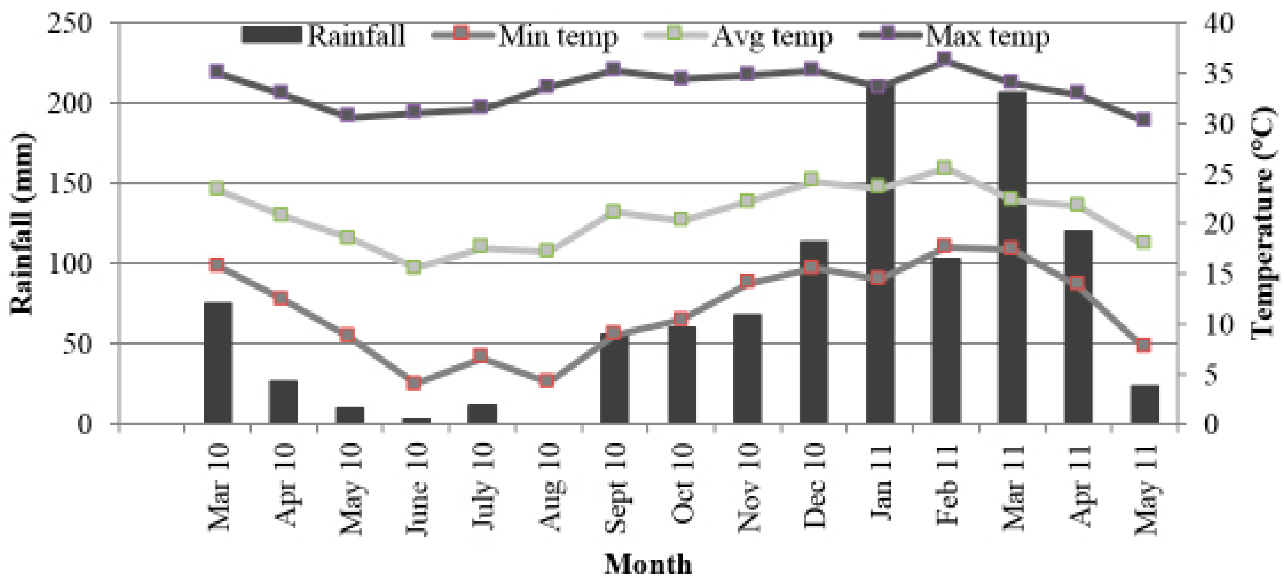

Figure 1. Monthly rainfall (mm) and minimum, average, and maximum temperatures (°C) from March 2010 to May 2011 in Taubaté, SP, Brazil.

The minimum monthly temperature was lower from May to October 2010 (end of the dry season and beginning of the rainy season). The lowest (4.0 °C) and highest (17.6 °C) minimum temperatures were recorded in June 2010 and February 2011, respectively. The maximum monthly temperature was the lowest in May 2011 (30.2 °C) and the highest in February 2010 (36.2 °C). The mean average temperature during the experimental period was 20.6 °C. The lowest (15.6 °C) and the highest (to 25.5 °C) average temperatures were recorded in June 2010 and February 2011, respectively (Figure 1).

Litterfall was collected monthly using 10 litter traps (1 m^2) made of nylon mesh (1 mm). Litter traps were installed at 0.5 m from the ground surface at randomly selected sites within an area of 0.5 ha. Litterfall was separated into leaflet and rachis fractions and packed them separately in paper bags. In the laboratory, samples were dried in a forced air oven (65 °C, 72 h) for dry weight determination.

Litter fractions were milled using a Wiley-type mill and subjected to sulfuric acid digestion (Tedesco et al., 1995). N, P, K, Ca, and Mg levels were determined. Two triplicates were performed, one corresponding to samples collected from litter traps one to five and the other, from litter traps six to ten. N content was determined through the micro Kjeldahl method. Metavanadate was used for the colorimetric determination of P content and absorbances were read on a conventional spectrophotometer. K, Ca, and Mg levels were determined by atomic absorption spectroscopy.

Results were subjected to the Shapiro–Wilk normality test and analysis of variance (ANOVA). Means were compared by Tukey's test at $p < 0.05$ and Pearson correlation coefficients were determined for litterfall and climate variables (rainfall, average, minimum, and maximum temperatures) using SISVAR version 5.3 (Ferreira, 2010).

3. RESULTS AND DISCUSSION

3.1. Litter production

Litterfall during the 15-month study period amounted to 9.2 Mg ha^{-1}, of which 53% were leaflets and 47% were rachis. Litter deposition was the highest in October 2010, representing 24% of the total biomass accumulated in the study period (Figure 2).

Total litter biomass was lower than that observed by Herrera (1989) in peach palm plantations. The author reported a green weight production of 61.5 Mg ha^{-1} $year^{-1}$, which is equivalent to 19.5 Mg ha^{-1} $year^{-1}$ on a dry weight basis; of this total, only 1.76 Mg ha^{-1} $year^{-1}$ was harvested as heart of palm. Litter biomass accumulation might have been lower in this study because our sample included only leaves and rachis that naturally fell into the collector, whereas Herrera (1989) considered all plant residues generated from heart of palm extraction. Godinho et al. (2013) analyzed litterfall in a seasonal semideciduous forest and found a biomass accumulation of 9.3 Mg ha^{-1} $year^{-1}$.

The monthly percentage of litter fractions did not follow a well-defined pattern during the study period. Leaflet litter deposition ranged from 0.05 to 1.04 Mg ha^{-1} $month^{-1}$, and rachis litter deposition ranged from 0.00 to 1.19 Mg ha^{-1} $month^{-1}$ (Figure 3).

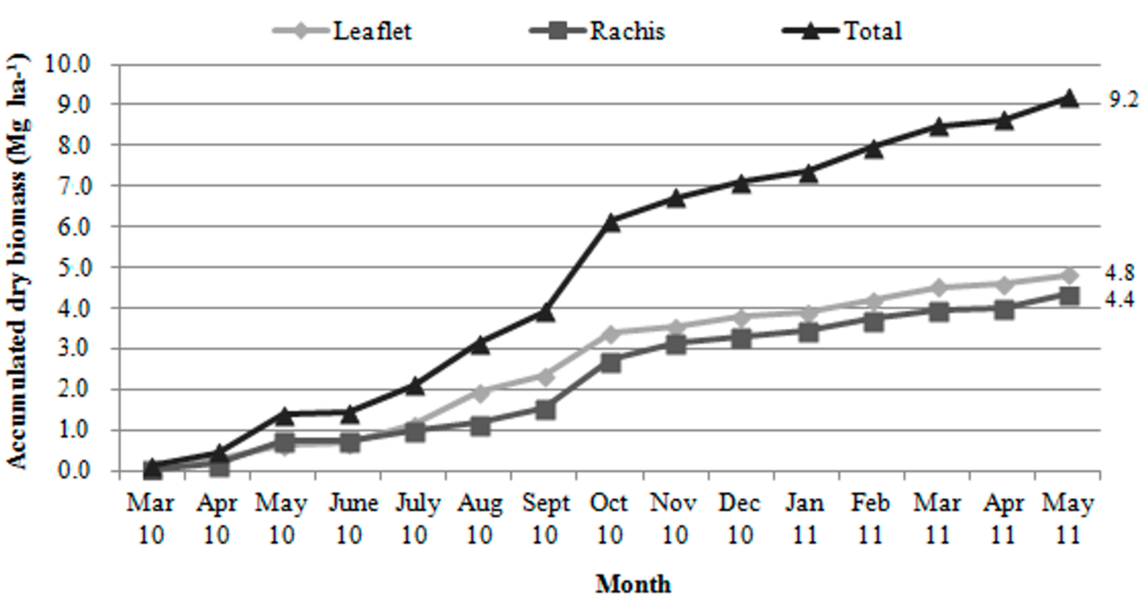

Figure 2. Biomass of litter and fractions (leaflet and rachis) produced in an experimental plantation of peach palm (*Bactris gasipaes* Kunth) from March 2010 to May 2011.

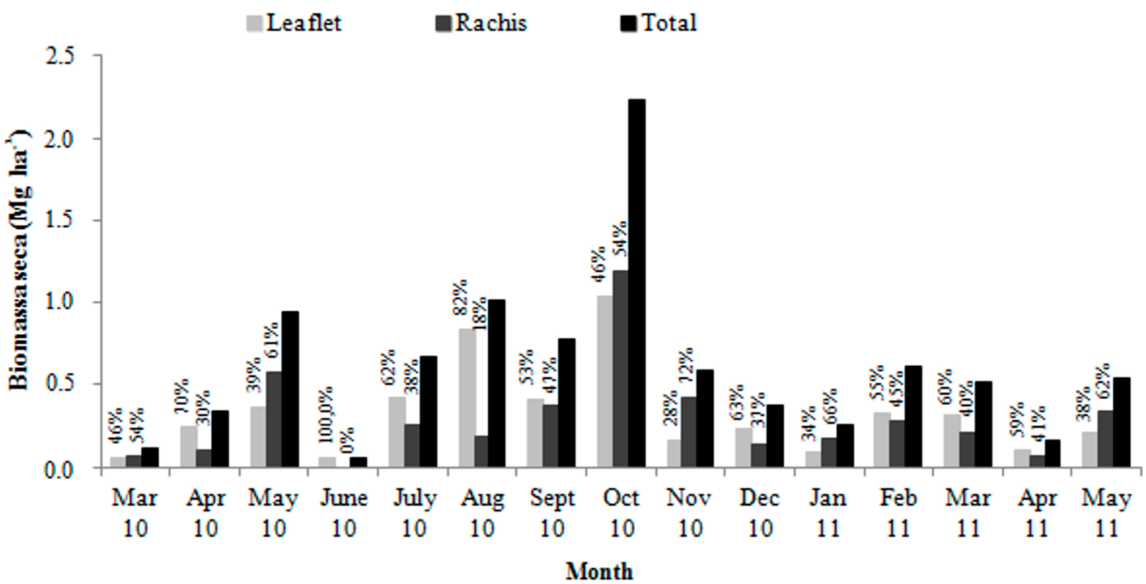

Figure 3. Monthly dry biomass of litter and fractions (leaflet and rachis) produced in an experimental plantation of peach palm (*Bactris gasipaes* Kunth) from March 2010 to May 2011. Percent values represent the proportion of leaflets and rachises in each litter sample.

The lowest litter depositions occurred in March 2010 (0.11 Mg ha^{-1}), June 2010 (0.05 Mg ha^{-1}), and April 2011 (0.16 Mg ha^{-1}) (Figure 3). We observed the highest litter depositions, 0.94, 1.02, 0.78, and 2.23 Mg ha^{-1}, in May, August, September, and October 2010, respectively. This period corresponds to the end of the dry season and beginning of the rainy season, in which there was low rainfall and lower minimum temperatures. According to Clement, Kalil Filho et al. (2009), peach palms are in bloom during these months. Gomes et al. (2010) observed similar results in fragments of tropical rain forest – dense ombrophilous forest, according to the classification of the Brazilian Institute of Geography and Statistics (IBGE).

The seasonality of litterfall was corroborated by the negative significant correlation between litterfall and rainfall and litterfall and minimum temperature (Table 1). However, we observed no significant correlations between litterfall and average and maximum temperatures.

Table 1. Pearson correlation coefficients of litterfall with rainfall, minimum, average, and maximum temperatures in an experimental plantation of peach palm (*Bactris gasipaes* Kunth) from March 2010 to May 2011.

Rainfall (mm)	Minimum temperature (°C)	Average temperature (°C)	Maximum temperature (°C)
−0.34*	−0.34*	-0.14^{ns}	-0.02^{ns}

* Significant at $p < 0.05$; ns: not significant.

In contrast to our results, Gomes et al. (2010) observed a significant positive correlation between litterfall and rainfall, average, minimum, and maximum temperatures in a dense ombrophilous forest. Giácomo et al. (2012) investigated litterfall in seasonal semideciduous and cerradão forests and observed no correlation between litterfall and rainfall or litterfall and temperature.

The average temperature during the study period (20.6 °C) was suitable for peach palm development. However, rainfall had an irregular distribution. The ideal conditions for peach palm growth are average temperature of 21 °C and uniform rainfall throughout the year (Neves et al., 2007). The total rainfall during the study period was lower than the average annual of 1,350 mm (Folhes & Fisch, 2006) and far from the average annual considered appropriate for peach palm (2,000 mm) (Neves et al., 2007).

The seasonal distribution of litterfall can be explained by the findings of Carmo et al. (2003). The authors reported that peach palm has a rapid growth and vegetative development in the rainy period and, thus, a lower production of litter. Pinto et al. (2016) and Godinho et al. (2013) observed a similar litterfall pattern in seasonal semideciduous forests. The authors stated that, in tropical forests, litterfall occurs throughout the year but can vary according to the season. Higher litter production is observed in the dry season as a result of leaf abscission in response to water stress. However, Bianchin et al. (2016), Souza et al. (2016), and Villa et al. (2016) pointed out that high litter production can occur during high rainfall periods, especially in dense ombrophilous forests.

3.2. Litter nutrient content

Nutrient contents varied according to litter fraction and season. In leaflets, nutrient content followed the order N > Ca > K > Mg > P, whereas, in rachises, the order of nutrient concentration was K > N > Ca > Mg > P (Table 2).

Marafiga et al. (2012) observed the same order of nutrient concentration in leaflet litter collected in a seasonal semideciduous forest. In the study by Gomes et al. (2010), the nutrient content of litterfall collected in a dense ombrophilous forest followed the order Ca > K > Mg > P. Diniz et al. (2015) studied the nutrient composition of litter produced in Atlantic Forest fragments at intermediate stages of succession and found the following order: Ca > N > K > Mg > P.

In leaflets, N and Ca contents did not vary significantly between months, indicating that climatic conditions (dry/rainy seasons) did not affect these parameters (Table 2). P content was significantly higher in July 2010 than in February, April, and May 2011. K was significantly higher in May 2010 than in the other months but did not differ between May, June, July and August 2010 (Table 2). Mg content also varied over the months: it was significantly higher in August 2010 than in March, November, and December 2010 and January and April 2011 but did not vary between August 2010 and the other months.

Table 2. Nutrient content in peach palm (*Bactris gasipaes* Kunth) leaflet and rachis litter collected from March 2010 to May 2011.

Sampling date	N (g kg^{-1})		P (g kg^{-1})		K (g kg^{-1})	
	Leaflet	Rachis	Leaflet	Rachis	Leaflet	Rachis
March 2010	13.31 Aa	8.40 Ab	1.64 ABCa	1.27 BCDb	2.59 CDb	5.05 BCDEa
April 2010	16.11 Aa	7.00 ABb	1.74 ABCa	1.55 BCDb	3.92 BCDb	13.58 Aa
May 2010	12.96 Aa	4.20 ABb	1.81 ABb	2.16 ABa	9.69 Aa	7.80 BCb
June 2010	12.04 Aa	0.00 Bb	1.45 ABCDa	0.00 Eb	5.41 ABCDa	0.00 Eb
July 2010	15.06 Aa	4.55 ABb	1.91 Ab	2.71 Aa	7.04 ABCb	9.98 ABa
August 2010	13.66 Aa	4.90 ABb	1.82 ABb	2.74 Aa	8.27 ABa	7.33 BCb
September 2010	11.73 Aa	4.55 ABb	1.36 ABCDb	2.04 ABCa	3.53 BCDb	6.75 BCDa
October 2010	14.01 Aa	4.37 ABb	1.77 ABCb	2.07 ABCa	4.06 BCDb	6.15 BCDa
November 2010	11.91 Aa	7.35 ABb	1.71 ABCa	1.45 BCDb	3.91 BCDb	6.14 BCDa
December 2010	12.43 Aa	4.02 ABb	1.20 ABCDa	1.49 BCDb	2.07 CDb	5.05 BCDEa
January 2011	14.88 Aa	4.72 ABb	1.30 ABCDa	1.36 BCDa	2.59 CDb	6.95 BCDa
February 2011	13.15 Aa	7.81 ABb	0.87 BCDa	0.60 DEb	1.12 Da	0.28 Eb
March 2011	12.95 Aa	3.70 ABb	0.98 ABCDb	1.31 BCDa	1.70 CDb	3.64 CDEa
April 2011	11.55 Aa	4.60 ABb	0.61 Db	1.14 CDa	0.70 Db	5.96 BCDa
May 2011	11.25Aa	5.95 ABb	0.77 CDb	0.98 DEa	1.22 Db	1.64 DEa
Mean	13.13 a	5.08 b	1.40 b	1.52 a	3.86 b	5.75 a
Standard deviation	1.41	2.06	0.43	0.74	2.70	3.53

Sampling date	Ca (g kg^{-1})		Mg (g kg^{-1})	
	Leaflet	Rachis	Leaflet	Rachis
March 2010	4.45 Aa	2.66 ABb	2.28 CDb	2.35 Aa
April 2010	5.31 Aa	1.67 ABb	3.67 ABa	1.66 Ab
May 2010	5.31 Aa	1.67 ABb	3.32 ABCa	1.48 Ab
June 2010	4.97 Aa	0.00 Bb	3.14 ABCDa	0.00 Bb
July 2010	5.44 Aa	2.00 ABb	3.66 ABa	1.74 Ab
August 2010	4.98 Aa	1.00 ABb	3.89 Aa	1.65 Ab
September 2010	4.29 Aa	1.80 ABb	2.82 ABCDa	1.88 Ab
October 2010	5.08 Aa	2.03 ABb	3.51 ABCa	1.78 Ab
November 2010	4.31 Aa	2.72 ABb	2.37 BCDa	1.98 Ab
December 2010	4.21 Aa	2.60 ABb	1.96 Db	2.22 Aa
January 2011	4.11 Aa	1.83 ABb	1.97 Da	1.41 Ab
February 2011	5.86 Aa	3.34 Ab	2.58 ABCDa	2.01 Ab
March 2011	5.40 Aa	1.82 ABb	2.99 ABCDa	1.43 Ab
April 2011	4.66 Aa	2.47 ABb	1.92 Db	2.11 Aa
May 2011	4.46 Aa	2.53 ABb	2.87 ABCDa	2.22 Ab
Mean	4.86 a	2.01 b	2.86 a	1.73 b
Standard deviation	0.54	0.80	0.67	0.56

Means followed by different uppercase letters in a column and lowercase letters in a row within each nutrient differ at $p < 0.05$ by Tukey's test. N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium.

In rachises, N content was only significantly higher in March 2010 compared with June 2010 (Table 2). The levels of P, which did not differ significantly, were significantly higher in March, April, June, November, and December 2010, and January and May 2011. K concentration was significantly higher in April 2010 in comparison with the other months, except in July 2010 (Table 2). The level of Ca was only higher in February 2011 than in June 2010. Mg was significantly lower in July 2010 but did not vary in the other months.

Mean N, Ca, and Mg contents were significantly higher in leaflets than in rachises: leaflets contained respectively 72%, 71%, and 62% of the total N, Ca, and Mg in litterfall. On the other hand, mean P and K levels were significantly higher in rachises, which contained respectively 52% and 60% of the total P and K in litterfall.

Throughout the study period, N concentration in leaflets was lower than the recommended (25–40 g N kg^{-1}) for peach palm leaflets (Fernandes et al., 2013; Silva & Falcão, 2002). Similarly, K concentration was lower than the optimal (8–27.8 g K kg^{-1}) in all months except May and August 2010, when K concentrations were within the ideal range (Fernandes et al., 2013; Silva & Falcão, 2002).

From March to November 2010, except September, P concentration in leaflets was within the recommended levels, that is, between 1.5 and 3.6 g kg^{-1} (Fernandes et al., 2013; Silva & Falcão, 2002). However, between December 2010 and May 2011, P content was lower than the optimal. During this period, rainfall was higher, litter production was lower, and P might have been redirected from the leaflet to the fruit during fruit ripening (Clement, Kalil Filho et al., 2009).

Ca and Mg contents were within the appropriate levels for leaflets, 2.0–12.7 g Ca kg^{-1} and 2.0–3.5 g Mg kg^{-1} (Fernandes et al., 2013; Silva & Falcão, 2002).

3.3. Nutrient cycling via litterfall

The amount of nutrient return through litterfall varied during the study period. The mean nutrient input followed the order N > K > Ca > Mg > P (Table 3).

Villa et al. (2016) observed that the concentration of nutrients recycled through litterfall in a 12-year-old dense ombrophilous forest followed the order N > Ca > K > Mg > P, similar to that found in our study. Diniz et al. (2015) observed a different order of nutrient content in litterfall of semideciduous forest fragments at intermediate succession stages (Ca > N > K > Mg > P) and advanced succession stages (N > Ca > K > Mg > P).

Table 3. Nutrient return via litterfall in an experimental plantation of peach palm (*Bactris gasipaes* Kunth) from March 2010 to May 2011.

Sampling date	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		Ca (kg ha^{-1})		Mg (kg ha^{-1})	
March 2010	1.21	B	0.16	B	0.44	B	0.40	B	0.26	B
April 2010	4.58	B	0.58	B	2.34	AB	1.44	B	1.05	B
May 2010	7.13	AB	1.90	AB	8.02	AB	2.89	AB	2.06	AB
June 2010	0.73	B	0.09	B	0.33	B	0.30	B	0.19	B
July 2010	7.40	AB	1.47	AB	5.43	AB	2.76	AB	1.96	AB
August 2010	12.27	AB	2.02	AB	8.24	AB	4.33	AB	3.54	AB
September 2010	12.86	AB	2.65	AB	8.56	AB	4.73	AB	3.63	AB
October 2010	39.35	A	8.71	A	25.93	A	14.87	A	11.46	A
November 2010	10.11	AB	1.98	AB	7.85	AB	3.67	AB	2.42	AB
December 2010	6.95	AB	1.06	B	2.74	AB	2.67	AB	1.50	B
January 2011	4.13	B	0.92	B	2.87	AB	1.57	B	1.01	B
February 2011	13.10	AB	1.00	B	1.15	B	5.95	AB	2.93	AB
March 2011	9.33	AB	1.14	AB	2.11	AB	4.08	AB	2.48	AB
April 2011	2.99	B	0.27	B	0.41	B	1.24	B	0.75	B
May 2011	9.33	AB	0.81	B	1.75	AB	4.17	AB	2.52	AB
Mean	9.43		1.65		5.21		3.67		2.52	
Standard deviation	9.18		2.09		6.50		3.51		2.70	
Total	141.46		24.76		78.17		55.07		37.77	

Means followed by the same uppercase letters in a column do not differ at $p < 0.05$ by Tukey's test. N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium.

The content of macronutrients (N, P, K, Ca, and Mg) was significantly higher in litter produced in October 2010 than in March, April, and June 2010 and January and April 2011 (Table 3). The amount of N recycled was the highest among nutrients during the study period, reaching 41.9% of the sum of nutrients returned. P was the least recycled nutrient, totaling only 7.3% of the sum of nutrients. Of this percentage, about 30% was returned to the soil in October 2010. There were months in which P return was less than 100 g ha^{-1}. The amount of K returned to the soil via litterfall was 78.2 kg ha^{-1}, which represents 23.2% of the sum of nutrients returned. This amount is sufficient to meet the short-term nutrient requirements of peach palm. According to Ares et al. (2003), 60–70 kg ha^{-1} of K is necessary to meet the minimum requirements for peach palm growth. The amount of Ca and Mg returned accounted respectively for 16.3% and 11.2% of the sum of nutrients returned.

Although the amounts of nutrients returned in October 2010 were not significantly higher than that in other months (Table 2), the higher values are explained by the higher amount of leaflets and rachises produced in this month (Figure 3). Various authors report that the nutrient content in litter can vary according to soil and climate conditions and plant age (Gomes et al., 2010; Diniz et al., 2015; Villa et al., 2016).

The results show that peach palms produce a large amount of litter, which favors the cycling of N, P, K, Ca, and Mg. Herrera (1989), Silva & Falcão (2002), and Fernandes et al. (2013) obtained similar findings.

4. CONCLUSIONS

We observed a seasonal pattern of peach palm litter production, as climate conditions influenced the monthly litterfall. The highest litterfall occurred at the end of the dry season and beginning of the rainy season, months in which there was low rainfall and low minimum temperatures. The concentration of macronutrients in leaflets followed the order N > Ca > K > Mg > P, whereas, in rachis, nutrient content followed the order K > N > Ca > Mg > P. During the 15-month study period, the accumulated litterfall was 9.2 Mg ha^{-1} (4.8 Mg ha^{-1} of leaflets and 4.4 Mg ha^{-1} of rachises). In total, 141.5 kg ha^{-1} of N, 24.8 kg ha^{-1} of P, 78.2 kg ha^{-1} of K, 55.1 kg ha^{-1} of Ca, and 37.8 kg ha^{-1} of Mg were returned to the soil through litterfall.

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