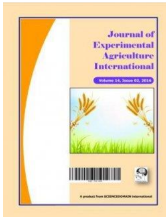

Journal of Experimental Agriculture International

25(2): 1-13, 2018; Article no.JEAI.41819
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Variability and Spatial Correlation between Phenotypic Attributes and Productivity of Papaya

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/41819
Editor(s):
(1) Slawomir Borek, Professor, Department of Plant Physiology, Adam Mickiewicz University, Poland.
Reviewers:
(1) Ramesh Prasad Bhatt, Institute of Ecology and Environment, Nepal.
(2) Rosendo Balois Morales, Universidad Autonoma de Nayarit, Mexico.
Complete Peer review History: http://www.sciencedomain.org/review-history/25829

Original Research Article

Received 1st May 2018
Accepted 1st August 2018
Published 8th August 2018

ABSTRACT

Aims: The characterisation of the spatial variability of plants attributes associated with productivity is important for the refinement of agricultural management practices and the evaluation of the effects of agriculture on environmental quality. The objective of this research was to study the correlations of phenotypic variables, the productivity of papaya and spatial variability using a geostatistical technique.

Place and Duration of Study: The research was carried out in a commercial crop of papaya (*Carica papaya* L.) located in the northern state of Espírito Santo, Brazil in a typical cohesive Yellow Ultisol, between June 2010 and June 2011.

Methodology: The following variables were measured in each sampled plant: height of the plants (HPL); diameter of the stem at 0.20 m from the ground (SDI); lower insertion height of the first flowers (IHF); number of leaves totally open (NTL); number of flower buds (NFB); crown diameter (CRD); the height of the first fruit harvest (HFR); the total number of fruits harvested; the mass of the harvested fruit; the average number of fruits produced per plant (NFR); the average fruit mass produced per plant (kg $plant^{-1}$) (MFP); the average mass of each harvested fruit, in kg (MFR); and

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the average productivity per ha, in Mg ha^{-1} (PRD).
Study Design: Data were submitted to the classical exploratory statistical analysis. In order to evaluate the interrelation between the variables under study, the Pearson (P = .05) correlation analysis was performed. The analysis and modeling of the spatial structure were evaluated using the geostatistical technique.
Results and Conclusion: There was a positive correlation between the initial productivity of papaya with the phenotypic variables: The greatest stem diameter, the lowest insertion height of the first flowers and fruits, the greatest foliar coverage and the highest number of fruit mass produced per plant. The maps of spatial distribution of phenotypic variable and the productivity of papaya permitted a visual interpretation of its behaviour in the area and corresponded to the existing correlation between the variables indicating a suitable condition for the delineation of regions with homogeneous characteristics of plants within the crop.

Keywords: Carica papaya L.; geostatistics; plant science; phenology; precision agriculture.

1. INTRODUCTION

The papaya (*Carica papaya* L.) is one of the most produced and consumed fruits in the world. It is a crop of great economic importance in Brazil, showing a 40 times increase in productivity in the period 1961 to 2016, approximately 2.0 million tons, highlighting it as the second largest producer in the world. Being that more than 80% of the papaya produced in Brazil comes from the region between the municipalities of Porto Seguro, Bahia state and Linhares, Espírito Santo state, Brazil. The state of Espírito Santo represents 22% of the area under cultivation in Brazil, producing 31% of the total, with annual productivity of 74 Mg ha^{-1}, considered the largest in the world [1,2,3].

Phenotypic characteristics, used to monitor the vegetative development of papaya plants such as the highest number of fruits per plant, the largest foliar cover area, the largest stem diameter, the lowest plant height and the first lowest flowering are desirable commercially because they are directly related to the yield and quality of the fruits produced [4,5]. Very important factor also in the process of improving the papaya [6,7].

Silva et al. [6] observed that papaya plants at the initial stage of development with larger stem diameter may result in more productive plants, due to the high genetic correlation between these two characteristics and also with flowering. Ferreira, et al. [8], studying morpho-agronomic relationships of papaya accesses, showed that the larger the diameter of the stem and crown, the size of the panel of fruits and the lower the height of the plants, the higher the number and the fresh mass of fruits per plant.

There is a trend of reduced productivity as the plants show reduced leaf area [4,5]. But, these relationships may vary according to the genetic nature of the cultivar, the soil and climatic conditions and the management adopted in the crop [9]. In particular, the spatial variability and correlations of these variables in the field, as studied in other cultures [10,11,12].

Considering the spatial variability in the correlations between the genotypic/phenotypic characteristics is very important for the definition of a parameter that guides the producers of papaya to increase productivity. This subject has not yet been studied with scientific parameters.

One way to study the spatial variability of agronomic variables is to use geostatistical analysis, a technique widely used in agrarian sciences, which allows the acquisition of information about the spatial and temporal distribution and the relationship of the variables in the field [10]. Several studies show the importance of considering the spatial variability in the field and the gain of information with the use of geostatistics as a tool in this type of study [13,14,15,16], including in the cultivation of papaya [17,18].

In this context, the objective of this work was to study spatial variability and correlations between phenotypic variables and papaya productivity using geostatistics.

2. MATERIALS AND METHODS

The research was carried out in a commercial crop of papaya (*Carica papaya* L.) cultivar

Golden THB, from the group Solo, located in the municipality of São Mateus, in the northern state of Espírito Santo, Brazil. The climate of the region, according to the classification of Köppen, is Aw type, with the dry season in winter and hot and rainy summer [19]. The average annual temperature is 25° C and the cumulative mean precipitation is 1290 mm [20]. The soil of the area was classified as a typical cohesive Yellow Ultissol (PAdx) of low activity clay [21]. The relief in the area is gently undulating, with an approximate slope of 3.0% and an altitude of 14 m. The mean particle size fractions in the 0.0-0.20 m layer are 891.8; 15.6 and 92.6 g kg^{-1} of total sand, silt and clay, respectively.

The area was fallow for six years and was prepared 40 days in advance of transplanting with mechanical scraping. Then, there was a haul broadcasted throughout the area to achieve 80% of base saturation (V%), as results of soil analysis, and then after the plowing depth of 0.20 m, followed by two passes of a harrow-dual action and finally plowing according to the spacing used: 3.3 x 2.0 x 1.90 m, in double rows (1,986 plants ha^{-1}). Fertilization, based on soil analysis and technical recommendations of Prezotti et al. [22] and management and phytosanitary and cultural controls, presented by Martins and Costa [23], were applied as commonly used in the production unit. Seedlings certified papaya with productive potential ≥ 80 Mg ha^{-1} year from the sexual propagation of self-pollination with reduced genetic variability [24], were transplanted with three seedlings per hill, chopped at the time of sexing [25], carried out 5.0 months after transplanting. When then selected is a plot with morphological features and apparently homogeneous management for trial, which was set in a regular grid of approximately 1.25 ha, 110 m long and 114 m wide, a total of 129 sampling points, with a minimum distance of 5.7 m (Fig. 1).

The georeferencing of each sampling point was performed using a pair of GPS receivers TechGeo®, GTR G2 geodetic model, data processed by the Brazilian Network for Continuous Monitoring (RBMC) of IBGE, showed an accuracy of 10.0 mm ± 1.0 ppm; in UTM (Universal Transverse Mercator) with Datum WGS-84.

After demarcation of the points with wood cuttings, the following variables were measured in each sampled plant: a) height of the plants (HPL) (cm), from the soil to the foliar meristematic region; b) diameter of the stem at 0.20 m from the ground (cm), obtaining the circumference and posterior calculation of the diameter (SDI); c) lower insertion height of the first flowers (IHF) (cm), region of insertion of the perfect flower lower than the soil; d) number of leaves totally open (NTL); e) number of flower buds (NFB); g) crown diameter (CRD) (cm), as an alternative measure of plant leaf area, carried out with a measuring tape comprising the distance between the ends of the laminas of the two most extreme opposite sheets in the direction of the planting line.

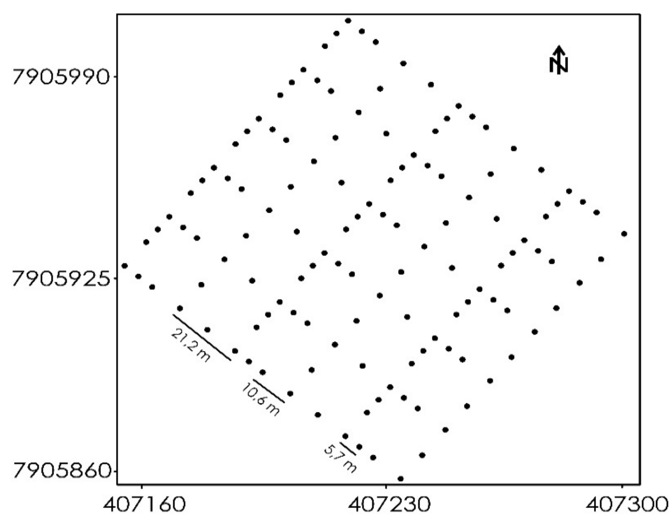

Fig. 1. Sample grid design
Source: Author data

At the ninth month after transplanting, the initial productivity of the papaya fruit was recorded until the 12th month of age, according to the maturity of the fruits, obtaining the following information: h) the height of the first fruit harvest (HFR) (cm), from the soil up to the height of the peduncular insertion of the lower ripe fruit; i) the total number of fruits harvested; (j) the mass of the harvested fruit (kg) determined on a digital scale with an accuracy of two grams. Considering the population density (1,986 plants ha^{-1}) and that the fruits were harvested at the maturation stage 2.0, with up to 25% yellowing of the bark [26], considering the georeferenced plant and the two plants adjacent to the crop line for the definition of the average per sampling point, with the purpose of greater representativeness, the following were calculated: k) the average number of fruits produced per plant (NFR); l) the average fruit mass produced per plant (kg $plant^{-1}$) (MFP); (m) the average mass of each harvested fruit, in kg (MFP); and n) the average productivity per ha, in (Mg ha^{-1}) (PRD).

Data were submitted to the classical exploratory statistical analysis, with the determination of the mean, median, standard deviation, minimum and maximum values, a coefficient of variation, frequency distribution, asymmetry coefficient and kurtosis. To test the hypothesis of data normality the Kolmogorov-Smirnov test (KS) ($p < 0.05$) was performed. In this analysis, the outliers were identified, according to the principles of Kerry and Oliver [27]. To evaluate the interrelation between the variables under study, the Pearson (P = .05) correlation analysis was performed, with the classification adopted by Kitamura et al. [28].

The analysis and modeling of the spatial structure were evaluated using the geostatistical technique, with the estimator by the method of the moments proposed by Matheron for the semivariogram, presented by Journel and Huijbregts [29] (equation i):

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

where: Z (x_i) is the value of the variable z in the location x_i; and N (h), the number of pairs of measured values: Z (x_i) and Z ($x_i + h$) separated by a distance h.

The semivariogram is represented graphically by the relationship of the semivariance γ (h) versus h, and provide estimates of the parameters necessary for the adjustment of the theoretical, spherical (ESF), exponential (EXP) and Gaussian (GAU) models: nugget effect (C_0); (a) and the threshold (C_0 + C). The adjustments of the semivariograms, according to their models, were made by the selection: a smaller sum of the squares of the deviations (SQR); higher coefficient of determination (R^2) and higher spatial dependence index (SDI) and a higher correlation coefficient of cross-validation (r-VC) between observed and estimated data. SDI is the relationship between the nugget effect and the plateau [(C) / (C_0 + C) * 100], considering the classification of Cambardella et al. [30] as SD ≤ 25%: strong spatial dependence; between 25% and 75%: moderate spatial dependence and ≥ 75%: poor spatial dependence. This analysis was performed using GS + software [31].

The cross-semivariogram was also adopted to verify the spatial correlation between phenotypic attributes and papaya productivity, through the equation ii:

$$\gamma(h)_{cr}=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[\begin{matrix}Z_1(x_i)-\\Z_1(x_i+h)\end{matrix}\right]\left[Z_2(x_i)-Z_2(x_i+h)\right] \qquad \text{(ii)}$$

where: Z_1 represents the productivity of the papaya and Z_2 each phenotypic variable evaluated.

For the variables that presented spatial dependence, the ordinary kriging interpolation method was used to estimate values in non-sampled locations and to construct thematic maps.

3. RESULTS AND DISCUSSION

The coefficients of asymmetry and kurtosis close to zero for most of the evaluated attributes of papaya, as well as the proximity of the mean and median values, indicate that the variables studied to follow the normal distribution, a fact confirmed by the Kolmogorov-Smirnov test (P = .05) (Table 1). These data are in accordance with the data presented by Grego, Vieira and Xavier [10] and Kitamura, et al [28].

For the application of geostatistics, it is important that the distribution of the variables does not present very elongated tails. However, most of the variables presented negative values of Ck, but close to zero, which did not compromise the definition of the semivariogram level in spatial analysis.

Table 1. Descriptive statistics of attributes of golden THB plants of the Solo group, sampled in 129 georeferenced points

Variable	Average	Median	S	Min	Max	V	Cs	Ck	DN
HPL	103.2	103.0	11.4	70.0	136.0	11.1	0.0	0.1	ns
IHF	86.7	86.0	11.0	63.0	126.0	12.7	0.7	0.9	ns
SDI	6.9	7.0	4.2	3.8	10.2	19.1	0.0	-0.4	ns
NFB	9.0	9.0	3.9	3.0	18.0	42.0	0.2	-1.0	ns
NTL	20.0	20.0	3.6	11.0	28.0	18.2	-0.2	-0.5	ns
CRD	145.7	147.0	20.3	99.0	191.0	13.9	-0.1	-0.3	ns
HFR	85.9	84.5	13.5	57.3	125.3	15.7	0.2	-0.4	ns
MFR	0.4	0.4	0.04	0.3	0.5	11.2	0.3	-0.1	ns
NFR	18.0	17.0	6.6	4.0	32.3	37.1	0.2	-0.6	ns
MFP	6.9	6.5	2.8	1.2	12.6	40.0	0.2	-0.7	ns
PRD	13.6	12.9	5.5	2.3	25.0	40.0	0.2	-0.7	ns

HPL: plant height (cm); IHF: height of insertion of the lowest flowers (cm); SDI: stem diameter (cm);NFB: number of flower buds; NTL: number of leaves; CRD: crown diameter in the direction of the planting line (cm); HFR: Harvest height of the first fruit (cm); MFR: average mass per fruit (kg); NFR: mean number of fruits harvested per plant; MFP: mean mass of fruits produced per plant (kg); PRD: average productivity of the evaluated area (Mg ha^{-1}); s: standard deviation; Min .: minimum value; Max .: maximum value; CV: coefficient of variation; Cs: asymmetry coefficient; Ck: kurtosis coefficient; DN: normal distribution test; ns: not significant at 5.0% by the Kolmogorov-Smirnov (KS) test, therefore, normal distribution of the data. Source: Author data.

The mean values of the attributes studied were: the average height of the plants (HPL) of 103 cm; insertions of the first flowers (IHF) at 86.7 cm; mean stem diameter (SDI) of 6.9 cm; 20 leaves per plant (NTL); 9.0 floral buds (NFB) per plant and 145.7 cm of average crown diameter (CRD). Silva, et al. [5], in sandy soil in the north of the state of Espírito Santo, recorded at the time of the sexing, plants of papaya cultivar Golden with average of 125 cm of height, 30 leaves; 11.8 cm in diameter of the stem and insertion of the first flowers to 70 cm of height. These authors emphasized that for greater productivity and longevity, the plants must present emission of the first flowers at a low height and greater number of leaves and diameter of the stem. They are good indicators of plant structure to support the weight of the fruit panel with its constant growth.

Silva et al. [6], also in the northern part of the state of Espírito Santo, studying morpho-agronomic characteristics of Golden papaya and other segregating populations, obtained in the sexing phase the first fruits at 75 cm in height and in the harvest phase, plants with 246 cm high and 11 cm diameter of the stem. Alves; Pacova and Galveas [24]; Costa and Pacova [25] describe that phenological patterns are primordial for selection of papaya plants, being ideal in the phase of sexing, height of flowering and fruiting of 50 to 80 cm and diameter of the stem greater or equal to 10 cm. Therefore, the results obtained in this work indicate that, on average, the plants presented a characteristic of wilting, with height of insertion of the first flowers and diameter of the stem above and below, respectively, the ideal indicated in the literature and observed by the papaya producers, who attributed to the quality of crop management and plant potential, by observing their phenological and phytotechnical characteristics. In contrast, Silva, et al. [6] and Silva, et al. [5] obtained characteristics within the ideal standards.

The significant differences between the results of the present study and the authors cited above can be attributed to random, uncontrollable factors of the climate and the interaction of management of the soil-plant system, such as the larger spacing used by Silva et al. [5] and the highest technological level adopted in the area studied by Silva et al. [6], even with the similarity of the evaluations of the works in the same geographic region.

Jimenes et al., [7] and Olubode et al. [9], affirm that environmental factors and crop management conditions greatly influence the productive response of the papaya crop due to the direct relation with the ecophysiology and the plant metabolism. For example, air temperature and nutritional status of plants are directly related to pollinating and fixing flowers and fruit development.

In the present study, the average height of the first fruits (HFR) was 86 cm, approximately the average height observed for the first floral insertions, during sexing, which may vary due to loss of flowers or new shoot [32].

The average yield of 18 fruits per plant (NFR), with a mean mass (MFR) of 0.40 kg fruit^{-1} was obtained, representing a yield of 6.9 kg plant^{-1} (MFP) and an average productivity (PRD) of 13.6 Mg ha^{-1} in the initial 3.0 months evaluated (270 to 365 days after transplanting - DAT). Costa and Pacova [25] mentioned that commercial fruits are those that are within the range of 0.35 to 0.55 kg, indicating that the fruits harvested in this work are within commercial standards, also obtained by Silva et al. [5], which harvested fruits with a mass of 0.30 to 0.47 kg, in a medium to high productivity crop: 24.9 to 39.1 Mg ha^{-1} at 280 DAT. Silva et al. [6] obtained fruits with an average of 0.62 kg and production of 20.13 kg plant^{-1} at 240 DAT, indicating the high production standard adopted by these authors. Oliveira et al. [33], obtained an average productivity of 18 Mg ha^{-1} in the first 6 months of harvest (270 to 420 DAT), with a positive correlation with the biometric variables of plants. Therefore, it is observed that the plants evaluated in the present study produced fruits within commercial standards, but in a lower number than those obtained with data from the literature.

The variability of an attribute can be classified according to the magnitude of its coefficient of variation (CV), which may be low (CV < 10%); mean (10% ≤ CV ≤ 20%); high (20% ≤ CV ≤ 30%); and very high (CV > 30%) (Pimentel-Gomez; Garcia, [34]). With this, we have a mean CV for 67% of attributes and very high for 33% of them (NFB, NFR, MFP and PRD), indicating the largest variations for attributes directly related to productivity.

The correlations between the variables evaluated (Table 2) were extra-high (80% ≤ r ≤ 100%) for 11% of the existing correlations: SDI x CRD, NFR x MFP, PRD x NFR, PRD x MFP; high (60% ≤ r ≤ 80%) for the HPL x IHF correlation; and the other significant correlations (82% of the total), being positive and / or negative, were moderate (40% ≤ r ≤ 60%) to low (20% ≤ r ≤ 40%), according to Kitamura et al. [28] classification. According to these same authors, low correlations between any two variables do not invalidate the hypothesis of occurrence of spatial dependence among them, as confirmed by cross-semivariograms (Fig. 2).

Unlike the simple semivariogram, the cross-semivariograms may be negative, indicating an inverse relationship between two variables. These are used in order to corroborate the interpretation of the spatial correlations visualized in the maps (Figs 3 and 4).

The correlations between the phenotypic attributes of papaya plants, such as SDI x CRD, demonstrate the relation of the favorable structural condition of the plants with their productive potential. Since the PRD x HPL correlation (r: 22%), indicates higher productive longevity, although the height of the plants is technically limiting to the exploitation, due to difficulties in harvesting fruits with a height of more than 3.0 m. This fact has led to the

Table 2. Pearson correlation (*P* = .05), in percentage (%), between the phenotypic variables and the yield of papaya cultivar Golden THB of the group Solo productivity

	HPL	IHF	SDI	NFB	NTL	CRD	HFR	MFR	NFR	MFP	PRD
HPL	100										
IHF	60	100									
SDI	48	-	100								
NFB	41	-37	42	100							
NTL	27	-	-	51	100						
CRD	37	-20	81	57	27	100					
HFR	-	45	-37	-34	-	-37	100				
MFR	-	-	-	-26	-	-	-	100			
NFR	27	-	58	20	-	38	-48	26	100		
MFP	22	-	52	-	-	31	-43	47	97	100	
PRD	22	-	52	-	-	31	-43	47	97	100	100

HPL: plant height (cm); IHF: height of insertion of the lowest flowers (cm); SDI: stem diameter (cm); NFB: number of flower buds; NTL: number of leaves; CRD: crown diameter in the direction of the planting line (cm); HFR: Harvest height of the first fruit (cm); PRF: average mass per fruit (kg); NFR: mean number of fruits harvested per plant; MFP: mean mass of fruits produced per plant (kg); PRD: average productivity of the evaluated area (Mg ha^{-1}); -: non-significant correlation (P = .05). Source: Author data conduction of papaya crops between 2.5 and 3.0 years old [5], which can be confirmed by the negative relation between PRD and HFR (r: -43% and Fig. 2), that is, a lower yield is obtained with plants that emit flowers, and consequently fruits, at a higher height in the stem (IHF x HFR, r: 45%). A physiological issue, which naturally reduces the plant's carrying capacity, with its height gain, and at the same time reduces the holding panel to the height of commercial exploitation of plants.

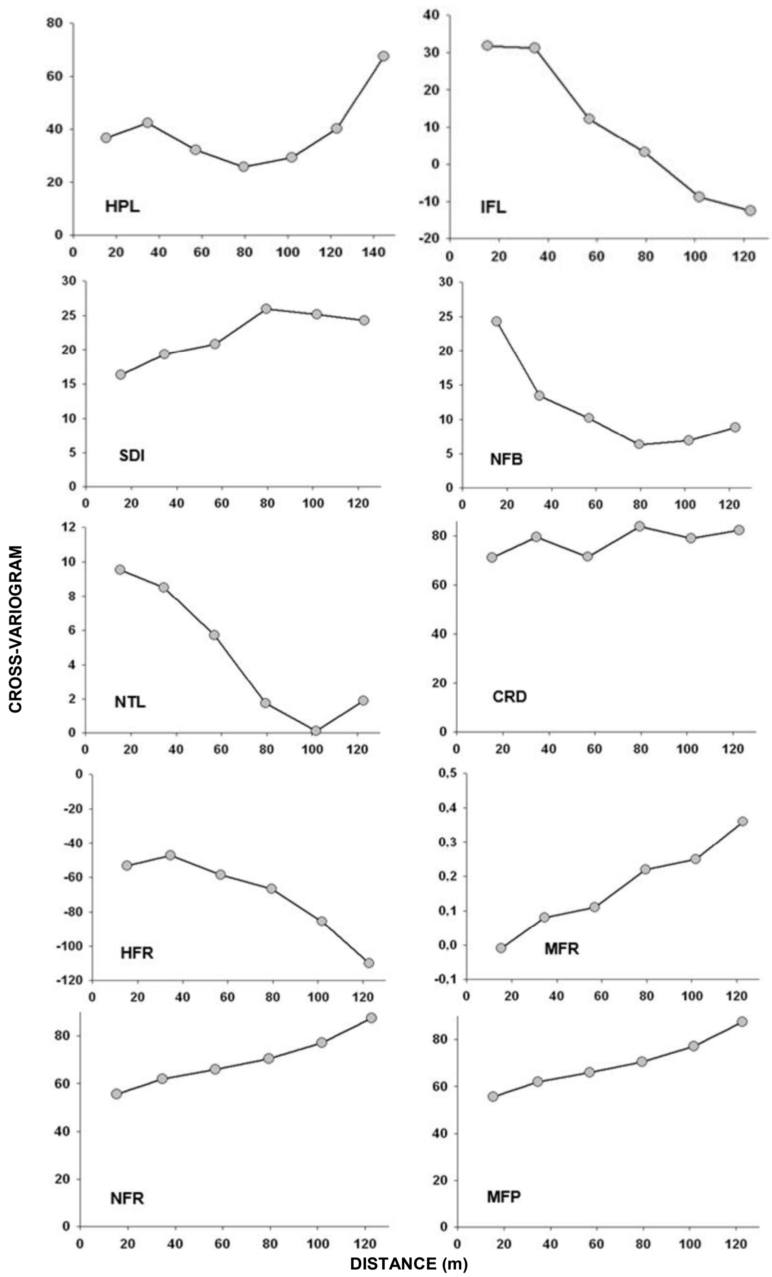

Fig. 2. Cross-variogram between papaya productivity (PRD) and plant height (HPL), lower flower bud insertion height (IHF), stem diameter at 0.20 m from soil (SDI), number of flower buds (NFB), number of leaves (NTL), diameter of the plant crown (CRD), and height of the first fruit (HFR), mean fruit weight (MFR), number of fruits produced per plant (NFR) and fruit mass produced per plant (MFP)

Source: Author data

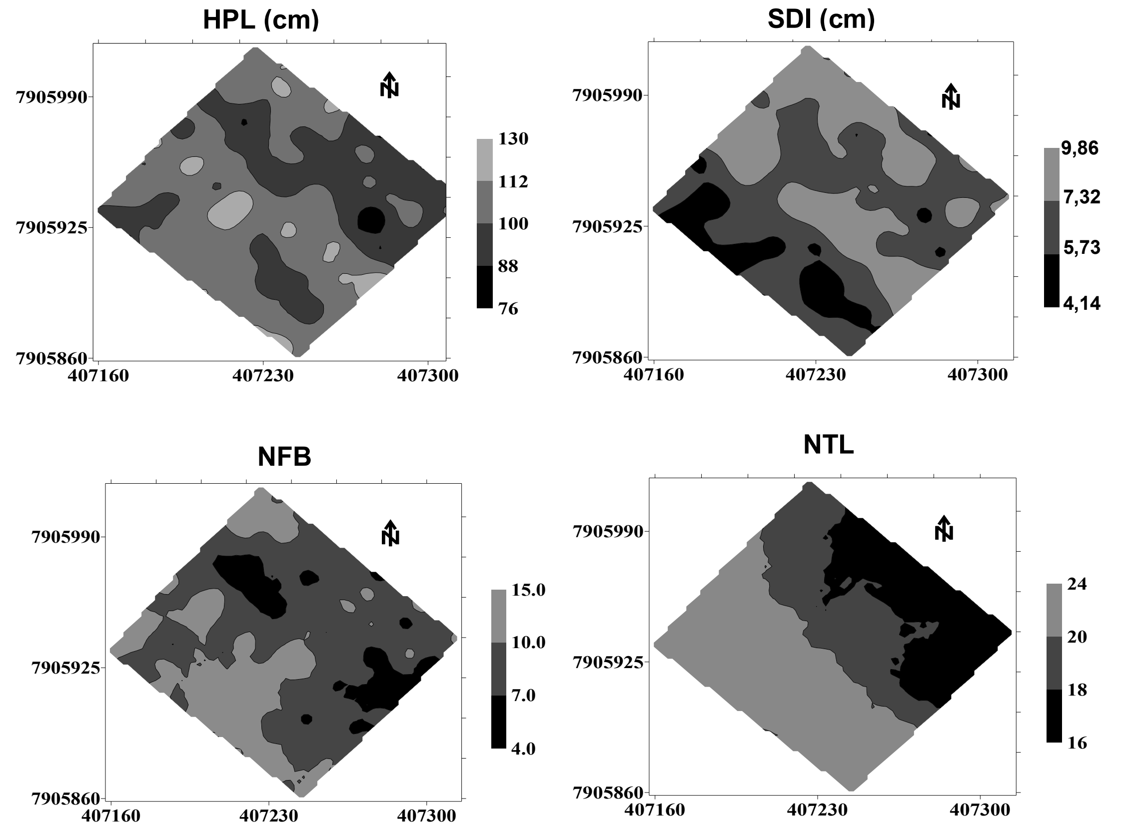

Fig. 3. Thematic maps of the attributes of papaya plants: Plant height (HPL), stem diameter (SDI), number of flower buds (NFB) and number of leaves (NTL)
Source: Author data

There was a positive correlation, even if low, between NFB and NFR (r: 20%) and a negative correlation between NFB and MFR (r: -26%). This indicates that a higher number of flower buds (NFB) and, consequently, a higher average number of fruits per plant (NFR) result in lower weight fruits, which may compromise commercial quality, as can be observed in the following spatial dependence maps (Figs 3 and 4). Silva et al. [6], who observed a negative correlation between NFR x MFR (r: -80%) and NTL x MFP (r: -24%), indicate that this fact may be due to photosynthetic limitations for fruit filling, justifying the need for thinning.

Positive PRD correlations with MFR (47%), NFR (97%) and MFP (100%) indicate that productivity will be as high as the greater number of fruits, of greater mass, is produced. In the present study, the use of PRD and SDI (52%) correlated directly with the phenotypic attributes of plants, as presented by several authors [5,25,33] which were confirmed in the present study by means of the cross-semivariogram, which confirmed the positive spatial correlation between PRD and SDI (Fig. 2). Silva et al. [6] obtained an extra-high correlation (r: 84%) between PRD and SDI and suggest that plants with higher SDI may result in higher productivity, due to the great capacity of absorption and translocation of water and nutrients, giving greater vigor plants that present a potential root system. Ferreira et al. [8] studying canonical correlations between genotypic and morpho-agronomic characteristics, observed that the increase in mass and number of fruits is achieved by increasing the diameter of the stem and canopy of the plants and a larger panel of fruits, with lower flower insertion.

The study of these interactions between phenotypic variables and productivity should be the object of studies in more advanced stages of the phenology of papaya cultivated under different cultivation conditions, so that its behavior can be analyzed with the development of the plants and, therefore, obtain more detailed information for the planning of crop interventions. This type of study is also indicated as much needed by Olubode, et al [9], given the lack of information related to the topic. The results obtained in the present study are indicative of their importance, as well as observed in other cultures.

Martin et al. [11], in the sunflower crop, observed effects of plant number and stature and stem diameter on grain yield, with a correlation of up to 59%. Pias et al. [35] studying the correlation between biometrics variables, in different phenological stages, and the wheat productivity components, observed that wheat plants higher (height and number of nodes) and reduced root length showed higher productivity.

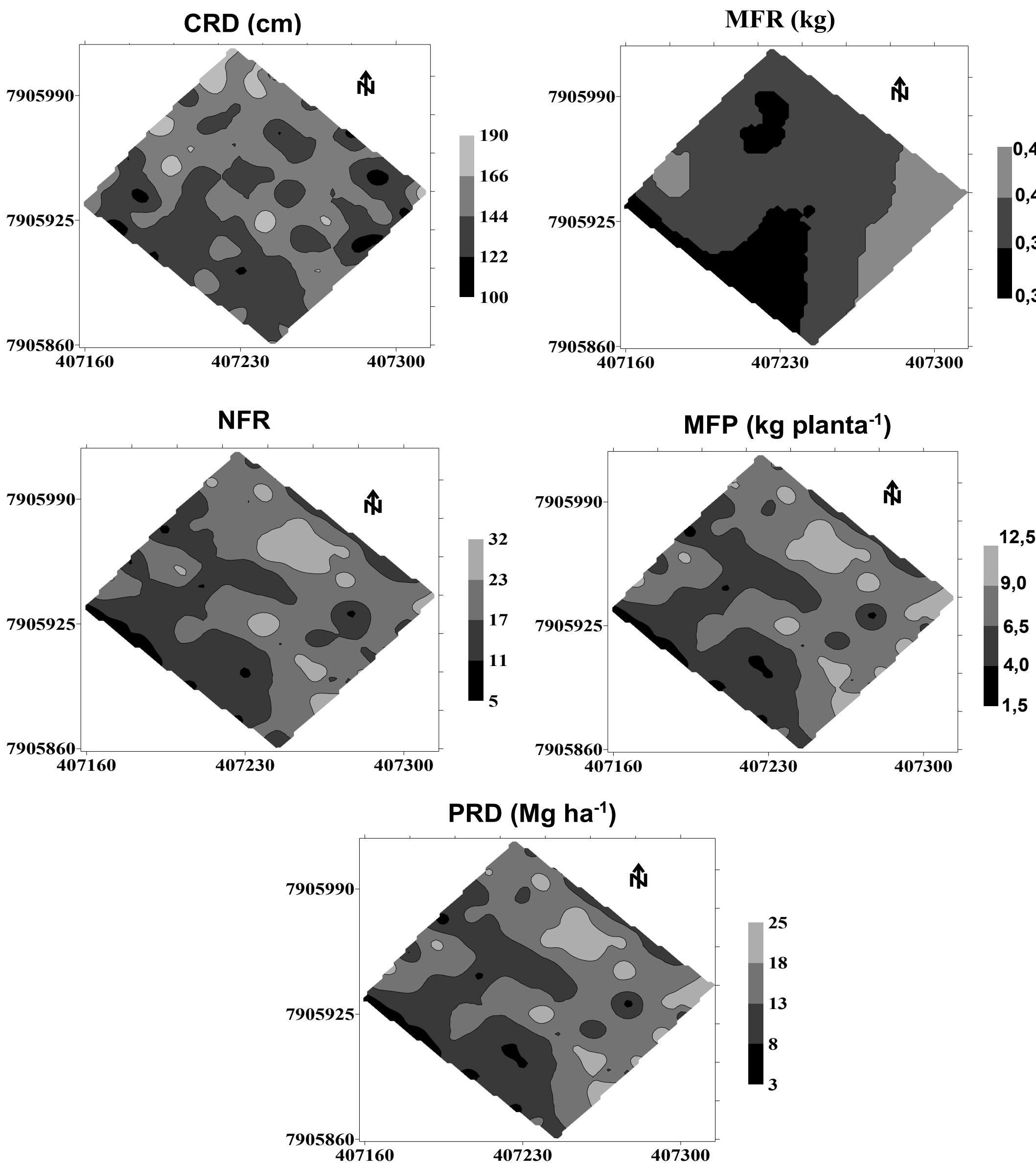

Fig. 4. Thematic maps of the attributes of papaya plants: Diameter of the crown of the plants (CRD), Average fruit weight (MFR), Number of fruits produced per plant (NFR), Fruit mass produced per plant (MFP) and Productivity for the period evaluated (PRD)
Source: Author data

It is verified that 81.8% of the variables presented spatial dependence in the sampling mesh used (Table 3), with models adjusted to the semivariograms presenting R^2 superior to 77% and correlation coefficient in the cross-validation (r-VC) significant to 5.0% probability.

According to the criteria of Cambardella et al. [30], the spatial dependence index (SDI) was moderate (25-75%) for the variables NFB, NTL and MFR; and strong (SDI <25%) for the others, evidencing that the distribution of these attributes in space is not random. Only the IHF and HFR attribute resulted in pure nugget effect (PNE), indicating random distribution in the area for distances greater than or equal to the shortest sampling distance (5.7 m).

Of the attributes studied, 45.5% adjusted to the exponential model of the semivariogram, 27.3% to the spherical model and 9.0% to the Gaussian model. In the work of spatialization of plant attributes, it is common to find semivariogram adjustment to the exponential and the spherical models [10,17,36].

The scope reflects the spatial continuity of a particular variable and is important for spatial dependence delineation, a definition of specific management zones and distance from which the samples are independent. Therefore, the larger the range and the stronger the SDI, the larger the area with samples of homogeneous characteristics. The minimum range in the present study was 15 m for NFB and CRD variables; and the highest was 100 m for NTL. The similarity between the scopes and the model adjusted for variables indicates or confirms a spatial correlation between them, as observed for the PRD and NFR variables, adjusted to the exponential model and with 22 and 23 m ranges, respectively, and visualized in the Figs from 2 to 3.

The spatial distribution maps of the attributes under study allowed the visual interpretation of the spatial behavior of each variable in the area and are presented in Figs 3 and 4. The maps of the biometric attributes NFR and MFP presented similarity with the map of PRD, presenting a spatial correlation confirmed by the positive cross-semivariogram (Fig. 2). This observation is consistent with the extra-high simple correlation of these data (Table 2).

As for the shape of the maps, it is observed that the area that presented lower PRD, from south to west, is the area where it produced lower NFR and lower MFP. Also, it is the area that presented higher plants (HPL), with higher NTL and NFB, with lower CRD and SDI. Although Pearson's correlation of IHF, NFB, and NTL variables with PRD was not significant, cross-referenced semivariograms (Fig. 2) indicate

Table 3. Parameters of the semivariograms adjusted to the variables studied of the papaya cultivar Golden THB of the Solo group

Variable	Model	C_o	C_o+C	a (m)	SDI	R^2	r-VC
HPL	ESF	0.122	1.04	24.0	12.0	83.0	38.0
IHF	PNE	-	-	-	-	-	-
SDI	EXP	0.064	1.02	43.5	6.0	90.0	50.0
NFB	EXP	0.362	1.02	15.0	35.0	77.0	32.0
NTL	GAU	0.694	1.16	100.0	60.0	96.0	50.0
CRD	ESF	0.079	0.95	15.0	8.0	91.0	35.0
HFR	PNE	-	-	-	-	-	-
MFR	ESF	0.413	1.03	88.0	39.0	94.0	66.0
NFR	EXP	0.071	0.96	23.0	7.0	93.0	40.0
MFP	EXP	0.179	0.92	31.5	19.0	83.0	46.0
PRD	EXP	0.205	0.91	22.0	2.0	91.0	46.0

*HPL: plant height (cm); IHF: height of insertion of the lowest flowers (cm); SDI: stem diameter (cm); NFB: number of flower buds; NTL: number of leaves; CRD: crown diameter in the direction of the planting line (cm); HFR: Harvest height of the first fruit (cm); PRF: average mass per fruit (kg); NFR: average number of fruits harvested per plant; MFP: average mass of fruits produced per plant (kg); PRD: productivity of the evaluated area (Mg ha^{-1}); ESF: theoretical spherical model; EXP: exponential theoretical model; GAU: Gaussian theoretical model; PNE: pure nugget effect; C_0: nugget effect; C_0 + C: threshold; a: scope of spatial dependence; SDI: spatial dependency index [(C / C_o + C) * 100]; R^2: coefficient of multiple determination of the fit of the model; and r-VC: regression coefficient between the values measured and estimated by cross-validation (significant P = .05). Source: Author data* a negative spatial relationship between them. This fact indicates that less structured plants, with early developmental tenderness symptoms, are less productive and tend to be less productive due to plant height being a limiting factor. This fact confirms that the producer is correct in adopting as a synonym of potentially productive plants, those well-leaved, not threaded, with lush and expanded crown, lower plants, without excess flowering, a larger diameter of the stem, as mentioned above.

The region with the highest PRD in the east coincides with the one with the lowest NTL, a result that is the reverse of that found by Coelho and Simões [4], which evidenced the reduction of papaya productivity with the reduction of the photosynthetically active leaf area. In the present work this result may be due to the photosynthetic sufficiency of the available leaf area in producing the fruits that provided the highest productivity of the area. In contrast, the area to the west, despite presenting higher NTL, also presented higher NFB, characterizing greater drainage, which gave less commercial fruit (NFR) of lower MFR and, consequently, lower PRD. Therefore, even with the positive correlation between NTL and CRD, there was a lower PRD. The PRD x CRD correlation indicates that a good leaf area, with no flowering excess, will allow a greater formation of photoassimilates to the fruit filling, as presented by Kist and Manica [37]. These behaviors are confirmed by the interaction of the correlations and the spatial distribution of each attribute and its influence on the productivity of the papaya tree.

The region east of the map presented, in addition to higher productivity (PRD), plants with more economically interesting characteristics (greater SDI, CRD, NFR, MFP and lower HPL, NTL y NFB), which may be directly related to the effects of the various attributes that influence it, both the measured ones and those relative unmeasured and with variability capable of influencing the productive result, as the soil and climatic characteristics of the region where the crop was cultivated [18]. Thus, a response to the production process is observed: an area that indicates two regions with predominant characteristics for most of the attributes. One from the center to the east, and the other in the opposite direction of the map, which benefits the delimitation of zones for specific handling.

The delimitation of these management zones will be more effective in considering the maximum information obtained for this same area, such as the spatial distribution of soil physical attributes [18] and the spatial variability of the nutritional status of papaya [17].

Obtaining this type of detail of agricultural production shows that the many studies found in the literature on the variability and correlations of the attributes related to cultivation (soil, climate, management, genotypes, etc.) with crop productivity [12,16,38, 39] have shown great benefits in obtaining more detailed information on the practice of a more efficient and sustainable agriculture [40].

This issue is of great importance for the future of agricultural production in Brazil [41], especially in highly technical crops such as papaya, and therefore, more detailed studies are encouraged based on the information obtained in this study.

4. CONCLUSIONS

There was a positive correlation between the initial productivity of the papaya and the phenotypic variables: larger stem diameter, the reduced height of insertion of the first flowers and fruits, greater leaf cover and greater number of fruits produced per plant.

Except for the lowest floral insertion height (IHF) and harvest height of the first ripe fruit (HFR), all others presented moderate to strong spatial dependence.

Spatial distribution maps of phenotypic variables and productivity of papaya allowed the visual interpretation of their behaviour in the area and corresponded to the linear correlations between the attributes, indicating suitable conditions for the delimitation of regions with plants of similar characteristics within the crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nishimura H, Miguel DS. Demands and requirements of the national papaya market regarding logistics and quality. In:

Martins D. dos S. (Ed). Papaya Brazil: quality of papaya for the domestic market. Victory: INCAPER. 2003;79-84.
2. IBGE- Brazilian Institute of Geography And Statistics. IBGE automatic recovery system -SIDRA. Available:http://www.sidra.ibge.gov.br/bda/tabela/protabl.asp?c=1613&z=p&o=18&i=P (Accessed on 20 Jun. 2017).
3. Food and Agriculture Organization of the United Nations-FAO. Statistical Databases. Available:http://faostat.fao.org/site/567/default.aspx#ancor (Accessed on 22 Jun. 2017).
4. Coelho EF, Simões WL. Productivity of papaya, cultivar tainung nº1, under different irrigation management in the coastal plains of the northeast. Magistra. 2010;22(1):35-40.
5. Silva MM, Broetto SG, Valbão SC, Costa, AFS, Silva DM. Vegetative and papaya fruit characteristics obtained by mass selection. Semina: Agrarian Sciences, Londrina, PR. 2010;31(1):29-38.
6. Silva FF. da Pereira, MG, Ramos HCC, Damasceno Junior PC, Pereira TNS, IDE CD. Genotypic correlations of morphoagronomic traits in papaya and implications for genetic breeding. Crop Breeding and Applied Biotechnology. Viçosa. 2007;7:345-352.
7. Jiménez VM, Mora-Newcomer E, Gutiérrez-Soto MV. Biology of the Papaya plant. In: Ming R, Moore P. (Eds) Genetics and genomics of papaya. Plant genetics and genomics: Crops and Models. 2014; 10:17-33. .
8. Ferreira JP, et al. Correlations between morpho-agronomic characteristics of papaya accessions. Encyclopedia Biosphere. 2012;8(14):246-257.
9. Olubode OO, Odeyemi OM, Aiyelaagbe IOO. Influence of environmetal factors and production pratices on the growth and productivity of pawpaw (*Carica papaya* L.) in the south western Nigeria – A review. Fruits. 2016;71(6): 341-361.
10. Grego CR, Vieira SR, Xavier MA. Spatial variability of some biometric attributes of sugarcane plants (variety IACSP93-3046) and its relation to physical and chemical soil attributes. Bragantia. 2010;69:107-119.
11. Martin TN, Pavinato PS, Lorentz LH, Zielinski RP, Refatti R. Spatial distribution of sunflower cultivars and the relationship between growth features. Revista Ciência Agronômica, Fortaleza, CE. 2012; 43(2):338-345.
12. Lima ES, Montanari R, Lovera LH, Ferrari S, Silva TS, Queiroz HA. Spatial correlation of productive component for peach palm crop and some physical atributes of Eutrochrept soil. Agrária–Revista Brasileira de Ciências Agrárias. 2016;11(3):163-170..
13. Almeida LS, Guimarães EC. Use of geostatistics in the sustainable management of coffee tree gall nematodes. Coffee Science. 2017;12(4): 471.
14. Fonseca AS, Lima DA, Silva JSDS, Xavier SDA, Drumondneto AC, AP. Spatial variability of the productivity and the nutritional condition of coffee canephora. Coffee Sicence. 2015;10(4): 420–428.
15. Lima JSS, Costa FP, Xavier AC, Oliveira RB, Silva SA. Spatial and temporal variability of the productivity of Cofee canephora. Coffee Science. 2014;3:400–407
16. Santos RO, Franco LB, Silva SA, Sodré GA, Menezes AA. Spatial variability of soil fertility and its relation with cocoa yield. Bras. Eng. Agríc. Ambiental. 2017; 2121(22):88–93
17. Lima JSSL, Alves DI, Coelho RI, Sturiao WP, Silva SA. Spatial variability in the diagnosis of nutritional status in the papaya. Revista Ciência Agronômica, Fortaleza, CE. 2016;47(2):264-274.
18. Lima JSS, Sturiao WP, Gontijo I, Silva SA. Spatial distribution of physical atributes of an ultisol under papaya crop. Comunicata Scientiae. 2017;8(4):526-536.
19. Alvares CA, et al. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift. 2013;22(6): 711–728.
20. Instituto Capixaba De Pesquisa, Assistência Técnica E Extensão Rural - INCAPER. Boletim agroclimático de São Mateus-ES. Available:http://hidrometeorologia.incaper.es.gov.br (Accessed on 20 Jun 2017).
21. Empresa Brasileira De Pesquisa Agropecuária- Embrapa. Sistema brasileiro de classificação de solos. Rio de Janeiro: Embrapa/CNPSo. 2006;306.
22. Prezotti LC, Gomes JA, Dadalto GG Oliveira JA. (Eds.). Manual of recommendation of liming and fertilization

for the state of Espírito Santo. 5th approx. Victory: INCAPER. 2007;305.
23. Martins D, Dos S, Costa A. De FS. (Eds). The culture of papaya: Production technologies. Victory: INCAPER; 2003.
24. Alves FL, Pacova BEV, Galveas PAO. Selection of papaya matrix plants, soil group, for seed production. In: Martins D, Dos S, Costa AFS. The culture of papaya: Production Technologies. Victory: INCAPER. 2003;105-115.
25. Costa AFS, Pacova BEV. Characterization of cultivars, strategies and perspectives of the genetic improvement of papaya. In: Martins DS, Costa AFS. The culture of papaya: Production technologies. Victory: INCAPER. 2003;59-103.
26. Ritzinger CHSP, Souza JS. (Org.) Papaya: Phytosanitary. Cross of souls: EMBRAPA. 2000;91.
27. Kerry R, Oliver MA. Determining the effect of asymmetric data on the variogram II Outiliers. Computers & Geosciences, New York, USA. 2007;33:1233-1260.
28. Kitamura AE, Carvalho MP, Lima CGR. Relation between the spatial variability of soil size fractions and bean productivity under no - tillage. Brazilian Journal of Soil Science, Viçosa, MG. 2007;31:361-369.
29. Journel AG, Huijbregts CJ. Mining geoestatistics. London: Academic Press. 1991;600.
30. Cambardella CA, et al. Field-scale variability of soil properties in central Iowa soils. Soil Science Society American Journal. 1994;58:1501-1511
31. GS+: Geostatistics for environmental sciences. 7.ed. Michigan: Plainwell, Gamma Desing Software. 2004;159.
32. Almeida FT, et al. Growth and yield of papaya under irrigation. Scientia Agricola, 2003;60(3):419-424.
33. Oliveira AMG, Caldas RC, Medina VM, Oliveira GXS, Quadros WS. Desenvolvimento vegetativo e qualidade dos frutos de mamoeiro Sunrise Solo em função de doses de nitrogênio, fósforo e potássio. Magistra, Cruz das Almas, BA. 2007;19: 69-75.
34. Pimentel-Gomez F, Garcia CH. *Estatística aplicada a experimentos* agronômicos e florestais: Exposição com exemplos e orientações para uso de aplicativos. Piracicaba: FEALQ. 2002;309.
35. Pias OHC, Damian JM, Cherubin MR, Santi AL. Biometric variables and productive attributes of wheat: Mapping and correlation among variables. Revista de Ciências Agroveterinárias, Lages. 2016; 15(3):227-236.
36. Vieira SR. Geoestatística em estudos de variabilidade especial do solo. In: Novais, PF, Alvares VH, Schaefer CEGR. Tópicos em ciência do solo, Viçosa: SBCS. 2000; 1:1-54.
37. Kist H, Manica I. Densidade de plantio, crescimento e produção do mamoeiro formosa (*Carica papaya* L.) em Porto Lucena RS. Pesquisa Agropecuária Brasileira, Brasília DF. 1995;30(5):657-666.
38. Aquino GS, Medina CC. Productivity and biometric and physiological indices of sugarcane grown under different amounts of straw. Pesq. agropec. bras. Brasília. 2014;49(3):173-180.
39. Gazolla-Neto A, Fernandes MC, Vergara RO, Gadotti GI, Villela FA. Spatial distribution of the chemical properties of the soil and of soybean yield in the field. Revista Ciência Agronômica. 2016;47(2): 325-333.
40. Lindblom J, Lunsdtröm C, Ljung M, Jonsson A. Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. Precision Agriculture. 2017;18:309–331.
41. Borghi E, Avanzi JC, Bortolon L, Luchiari Junior A, Bortolon ESO. Adoption and use of precision agriculture in Brazil: Perception of growers and service dealership. Journal of Agricultural Science. 2016;8(11).

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