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Spatial variability in the diagnosis of nutritional status in the papaya[1]

Variabilidade espacial na diagnose do estado nutricional do mamoeiro

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ABSTRACT - Leaf analysis is widely used to study the nutritional status of plants, based on the fact of there being a direct correlation between rate of growth and the nutrient levels in leaf tissue. This study was carried out on a commercial crop of Golden THB papaya, in the north of the State of Espirito Santo, Brazil, to determine the spatial variability of nutrients in the petiole of leaf samples collected when carrying out sexing in a regular grid of 129 georeferenced points. Harvesting was carried out manually 270-365 days after transplanting. All the characteristics displayed a strong spatial dependence, the spherical and exponential semivariograms being adjusted for the data. The greatest and smallest ranges were found for the micronutrients Mn and Zn respectively. Mean productivity was considered to be low at 13.6 Mg ha^{-1}. Geostatistical analysis of the data aided in the preparation of thematic maps showing the different areas of productivity and foliar application of fertiliser in the papaya. However, the largest regions in the area were displayed by those classes which included the mean value for an attribute, indicating the use of the mean values in the recommendation of foliar fertilisation, with the exception of P and K.

Key words: Geostatistics. Semivariogram. Leaf petiole.

RESUMO - A análise foliar é muito utilizada para o estudo do estado nutricional de plantas e baseia-se no fato de existir uma correlação direta entre a taxa de crescimento e o teor de nutrientes nos tecidos foliares. O trabalho foi desenvolvido em uma lavoura comercial do mamoeiro Golden THB, na região norte do estado do Espírito Santo, para determinar a variabilidade espacial dos nutrientes do pecíolo foliar em amostras de folhas coletadas na época da sexagem, em uma malha regular de 129 pontos georeferenciados. A colheita manual foi realizada a 270 a 365 dias após transplantio. Todos os atributos apresentaram forte dependência espacial, com ajustes dos semivariogramas esféricos e exponencial aos dados. O maior e menor alcance foi encontrado para os micronutrientes Mn e Zn, respectivamente. A produtividade média encontrada foi 13,6 Mg ha^{-1} considerada baixa. A análise dos dados pela geoestatística auxiliou na confecção de mapas temáticos indicando zonas diferenciadas de produtividade e de aplicação de fertilizantes via foliar para o mamoeiro. Entretanto, apresentaram maiores regiões na área as classes em que estavam contidos os valores médios dos atributos, indicando utilizar o valor médio para a recomendação da adubação foliar, com exceção para o P e K.

Palavras-chave: Geoestatística. Semivariograma. Pecíolo foliar.

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INTRODUCTION

In studying development in the papaya, as in other crops, nutrient levels in the leaf tissue have been used as a reference in evaluating nutritional status and its effects on productivity. Each nutrient has its relative importance, some important throughout the production cycle, and others more significant, even essential, at the beginning.

Foliar analysis is widely used in diagnosis of the nutritional status of plants, and is based on the fact that there is a direct correlation between the growth rate and nutrient levels in the leaf tissue. Nutritional diagnosis combined with soil analysis, therefore constitutes an efficient tool to detect imbalances, and aid in the process of plant fertilisation. Lima, Silva and Silva (2013) claim that soil fertility is a decisive factor in the satisfactory performance of agricultural crops, with their spatial, horizontal and vertical distribution being able to significantly alter the average productivity of a cultivated area.

According to Correa *et al*. (2001), the greatest advantage of diagnosis in studying the nutritional status of plants lies in considering the plant itself as extracting nutrients from the soil and in allowing a direct assessment of its status, thereby evaluating nutrient concentrations and the relationship between nutrients. Rozane *et al*. (2007) state that the most suitable way of sampling plant tissue is the one that represents the best possible area. This results in a representative sample of the population, so that the results of foliar analysis can be technically and scientifically validated.

Marinho *et al.* (2002) report that many researchers compare the sensitivity of the leaf blade and the petiole when studying diagnosis of the nutritional status of the papaya, obtaining mixed results. These authors, using leaf tissue dry matter from six varieties and three groups of papaya, found differences between the values obtained for any one nutrient.

The diagnosis and recommendation integrated system (DRIS) has been used in studies of the diagnosis of nutritional status in crops. This makes it possible to carry out the nutritional diagnosis of a plant and/or crop based on the calculation of indices for each nutrient, evaluated by the ratio of each element to the other elements, and comparing them in pairs with other standard ratios, whose mineral composition is obtained from a population of highly productive plants (BARBOSA *et al*., 2006). Silva, Lima and Queiroz (2011) applied this method to the spatial distribution of the DRIS index in a crop of Arabica coffee, and found significant correlation with productivity.

The techniques and concepts used in precision agriculture take into consideration, among other requirements, the distance between samples in the study of the spatial and temporal variability of the physical and chemical attributes of the soil and of those relative to plants under various forms of land use, in such a way as to make more accurate representations, optimise resources and reduce costs. In such cases, classical statistical techniques together with geostatistics are used to map and analyse the presence of different areas for crop management (LIMA; SOUZA; SILVA, 2010).

Based on this approach, the aim of this experiment was to study the spatial variability of the diagnosis of nutritional status via the chemical analysis of dry matter samples of the leaf petiole and of productivity in the papaya cv. Golden THB, group Solo.

MATERIAL AND METHODS

The research was carried out on a commercial plantation cultivated with the Golden THB variety of papaya (*Carica papaya* L.) from the Solo group, during the 2010/2011 crop year, in an area of 17.8 ha, located in the town of São Mateus in the north of the State of Espírito Santo, Brazil. The soil is a Dystrocohesive Yellow Argisol of low-activity clay and average granulometric fractions: coarse sand = 727.4, fine sand = 164.4, clay = 92.6 and silt = 15.6 (g kg^{-1}). The terrain is rolling, with a slope of 3.0% and an altitude of 40.0 m: a typical soil of the coastal-plain region (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2006). The climate according to the Köppen classification is type Aw, with a dry season in the winter and a hot, rainy summer, a mean annual temperature of 25.0 °C and cumulative mean rainfall of 1,290 mm.

Before preparing the soil, limestone was applied by broadcasting throughout the area, following the results of the chemical analysis of the soil and the recommendations for achieving 80% of base saturation (V%), giving a pH of 5.46 ($CaCl_2$) at a depth of 0.0 to 0.20 m. Mechanised soil preparation of the area was carried out 40 days before transplanting, comprising one ploughing, double-action harrowing and furrowing in rows 0.20 m deep. In-furrow fertilisation when transplanting consisted of the application of 1.50 kg of poultry litter and 0.06 kg of P_2O_5 per linear metre in the form of single superphosphate (composition: 18.0% P_2O_5, 25.0% CaO and 12.0% S), as recommended by Prezotti *et al*. (2007). After fertilisation, subsoiling was carried out in the furrows at a depth of 0.55 m.

The crop was planted in July of 2010 at a spacing of 3.3 x 2.0 x 1.9 m in double rows. Sampling points were selected from the centre of the area, forming a regular grid of approximately 1.20 ha, with a length of 110.0 m and a width of 114.0 m, giving a total of 129 points, each sampling point representing an area of 3.8 m^2 and containing one plant. To mark out the points, identified wooden stakes were used, so that the greatest distance between points was 10.6 m and the shortest 5.7 m. The geo-referencing of each point was done using a pair of TechGeo® geodetic GPS receivers, model GTR G2.

Seedlings produced on the property were used for transplanting, and placed three seedlings per planting hole. Thinning was carried out at four months, keeping only one hermaphrodite plant per hole.

Topdressing consisted of applying 0.03 kg ammonium sulphate plant^{-1} (composition: 20.0% N and 24.0% S) to the soil two months after transplanting, with the remaining fertilisers applied via the leaves at 10 day intervals, from 50 days after transplanting until sexing, as per Prezotti *et al*. (2007).

Water management in the area was by localised micro-sprinkler with a flow rate of 64 L h^{-1}, with the irrigation schedule varying according to actual evapotranspiration and the crop coefficient for the papaya, as demonstrated by Posse *et al*. (2008).

Sampling of the leaves when sexing, their processing and the determination of macro and micro nutrients in the leaf petioles were performed according to a methodology described by Marinho *et al*. (2002), with the fully-expanded, newly mature leaves being collected in the morning (0900) and identified by the youngest flower on the plant in the axil.

From the ninth month after transplanting, initial productivity in the papaya was recorded by manual collection until the 12th month, carried out according to maturation of the fruit at stage 2 with up to 25% yellowing of the skin, considering the georeferenced plant and the two adjacent plants in the crop row when defining the average per sampling point, so as to determine the mean productivity per ha (Mg ha^{-1}) (PRD).

In the exploratory data analysis and study of the presence of outliers, the boxplot was used, which considers the interquartile ratio in the definition of those values. This method uses the upper limit (UL) and the lower limit (LL) of the data set, determined by the following equations.

$$LS = (Q3 - Q1)* 1,5 + Q3 \quad (1)$$

$$LI = (Q3 - Q1)* 1,5 + Q1 \quad (2)$$

where Q1 = first quartile and Q3 = third quartile.

According to Ortiz *et al*. (2006), an analysis of data dispersion is more suitable when considering quartiles, as this will not be influenced by extreme values. After this procedure, the data were analysed using descriptive statistical analysis to define the measurements for position and dispersion, and the Shapiro-Wilk test of normality. In this test, if the calculated value of W is statistically significant ($p \leq 0.05$), then the hypothesis that the distribution is normal will be rejected. Seeking an interrelationship between the attributes under study, Pearson correlation analysis was performed ($p<0.05$), adopting the classification proposed by Kitamura, Carvalho and Lima (2007), i.e. extra-high: if $0.80 < r \leq 1.0$; high: if $0.60 < r \leq 0.80$; Moderate: if $0.40 < r \leq 0.60$; low: if $0.20 < r \leq 0.40$; and null: if $0.0 \leq r \leq 0.20$.

The geostatistical analysis to determine the existence of spatial dependence in the chemical attributes of leaf-petiole dry matter, and in productivity in the papaya, was carried out by means of the experimental semivariogram, according to Equation 3:

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \quad (3)$$

where: *N(h)* is the number of pairs of experimental observations Z ($_{Xi}$), Z(x_i+h), separated by a vector h. In adjusting the semivariogram for each attribute, the parameters were determined for: nugget effect (C_0), sill (C_0+C), and range of spatial dependence (r).

In adjusting the semivariograms, models with a sill representing second-order stationarity were tested. Basically four theoretical functions that fit the models of empirical semivariogram were evaluated: linear with sill, spherical, exponential and Gaussian. The first two functions present the sill and scope as clearly defined, with the nugget effect usually small in relation to the sill (KERRY; OLIVER, 2008). In the last two functions, semivariance grows more slowly from the origin towards the sill, which is reached asymptotically (KERRY; OLIVER, 2008).

The choice of model was based on the results of cross-validation, given by the correlation of observed value with estimated value for each sampling point. To determine the degree of spatial dependence (DSD) the relationship [$C_0/(C_0+C_1)$] was used, as per criteria established by Cambardella *et al*. (1994), which considers weak (SDS > 75%), moderate (25% < GDE ≤ 75%) and strong (GDE < 25%) spatial dependence.

Ordinary kriging was used to estimate values for the variables in locations which were not sampled and construct the thematic maps. This geostatistical interpolation makes use of a linear unbiased estimator with minimum variance, and takes into account the spatial variability structure found for the attribute, being defined by the following equation:

$$Z^*(\chi_i, \chi_i + h) = \sum_{i=1}^{n} \lambda i Z(\chi_i, \chi_i + h) \text{ subject to } \sum_{i=1}^{n} \lambda i = 1 \quad (4)$$

where: $Z^*(x_i, x_i+h)$ is the estimator for a point (x_i, x_i+h) in the region and λi are the weightings used in the estimation.

RESULTS AND DISCUSSION

After laboratory determination of the attributes, an exploratory analysis of the data was performed; the presence of outliers was not found in the set of sample data.

A descriptive analysis of the data is presented in Table 1, where the attributes K, Ca, Mg and S show very close values for the measurements of central tendency (mean and median), leading the data to present a normal distribution, which was confirmed by the Shapiro-Wilk test ($p<0.05$). For nutrients where these measurements were different, their distance from normality is due to a flattening of the curve and stretching of the tail to the right of the normal distribution curve, as shown by the negative coefficient of kurtosis (Kc) and positive coefficient of skewness (Ks) and a mean value greater than the median.

Initial productivity (270-365 days after transplanting - DAT) showed a mean value of 13.60 Mg ha^{-1}, reaching a minimum value of 2.30 and a maximum of 25.00 Mg ha^{-1}. Silva, Lima and Alves (2010), collecting papaya fruit in a crop of high to average productivity (PRD), obtained values from 24.9 to 39.1 Mg ha^{-1} at 280 DAT. It can therefore be seen that the plants evaluated here produced fruit below the commercial standard, represented by the lower productivity.

The variability of the data in relation to the mean, as measured by the coefficient of variation (CV), was based on limits proposed by Wilding and Drees (1983), indicating low variability (CV < 15%) for N; moderate (15% < CV < 35%) for K, Ca, Mg, Z and Mn, and high (CV > 35%) for P, S and PRD.

The mean value for nitrogen (N) found in the leaf petiole was 9.02 g kg^{-1}, being between the values of 6.00 to 12.00 g kg^{-1} determined by Marinho *et al*. (2002) when studying varieties of the solo and formosa group. According to Marinho *et al*. (2002), the levels of N in the petiole show the absorption capacity of the plant for this nutrient and promotes vegetative growth. Cruz *et al*. (2004) state that the effect of nitrogen deficiency on the accumulation of soluble sugars has generated differing results, depending on the variety under study. For Lavres Junior *et al*. (2005), in foliar analysis of the castor bean crop, N is the first element to present visual symptoms of deficiency.

The mean level for P of 2.98 g kg^{-1} is less than the values found by Marinho *et al*. (2002) (3.1 to 3.5 g kg^{-1}), but within the ideal range determined by Awada and Long (1978), from 2.0 to 4.0 g kg^{-1}. An inverse relationship between the average levels of N and P was seen by Marinho *et al*. (2002) in petiole dry matter, i.e. an increase in N resulted in a reduction in P, and vice versa. According to Oliveira and Caldas (2004), during the first year of growth in the papaya, the plant has a high demand for soil nutrients. Because of this, the least extracted nutrient in their analysis was P. In the study by Mesquita *et al*. (2010) where papaya in the field was fertilised with biofertiliser, an increase in N and P was seen in leaf-blade dry matter for increases in the applied dose.

In the analysis of petiole dry matter, the mean value for K was 20.00 g kg^{-1}, which was well below the ideal range of 30.0 to 60.0 g kg^{-1} quoted by Reuther and Robinson (1986), showing a deficiency of this nutrient in the present study. According to Mesquita *et al*. (2010), K is one of the nutrients which are most required by the papaya, being in constant and increasing demand throughout the crop cycle, and one of the most exported by the fruit, with higher levels for sugars and total soluble solids.

Table 1 - Descriptive statistics and frequency distribution for the levels of foliar nutrients

Attribute	n	M	MD	Min	Max	Q1	Q3	S	Ks	Kc	CV	W	p
N (g kg^{-1})	129	9.02	8.75	6.65	11.55	8.40	9.80	0.98	0.45	-0.11	10.82	0.96	0.00
P (g kg^{-1})	129	2.98	2.67	1.08	6.75	1.89	3.85	1.32	0.78	-0.21	44.50	0.93	0.00
K (g kg^{-1})	129	20.00	20.00	8.10	34.70	16.00	23.30	5.38	0.30	0.01	26.96	0.99	0.40
Ca (g kg^{-1})	129	12.86	12.61	6.52	20.84	10.61	14.90	3.03	0.27	-0.39	23.53	0.99	0.35
Mg (g kg^{-1})	129	3.78	3.69	1.66	5.80	3.20	4.24	0.83	0.31	-0.18	21.95	0.99	0.18
S (g kg^{-1})	129	3.36	3.29	0.75	6.83	2.31	4.38	1.42	0.29	-0.61	42.26	0.98	0.12
Zn (mg kg^{-1})	129	21.33	21.00	12.69	34.75	17.66	24.46	4.99	0.45	-0.35	23.41	0.16	0.00
Mn (mg kg^{-1})	129	42.22	41.51	21.68	72.90	32.26	50.84	11.81	0.39	-0.60	27.98	0.97	0.01
PRD (Mg ha^{-1})	129	13.60	12.90	2.30	25.00	9.60	17.40	5.50	0.20	-0.70	40.00	0.98	0.15

n: number of observations; M: mean; MD: median; Min: minimum value; Max: maximum value; Q1: first quartile; Q3: third quartile; S: standard deviation; Ks: coefficient of skewness; Kc: coefficient of kurtosis; e CV: coefficient of variation

Physiological disorders in fruit of the papaya, such as softening of the pulp, may be caused by a lack of nutrients, mainly a deficiency of Ca, as described by Marschner (1995). The mean value found for Ca was 12.86 g kg^{-1}, within the proper range (10.00 to 25.00 g kg^{-1}) indicated by Reuther and Robinson (1986). Campostrini *et al*. (2005) found a relationship between the availability of Ca in leaf tissue and changes in temperature, with the incidence of physiological staining in the papaya, thus influencing the quality of the fruit.

According to Costa (1995), the appropriate range for Mg in the petiole is between 5.30 and 5.70 g kg^{-1}; the mean value of 3.78 g kg^{-1} found in the present study is below this range, indicating a characteristic of coastal-plain soils, as mentioned by Marinho *et al*. (2002). Mesquita *et al*. (2010) found an increase in Mg with an increase in biofertilisers to the soil. An increase was also seen in the study by Almeida *et al*. (2002), with increasing variations in the amount of irrigation water. Mg actively participates in the processes of photosynthesis, and aids in the absorption and translocation of P.

The mean value for S of 3.36 g kg^{-1} is within the range of 3.00 to 8.00 g kg^{-1}, based on Reuther and Robinson (1986), showing that at the time of flowering the crop was well-balanced, as noted and commented upon by Mesquita *et al*. (2010). This nutrient functions in the plant to determine increases in production and fruit quality.

The mean value of 21.33 mg kg^{-1} is above the range of 12.5 to 17.5 mg kg^{-1} for Zn. The value of 42.22 mg kg^{-1} for Mn is within the range of 27 and 50 mg kg^{-1} determined by Marinho *et al*. (2002) for the papaya. According to those authors, the mean values found may be related to the level of nitrogen fertiliser received.

The Pearson linear correlation analysis ($p<0.05$) between the chemical properties of the leaf petioles and productivity (PRD) is shown in Table 2.

According to Figueiredo Filho and Silva Júnior (2009), two variables are associated when there are similarities in the distribution of their scores, with the Pearson coefficient being a measure of the shared variance between the two variables. They further state that it is difficult to say which varies in relation to which, and it is simpler to say that there are similarities of differing degree and direction.

It can be seen from the spatial analysis that the chemical attributes of the leaves being studied display spatial dependence (Table 3 and Figures 1 and 2), as does initial production, indicating that they suffer variation due to the distance between samples, which affects their spatial behaviour.

As the semivariograms have well-defined sills, intrinsic stationarity was assumed in this case. Correlation analysis between observed values and those estimated by cross-validation for all attributes showed a significant inclination for the slope of the line ($p<0.05$).

The theoretical model of semivariogram that showed the best fit to the data was the exponential, with 66.7% of the attributes; the same model and the same spatial distribution pattern being seen for N, P, K, S and PRD, with a reach close to 18, 24, 19, 20 and 22 m respectively, despite not showing a significant linear correlation between N x PRD. The spherical model was adjusted for Ca (r = 20 m), Mg (r = 13 m) and Zn (r = 12 m). Oliveira *et al*. (2010) also only found a fit of the data to the spherical model for CA (r = 29.4 m), Mg

Table 2 - Significant analysis of the Pearson correlation ($p < 0.05$) between the attributes and productivity

	N	P	K	Ca	Mg	S	Zn	Mn	PRD
N	1.00	0.34	-	-	-	0.47	0.49	-0.24	-
P		1.00	0.48	-0.23	-	0.67	0.61	-0.22	-
K			1.00	-0.29	-	0.54	0.42	-0.22	-
Ca				1.00	-	-	-	-	0.26
Mg					1.00	-	-	-	-
S						1.00	0.51	-0.27	-
Zn							1.00	-	-0.23
Mn								1.00	-
PRD									1.00

Significant linear association can be seen between the attributes: high ($0.6 \leq r < 0.8$) for P x S (r = 0.67) and P x Zn (r = 0.61); moderate ($0.4 \leq r < 0.6$) for S x N (r = 0.47), S x K (r = 0.54), S x Zn (r = 0.51) and K x Zn (r = 0.42); and low ($0.2 \leq r < 0.4$) for Mn x N (r = -0.24), Mn x P (r = -0.22), Mn x K (r = -0.22), Mn x S (r = -0.27) PRD x Ca (r = 0.26), PRD x Zn (r = -0.20) Ca x P (r = -0.23) and Ca x K (r = -0.29)

Table 3 - Models and parameters of the semivariograms for the attributes that characterise nutritional status and productivity in the papaya

Attribute	Model	C_0	C_0+C	r (m)	DSD (%)	R^2 (%)
N (g kg^{-1})	EXP	0.01	1.04	18.0	1.0	93.0
P (g kg^{-1})	EXP	0.01	1.58	24.0	1.0	90.0
K (g kg^{-1})	EXP	5.20	39.0	19.0	13.0	91.0
Ca (g kg^{-1})	SPH	0.01	9.00	20.0	1.0	98.0
Mg (g kg^{-1})	SPH	0.01	0.55	13.0	1.0	90.0
S (g kg^{-1})	EXP	0.46	2.23	20.0	20.0	93.0
Zn (mg kg^{-1})	SPH	12.0	30.0	12.0	40.0	79.0
Mn (mg kg^{-1})	EXP	0.10	145.0	32.0	1.0	93.0
PRD (Mg ha^{-1})	EXP	2.33	27.0	22.0	8.0	95.0

EXP: exponential model; SPH: spherical model; C_0: nugget effect; C_0+C: sill; r: reach of spatial dependence; DSD: degree of spatial dependence; R^2: adjusted coefficient of multiple determination

Figure 1 - Experimental semivariograms for macronutrients in the petiole that characterise nutritional status in the papaya

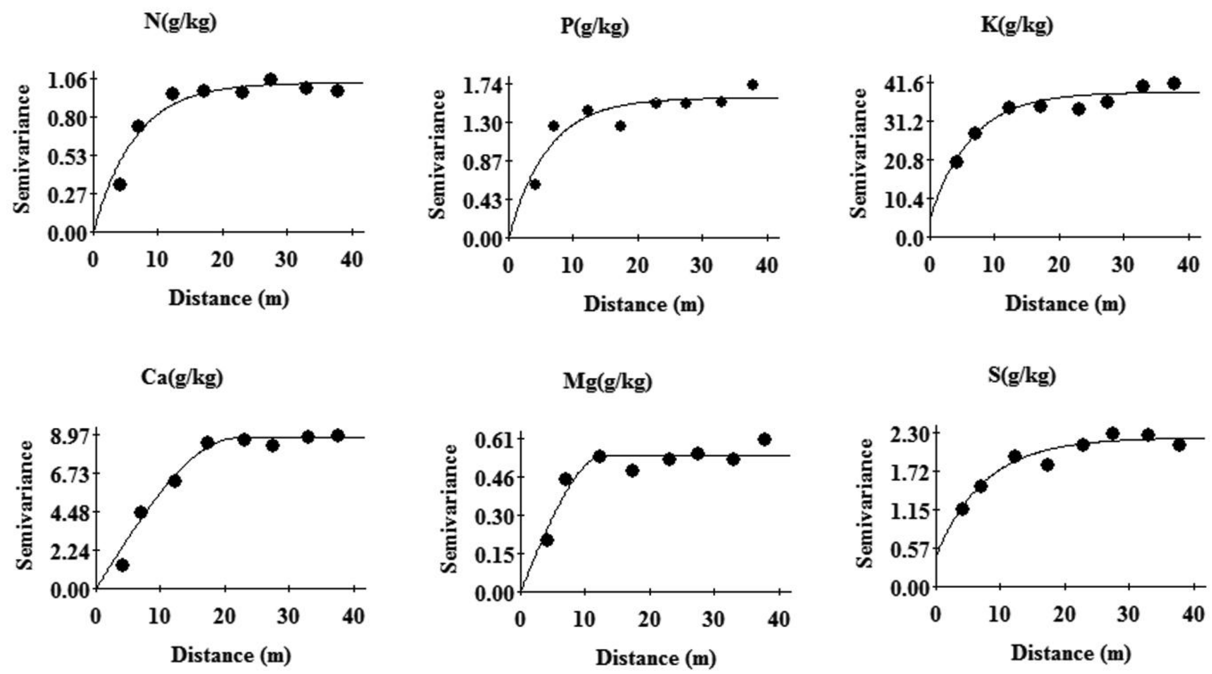
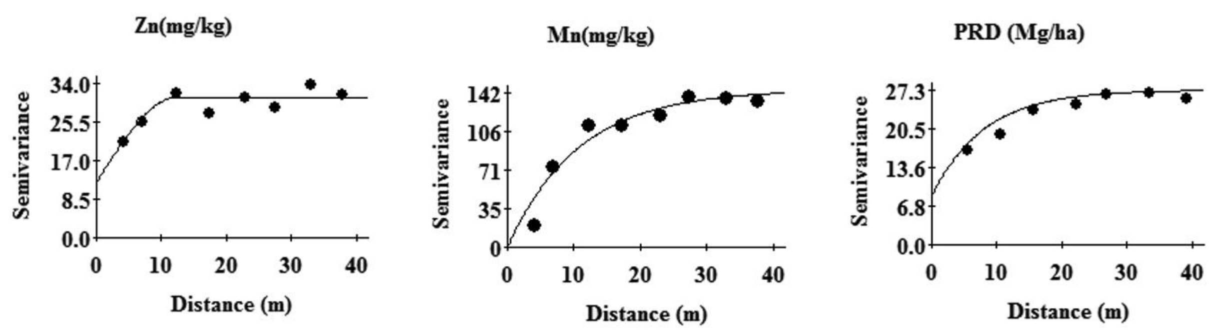


Figure 2 - Experimental semivariograms for macronutrients in the petiole that characterise nutritional status and productivity in the papaya



(r = 40.3 m) and Zn (r = 16.5 m), for conilon coffee in a study of the spatial variability of nutritional status. The exponential model is similar to the spherical by the fact that both gradually reach the sill; however, it differs from the spherical model in the rate by which the sill is reached and the fact that the model and the sill never converge (MOTOMIYA; CORÁ; PEREIRA, 2006).

The attribute that showed the greatest reach of spatial dependence was Mn (r = 32.0 m), with the lowest seen for Zn (r = 12.0 m), both micronutrients. The reach of spatial dependence (r) is an important parameter in the study of spatial variability, indicating the zone of influence of a sample, i.e. it defines the maximum distance for the value of an attribute to have a relationship of spatial dependence with its neighbour (SILVA; LIMA; ALVES, 2010). Lower values for reach may adversely affect the quality of the estimates, since few neighbouring points are used in the interpolation to estimate values at locations that are not measured (CORÁ *et al*., 2004). Souza *et al*. (2006) and Lima, Souza and Silva (2010) mention that using the range of soil properties of a semivariogram can reduce the number of samples, in relation to the use of sampling procedures defined in classical statistics.

An important parameter to be observed in this analysis is the nugget effect (C_0), which describes the behaviour of the implicit correlation function in the model when the distance between samples tends towards zero. Vieira *et al*. (2009) state that it represents the unexplained or random variance, often caused by errors in edition or variations in the attributes that cannot be detected at the sampling scale. In general terms, the values for C_0 were low for the variables, with the exception of K, S and Zn, showing that the sampling grid was effective in determining the spatial component of the variability existing in the study area, as discussed by Silva, Lima and Queiroz (2011).

Paz-Gonzalez, Taboada Castro and Vieira (2001) state that when the normality of the data is satisfied, estimation of the values for locations which are not measured, using the method of Kriging interpolation, shows increased efficiency, giving better results than other methods. According to Cressie (1991) however, normality of the data is not a requirement of geostatistics, and the only recommendation is that the tails of the normal distribution not be too stretched. According to that author, when the data follow a normal distribution, the Kriging estimators are general and conditionally unbiased, which in distributions where the asymmetry values are not far from zero, even under conditions of non-normal behaviour, is also seen. Bregt, McBratney and Wopereis (1991), comparing estimates for ordinary Kriging based on non-normal distributions and data transformed for normal distributions (log-normal), observed robustness of the interpolator for certain degrees of asymmetry of the distribution and the absence of normality.

Lima, Souza and Silva (2010) state that when the spatial dependence is confirmed, it becomes necessary to consider the distance between samples in the statistical analysis, i.e. in order for the samples to be independent, one of the principles of classical statistics, the samples of leaves for each attribute being studied should be collected at a greater distance than the range found for each attribute.

A direct relationship between the value of the coefficient of variation (CV) and the reach (r) for the attributes was not demonstrated, as found and reviewed by Silva, Lima and Alves (2010) in a spatial study of two varieties of Arabica coffee, in which the greatest values for CV were obtained at the smallest values for reach.

In analysis of the degree of spatial dependence (DSD), according to criteria established by Cambardella *et al*. (1994), the DSD showed a strong dependence for all attributes, with values less than 25.0%, except for Zn (DSD = 40%); because of this, the contribution of spatial variance to the total variance of the data was greater, and estimates of values determined by ordinary kriging for unsampled locations were better. In a study of the spatial variability of the nutritional status of conilon coffee, Oliveira *et al*. (2010) found a moderate to strong DSD, which according to the authors justifies the analysis of data by geostatistics in the construction of maps of the differing and localised application of foliar fertilisers on coffee plantations.

Figures 3 and 4 show thematic maps of the spatial distribution of leaf-petiole attributes, obtained with the ordinary method of kriging interpolation. The maps were split into class following the minimum and maximum limits as reference, making it possible to see the regions with different concentrations of foliar nutrients in the papaya. The spatial distribution of N covers the largest region in the area, with values between 9.00 to 12.00 g kg^{-1}, which are greater than the average, especially in the central region, with a recommendation for a variable rate of application. For P, the largest region on the map is less than 3.10 g kg^{-1}, a region which includes the mean value of 2.98 g kg^{-1}, and is therefore below the minimum; the recommendation being for a variable rate of application.

On the map showing the distribution of K, almost the whole area is well below the minimum (30.00 g kg^{-1}), showing a deficiency of the nutrient throughout the area. The value for K is far from that recommended, and in this case, a steady rate of application is suggested throughout the area, using the reference value (between 30.00 to 60.00 g kg^{-1}). For Ca, the mean value (12.90 g kg^{-1}) is included in the classes of 10.00 to 25.00 g kg^{-1}, therefore, a variable rate of application should be adopted for this nutrient in the area.

Figure 3 - Map of the spatial distribution of macronutrients in the petiole of the papaya

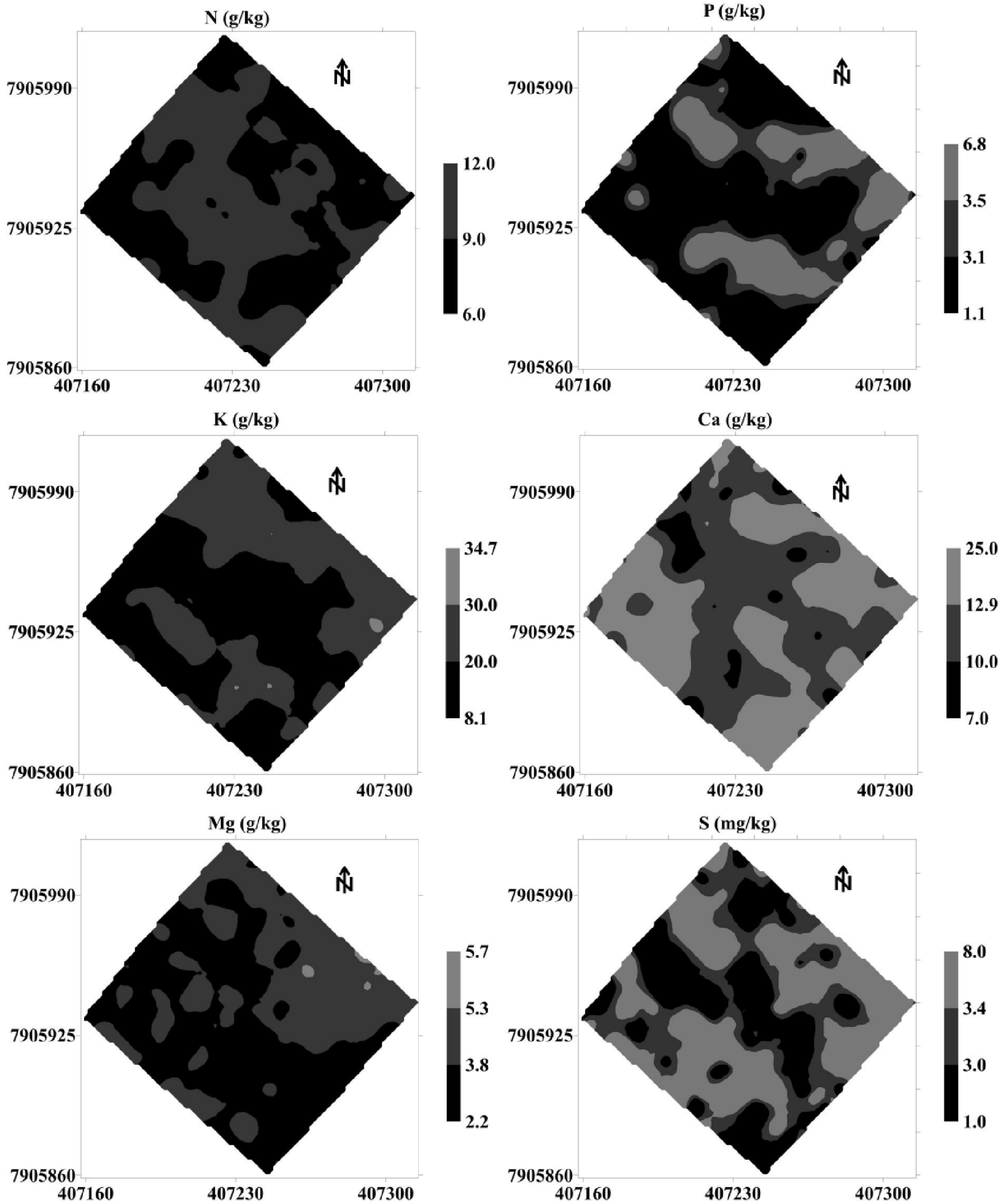
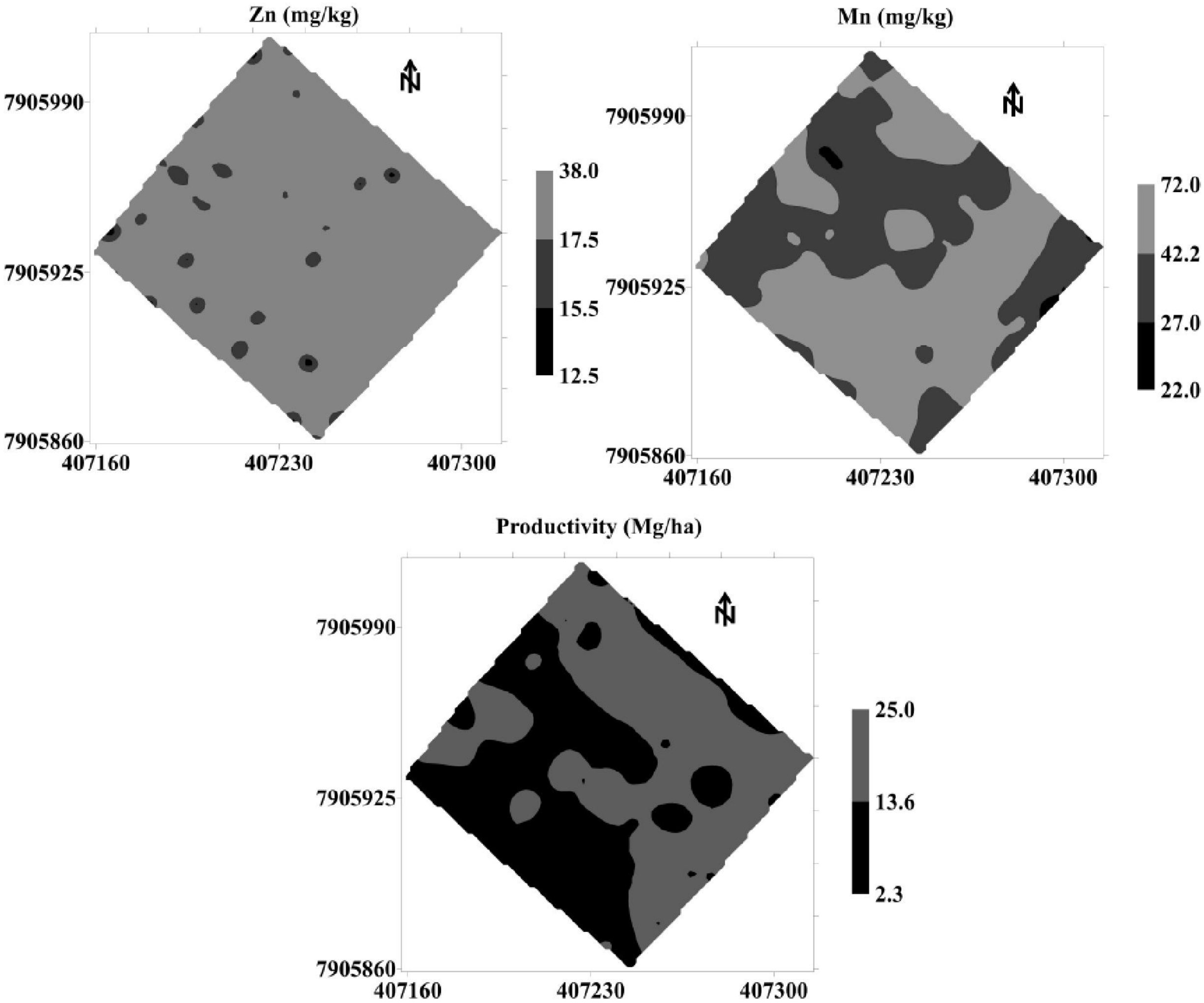


Figure 4 - Maps of the spatial distribution of micronutrients in the petiole of papaya and of initial productivity



For Mg, the same reasoning used for K should be applied; with a mean value far from the minimum, it is recommended that the reference value (from 5.30 to 5.70 g kg^{-1}) be adopted for applying the fertiliser throughout the area. In the case of S, the rate of application should be variable, depending on the displayed distribution. No deficiency is seen for Zn in the area, and the mean value can be used for maintenance applications. Mn should be applied at a variable rate throughout the area, depending on the distribution displayed between reference intervals.

The map of spatial distribution for productivity (Figure 4) shows a larger area for the intervals from 13.60 to 25.00 Mg ha^{-1} in the upper right region, i.e. a concentration of values which are greater than the mean (13,60 Mg ha^{-1}), where the classes include regions with the highest mean values for Ca, S and Mn.

CONCLUSIONS

1. All the attributes that characterise a diagnosis of the nutritional status of petiole dry matter in the papaya showed spatial dependence;
2. The largest and smallest reach for spatial dependence were determined for the micronutrients Mn and Zn respectively;
3. The attributes N, P, K, S and initial productivity (PDR) showed the same pattern of spatial distribution in the study area, the same model and parameters, and close values for reach.

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