ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.21, n.2, p.94-99, 2017
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v21n2p94-99

Management zones in coffee cultivation

João L. Jacintho[1], Gabriel A. e S. Ferraz[2], Fabio M. da Silva[2] & Sthéfany A. Santos[2]

[1] Instituto Federal do Norte de Minas Gerais/Campus Araçuaí. Araçuaí, MG. E-mail: joao.jacintho@ifnmg.edu.br (Corresponding author)
[2] Universidade Federal de Lavras/Departamento de Engenharia. Lavras, MG. E-mail: gabriel.ferraz@deg.ufla.br; famsilva@deg.ufla.br; sthefanyairane@engagricola.ufla.br

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Key words:
Coffea arabica L.
precision agriculture
yield
thematic mapping

ABSTRACT

This study aimed to apply precision agriculture techniques in coffee production, using correlation analysis in the definition of management zones. This work was carried out in a 22-ha area of coffee (*Coffea arabica* L.), cv. 'Topázio MG 1190', which was sampled on a regular grid, using a topographic GPS, totaling 64 georeferenced samples (on average, 2.9 points per ha). Descriptive analysis was used in the data, followed by Pearson's correlation analysis at 0.05 significance between soil chemical attributes, agronomic characteristics of the plants and altitude. It was possible to verify the correlation of soil chemical attributes, agronomic characteristics of the plants and altitude with coffee yield. Altitude was the variable most correlated with coffee yield through correlation analysis. Therefore, it was chosen as the best variable to define management zones and thematic maps capable to support coffee farmers. Three maps were generated to characterize the area in two, three and four management zones. There was a direct influence on mean yield.

Palavras-chave:
café
agricultura de precisão
produtividade
mapeamento temático

Definição de zonas de manejo para cafeicultura

RESUMO

Objetivou-se, com o presente estudo, aplicar técnicas de agricultura de precisão no cultivo do café utilizando análise de correlação na definição de zonas de manejo. O trabalho foi desenvolvido em uma área de 22 ha de lavoura de cafeeiro (*Coffea arabica* L.) da cultivar Topázio MG 1190. Demarcou-se na área em estudo e com a utilização de GPS topográfico, uma malha amostral regular totalizando 64 pontos amostrais georreferenciados (em média 2,9 pontos por ha). Utilizou-se o método de análise descritiva dos dados seguido da análise de correlação de Pearson a 0,05 de significância entre os atributos de solo, características agronômicas da planta e altitude. Foi possível verificar a correlação dos atributos do solo, das características agronômicas das plantas e da altitude com a produtividade. Através da análise de correlação observou-se que a altitude foi a variável que mais se correlacionou com a produtividade sendo, assim, selecionada como variável mais propícia para geração de zonas de manejo e de mapas temáticos capazes de auxiliar os cafeicultores. Foram gerados três mapas que caracterizam a área em duas, três e quatro zonas de manejo. Verificou-se que houve influência direta na média da produtividade.

Ref. 027-2016 – Received 21 Mar, 2016 • Accepted 18 Nov, 2016 • Published 5 Jan, 2017

INTRODUCTION

According to Ferraz et al. (2012), coffee is one of the most important crops for the Brazilian economy and the deep knowledge on all management steps of this crop is of great relevance for the success of its production.

Precision Agriculture (PA) allows to monitor production, quality and quantity of the agricultural production and also allows the better use of resources, maintaining the quality of the environment and enhancing yield (Gebbers & Adamchuk, 2010). According to Silva et al. (2008), the methods and equipment for the adoption of PA are already well known for the cereal crops. For coffee cultivation, the same cannot be said, since there are gaps to be filled.

According to Molin et al. (2010), coffee is one of the few agricultural products whose price is based on qualitative parameters and its value suffers significant variations as its quality increases. Considering the necessity of qualitative and quantitative improvements in coffee production, new methods to increase the efficiency of this production system must be elaborated and new management techniques must be used (Lima et al., 2013).

One of the obstacles in the application of PA techniques to increase yield and environmental quality is the definition of management zones - planting areas where inputs are dosed, generating economic return or reduction of environmental impacts (Jaynes et al., 2005), offering advantages in the management and administration of planting areas.

This study aimed to apply PA techniques in coffee cultivation using the correlation analysis in the definition of management zones, a methodology little used for this crop and of great importance for its producers.

This study aims to select, specifically, the variable most favorable for the definition of management zones and generate maps that assist crop management and decision-taking and also contribute to spreading PA techniques in the coffee crop, as well as contribute to the expansion in the use of management zones in agriculture.

MATERIAL AND METHODS

The field experiment was carried out at the Brejão Farm, located in the municipality of Três Pontas, southern Minas Gerais, Brazil, in a 22-ha area of coffee cultivation (*Coffea arabica* L.), cultivar Topázio MG 1190, transplanted in December 2005, at the spacing of 3.8 m between rows and 0.8 m between plants, totaling 3289 plants ha^{-1}. The central point of the area is located at the geographic coordinates of 21° 25' 58" S and 45° 24' 51" W. The maximum altitude of this area is 914.7 m. The limit points of the area were obtained using a topographic GPS (Topcon FC 100).

The soil of the area was classified as clayey dystrophic Red Latosol and the local climate is characterized as mild, tropical of altitude, with moderate temperatures, hot and rainy summer, classified as Cwa according to Köppen's classification. Based on Precision Agriculture, the management imposed on the area in the seasons of 2007/2008 and 2008/2009 was differentiated fertilization, as described by Ferraz et al. (2011); in the other seasons, fertilization was performed in the conventional way.

A regular sampling grid was delimited in the studied area using a Topcon FC 100 topographic GPS (mean error of 10 cm), with points spaced by 57 x 57 m, totaling 64 georeferenced sampling points (on average, 2.9 points per ha). Each sampling point corresponded to four plants: two plants located in the coffee row where the point was georeferenced, and other two plants located in each lateral row at the reference point.

Soil samplings were performed in June 2011, by collecting subsamples under the crown projection in the layer of 0-20 cm, using a Dutch auger, in each plant composing the sampling point. These subsamples were homogenized to form a composite sample representative of the point in question and sent to the Laboratory of Soil Analysis of the Department of Soil Science of the Federal University of Lavras. The following soil chemical attributes were evaluated: pH, availability of phosphorus (P) (Mehlich 1 extractor), remaining P (Prem), availability of potassium (K) (Mehlich 1 extractor), Exchangeable Calcium (Ca^{2+}) (Extractor: 1 mol/L KCL), Exchangeable Magnesium (Mg^{2+}) (Extractor: 1 mol/L KCL), Exchangeable Acidity (Al^{3+}) (Extractor: 1 mol/L KCL), Potential Acidity (H + Al) (Extractor: SMP), Aluminum saturation (m), Potential CEC (T), Effective CEC (t), Sum of bases (SB), Base saturation (V) and Organic matter (OM), following the methodology described by Lopes & Alvarez V. (1999).

In July 2011, five attributes related to the plant were measured: yield, maturation index, leaf retention, plant height and crown diameter.

Coffee yield (L plant^{-1}) was obtained through manual harvest on cloths of the four plants around the sampling point and the volume harvested from each plant, after shaking, was measured in a graduated container (L). After this measurement, the mean production of these four plants was obtained, resulting in the value of yield for the sampling point.

After the yield measurements, the detached fruits from the set of four plants forming this point were placed in a same container and homogenized; then, a 0.5-L sample of fruits was collected (Silva, 2008). This volume was used for the count of fruits for each maturation stage (dry, overripe, cherry and green), transforming it into percentage to use in the calculation of the maturation index, described by Alves et al. (2011).

Leaf retention was evaluated using the visual scale proposed by Boldini (2001) in which variations occur from 0 to 20, 21 to 40, 41 to 60, 61 to 80 and 81 to 100%.

In the set of plants forming the sampling point, plant height and crown diameter were measured using a ruler graduated in millimeter. Plant height was obtained considering the distance from the upper part of the plant to the soil surface. Crown diameter corresponded to the measurement of the longest branch. Subsequently, plant height and crown diameter for each sampling point were measured in meters.

Following the method proposed by Bazzi et al. (2013) to identify the attributes used to generate the management zones, it was verified which variables had highest correlation with yield, ordering them according to the highest values of correlation, i.e., variables with highest correlation are better candidates to define management zones. Among the variables that showed correlation with each other, those with highest absolute correlation with yield were selected. Considering that there was correlation between them, the variable of highest absolute value was selected to generate management zones.

The management zones were defined using the variable that was most correlated with yield. The intervals between groups were defined in identical intervals so that the predicted values of this interval are the same for each area, according to the number of zones. Maps of two, three and four management zones were generated for each selected variable, to verify the behavior of mean yield per grouped regions.

Results and Discussion

The descriptive analysis of soil chemical attributes and the agronomic characteristics of the coffee crop are shown in Table 1.

Gomes & Garcia (2002) claim that the magnitude of the coefficient of variation (CV) of an attribute is able to classify its variability, which can be: low, when below 10%; moderate, between 10 and 20%; high, between 20 and 30% and very high, when above 30%. The variables altitude, plant height, crown diameter, leaf retention and pH showed low CV. The variables CEC(T) and OM showed moderate CV. The variables maturation index, H+Al and CEC(t) showed high CV. The variables P, K, Ca, Mg, Al^{+3}, SB, V, m, Prem and yield showed a very high CV. The CV of the altitude, although considered as low, is similar to that found by Bazzi (2011). The results referring to the variables pH, H + Al, Al^{+3}, Ca and Mg are similar to those reported by Santos et al. (2014). The result of the variable SB is similar to that observed by Silva et al. (2010). The result of the variables P, K, T, m and OM is similar to that found by Silva & Lima (2012). The result of the variables plant height and yield is similar to that reported by Carvalho et al. (2013), and the yield was also similar to that found by Fonseca et al. (2015).

Table 1. Descriptive analysis of soil chemical attributes and agronomic characteristics of the coffee crop

Attributes	Minimum	Mean	Maximum	SD	CV
Altitude (m)	884.66	903.16	914.66	7.31	0.81
Plant height (m)	1.67	1.92	2.16	0.09	4.77
Crown diameter (m)	1.54	1.73	1.92	0.09	5.12
Maturation index (%)	8.21	64.04	90.77	19.01	29.69
Leaf retention (%)	78.75	87.46	95.00	3.21	3.67
Acidity (pH)	4.10	4.79	5.90	0.37	7.80
P (mg dm^{-3})	1.71	9.33	107.11	14.92	159.83
K (mg dm^{-3})	42.12	103.37	199.68	31.90	30.86
Ca (cmol$_c$ dm^{-3})	0.20	1.15	3.20	0.72	62.54
Mg (cmol$_c$.dm^{-3})	0.10	0.22	0.90	0.15	68.57
Al^{+3} (cmol$_c$ dm^{-3})	0.10	0.81	1.80	0.48	58.60
H + Al (cmolc dm^{-3})	2.90	6.95	12.28	2.03	29.17
SB (cmol$_c$ dm^{-3})	0.41	1.63	4.51	0.91	55.50
t (cmol$_c$ dm^{-3})	1.75	2.45	4.61	0.55	22.44
T (cmol$_c$ dm^{-3})	5.99	8.58	12.68	1.38	16.09
V (%)	3.22	20.39	60.91	13.12	64.33
m (%)	2.17	36.52	81.52	23.12	63.32
Organic matter (dag kg^{-1})	1.64	2.77	4.60	0.46	16.64
Prem (mg L^{-1})	3.92	9.71	16.88	2.97	30.55
Yield (L plant^{-1})	1.40	4.26	7.45	1.42	33.27

Minimum - Minimum value; Maximum - Maximum value; SD - Standard deviation; CV - Coefficient of variation; m – Aluminum saturation; T – Cation exchange capacity; V – Base saturation; t – Effective cation exchange capacity

Using all variables altitude, plant height, crown diameter, maturation index, leaf retention, P, K, Ca, Mg, pH, Al^{+3}, H + Al, SB, CEC(t), CEC(T), V, m, OM and Prem] and yield as the main variable, it was possible to apply Pearson's correlation analysis (Table 2).

The analysis evidenced that the variables plant height, maturation index, leaf retention, H + Al, CEC(T), OM and Prem were not correlated with yield. It was possible to observe correlation between yield and the variable altitude, crown diameter, pH, P, K, Ca, Mg, Al, SB, CEC(t), V and m.

The correlation with yield was negative for the variables altitude, P, Al and m, indicating that, while their values decreased, the value of yield increased. The others showed positive correlation, indicating that, as their contents increased, the values of yield increased.

In order to select the layers to generate the management zones, the variables plant height, maturation index, leaf retention, H + Al, CEC(T), OM and Prem were eliminated, because they were not correlated with yield.

Then, it was verified which variables (among those which were significantly correlated with yield) were correlated with each other. The variable altitude was correlated with the variables pH, Ca, Al, SB, V, m and Prem, showing a higher absolute value of correlation with yield, compared with all of them.

The variable altitude proved to be the best option through the correlation analysis and was selected to generate the management zones. The categorization of the management zones considered the identical division in the interval of

Table 2. Correlation matrix of the studied variables

Variable	Altitude	Crown diameter	pH	P	K	Ca	Mg	Al	SB	CEC(t)	V	m	Yield
Altitude	1												
Crown diameter	0.069	1											
pH	-0.299*	0.039	1										
P	0.230	0.005	-0.229	1									
K	-0.171	-0.024	0.720*	-0.236	1								
Ca	-0.270	0.004	0.918*	-0.172	0.646*	1							
Mg	-0.116	0.047	0.860*	-0.113	0.640*	0.853*	1						
Al	0.303*	0.079	-0.900*	0.162	-0.591*	-0.862*	-0.733*	1					
SB	-0.249*	0.009	0.935*	-0.176	0.708*	0.995*	0.900*	-0.864*	1				
CEC(t)	-0.147	0.083	0.761*	-0.151	0.655*	0.884*	0.848*	-0.557*	0.899*	1			
V	-0.254*	0.005	0.946*	-0.154	0.686*	0.971*	0.908*	-0.895*	0.982*	0.842*	1		
M	0.320*	0.092	-0.913*	0.203	-0.665*	-0.903*	-0.744*	0.978*	-0.899*	-0.635*	-0.910*	1	
Yield	-0.453*	0.253*	0.383*	-0.261*	0.327*	0.386*	0.308*	-0.328*	0.386	0.352*	0.333*	-0.355*	1

* significant

minimum and maximum values of the samples and the regions were classified and referred to as zones of "low" and "high" values, for two management zones, zones of "low", "medium" and "high" values, for three management zones and "low", "between low and medium", "between medium and high" and "high", for four management zones, since the variable altitude showed significant correlation with various attributes related to soil chemical characteristics. The descriptive statistics of yield was verified by the zones defined by altitude in two, three and four management zones (Table 3). It should be pointed out that the correlation between yield and altitude was negative, and the mean yield was higher in the zone of low altitudes and lower in the zones of higher altitudes.

When two management zones were defined using the variable altitude, the zone considered as of low altitude (between 884.66 and 898.64 m) concentrated 20 samples (31.25%) in an area of 5.3 ha, while the zone of higher altitudes (between 900.27 and 914.66 m) concentrated 44 samples (68.75%) in an area of 15.9 ha.

The CV of the variable yield was considered as high (23%) in the zone of low altitudes and as very high (35%) in the zone of high altitudes. The mean yield was 5.14 L plant^{-1} in the zone of lower altitudes and 3.86 L plant^{-1} in the region of higher altitudes.

When three management zones were defined using the variable altitude, the zone considered as of low altitude (between 884.66 and 892.63 m) concentrated 6 samples (9.38% of the total) in an area of 1.84 ha, the zone of medium altitudes (between 894.98 and 904.12 m) concentrated 29 samples (45.31% of the total, in an area of 9.34 ha), as well as the zone of higher altitudes (between 905.12 and 914.66 m), concentrating 29 samples in 10 ha.

The CV values of the variable yield were considered as high in the zones of low and medium altitudes (24 and 26%, respectively) and as very high (36%) in the zone of high altitudes. The mean yields were equal to 5.22, 4.81 and 3.52 L plant^{-1}, for regions of low, medium and high altitudes, respectively.

Using four management zones based on the variable altitude, the zone considered as of low altitude concentrated 5 samples (7.81% of the total) in an area of approximately 1 ha; the zone of altitudes between medium and low concentrated 15 samples (23.44% of the total) in an area of 4.3 ha; the zone of altitudes between medium and high concentrated 20 samples (31.25% of the total) in an area of 8.5 ha and the zone of higher altitudes concentrated 24 samples (37.50% of the total) in an area of 7.4 ha.

The CV value of the variable yield in the zone of low altitudes was considered as moderate (12%); in zones of altitudes between low and medium, and between medium and high, it was considered as high (26 and 28%, respectively) and, in the zones of high altitudes, very high (38%). The mean yields were equal to 5.66, 4.97, 4.35 and 3.46 L plant^{-1}, for regions of low, between low and medium, between medium and high and high altitudes, respectively.

The software ArcGIS was used to interpolate two points according to their values of altitude, crown diameter and phosphorus, based on the mathematical model called "inverse of the distances", i.e., the model assumes that, the closer two points are, the higher the probability of correlation between them. Then, the result was classified into two, three and four categories.

The maps of management zones of the variable altitude are presented in Figure 1 (A, B and C). In the management zones generated using the variable altitude, it is possible to observe that the groups were more delimited when two and three classes were considered, although in the first map (Figure 1A) the class of higher altitudes separates the class of lower altitudes geographically and despite the slight invasion of sub-plots of different zones, which can be observed in the northwestern portion of the map. The map generated for four management zones (Figure 1C) showed behavior similar to that of the first map, with subgroups aligned in different zones. These results are similar to those reported by Santos et al. (2003), who evaluated potential management zones in a 40-ha area cultivated with rainfed maize using soil-plant-climate patterns.

It is recommended to use maps of two and three management zones based on the values of altitude, since this variable is correlated with the variables pH, Ca, Al, SB, V, m and Prem. Molin & Castro (2008), delimiting management zones using electrical conductivity and soil chemical attributes, understood that maps generated with up to three management zones have a reasonable number of regions for practical applications.

According to Ronquim (2010), pH provides indications about the chemical conditions of a soil and, when it has low pH values (high acidity), it is usually poor in bases, with high content of aluminum and deficiency of some micronutrients. The macronutrients Ca and Al are constituents of the minerals and organic matter of the substrate where the plant develops and are also found dissolved in the soil solution. The sum of bases (SB) presents itself as an indication of the general conditions of soil fertility. Base saturation (V) can indicate the amount of cations, such as Ca, Mg, K, and identify if the soil is acidic at a level that is harmful to the crop. The calculation of Al saturation (m) is considered as the most correct form to evaluate Al toxicity in the soil. According to Rampim et al. (2013), the remaining phosphorus (Prem) allows to

Table 3. Descriptive statistics of coffee yield with the variable altitude for two, three and four management zones

Number of zones	Type of zone	Minimum	Maximum	Mean	SD	Var	CV
Two	Low	3.02	7.45	5.14	1.21	1.45	0.23
	High	1.40	7.27	3.86	1.34	1.78	0.35
Three	Low	3.02	6.75	5.22	1.24	1.54	0.24
	Medium	2.82	7.45	4.81	1.25	1.57	0.26
	High	1.40	6.70	3.52	1.26	1.60	0.36
Four	Low	4.88	6.75	5.66	0.69	0.48	0.12
	Low-Medium	3.03	7.45	4.97	1.31	1.71	0.26
	Medium-High	2.83	7.28	4.35	1.20	1.45	0.28
	High	1.40	6.70	3.46	1.33	1.76	0.38

SD - standard deviation; Var - variance; CV - coefficient of variation

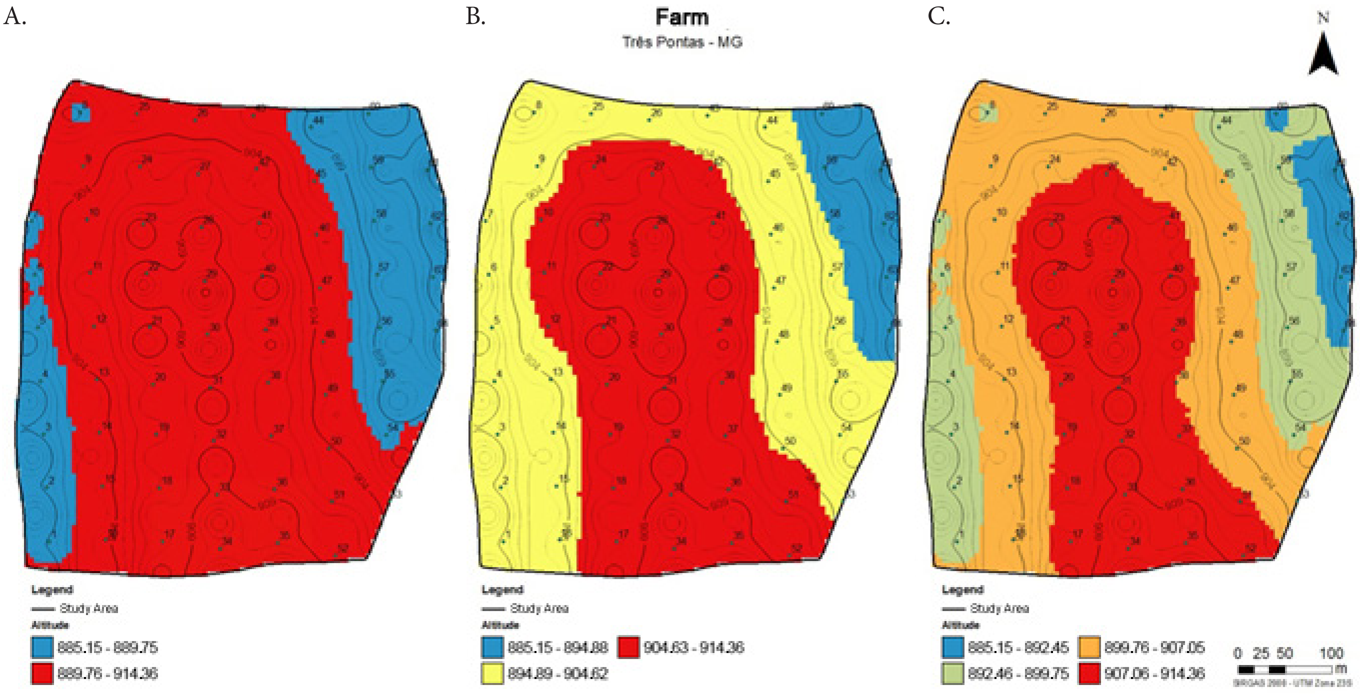

Figure 1. Management zones based on the variable altitude in: (A) two zones, (B) three zones and (C) four zones

define a dose of P and/or S necessary for physicochemical determinations.

Since all variables correlated with the altitude and yield are directly related to fertility and amount of nutrients in the soil, the maps recommended for use provide the producer with a tool capable of reducing the amount of samples for future analyses, because they show sub-regions with homogeneous characteristics in their attributes. It should be pointed out that delimiting management zones is a dynamic action and can be influenced by the annual management of the coffee crop and by the variable adopted in its definition.

CONCLUSIONS

1. It was possible to verify the correlation of soil and plant attributes with yield and select those that were conducive to the definition of management zones in the coffee crop.

2. It was possible to define management zones with the variable altitude, which was most correlated with yield, and observe the correlation of mean yields in these zones.

3. It was possible to elaborate management zones for the coffee crop based on soil and crop data, using interpolation tools to improve crop management and the rational use of resources.

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