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# SPATIAL VARIABILITY IN LEAF ANALYSIS AND PRODUCTIVITY OF FERTIRRIGATED AÇAÍ

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**KEYWORDS**

Amazon, management zones, multivariate analysis, nutrient contents, precision agriculture.

## ABSTRACT

This study aimed to define management zones (MZs) for fertirrigated açaí cultivation, based on spatial variability of the foliar nutrients and productivity data. The work was carried out in an area of 5.75 ha of a 7-year crop, with 80 georeferenced sample points. Fresh fruit productivity and nutrient (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn) contents were determined. The average contents of macronutrients were considered adequate for adult açaí plants, and their spatial dependence associated with fruit productivity allowed the representation of their distributions through maps of variability. Through multivariate analysis, three main components were highlighted. These components explained 51.5 % of the total variability of the data, where PC1 showed a higher correlation with Ca, Mg, K, and P. In addition, three MZs were obtained, out of which one with the highest productivity showed the best Ca, Mg, S, B, and Fe leaf contents. Principal component analysis and determination of MZs emphasized Ca and Mg nutrition as being more related to spatial variability and açaí fruit productivity.

## INTRODUCTION

The State of Para is the largest producer of açaí (*Euterpe oleracea* Mart.) fruit, with about 154 thousand hectares cropped, representing approximately 92 % of the Brazilian production (IBGE, 2017). The primary aspects involved in the increasing demand for açaí in the domestic and international markets are its nutritional value for consumption as food, its aesthetic use, and its popularization as a healthy food (Bonomo et al., 2014). As a consequence, açaí cultivation has been dramatically expanding in drylands with small, medium, and large producers (Homma et al., 2006; Farias Neto et al., 2011). Large producers, and even medium producers, make use of fertilization and irrigation, or even fertirrigation.

The optimization of the use of inputs is very important for the generation of income and for minimizing possible environmental impacts (Silva et al., 2015; Oliveira et al., 2015; Silva Carneiro et al., 2016). Hence, the development of management zones (MZs) has been a very widespread technique in several commercial crops (Davatgar et al., 2012).

Regarding precision agriculture, MZs are the subdivision of the land into parts with similar attributes to be treated with uniform dose of inputs, such as the application of fertilizers (Ferguson et al., 2003). MZs can be determined using information related to soil analysis (Davatgar et al., 2012), crop productivity maps (Diker et al., 2004), electromagnetic induction and apparent electrical conductivity sensors (Valente et al., 2012), gamma-ray spectrometry (Wong et al., 2008), SPAD index (Soil Plant Analysis Development), and foliar nutrition (Rodrigues Jr. et al., 2011).

By using one or more of the data sources listed above, the number of MZs can be found through principal component analysis (PCA) (Silva & Lima, 2012), which summarizes the variables of the data into importance groups (main components) within a particular area. After that, the distinction of sub-regions is performed by using cluster analysis (Tripathi et al., 2015).

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In field evaluations with açaí, producers usually observe a high variability in plant performance and productivity within the same growing area. This factor may be related to the genetic variability of the açaí species of the Eastern Amazon (Sousa et al., 2017). Two existing registered cultivars (BRS–Pará and BRS Pai d'Égua) are barely accessible to producers. Nevertheless, studies report that there is a lot of variation in the nutritional contents of adult plants within different cultivars under field conditions (Brasil et al., 2008). The lack of information on the fertility management and nutrition of açaí may contribute to the unevenness of production.

In this context, the use of precision agriculture in the determination of MZs may be useful to understand the variability in nutrient contents of plants, thereby, leading to the best cultivation practices throughout the productive cycle of the açaí palm and reducing production costs and environmental risks.

The objective was to define MZs for fertirrigated açaí cultivation based on spatial variability of the leaf analysis and productivity data.

## MATERIAL AND METHODS

The study area was a commercial farm field in the municipality of Tomé-Açu, in the north-eastern part of the State of Pará (02°28'43.6" latitude S and 48°18'16.8" longitude W), in the Eastern Amazon. The study site lies in an area classified as a local Agricultural Cooperative. The açaí plants were grown for seven years in the experimental area, with a spacing of 5 x 5 m, always leaving 3 plants per clump (400 clumps per hectare). The predominant climate in the region is of the Ami type, according to the Köppen classification, with average temperature of 26.4 °C, relative air humidity ranging from 71 to 91 %, and average annual rainfall above 2000 mm (Alvares et al., 2013).

The area has an irrigation system implanted at the fifth year after planting. The system consisted of a grid distribution with micro-sprinklers with capacity for 70 L $h^{-1}$. Irrigation was measured by considering evapotranspiration at 5 mm and a crop coefficient (Kc) of 1.

According to Santos et al. (2018), the soil was classified as yellow latosol, medium texture, whose attributes were determined according to Teixeira et al., (2017). The fertilization of the area was carried out via fertirrigation, and the fertilizer doses, replicated for two years, were as follows: N (32.10 kg $ha^{-1}$); $P_2O_5$ (32.03 kg $ha^{-1}$); $K_2O$ (343.11 kg $ha^{-1}$); S (4.88 kg $ha^{-1}$); Ca (8.78 kg $ha^{-1}$); Mg (10.01 kg $ha^{-1}$); B (3.9 kg $ha^{-1}$); sources of soluble potassium sulfate (20.2 kg $ha^{-1}$); ammonium sulfate + fermented glutamate residues (18.48 kg $ha^{-1}$); potassium monophosphate (61.6 kg $ha^{-1}$); magnesium nitrate (107.8 kg $ha^{-1}$); potassium nitrate (77 kg $ha^{-1}$); calcium nitrate (46.2 kg $ha^{-1}$); and boric acid 17 % (23 kg $ha^{-1}$).

The sampling grid consisted of 80 georeferenced points, each one being taken in the center of a group of five clumps—one central and four adjacent points (Figure 1). Plant matter was collected in October 2015, which corresponds to the less rainy period and to the greatest production of açaí tree bunches. The 80 composite samples consisted of six central leaflets of the medium leaf (which ranges from the 4th to the 5th leaf) taken from the oldest stem (mother-plant) of each of five sample clumps. The levels of N, P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, and B in the plant material were determined according to the methodology described by Malavolta et al. (1997).

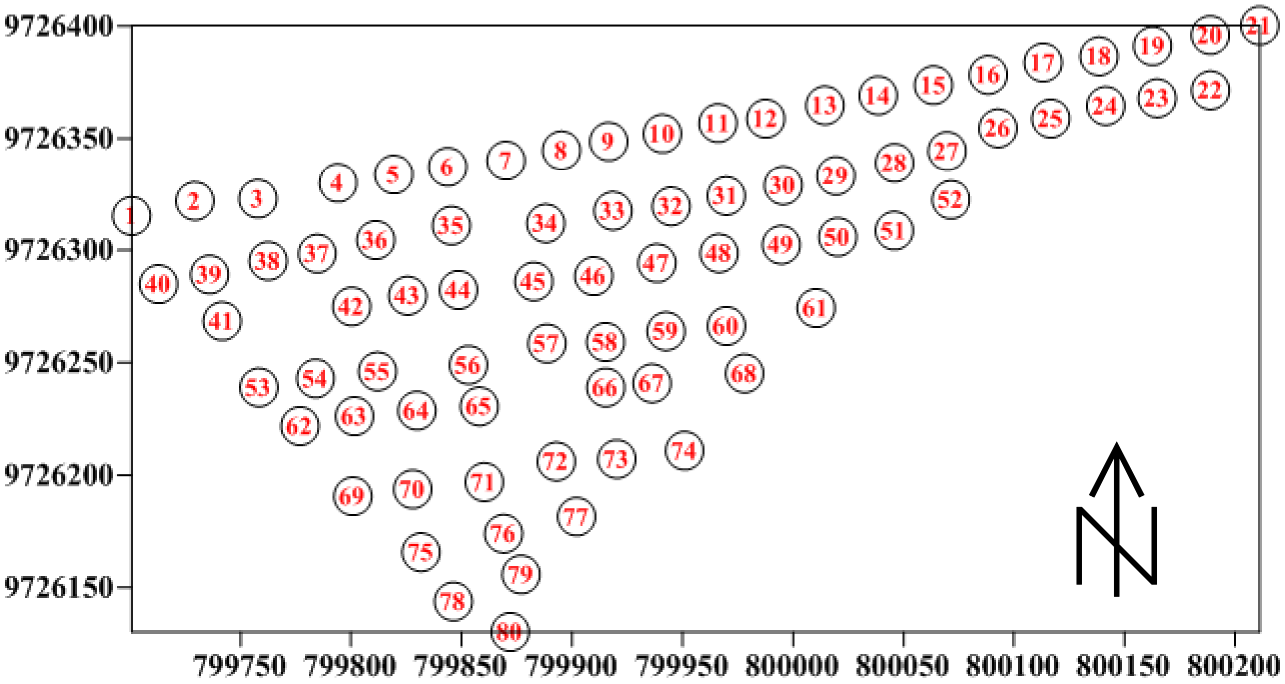

FIGURE 1. Sampling grid of açaí fertirrigated cultivation in northeast of Pará State.

Evaluation of productivity was performed from November 2015 to January 2016 through collection of bunches at each sampling point. The weight, in kilograms, of the fresh fruit was estimated by the difference between the weight of the full bunch and that of the empty bunch, and then multiplied by 400 to be transformed into kg/ha.

The nutrient contents and productivity were subjected to an exploratory analysis to evaluate the position measurements (mean and median) and dispersion (maximum, minimum, standard deviation, variance, and coefficient of variation).

The levels of leaf nutrients and productivity were subjected to the adjustment of theoretical functions to the experimental variogram models, based on the assumption of stationarity of the intrinsic hpothesis and according to the equation:

$$\gamma(h) = \sum\left\{[z(x_i) - z\,(x_i + h)]^2 - \sum\left[\frac{z\,(x_i - z(x_i + h))}{n}\right]\right\}/2n$$

Where:

> N (h) is the number of experimental pairs of observations Z ($x_i$) and Z ($x_i$ + h), and separated by a vector h.

The spherical, exponential, Gaussian, and linear models were tested in the adjustment of the theoretical models to the experimental variograms. The GS+ software 7.0 (Gamma Design Software, LLC, Michigan, USA) was used to determine the coefficients of the nugget effect (C0), the plateau (C0 + C), sill (C), and range (a). The criteria for adopting the models was the highest value of $R^2$ (coefficient of determination), the lowest RSS (residual sum of squares), and the highest value of the correlation coefficient obtained with the cross-validation method.

The spatial dependence index (SDI) was analyzed by the C/(C0 + C) ratio, following the proposed interpretation of Dalchiavon & Carvalho (2012), where SDI < 20 % indicated very low spatial dependence, 20 % ≤ SDI < 40 % indicated low spatial dependence, 40 % ≤ SDI < 60 % indicated average spatial dependency, 60 % ≤ SDI < 80 % indicated high spatial dependence, and SDI ≥ 80 % indicated very high spatial dependence. Following spatial dependence analysis, the ordinary kriging interpolation method was used, according to Betzek et al., (2017), in order to estimate values in unmeasured locations. Then, two multivariate statistical methods were applied: the principal component analysis (PCA) and the non-hierarchical k-mean clustering using the software Statistica, version 10 (Statsoft, 2010).

The Principal component analysis (PCA) was performed based on the diagonalization of its symmetric correlation matrix, after analyzing the variance of data. This analysis was performed to identify new variables that would explain most of the variability, following the methodology used by Silva et al. (2015) and Silva & Lima (2012), where values with a correlation higher than 0.5 were selected. The selection of the component was based on the Kaiser method, which uses the components related to eigenvalues greater than 1 (Kaiser, 1958) and in the correlation of the components with leaf nutrients.

In order to distinguish the MZs, a non-hierarchical clustering analysis was performed, using the k-means algorithm, through data of nutrient contents and productivity. For division of the values of each set of data into groups, the number of groups selected within the variance of the principal component analysis was used. The sequences of partitions were produced directly in a k fixed number of groups, which allowed characterization of the pattern of the variables per group (Linden, 2009). The k-means algorithm allows the variations of the analyzed data to be used together in the definition of MZs, thus allowing the user to control the number of identified areas and providing better management of those areas (Rodrigues Jr et al., 2011). Groups were separated at maximum distance between the clusters, making it possible to differentiate the productivity zones and their nutrient contents.

The k-means clustering method was used to determine each group (Hair Jr. et al., 2009) through the number of classes. Furthermore, the SNK test was used to observe the statistical difference between groups for each variable.

## RESULTS AND DISCUSSION

### Descriptive analysis of the nutrients and productivity

All nutrients showed close values of central (median and median) measures, therefore indicating data symmetry (Table 1). The greatest deviations were observed in the Fe and Mn contents, where the amplitude of the data, in relation to the mean, was observed. The variations in all leaf nutrients and productivity ranged from 12 to 47 %; therefore, they were considered average, according to the classification proposed by Warrick & Nielsen (1980): CV < 12 % for low variation; 12 % < CV < 60 % for medium variation; CV> 60 % for high variation. Only the nitrogen content in the leaves showed a low coefficient of variation, while the other levels and productivity showed values considered average.

TABLE 1. Descriptive statistics of the nutrients, productivity, and soil fertility of açaí plants in a commercial farm of Tomé-Açu, Pará.

| Leaf | Mean | SD | Min. | Max. | CV % | Soil | Mean | SD | Min. | Max. | CV % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N (g kg$^{-1}$) | 19.5 | 2.25 | 16 | 23 | 11.53 | pH (CaCl$_2$) | 5.6 | 0.4 | 4.7 | 7 | 7.14 |
| P (g kg$^{-1}$) | 1.75 | 0.39 | 0.88 | 2.3 | 22.31 | P (mg dm$^{-3}$) | 239 | 30.57 | 150 | 280 | 12.79 |
| K (g kg$^{-1}$) | 8.5 | 1.35 | 5.6 | 12 | 15.9 | K (cmol$_c$ dm$^{-3}$) | 114.65 | 27 | 56 | 170 | 23.58 |
| Ca (g kg$^{-1}$) | 5.6 | 1.62 | 3 | 9.8 | 28.1 | Ca (cmol$_c$ dm$^{-3}$) | 3.65 | 0.9 | 1.7 | 7.5 | 24.61 |
| Mg (g kg$^{-1}$) | 1.11 | 0.38 | 0.5 | 2.2 | 34.01 | Mg (cmol$_c$ dm$^{-3}$) | 0.88 | 0.3 | 0.3 | 1.5 | 33.78 |
| S (g kg$^{-1}$) | 3.09 | 0.53 | 1.6 | 3.7 | 17.1 | S (mg dm$^{-3}$) | 6.39 | 0.6 | 5 | 8 | 9.81 |
| B (mg kg$^{-1}$) | 50.95 | 10.37 | 29 | 72 | 20.35 | B (mg dm$^{-3}$) | 0.23 | 0.05 | 0.2 | 0.3 | 20.27 |
| Cu (mg kg$^{-1}$) | 5.51 | 2.61 | 1 | 12 | 47.33 | Cu (mg dm$^{-3}$) | 2.42 | 1.56 | 0.7 | 9.6 | 64.72 |
| Fe (mg kg$^{-1}$) | 366.37 | 89.45 | 217 | 647 | 24.42 | Fe (mg dm$^{-3}$) | 111.29 | 61.79 | 23 | 306 | 55.52 |
| Mn (mg kg$^{-1}$) | 250.89 | 116.35 | 42 | 557 | 46.38 | Mn (mg dm$^{-3}$) | 29.15 | 11.53 | 10 | 78 | 39.57 |
| Zn (mg kg$^{-1}$) | 24.54 | 4.77 | 15 | 42 | 19.42 | Zn (mg dm$^{-3}$) | 7.81 | 2.19 | 3.5 | 13 | 28.09 |
| Productivity (t ha$^{-1}$) | 5.2 | 2.1 | 0.48 | 9.6 | 40 | M.O. (g kg$^{-3}$) | 20.06 | 8.66 | 10 | 75 | 43.18 |
| | | | | | | Sand (%) | 65.26 | 5.15 | 51 | 74 | 7.89 |
| | | | | | | Silt (%) | 11.72 | 2.66 | 6 | 17 | 22.67 |
| | | | | | | Clay (%) | 22.19 | 4.89 | 9 | 37 | 22.06 |

SD - Standard deviation; CV - Coefficient of variation

There are still no adequate nutritional ranges published for açaí, however average macronutrient contents showed values within the ranges considered adequate by Brasil et al. (2008) for adult açaí trees and close to the ideal ranges for economically important species of the Arecaeae family, such as the oil palm *Elaeis guineensis* Jacq. (Matos et al., 2016) and peach palm *Bactris gasipaes* Kunth (Fernandes et al., 2013). Soil fertility parameter averages showed good levels except for boron, which was considered low according to the soil interpretation ranges of Ribeiro et al. (1999).

**Spatial variability of leaf nutrient content.**

The values of N, K, S, B, P, Mg, Zn, Mn, and Fe showed high spatial dependence according to classes set by Dalchiavon & Carvalho (2012), indicating that leaf nutrient contents are not randomly distributed (Table 2). These results agree with those reported by Behera et al. (2016), Lima et al. (2016), and Gazola et al. (2017), who also found spatial dependence of leaf nutrient contents in oil palm, papaya, and soybeans, respectively. From the spatial dependence, it was possible to obtain maps for individual definition of the spatial variability of the nutrients.

TABLE 2. Parameters and models of the variograms adjusted for nutrient content in açaí crops in a commercial farm of Tomé-Açu, Pará.

| Variables | Models and parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| | Model | C0 | C0+C | a | IDE | R$^2$ | RSS |
| N | Gaussian | 2.27 | 6.1 | 91 | 62.8 | 0.633 | 0.251 |
| P | Spherical | 0.031 | 1.31 | 63 | 62.7 | 0.498 | 0.00053 |
| K | Exponential | 1.55 | 4 | 77.27 | 61.3 | 0.5 | 4.1 |
| Ca | Gaussian | 2.6 | 13.16 | 102.2 | 80.2 | 4.49 | 9.96 |
| Mg | Spherical | 0.34 | 1.34 | 82.3 | 74.9 | 5.12 | 0.0059 |
| S | Gaussian | 0.85 | 2.88 | 90.9 | 70.4 | 0.759 | 0.036 |
| B | Gaussian | 9.6 | 24.48 | 83.76 | 60.6 | 0.582 | 68 |
| Cu | Gaussian | 6.39 | 13.66 | 91 | 53.3 | 0.411 | 2.08 |
| Fe | Exponential | 18.6 | 78.46 | 126 | 76.3 | 0.913 | 0.0019 |
| Mn | Exponential | 12.4 | 43.25 | 91 | 71.2 | 0.482 | 6.91 |
| Zn | Spherical | 18.02 | 50.77 | 63 | 64.5 | 0.374 | 82.5 |
| Productivity | Gaussian | 4.28 | 8.24 | 91 | 50 | 54.5 | 1.32 |

C0 - nugget effect; C0+C - plateau; IDE - spatial dependence index (C/C0 + C); a - range; R$^2$ - coefficient of determination of the variogram model; RSS - residue square sum.

Leaf contents of N (Figure 2A) and S (Figure 2F) showed the highest spatial homogeneity in the area, reflecting the fertilization efficiency of these nutrients, whereas the other parameters, especially micronutrients and productivity, showed a high variability (Figure 2).

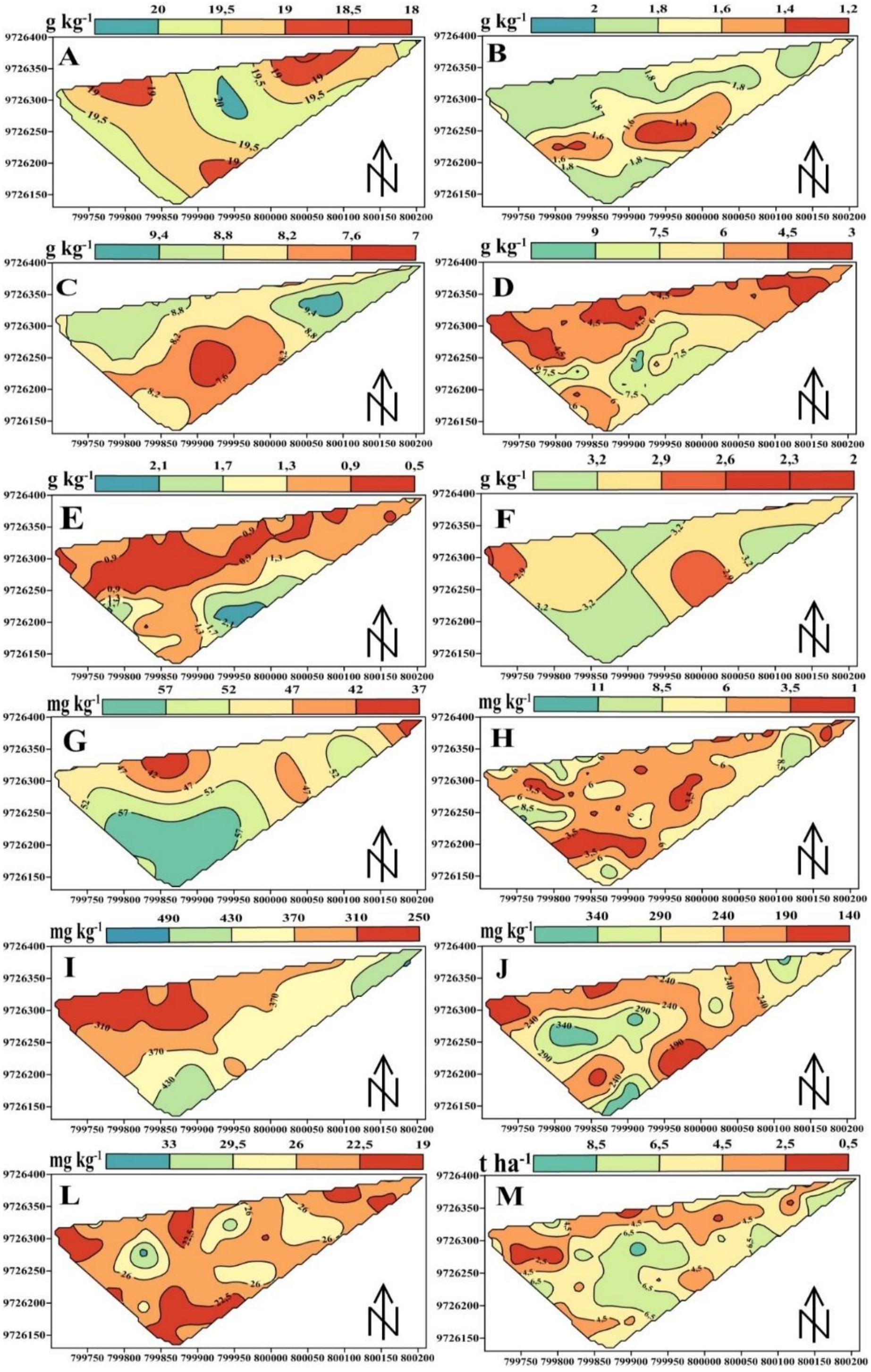

FIGURE 2. Maps of the spatial distribution of N (A), P (B) content, K (C) content, Ca (D) content, Mg (E) content, S (F) content, B (G), Cu (H), Fe (I), Mn (J), Zn (L), and productivity (M) in açaí planting in a commercial farm of Tomé-Açu, Pará.

## Principal component analysis for leaf contents

The first three main components showed a cumulative variance of 51.49 % of the total, being selected to represent the variation of the components (Table 3). The other components did not achieve 10 % variation and were excluded, according to the criteria adopted by Silva & Lima (2012). In addition, the most important principal components are those that correlate with the greatest number of variables (Hair Jr. et al., 2009).

TABLE 3. Summary of the principal components of the multivariate analysis of leaf contents of nutrients in açaí crop from a commercial farm of Tomé-Açu, Pará.

| Number of components | Eigenvalue | Variance percentage | Accumulated variance percentage |
|---|---|---|---|
| **1** | **2.528961** | **22.99055** | **22.9906** |
| **2** | **1.836450** | **16.69500** | **39.6855** |
| **3** | **1.298742** | **11.80675** | **51.4923** |
| 4 | 1.080126 | 9.81933 | 61.3116 |
| 5 | 1.012964 | 9.20877 | 70.5204 |

*Components in bold are above 10% of variation.

The principal component 1 (PC1) explained 22.99 % of the data variance, and is more related to the nutrients Ca, Mg, K, and P (Table 4). The Ca and Mg showed a positive correlation with regards to PC1, while P and K, showed a negative correlation. The PCA emphasized those macronutrients as the most determinant to the nutritional status of açaí. This result is based for Ca, because it is an over demanded nutrient in the productive phase of the açaí.

The PC2 explains 16.69 % of the total variance and showed a direct correlation with the nutrients S, Cu, and Fe. The PC3 (11.80 % of total variance) showed direct correlation with Mn and Zn.

TABLE 4. Correlation between original variables and principal components of the fresh fruit productivity and nutrient contents in açaí leaves from a commercial farm of Tomé-Açu, Pará.

| Attributes | Components | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| N | 0.0335 | 0.4525 | 0.0677 | 0.5998 | 0.5454 |
| P | **-0.7385** | 0.2133 | -0.0496 | 0.0684 | -0.1184 |
| K | **-0.6607** | 0.4203 | -0.3144 | -0.2724 | 0.0225 |
| Ca | **0.8571** | 0.0595 | -0.1045 | -0.0725 | 0.0409 |
| Mg | **0.7452** | 0.0672 | -0.4718 | -0.0485 | 0.0987 |
| S | 0.1099 | **0.6485** | -0.0312 | -0.4944 | -0.1917 |
| B | 0.3811 | 0.3590 | 0.0210 | 0.2167 | -0.6185 |
| Cu | -0.1634 | **0.5041** | -0.4046 | 0.4259 | -0.1788 |
| Fe | 0.1879 | **0.5600** | -0.1690 | -0.1604 | 0.2961 |
| Mn | 0.1825 | 0.3580 | **0.6774** | 0.2072 | -0.2458 |
| Zn | 0.0577 | 0.3951 | **0.5539** | -0.3040 | 0.3003 |
| Productivity | 0.0971 | 0.1145 | 0.2580 | 0.5020 | 0.5808 |

Boldface indicates significance at 5 % probability.

Because leaf nutrients are individually represented (Figure 2), recommendations of areas for correction of nutritional management would become highly complex in the field. As a result, the establishment of MZs involving groups of variables is paramount in order to generate more uniform areas.

According to the clustering analysis through the k-means method, the MZs were defined based on the nutritional status and productivity of the açaí trees (Figure 3). The highest productivity was observed in MZ3 and coincides with higher Ca, S, B, and Fe content (Table 5) that can be confirmed with its concentration not alone within each zone (Figure 3). According to those nutritional zones, it is necessary to adjust the fertilization with boron, a micronutrient which in general presents low values in the soil (Table 1).

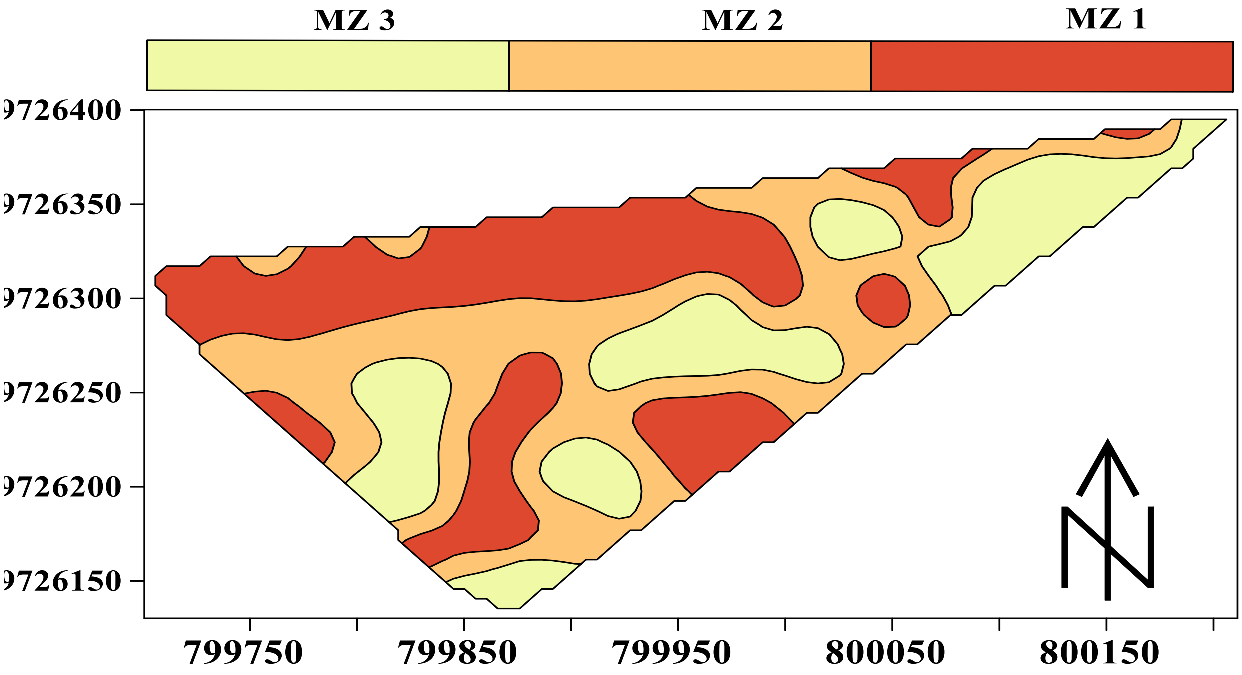

FIGURE 3. Map of the management zones (MZs) based on the nutritional status of açaí tree from a commercial farm of Tomé-Açu, Pará.

TABLE 5. Average of each leaf nutrient content and fresh fruit productivity of açaí management zones (MZs), established on a commercial farm in Tomé-Açu, Pará.

| Zones | n | N | P | K | Ca | Mg | S | B | Cu | Fe | Mn | Zn | Productivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------------------- g kg ---------------------- | | | | | | ------------------- mg kg ------------------ | | | | | --- t ha$^{-1}$ --- |
| MZ 1 | 36 | 19.22a | 1.84a | 8.89a | 4.70b | 0.98b | 3.14ab | 46.75b | 5.77a | 361.27b | 230.08b | 24.30a | 4.69b |
| MZ 2 | 20 | 19.65a | 1.81a | 8.57a | 5.39b | 0.92b | 2.88b | 50.40b | 5.55a | 319.25c | 299.00a | 25.80a | 5.41ab |
| MZ 3 | 24 | 19.45a | 1.53b | 7.78b | 7.15a | 1.46a | 3.22a | 58.16a | 5.08a | 401.79a | 249.54ab | 23.25a | 5.80a |
| Mean | - | 19.5 | 1.59 | 8.7 | 6.4 | 1.35 | 2.65 | 50.5 | 6.5 | 381.5 | 299.5 | 28.5 | 5.04 |

n – number of repetitions. Following the SNK test ($P < 0.01$), values in the column with different letters are significantly different.

It is important to emphasize that Ca is the second nutrient with the largest amount in the açaí fruit (Menezes et al., 2008). It has always been pointed out as one of the most important nutrients in palm nutrition (Sousa et al., 2004; Fernandes et al., 2013), which can be easily supplied by liming. In relation to B, species of the Arecacea family needs an adequate supply for proper growth and productivity (Pinho et al., 2015).

Despite this, liming and borated fertilization are still largely neglected in açaí cultivation on Pará state. Liming, when properly done, is applied only in plantation, and not to meet the demand of the whole cycle of açaí, which can reach over 17 years of production. Adequate ranges for foliar micronutrients are still non-existent in the literature for the adult açaí, making it impossible to compare their values.

## CONCLUSIONS

The foliar nutrients and the fresh fruit productivity of açaí have spatial dependence, as shown in the sample grid, allowing the application of precision agricultural techniques for the development of this crop.

Three MZs were defined considering nutrient contents and productivity of açaí trees. According to these zones, Ca and Mg supply, with liming, as well as sulfate and micronutrients fertilization (especially boron), are key practices for improving nutrition and thus, increasing productivity in this palm.

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