

Spatial variability of soil fertility attributes and productivity in a coffee crop farm

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Abstract. Coffee cultivation is of great importance to Brazilian agribusiness, as coffee occupies extensive production areas and is one of the most exported Brazilian products. To maintain coffee production numbers, productive techniques must be adopted that optimize productive system use. The objective of this work was to apply geostatistical techniques in the evaluation of soil fertility attributes to construct maps of variability in soil fertility parameters and the productivity of a coffee crop in the municipality of Monte Carmelo, Minas Gerais (MG), Brazil. The work was developed with coffee of the cultivar Mundo Novo 379/19, and 19 sample points were georeferenced in Universal Transverse Mercator coordinates. Spatial dependence of the fertility and productivity parameters was analysed via classic semivariogram fitting and interpolation by ordinary kriging using the statistical computer system, R. All parameters evaluated showed high degrees of spatial dependence. The attribute values varied along the sampling points, except for the sodium (Na) contents, which had similar values in all samplings. The studied parameters ranged from 80 to 200 metres. It is conclusion, the use of productivity maps linked to soil chemical attributes can be useful for determining the occurrence of variable productivity rates throughout the area, allowing the adoption of corrective practices for subsequent crops and thus making the maps very useful tools for producers.

Key words: precision coffee cultivation, geostatistics, spatial maps, semivariograms.

INTRODUCTION

Coffee cultivation plays a prominent role in Brazilian agribusiness, with Brazil being the world's largest producer and exporter of the grain. To maintain the competitiveness of Brazilian coffee production, management practices must be adopted that better utilize environmental resources and consequently optimize productivity (Embrapa, 2017).

Soil fertility is a limiting factor for coffee productivity, and fertilizer recommendation practices become necessary to supply the nutrients that coffee demands (Costa, 2011).

Applying inputs locally at variable rates by adopting precision agricultural techniques has attracted much research. Productive fields have highly variable soil attributes, and the conventional recommendation system assumes the homogeneity of a given area; the system thus recommends values that meet the needs of the crops (Tschiedel & Ferreira, 2002), which may be ineffective and may generate unnecessary expenses via purchasing fertilizers and reducing crop productivity.

This study used geostatistical techniques to correlate the soil fertility attributes with crop productivity in the municipality of Monte Carmelo, Minas Gerais (MG), Brazil, to construct spatial variability maps of these attributes.

MATERIALS AND METHODS

The experiment was conducted at the Sabana Grande farm in the municipality of Monte Carmelo, MG, Brazil, in an area covering 10 hectares cultivated with coffee (*Coffea arabica* L.) of the cultivar Mundo Novo 379/19, planted with spacing 4.5 x 0.5 meters. The area is between the geographical coordinates 18°40'05"S latitude and 47°31'48"W longitude.

According to Koppen classification, modified by Alvares et al. (2013), the climate at the site is Aw, classification of tropical climate with dry winter, with an average annual temperature of 21 °C and average rainfall of 1,444 mm. The area has an average altitude of 1,000 meters above sea level. The soil in the area is classified as Dystroferic Red Latosol, according to the Brazilian Classification of Soils - SiBCS (Embrapa, 2018), with Latosols being equivalent to Ferralsols e Oxisols, with WRB and Soil Taxonomy respectively.

To collect soil samples for the soil fertility analysis, 19 sample points were georeferenced using a global positioning system (GPS) model Garmin. At each point, 1 point per half hectare samples were collected at 0.0–0.2 m deep. The samples were analysed by the Laboratório Brasileiro de Análises Agrícolas Ltda. (LABRAS) in Monte Carmelo, MG, Brazil. The following parameters were analysed: soil pH in water, available: phosphorus (P - mg dm⁻³), sodium (Na - cmol_c dm⁻³), potassium (K - cmol_c dm⁻³), calcium (Ca - cmol_c dm⁻³), magnesium (Mg - cmol_c dm⁻³), aluminium (Al - cmol_c dm⁻³); acidity potential (H + Al - cmol_c dm⁻³), organic matter (OM – dag kg⁻¹), sum-of-bases (SB - cmol_c dm⁻³), cation exchange capacity (T - cmol_c dm⁻³), base saturation (V%) and Al saturation (m%).

To estimate coffee productivity, the fruits were harvested manually on cloths and measured in a graduated container in litres. Fruits were collected from plants around the georeferenced sampling point. From these plants, a mean was obtained for the sampling point.

Spatial dependence of the fertility and productivity parameters was analysed using classic semivariogram fitting and ordinary kriging interpolation. The classic semivariogram was estimated using the equation (1), according to Matheron (1963).

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

where $N(h)$ represents the number of pairs of values observed, $Z(xi)$ represents a value observed at a given point, and $Z(xi + h)$ represents the value observed at a 2nd point separated by a distance (h).

The semivariogram is a graph of $\hat{\gamma}(h)$ versus the corresponding values of h. The semivariogram model was fitted by ordinary least squares (OLS). Spherical, exponential, and Gaussian models were tested for all parameters. After fitting the semivariogram, data were interpolated by ordinary kriging to enable visualising the spatial distribution patterns of the plantation variables by building spatial maps.

For descriptive statistical and geostatistical analyses and mapping, the statistical computer system, R, (R Development Core Team, 2017) was used through the geoR library (Ribeiro Junior & Diggle, 2001). The maps were generated from data in Universal Transverse Mercator (UTM) coordinates in Zone 23K, which is the municipality of Monte Carmelo, MG, Brazil.

RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics for the variables soil chemical analysis of the study area. The attribute values varied along the sampling points except for the Na contents, which had similar values in all samplings.

Table 1. Descriptive statistics for soil chemical attributes

	Unit	SD	Mean	Maximum	Minimum	CV (%)
pH	(water)	0.22	5.50	5.90	5.00	4.00
P resin	mg dm ⁻³	14.34	34.36	62.00	13.90	41.73
Na	cmolc.dm ⁻³	0.00	0.01	0.01	0.01	0.00
K		0.08	0.26	0.43	0.12	31.14
Ca		0.36	1.88	3.00	1.46	19.17
Mg		0.24	1.32	2.07	0.94	18.20
Al		0.03	0.01	0.11	0.00	216.17
H+Al		0.99	4.35	6.60	2.90	22.75
MO	dag kg ⁻¹	0.36	2.95	3.82	2.45	12.19
SB	cmolc dm ⁻³	0.59	3.46	5.30	2.53	6.47
T		0.88	7.81	9.56	6.47	11.27
V	%	8.13	44.68	58.20	28.60	18.19
m		0.91	0.44	3.40	0.00	205.91
Prod	L/pl	2.74	13.76	18.80	10.00	19.93

The attributes varied throughout the study area as evidenced by their high coefficients of variation (CV). As evidenced by Silva et al. (2007), the pH had a low coefficient of variation. Per Gomes & Garcia (2002), data with coefficients of variation less than 10% show homogeneity in the readings, but where this variation occurs cannot be detected spatially using only the data presented in Table 1. Geostatistics are needed to construct spatial variability maps of the area under study and interpret them.

The model most commonly used to fit semivariograms in geostatistics (Webster & Oliver, 2007) and in studies involving soil science (Grego & Vieira, 2005) is the spherical model. Silva et al. (2007, 2008, 2010) and Faulin (2010) also fitted the spherical model to their data for studying coffee productivity and soil attributes.

The nugget effect is an important parameter in semivariograms because it corresponds to the data variability not explained by the model or that occurs at random and accounts for the distance (Mcbratney & Webster, 1986). The nugget effect may also be a consequence of sampling errors or attribute variations that cannot be detected with the sampling scale used (Vieira, 2000).

The relationship between the nugget effect and the semivariogram sill determines the degree of spatial dependence (Trangmar et al., 1985). Based on the degree of dependence classified by Cambardella et al. (1994), semivariograms with nugget effects that are 25% lower than the sill are considered to have high degrees of dependence. Further, when the percentage is between 25 and 75%, dependence is moderate, and when it is greater than 75%, dependence is weak. Table 2 shows that all evaluated parameters had strong degrees of spatial dependence, similar to the results of Machado et al. (2007) for the pH in water, Mg, and base saturation variables. Corá et al. (2004) found a moderate degree of dependence for all fertility attributes evaluated in their study on sugarcane.

Table 2. Estimated models and parameters of experimental semivariograms for soil fertility components and coffee crop productivity (L plant⁻¹). C0 (nugget effect), C1 (contribution), C0+C1 (sill), a (range), $[C0/(C0+C1)] \times 100$ (degree of dependence)

Parameters	Model	C0	C1	(C0 + C1)	a (m)	$[C0/(C0+C1)] \times 100$
pH in water	spherical	0.20	0.60	0.80	200.00	25.00
P	spherical	2.00	120.00	122.00	100.00	1.64
K	spherical	0.01	120.00	120.01	105.00	0.01
Ca	spherical	2.00	120.00	122.00	105.00	1.64
Mg	spherical	2.00	120.00	122.00	100.00	1.64
Al	spherical	2.00	120.00	122.00	100.00	1.64
H + Al	spherical	2.00	120.00	122.00	100.00	1.64
SB	spherical	0.00	120.00	120.00	105.00	0.00
T	spherical	0.10	0.80	0.90	80.00	11.11
V%	spherical	0.10	0.80	0.90	80.00	11.11
m%	spherical	0.10	0.80	0.90	80.00	11.11
productivity	spherical	2.00	120.00	122.00	100.00	1.64

Another parameter of considerable importance is the range of the semivariogram for determining the spatial dependence limit, which may also serve to delimit the interval between soil mapping units, where samples collected within the maximum extent of the range are spatially correlated (Grego & Vieira, 2005). The studied parameters ranged from 80 to 200 metres, with the lowest ranges obtained for the cation exchange capacity (T), base saturation (V%) and Al saturation (m%); soil pH had the largest range (Table 2).

Silva (2007) found that the ranges reached levels of 347.82 metres for K and 60.43 metres for productivity. The other variables, such as pH, Ca and SB, reached a range of 70 metres. Faulin obtained ranges similar to those of the present study for P and K. Ferraz et al. (2010) obtained spatial dependence values greater than 200 m for coffee productivity during a 3-year study.

The spatial variability of the soil attributes might be explained by pedogenetic process and by the different management practices, providing changes in physical, chemical, biological and mineralogical attributes, and direct impacts on crop

productivity (Silva et al., 2008). Thus, the study of spatial variability of soil acts as a tool for precision agriculture, which in the case of the coffee crop, as a tool for precision coffee cultivation (Ferraz et al., 2012).

The soil attributes required for coffee according to Alvarez et al. (1999) might be characterized goods for class intervals determined by limits of 6.1–7.0 for pH; 12.1–8.0 mg dm⁻³ for P; 71–120 mg dm⁻³ for K; 2.41–4.00 cmolc dm⁻³ for Ca; 0.91–1.50 cmolc dm⁻³ for Mg; 1.01–2.00 cmolc dm⁻³ for Al; 5.01–9.00 cmolc dm⁻³ for H + Al; 4.01–7.00 dag kg⁻¹ for OM; 3.61–6.00 cmolc dm⁻³ for SB; 8.61–15.00 cmolc dm⁻³ for the T; 60.1–80.0% for V and 50.1–75.0% for m.

Spatial maps were constructed of the variability in the studied attributes as shown in Figs 1, 2 and 3 which allowed visualising the spatial patterns of the attributes throughout the area.

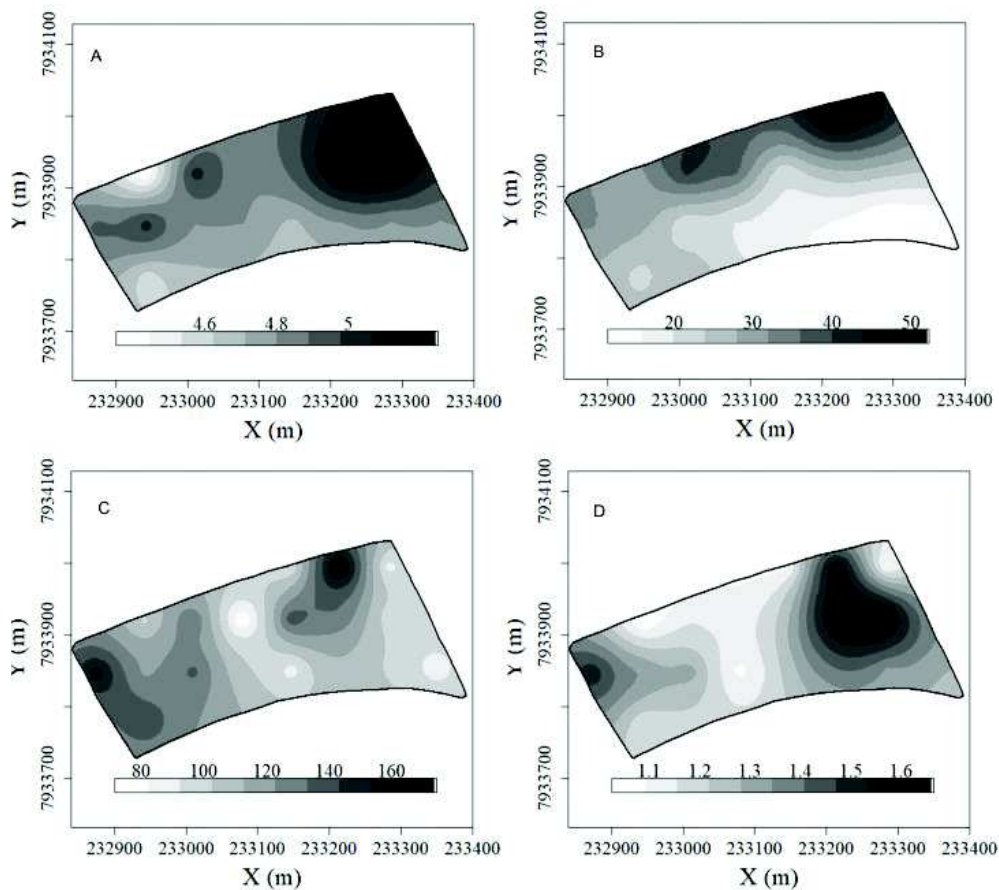


Figure 1. Maps of soil chemical attribute variability – A) pH, B) P mg dm⁻³, C) K mg dm⁻³ and D) Mg cmolc dm⁻³.

The pH plot (Fig. 1, A) shows that the east and northeast areas had the highest pH level values, which were near the ideal range for good coffee cultivation development and productivity. Soil pH is an important factor in soil fertility since the ideal range for good development of most crops is between 6.0 and 7.0; at values below this range,

nutrients are less available to plants (Luz et al., 2002). The use of conventional techniques, abstaining from the practice of precision agriculture, provides pH correction failure in this area of study with incorrect use of limestone in the implantation of the crop, which can explain the variation of the pH values.

Phosphorus is a macronutrient whose availability decreases at low pH because the phosphate anion is retained by the positively charged particles on the oxide surfaces (Zoz et al., 2009). Fig. 1, A shows that the soil pH was closest to neutral in the areas of the highest available P levels. The other nutrients were also more concentrated in the area's northeast region.

For the Al potential acidity (H + Al) (Fig. 2, C) and Al saturation (m%) (Fig. 3, C), the highest levels occurred at sites with higher soil acidity (low pH) because in acidic soil, Al is solubilized in the soil solution, thus increasing its concentration (Hartwig et al., 2007).

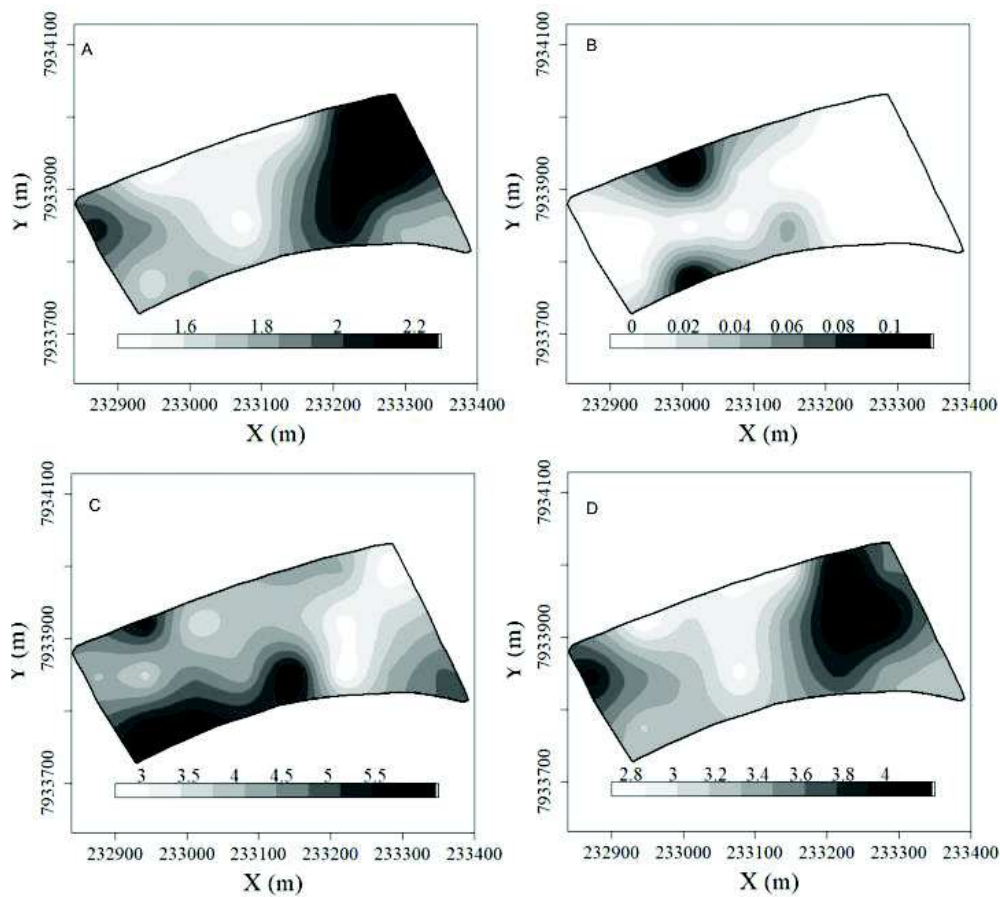


Figure 2. Maps of soil chemical attribute variability – A) Ca $\text{cmol}_c \text{dm}^{-3}$; B) Al $\text{cmol}_c \text{dm}^{-3}$; C) H+Al dag kg^{-1} and D) SB $\text{cmol}_c \text{dm}^{-3}$.

The average productivity in the area was 13.76 L plant⁻¹ (Table 1). The productivity map shows (Fig. 3, D) that the highest productivity occurred in the southeastern and southwestern areas. The other regions showed productivity values near the mean.

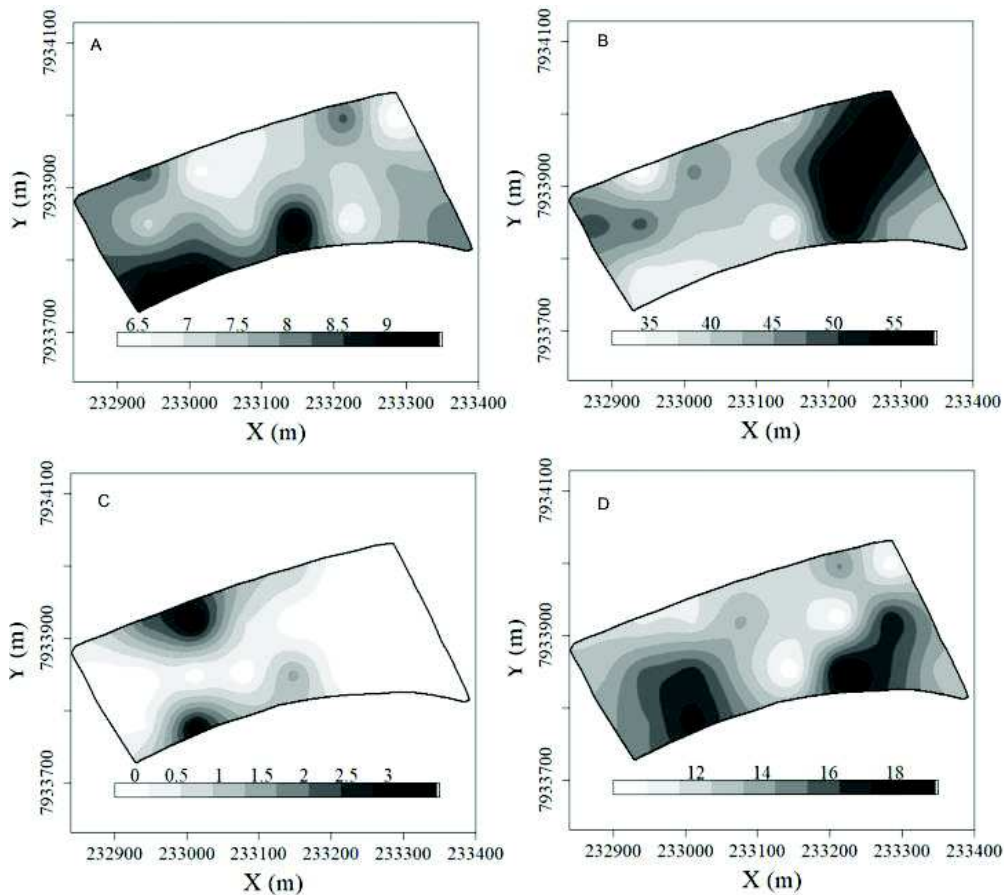


Figure 3. Maps of soil chemical attribute variability – A) T cmol_c dm⁻³; B) V (%); C) m (%) and D) coffee productivity (L pl⁻¹).

Procafé (2018) suggested that soil pH values between 5.0 and 6.0 present a medium nutritional level to the coffee. The pH variability map in Fig. 1 indicates that in every area under study, even when the observed values varied, all observations were within the medium range. Both P and Mg presented levels throughout the area that classified their nutritional levels as low, middle and high. Ca and K presented values in the low and medium nutritional ranges. Ferraz et al. (2012) also found P levels that fit all 3 fertility levels.

Productivity maps linked to soil chemical attributes may be useful for determining the occurrence of variable productivity rates throughout an area, allowing adoption of corrective practices for subsequent crops (Ferraz et al., 2017). The corrective practice most used within the context studied involved applying inputs at variable rates, which saves money for producers and allows greater application efficiency (Chang et al. 2003;

Wang et al., 2006). Ferraz et al. (2012) described the benefits of using spatial variability maps of soil fertility attributes since these maps enable easily identifying the locations where corrections and fertilizer application are necessary. These authors further described the problem of using the mean value to recommend soil fertilization.

CONCLUSIONS

Semivariograms allow characterization of the occurrence of spatial variability of the studied attributes and the variability maps are important tools for managing coffee production. The parameters that most strongly influenced coffee productivity were Ca and V in the southeast section and H + Al, SB and T in the southwest section.

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