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Seasonal variation of nutrients in macaw palm (*Acrocomia aculeata*) leaves and sampling time definition

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ABSTRACT: Macaw palm (*Acrocomia aculeata*) is a widespread tree in Brazil, and the oil industry has been increasing interest in this tree due to its high oil concentrations, rusticity, and adaptability to different environments. Currently, macaw palms are being domesticated and are in an early rational cultivation process. Foliar diagnosis can contribute to managing fertilization, but there is no protocol for leaf sampling. This study aimed to evaluate the seasonal variation of leaf nutrient contents and indicate an adequate period for leaf sampling. Leaf contents of macro (N, P, K, Ca, Mg and S) and micronutrients (Cu, Mn, Fe and Zn) from composed samples of leaflets collected from the middle part of the tenth leaf were evaluated in 12 uninterrupted sampling times (January to December 2016). The data were submitted to analysis of variance. The distance from Mahalanobis and Tocher optimization methods was used to group sampling times of similar seasonal variations. Contents of N, P, K, Ca, S, Mn and Fe varied throughout the months. May and June are adequate to sample diagnostic leaves of macaw palm to analyze the nutritional status. Seasonal variation of N, S and Ca mostly contributed to the indication of leaf sampling time of macaw palm.

Keywords: nutrition, leaf diagnosis, fertilizer management, bioenergy.

INTRODUCTION

Macaw palm [*Acrocomia aculeata* (Jacq.) Lodd. ex Mart.], also known as *bocaiúva* or *macaíba*, is a palm tree from Arecaceae family, naturally occurring throughout Tropical America (Henderson et al., 1995; Motoike et al., 2013). In Brazil, macaw is the most widespread palm tree, adapted to different soils and environments (Henderson et al., 1995; Motta et al., 2002; Teles et al., 2011).

Macaw palm has been considered promising for biofuel production (Motoike and Kuki, 2009; Lanes et al., 2014), and there has been increasing interest from the vegetable oil sector due to its productive potential (up to 6200 kg ha^{-1} of oil) (Pires et al., 2013), and the diversity of products and co-products with added energetic value (Evaristo et al., 2016). However, macaw palm is in the domestication stage, in transition from extractivism to exploitation as an agricultural crop. Domestication requires breeding techniques and improvement in agricultural production system to establish rational crops on a larger, sustainable, and competitive scale. Several studies have contributed to the viability of macaw palm exploitation, such as propagation (Motoike et al., 2007; Prates-Valério et al., 2019), genetic improvement (Manfio et al., 2011, 2012; Lanes et al., 2014), ecophysiology (Pires et al., 2013), harvesting and postharvest (Goulart, 2014; del Río et al., 2016; Evaristo et al., 2016; Silva et al., 2019), distribution of root system and development of agricultural practices and fertilization (Pimentel et al., 2011, 2016). Fertilization program can guarantee crop yield by evaluating nutritional imbalances and rational fertilizer use.

Foliar analysis is an important tool to assess the nutritional status of plants, given the well-defined relationship between leaf nutrient contents and vegetative growth and yield (Malavolta, 2006; Marschner, 2012). However, using foliar analysis must be rigorous regarding sampling time because the foliar nutrient contents may vary according to season, leaf age, canopy position, and absorption and translocation mechanisms. Ideally, the best period for collecting leaf samples should have greater stability in nutrient content (Malavolta et al., 1997).

Leaf collection of coconut trees must be done at the beginning of the dry season (Frémond et al., 1966) and in the low rainy period, at least 3-4 months after fertilizer applications for oil palm (Rodrigues et al., 2006). False conclusions about nutritional status and errors in corrective and fertilizer predictions may happen if carried out outside this period.

There are no studies recommending the specific leaf sampling period for macaw palm. The standardization of sampling methodology may contribute to great advances in nutrient diagnosis and adjustments to corrective and fertilizer recommendations. This study aimed to evaluate the seasonal variation of leaf nutrient contents, indicate a better leaf sampling time, and assess macaw palms' nutritional status.

MATERIALS AND METHODS

Experimental conditions

The study was carried out at the Experimental Station of Araponga (20° 40' 1" S, 42° 31' 15" W) of Federal University of Viçosa (UFV), in Araponga municipality, Minas Gerais State, Brazil. The region is around 1000 m altitude, and presents the Cw_b (subtropical altitude) climate, according to the Köppen classification system (Sá Júnior et al., 2012), with rainy summers and dry winters. Climatic conditions of the microregion are presented in figure 1, based on data from the 5th Station of the National Institute of Meteorology of Brazil (Inmet, 2016).

The soil of the experimental area is classified as *Latossolo Vermelho-Amarelo argissólico*, according to Santos et al. (2006), an Oxisol (Soil Survey Staff, 2014). It is characterized by low natural fertility, high acidity, and favorable organic matter content. This area was exploited by natural pasture before the establishment of macaw palm (Table 1).

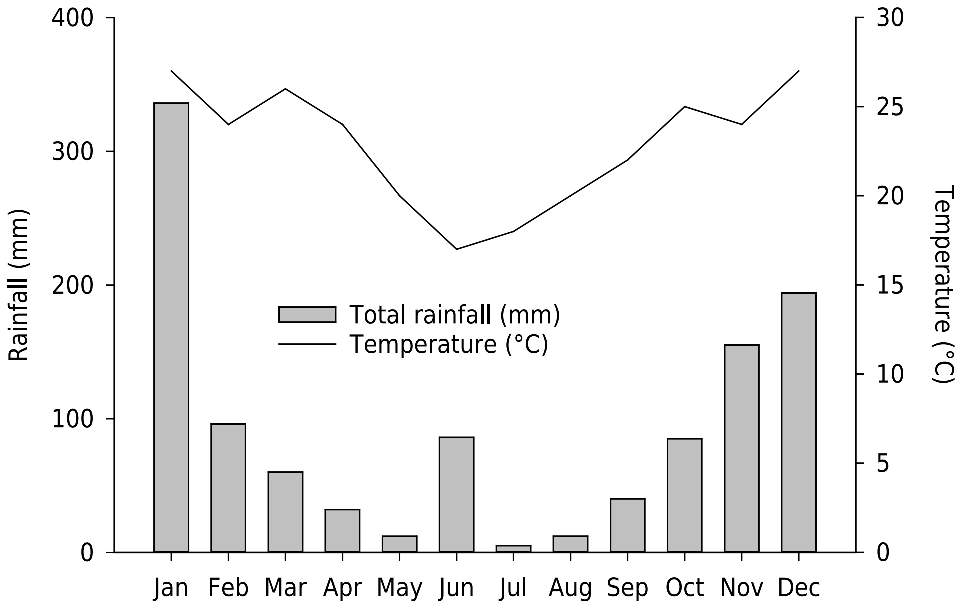

Figure 1. Rainfall and average temperatures at the experimental station (UFV), between January 2016 and December 2016.

Macaw palm plants were planted in March 2009, spaced at 5 × 5 m (density of 400 plants ha^{-1}) and cultivated in a rainfed system. By the time of leaf sampling, the plants were six years old, showed good vegetative development, and were mostly in the second-year fruit production (Table 2). The experiment was designed as a randomized block with three replications and three experimental units in each repetition.

Soil corrections and fertilizers were based on the recommendations of Pimentel et al. (2011). Liming was carried out to reach base saturation of 60 %. It was applied 317 g $plant^{-1}$ of N, 520 g per plant of K_2O, 182 g per plant of P; 187.2 g per plant of Ca; 72.8 g per plant of Mg; 1.04 g per plant of B; 0.52 g per plant of Cu; 3.12 g per plant of Mn; 5.72 g per plant of Zn and 104 g per plant of Si. Half of N and K were applied in October 2015, and the other half were applied in February 2016, using the other correctives and fertilizers.

Sample collection and analysis

Twelve sampling times of macaw palm leaves were performed, with 30-day intervals, with one sampling each month from January 2016 to December 2016. Leaf samples were collected within the first five days of the month. Samples were composed of leaflets from the tenth leaf (Figure 2a), according to Santos (2015).

Leaflets inserted at different angles were collected from both sides of the rachis using a pruning shear (Figure 2b). Subsequently, the distal and proximal parts of the leaflets were dispensed, and the middle portion was placed in paper bags for the forthcoming analysis (Figures 2c and 2d).

Leaflets were dried in a forced air circulation oven at 65 °C for 72 h and ground in a stainless-steel Willey mill. Milled samples were submitted to sulfuric digestion (Jackson, 1958) to determine N, and submitted to nitroperchloric digestion to determine P, K, Ca, Mg, S, Cu, Fe, Mn and Zn contents (Johnson and Ulrich, 1959). Nitrogen was quantified by Kjeldahl colorimetric method, according to Bremner (1965). Phosphorus was determined by phosphomolybdate method and vitamin C reduction, modified by Braga and Defelipo (1974); K by flame photometry; S by barium sulfate turbidimetry (Blanchar et al., 1963); and Ca, Mg, Cu, Fe, Mn and Zn were quantified by flame atomic absorption spectrometry (Horwitz and Latimer Jr., 1975).

Table 1. Physical and chemical analysis of the soil from the experimental area

Property	Soil layer	
	0.00-0.20 m	0.20-0.40 m
pH(H_2O)	4.60	4.70
P (mg dm^{-3})[(1)]	6.10	4.70
K (mg dm^{-3})[(1)]	105.00	90.00
Ca^{2+} ($cmol_c$ dm^{-3})[(2)]	1.04	1.01
Mg^{2+} ($cmol_c$ dm^{-3})[(2)]	0.10	0.10
S (mg dm^{-3})[(3)]	19.80	16.90
Al^{3+} ($cmol_c$ dm^{-3})[(2)]	1.60	1.40
H+Al ($cmol_c$ dm^{-3})[(4)]	15.20	13.40
SB ($cmol_c$ dm^{-3})	1.41	1.34
CEC (t - $cmol_c$ dm^{-3})	3.01	2.74
CEC (T - $cmol_c$ dm^{-3})	16.61	14.74
V (%)	8.50	9.10
m (%)	53.20	51.10
OM (dag kg^{-1}) [(5)]	7.10	6.08
P-rem (mg L^{-1})	6.50	4.00
B (mg dm^{-3})[(6)]	0.97	0.88
Cu (mg dm^{-3})[(1)]	0.81	0.84
Mn (mg dm^{-3}) [(1)]	2.90	2.90
Fe (mg dm^{-3}) [(1)]	94.20	110.80
Zn (mg dm^{-3}) [(1)]	2.81	2.18
Clay (g kg^{-1})	460	500
Silt (g kg^{-1})	100	90
Sand (g kg^{-1})	440	410
Textural class	Sandy clay	Sandy clay

[(1)] P, K, Fe, Zn, Mn, Cu: extractor Mehlich-1; Ca^{2+}, Mg^{2+}, Al^{3+}: extractor KCl 1 mol L^{-1}; H+Al: extractor calcium acetate 0.5 mol L^{-1}, pH 7.0; B: extractor hot water; S: extractor monocalcium phosphate acetic acid; SB: sum of bases; CEC (t): cation exchange capacity effective; CEC (T): cation exchange capacity in pH 7.0; V: bases saturation; m: aluminum saturation; OM: organic matter, by oxidation with $Na_2Cr_2O_7$ 2 mol L^{-1} + H_2SO_4 5 mol L^{-1}; P-rem: remaining phosphate in solution with 60 mg dm^{-3} de P.

Statistical analysis

Data of foliar nutrient contents were submitted to analysis of variance by F test. Then, the means of each month were grouped by Scott & Knott test at 5 % significance for observing the seasonal variation of nutrient contents.

Clustering technique of multivariate analysis was used to determine a common sampling time for all nutrients. The grouping procedure involved the dissimilarity among months characterized by generalized Mahalanobis distance and the Tocher optimization method to delimit groups (cited by Rao, 1952). Additionally, the relative contribution of nutrients to form groups of sampling times was quantified by generalized Mahalanobis distances, according to Singh (1981). Statistical analyses were carried out using GENES software (Cruz, 2013).

Table 2. Characterization of macaw palm plants used to collect leaf samples at Araponga Experimental Station (UFV), 2016

Traits	Average value (n = 27)
Plant height (m)	7.29
Number of leaves	20.37
Canopy projection (Diameter, in m)	5.83
2015/2016 Harvest (kg fruits per plant)	2.87
2016/2017 Harvest (kg fruits per plant)	14.26

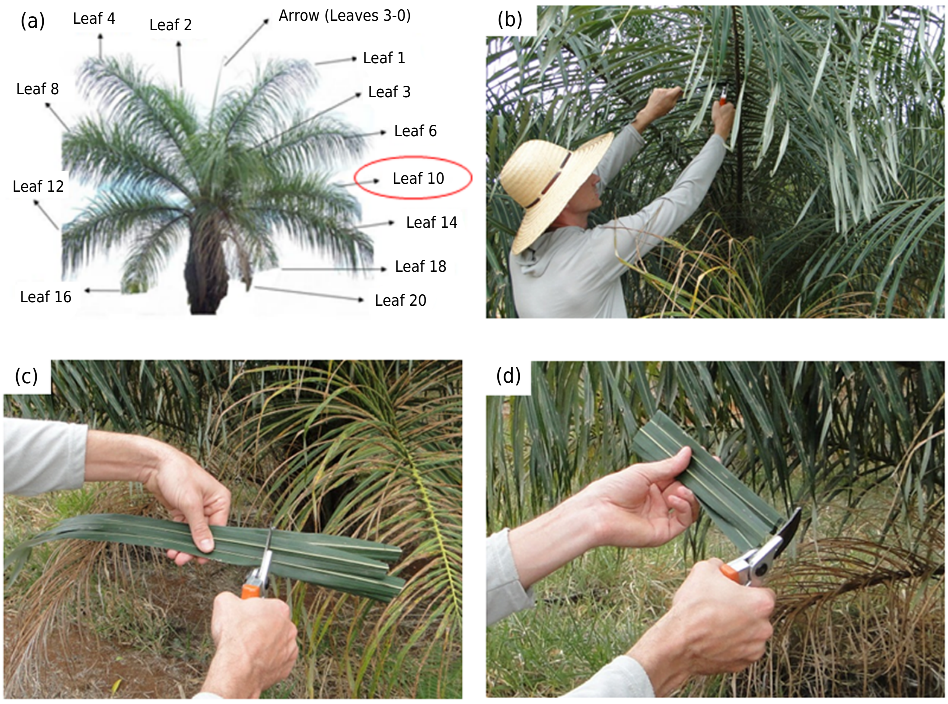

Figure 2. Leaf sampling methodology of macaw palm adopted in the experiment. Source: 2a - Adapted from Santos (2015). (a) Arrangement of macaw palm leaves indicating where the leaf sampling was carried out; (b) Sampling of leaflets collected in the middle part of the 10th leaf; (c) Removal of the basal part of the leaflets.; and (d) Removal of the apical part of the leaflets.

RESULTS

Macronutrients

Nutrient contents showed significant seasonal variation in 70 % of the cases. All macronutrients presented a greater percentage of significant effect in response to sampling times, except Mg (Table 3).

The highest N contents were observed from October to December; with a maximum value in November (25.11 g kg^{-1} - Table 4). Intermediate values were observed between January and August, and the lowest value was in September (16.92 g kg^{-1} - Table 4). The lowest P (1.07 dag kg^{-1}) was in September, and the highest was in January, February and June (1.27 g kg^{-1} - Table 4). Potassium content was higher in February (7.57 g kg^{-1}), March (7.24 g kg^{-1}), and April (7.18 g kg^{-1}), and lower in September (6.02 g kg^{-1}), such as N and P (Table 4).

Seasonal variation was not detected among sampling times for Mg contents (Tables 3 and 4). However, the behavior of contents throughout the year was such K and P, with a maximum value in February (0.95 g kg^{-1}) and a minimum (0.68 g kg^{-1}) in September (Table 4). The highest Ca content was observed in January (12.84 g kg^{-1}) and minimum in September (6.95 g kg^{-1}), forming a group with the sampling carried out in August (Table 4). Seasonal variation of S contents presented an inverse tendency of most other macronutrients with low values in rainy periods and high values in drier ones, except in August and September (Table 4). The highest S content was in June (10.08 g kg^{-1}) and the lowest in September (5.97 g kg^{-1}).

Table 3. Analysis of variance for macronutrient (N, P, K, Ca, Mg, and S) and micronutrient (Cu, Mn, Fe, and Zn) contents in macaw palm leaves in twelve sampling times

SV	DF	N	P	K	Ca	Mg	S	Cu	Mn	Fe	Zn
		Mean squares									
Block	2	4.802	0.047	1.052	20.698	0.064	0.624	28.884	114.348	79.213	19.395
Time	11	21.979**	0.010**	0.448**	6.879**	0.018^{ns}	8.834**	12.861^{ns}	12.233**	898.442**	18.058^{ns}
Error	22	0.727	0.001	0.073	0.404	0.006	0.382	10.069	1.809	177.012	12.762
CV (%)	-	4.19	2.81	3.96	6.94	9.48	8.08	42.58	4.57	12.10	24.18

^{ns}: not significant. * and **: significant by the F test at 5 and 1 % significance, respectively. SV: Source of variation; DF: Degrees of freedom.

Micronutrients

Among micronutrients, Cu and Zn did not present significant seasonal variation (Tables 3 and 4). Variations of Mn leaf contents were not clear, with some similarity to the Ca content but forming three statistically different groups. The group with the highest Mn contents was discontinuous (January, May and June), as well as the group with the lowest values (September, October and December - Table 4). The highest Mn content was observed in January (≈33 mg kg^{-1}), while the lowest (≈27 mg kg^{-1}) was in September.

Iron presented the clearest seasonal variation, with the lowest contents from January to May, and September to December, and a group of highest contents from June to August (Table 4). The highest Fe content was observed in August (≈147 mg kg^{-1}), and the minimum was in February (≈87 mg kg^{-1} – Table 4).

Sampling time definition

Tocher's optimization technique separated the sampling times into four groups of greater similarity among monthly variations of leaf concentrations. The first group consisted of four months (33.33 %), the second of five months (41.66 %), the third of two months (16.66 %) and the fourth of only one month (8.33 %) (Table 5).

The analysis to estimate the relative contribution of the seasonal variation of each nutrient to the expression of groups of common sampling periods indicated a large contribution of macronutrients (92.6 %), highlighting the individual contributions of N (35.93 %), S (29.77 %) and Ca (17.07 %). Among micronutrients, the largest individual contribution was Zn (3.50 %) (Table 6). The longest similar sampling time among seasonal variations of all studied nutrients were March, April, May, June and July (Group II) (Table 5).

Table 4. Average leaf contents of N, P, K, Ca, Mg, S, Cu, Mn, Fe and Zn in macaw palm, in twelve different sampling times

Sampling time	N	P	K	Ca	Mg	S	Cu	Mn	Fe	Zn
	g kg^{-1}						mg kg^{-1}			
January	19.29 b	1.27 a	6.75 b	12.84 a	0.89 a	6.51 c	4.42 a	32.98 a	110.78 b	19.14 a
February	19.52 b	1.27 a	7.57 a	8.87 c	0.95 a	6.51 c	10.74 a	29.52 b	86.7 b	13.58 a
March	19.80 b	1.23 a	7.24 a	8.68 c	0.90 a	7.74 b	9.15 a	29.89 b	94.45 b	13.67 a
April	19.33 b	1.24 a	7.18 a	9.12 c	0.81 a	9.77 a	6.24 a	30.03 b	102.22 b	13.08 a
May	19.18 b	1.20 a	6.72 b	9.46 c	0.81 a	9.80 a	4.35 a	31.33 a	102.54 b	14.16 a
June	18.67 b	1.27 a	6.72 b	10.57 b	0.84 a	10.08 a	9.82 a	32.31 a	124.05 a	20.54 a
July	18.64 b	1.25 a	6.67 b	9.54 c	0.80 a	9.96 a	5.80 a	28.59 b	132.53 a	15.13 a
August	18.80 b	1.23 a	6.92 b	7.31 d	0.73 a	6.55 c	6.47 a	26.77 b	147.37 a	13.45 a
September	16.92 c	1.07 b	6.02 c	6.95 d	0.68 a	5.97 c	8.89 a	26.69 c	112.14 b	12.96 a
October	24.67 a	1.26 a	6.57 b	8.26 c	0.74 a	6.16 c	8.75 a	27.75 c	108.95 b	13.70 a
November	25.11 a	1.26 a	6.78 b	9.01 c	0.83 a	6.59 c	7.24 a	29.06 b	103.02 b	14.42 a
December	24.19 a	1.25 a	6.73 b	9.31 c	0.78 a	6.21 c	7.58 a	28.19 c	94.59 b	13.50 a

Group of means followed by the same letter in the column do not differ from each other by the Scott Knott test at 5 % significance.

Table 5. Grouping of 12 months of macaw palm leaf sampling

Groups	Sampling Times*					Percentage
						%
I	NOV	DEC	OCT	FEB		33,33
II	APR	MAY	JUL	JUN	MAR	41,66
III	AUG	SEP				16,66
IV	JAN					8,33

* Delimitation of groups by Tocher optimization method.

DISCUSSION

Macronutrients

Growth of plants, especially releasing new leaves, is a considerable nutrient sink, and leaf production of palm trees can be influenced by several environmental factors, such as water availability, light, and temperature (Steven et al., 1987; Sampaio and Scariot, 2008; Tucci et al., 2010; García et al., 2015; Woittiez et al., 2017). With adequate nutritional management, Macaw plants can release 11.8 leaves per year (Barleto, 2011). A greater frequency of releasing new leaves is observed in the rainy season, like in other palm trees (Leite and Encarnação, 2002; Tucci et al., 2007).

Flowers are a strong nutritional sink (Malavolta, 2006). Scariot et al. (1991) reported a flowering peak of macaw plant in November and December in Central Brazil, while Brito (2013) and Montoya et al. (2016) reported greater flowering in December and January in Minas Gerais State, with flowering occurring during the rainy season, as observed in the present study.

Choosing a sampling time out of flowering stage is essential to avoid interference with the leaf contents. In the present study, the seasonal nutrient variation followed previous studies carried out with star fruit (*Averrhoa carambola*) and cherry fruit (*Malpighia emarginata*) (Prado and Natale, 2004; Lima et al., 2007, 2008).

Leaf N contents are close to that reported by Pires et al. (2013) in two years old macaw plants, however above the values of adult macaw palm found by Teles et al. (2008) and Santos (2015), and below 30.70 g kg^{-1} than that reported by Pimentelet al. (2015). The greatest flowering period explains the decrease in N from samples taken in January and subsequent months. Probably, the strong sink represented by the developing fruits may

Table 6. Relative importance of seasonal variation of leaf nutrient contents in macaw palm for sampling times

Nutrients	Value*
	%
Nitrogen (N)	35.93
Phosphorus (P)	3.83
Potassium (K)	5.54
Calcium (Ca)	17.07
Magnesium (Mg)	0.46
Sulfur (S)	29.77
Copper (Cu)	1.11
Manganese (Mn)	1.70
Iron (Fe)	1.09
Zinc (Zn)	3.50

* Groups of sampling times generalized by Mahalanobis distances.

be responsible for the low N content in the leaves due to the nutrient redistribution to the floral drains (spatulas, flowers) and marked an initial fruit growth, with large dry matter accumulation in the first fifteen weeks after anthesis (Montoya et al., 2016).

Santos (2015) found similar contents of P, but Teles et al. (2008) observed values around 2.20 g kg^{-1}, both in adult macaw palm. Pimentel et al. (2015) reported the best development of 2-year-old macaw plants with leaf contents around 1.67 g kg^{-1}, close to that observed by Pires et al. (2013) for young plants of the same age. Samplings for analyzing P could be performed at any time of the year, except in September, due to the greater variation compared to other months. It stands out that P management is very important due to its natural deficiency in tropical soils and its strong interaction with clayey soils, leading to high adsorption losses and low phosphate fertilizer efficiency (Novais et al., 2007).

Potassium content described by Santos (2015) and Pires et al. (2013) was in the range of seasonal variation of the present study, whereas Teles et al. (2008) report contents around 9.50 g kg^{-1}. Pimentel et al. (2015) also found higher leaf contents (13.64 g kg^{-1}) in young plants. There is a group with intermediate K content and low variations among sampling times (January, May to August and October to December), which is not a continuous period, being quite representative of the nutritional status of macaw palm (Table 4). Macaw palm absorbed K at the greatest soil availability time (fertilization plus rainy monthly) and, later, translocated to new leaves, inflorescences, flowering, and fruit setting and filling, which may indicate luxury consumption of K.

Leaf Mg contents were below the averages observed by Teles et al. (2008), Santos (2015), Pires et al. (2013) and Pimentel et al. (2015), with 1.60, 1.85, 2.20, and 1.48 g kg^{-1}, respectively. Malavolta et al. (1997) report that Mg^{2+} absorption can be inhibited by high soil contents of K^+, Ca^{2+} and NH_4^+, which justifies the low leaf contents observed; however, the soil of the experimental area has very low Mg^{2+} availability (Alvarez V et al., 1999) and consequently large Ca/Mg ratio (Table 2), around 10/1, which may be contributed even more to the low leaf contents. Given the non-significant seasonal variation observed, sampling for Mg evaluation could be performed at any of the months.

Additionally, N, P, Mg and K are mobile elements in phloem (Marschner, 2012), and its translocation from older leaves to sink organs may result in low contents in the index leaves (leaf 10 - middle part of the canopy), in response to non-replacement of these elements in tissues due to low absorption during drought period. Low contents observed for these nutrients in September is because the sampling was preceded by the most pronounced rainfall deficit throughout the first and second quadrimesters, so these elements must translocate from older to younger leaves, and there is low reposition from soil solution (Table 4).

Calcium contents are close to those reported by Teles et al. (2008) and Santos (2015) in adult plants and above than those observed by Pimentel et al. (2015) in two-year-old plants. Calcium is a constituent of the cell's middle lamella (Taiz and Zeiger, 2013), and in macaw palm, fruits are the third most abundant nutrient (Cetec, 1983; Santos, 2015). The monthly fluctuation observed for Ca somewhat follows the pattern of macaw palm fruit growth and development described by Montoya et al. (2016), noting that the second highest Ca content coincides with the stabilization of dry matter accumulation of fruits in June.

Leaf diagnosis for macaw plants, regarding Ca, should be used carefully and may not present low contents in case of nutritional imbalance, since Ca is a low mobile element in phloem (Marschner, 2012). Thus, the use of leaf diagnosis demands greater observation, since most of the Ca is absorbed via transpiration activity, which leads to greater deficiency problems in fruits and low transpiration of fruits. However, the present study observed no abnormalities in macaw plants and fruits.

Sulfur contents were higher than those observed by Teles et al. (2008), Santos (2015) and Pimentel et al. (2015). Observation of S contents above the literature values may be related to the high soil S contents classified as appropriated (Alvarez V et al., 1999). Sulfur is a poorly mobile element in phloem (Malavolta et al., 1997), with no easy remobilization to young leaves in most species (Taiz and Zeiger, 2013), and may present high demand at times of high metabolic demand.

In order to choose a sampling time to evaluate the S status, it is necessary to observe other nutrients' seasonal variation, given the larger group with seven sampling times (January, February, August and September, October, November and December) with the lowest contents, and a smaller group, also representative, with four months (April, May, June and July) presenting the highest leaf contents (Table 4).

Micronutrients

Leaf contents of Cu within the range of the present study were found by Teles et al. (2008) and Santos (2015). Pimentel et al. (2015) related the best development of macaw plants (two years) with Cu leaf content (4.0 mg kg^{-1}) slightly below the minimum observed in the present study. Copper is the less required element by macaw palm (Pimentel, 2012; Santos, 2015; Pimentel et al., 2015), but it has important functions, such as protein constituent and enzymatic activator (Malavolta, 2006; Marschner, 2012; Taiz and Zeiger, 2013). Leaf sampling for nutritional evaluation of macaw palm for Cu can be done any time of the year.

Higher Mn contents were found by Teles et al. (2008) and Santos (2015) in adult plants; 49 mg kg^{-1} and 62 mg kg^{-1}, respectively. Pimentel et al. (2015) reported leaf contents within the seasonal variation range observed for Mn, but in 2-year-old plants.

Manganese functions are related to enzymatic activation and water photolysis to capture light energy in photosynthesis (Malavolta, 2006). Lower Mn contents observed in the rainy season samplings, except in January, may be related to the occurrence of larger plant sink (Montoya et al., 2016) and a possible low soil Mn availability. On the other hand, high nutrient leaf contents in May and June sampling may be related to low plant energy demand, since it coincides with the period described by Montoya et al. (2016) as a steady state in dry mass accumulation of macaw palm fruits.

Iron contents reported by Teles et al. (2008), Pires et al. (2013) and Santos (2015) were higher than those observed in this study, with the maximum observed by Teles et al. (2008) - 200 mg kg^{-1}. Iron has an important role in respiration, hormonal balance, and photosynthesis processes (Malavolta, 2006; Marschner, 2012; Taiz and Zeiger, 2013). Therefore, the seasonal variation of Fe contents in macaw palm leaves may have followed the balance of the plant's energy demand, with low foliar contents in high-demand occasions of sink organs (Scariot et al., 1991; Brito, 2013; Montoya et al., 2016). Low Fe leaf contents may also occur because of inhibition due to high soil availability of K, Ca, Mg, Cu and Zn during the rainy season.

Zinc presented monthly variation very close to that observed for Mn (Table 4). Average Zn contents found by Teles et al. (2008) and Santos (2015) were within the range of variation of the maximum and minimum contents observed during the sampling season. Abreu et al. (2007) report that environmental conditions that may reduce their availability in soil are very similar to those affecting Mn, such as high humidity and association with organic matter. Zinc is an intermediate mobile nutrient in phloem, therefore, the plant redistribution depends on thi nutrient content in the tissues (Malavolta, 2006; Marschner, 2012). An appropriate sampling time for the assessment of the nutritional status of Zn in macaw plant may prevent deficiencies and productivity reduction.

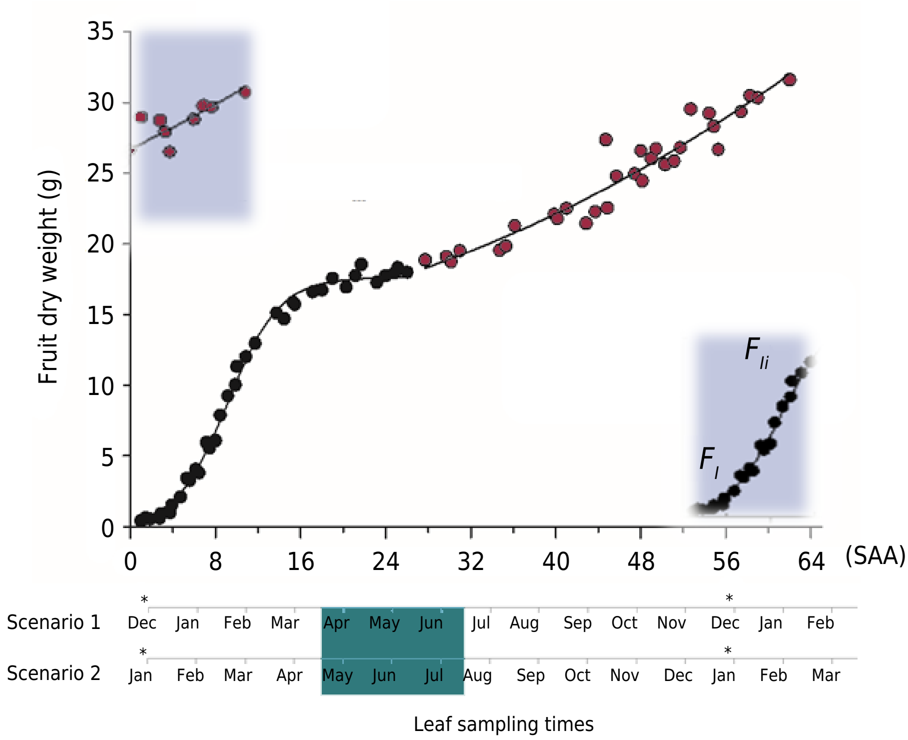

Figure 3. Accumulation of dry matter in macaw palm fruits after anthesis (*), according to the positioning of leaf sampling times. Adapted from Montoya et al. (2016).

Sampling time definition

A common sampling time for all studied nutrients based on periods of greatest stability of minerals content was not possible. Difficulties in selecting a common leaf sampling time based on the lowest seasonal variation of each nutrient have also been reported for other crops such as *Carya illinoinensis* (Cresswell and Wickson, 1986), *Malpighia emarginata* (Amaral et al., 2002; Lima et al., 2007, 2008), *Jatropha curcas* (Lima et al., 2011) and *Musa* spp. (Maia, 2012).

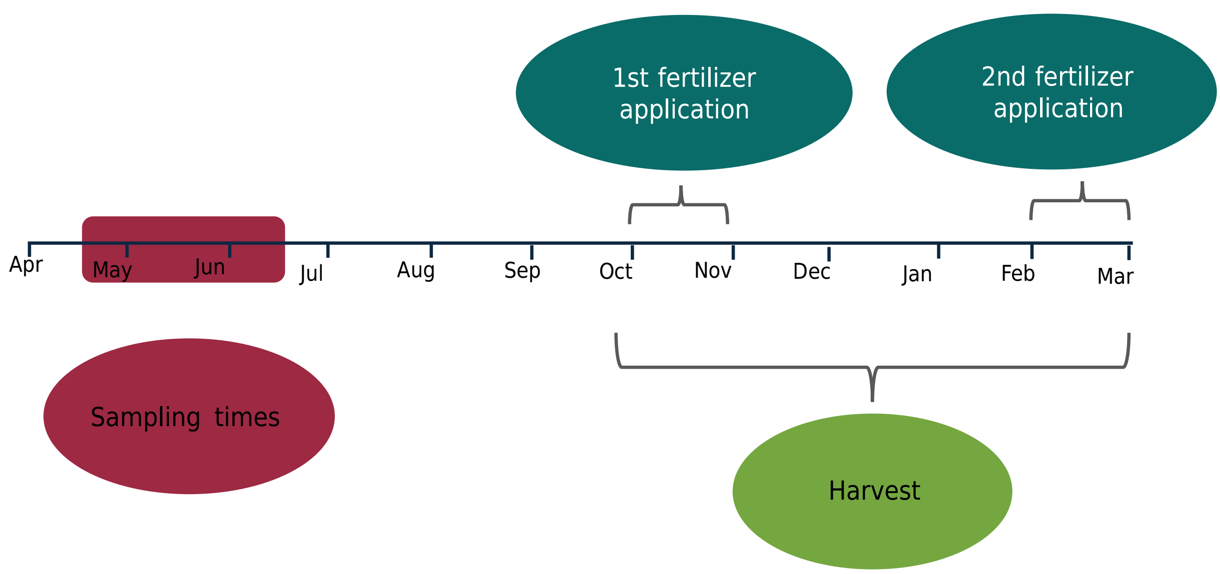

Figure 4. Positioning of the recommended leaf sampling (May and June) considering the operational flow chart of macaw palm.

Given all the observations, the leaf sampling to assess the nutritional status of macaw plants must be carried out from May to June (Figures 3 and 4), which presents a low influence of deficit or excess rainfall, and demand (drain) of forming organs (spars, flowers, young leaves, and fruits). Similar leaf sampling periods were recommended for other palm trees. Frémond et al. (1966) recommend sampling for the coconut tree at the beginning of the dry season and Rodrigues et al. (2006) recommend sampling during the low rainy period and at least 3-4 months after fertilization.

CONCLUSIONS

Leaf contents of N, P, K, Ca, S, Mn and Fe in macaw palm plants varied throughout the crop year. May and June are adequate months to sample diagnostic leaves of macaw palm to analyze the nutritional status The monthly variation of N, S, and Ca mostly indicated a common leaf sampling time for the macaw crop.

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