

# SPATIAL VARIABILITY OF SOIL ACIDITY ATTRIBUTES AND LIMING REQUIREMENT FOR CONILON COFFEE

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**ABSTRACT:** The soils of Espírito Santo State are low natural fertility level, which frequently limit crop yields due to deficiencies of some soil elements, however, it presents high production potential. The purpose of this work was to describe the spatial variability of attributes related to soil acidity (pH, potential acidity, aluminum, calcium, magnesium), organic matter and liming requirement in a conilon coffee plantation (*Coffea canephora* Pierre) in a typical dystrophic Yellow Latosol (LAd). The study was carried out in a farm area, in the Northern part of the state of Espírito Santo, Brazil. The experimental area was 20 x 61.6 m (1.232 m<sup>2</sup>) in a regular grid where 60 samples were equally spaced in grids of 5.6 x 5 m, at a soil depth of 0-20 cm. All property semivariograms disclosure were satisfactorily described by spherical model with a moderate and strong spatial structure with ranges of spatial structure varying from 8.0 m to 33.58 m

**Index terms:** *Coffea canephora*, spatial distribution, geostatistics.

## VARIABILIDADE ESPACIAL DOS ATRIBUTOS DE ACIDEZ DO SOLO E NECESSIDADE DE CALAGEM PARA CAFÉ CONILON

**RESUMO:** Estudos que visem elucidar a variação espacial de atributos de solo podem contribuir para a aplicação racional de insumos, possibilitando ganhos econômicos e ambientais. Objetivou-se, no presente trabalho, descrever a variabilidade espacial dos atributos relacionado à acidez do solo (pH em água, acidez potencial, alumínio, cálcio e magnésio), matéria orgânica do solo e necessidade de calagem em uma lavoura de café conilon (*Coffea canephora* Pierre), localizada no Norte do estado do Espírito Santo. O experimento foi conduzido em uma lavoura de café conilon, plantada no espaçamento 1,8 x 1,0 m (5.555 plantas ha<sup>-1</sup>), em um Latossolo Amarelo distrófico típico (LAd). As análises de solo foram realizadas no Laboratório Agrônomo de Análise de Solo, Folha e Água no Centro Universitário do Norte do Espírito Santo da Universidade Federal do Espírito Santo. O presente estudo foi instalado em uma malha retangular de 20 x 61,6 m (1.232 m<sup>2</sup>). Em cada ponto amostral foram coletadas amostras de solo, na profundidade de 0,0 – 0,2 m, totalizando 60 pontos amostrais, distanciados de 5,6 m entre linhas e 5,0 m na linha de plantio, as fileiras da lavoura estão dispostas no sentido Norte-Sul.

**Termos para indexação:** *Coffea canephora*, distribuição espacial, geoestatística.

### 1 INTRODUCTION

The production of processed conilon coffee, one of the main cultures of the state of Espírito Santo, represents 75.2% of the national production, extending over an area of approximately 280 thousand hectares (COMPANHIA NACIONAL DE ABASTECIMENTO - CONAB, 2012). Soils in Espírito Santo are considered acidic, which associated to the low exchangeable Ca values, which reinforces the importance of planning lime application in growing areas. A survey of the fertility degree in the state of Espírito Santo showed that approximately 89% of the soils were classified as medium to high potential acidity, which explains the high contents of exchangeable Al<sup>3+</sup> in soils with medium to high potential acidity (PIRES et al., 2003).

However, there is a little information in relation to the spatial variability of attributes linked with soil acidity attributes in soils cultivated with conilon coffee.

In many agricultural regions, liming is a common and well established practice, both in conventional and conservation production systems. However, there is a common large spatial variability of the conditions of soil acidity, even in apparently homogeneous crop areas (HURTADO et al., 2009). According to Pierce and Novak (1999), in the calculation of the lime requirement, besides considering the soil buffer capacity and crop tolerance to soil acidity of the soil acidity attributes. This way, it is great the chance to have over liming in some parts of the land and use of limestone sub doses in other parts of the field.

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Geostatistics is a tool that allows continuous measurement of a variable of interest, in an entire field of study, showing spatial variation of chemical properties of soil by maps of variability. One of the major applications of geostatistics is the possibility of constructing thematic maps that allow the analysis of the study variable (LEMO FILHO et al., 2008). In the case of the management of fertilization of the culture of conilon coffee (*Coffea canephora* Pierre) in the state of Espírito Santo, spatial distribution of soil nutrients should be known, so that more efficient fertilization techniques, involving the determination of zones of different applications of inputs, are developed in coffee plantations.

Through the study of spatial variability, the grower can identify the precise location of areas of higher and lower yield (depending on the level of soil nutrient), by mapping the cultivation area. Therefore, it is possible to perform fertilization and the necessary soil acidity correction in the cultivation area, considerably reducing production costs and environmental impacts, and providing a significant contribution to the environment (FARIAS et al., 2003; OLIVEIRA et al., 2009).

Souza et al. (2007) studied the spatial variability of soil chemical parameters in a Oxisol cultivated with sugarcane crop, found that the need liming using the conventional method without considering the spatial variability of soil attributes was 1.5 t ha<sup>-1</sup>. In this situation, 72% of the study area receive liming rate above the required. However, when the variable rate application is adopted, there is a great saving in production cost. Oliveira et al. (2008) studied the spatial variability in a conilon coffee plantation, it was observed that when the spatial analysis was used, especially for the data concerning the soil acidity attributes, it was possible to identify areas of deficit or excess of limestone in the experimental field.

The purpose of this study was to describe the spatial variability of attributes related to acidity in soils (pH, H+Al, Al, Ca and Mg), the organic matter content and liming requirement in a conilon coffee plantation in São Mateus, state of Espírito Santo, Brazil.

## 2 MATERIAL AND METHODS

The study was carried out on a conilon coffee plantation, planted in 1.8 x 1.0 m spacing (5.555 plants ha<sup>-1</sup>), located in São Mateus, a county in the northern part of the state of Espírito Santo, Brazil.

The geographical coordinates are 18° 41' 58" South and 40° 03' 00" West, with an average elevation of 30 m. The soil was classified as typical dystrophic Yellow Latosol (LAd) (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA, 2006).

Soil analyses were performed in the Agricultural Laboratory of Soil Analysis (LAGRO) of Federal University of the Espírito Santo (UFES). A quadrangular mesh of 20 x 61,6 m (1.232 m<sup>2</sup>) with 60 sampled points distanced of 5,6 meters away from each other between the crop row and 5,0 meters in the crop row (Figure 1), the crop rows are arranged in north-south direction. A measuring tape was used to demarcate the sampling points. At each sampling site, four sub-samples of soil were collected in the crown projection area, forming a composite sample from 0-20 cm soil depth. In each soil sample, chemical analysis was made of the following chemical properties: pH, potential acidity, aluminum calcium, magnesium and organic matter, according to EMBRAPA (1997), the liming requirement was calculated according to Prezotti et al. (2007). For the calculation of the liming requirement, was used the base saturation method in order to elevate the value of base saturation until 60%, it was considered a limestone of 100% of PRNT.

When the coffee crop was formed, soil acidity correction was performed with the application of 2.000 kg ha<sup>-1</sup> of dolomitic limestone. In planting, for each meter of furrow, 5 kg of a tanned mixture in the proportions of 3:2 of straw coffee with chicken manure, besides 300 g of superphosphate. In the first year after planting (formation of conilon coffee crop), monthly fertilizations were done using a formulation of 25-00-25, with increasing doses of 20 g plant<sup>-1</sup> up to 50 g plant<sup>-1</sup>. Annual fertilizations from the second year after planting were divided into four applications of the formulation of 25-00-25, according to technical recommendations based on the soil analyses.

The results of the analysis of the samples underwent exploratory data analysis using descriptive statistics, to obtain the following parameters: arithmetic mean, median, sample variance, standard deviation, coefficient of variation, maximum and minimum values, spatial range and coefficient of skewness and kurtosis. The hypothesis of normality of data was tested by the Shapiro-Wilk test at 5% probability, using the statistical package SISVAR (FERREIRA, 2000).

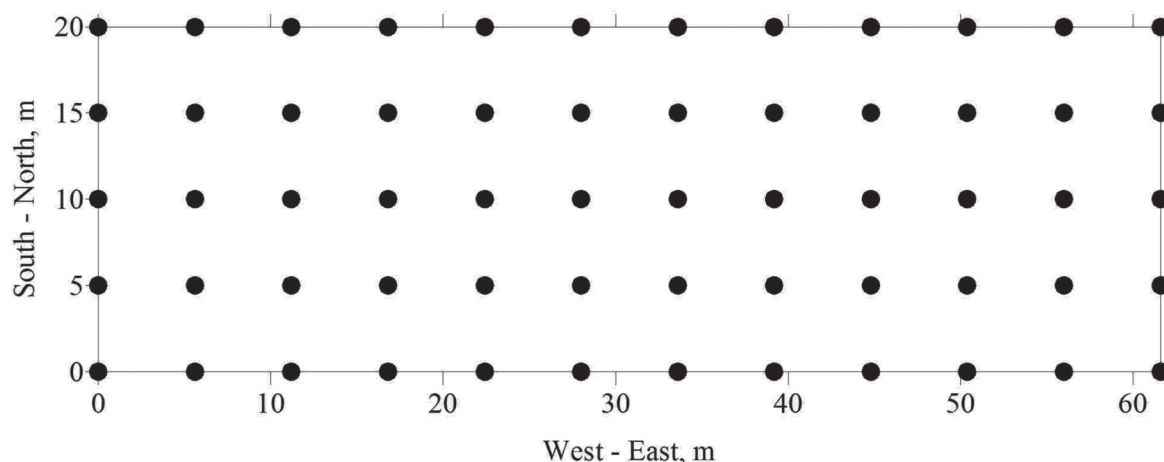


FIGURE 1 - Sampling grid in the experimental area, in meters.

Data were subjected to geostatistical techniques for the definition of the model of spatial variability of the soil attributes involved in this study. Then, the semivariograms and subsequently the mapping of each chemical attribute studied was obtained by kriging. The study of spatial dependence was made by geostatistics with the aid of GS<sup>+</sup>® Version 7.0 (GAMMA DESIGN SOFTWARE, 2004), which performs the calculations of sample semi-variances, whose expression can be found in Vieira et al. (1983), equation 1:

$$\gamma(h) = \frac{\sum_{i=1}^{n(h)} [z(x_i+h) - z(x_i)]^2}{2n(h)} \quad \text{Eq. (1)}$$

where:  $n(h)$  number of sample pairs  $[z(x_i); z(x_i+h)]$  separated by vector  $h$ , being  $z(x_i)$  and  $z(x_i+h)$ , numerical values observed for the analyzed attribute, for two points  $x_i$  and  $x_i+h$  separated by vector  $h$ .

The data were interpolated using the kriging technique, which uses the parameters of the semivariogram. In cases of doubt as to the model to be chosen for one semivariogram, the highest value of the correlation coefficient obtained by the cross-validation method and the smallest sum of the squares of residues (SSR) were considered. The spatial dependence ratio was calculated (GD), which is the percent of the nugget effect ( $C_0$ ) relative to the baseline ( $C_0+C$ ), given by equation 2:

$$GD = \frac{C_0}{C_0+C} 100 \quad \text{Eq. (2)}$$

According to Cambardella et al. (1994), spatial dependence can be classified into the following proportion: (a) strong dependence < 25%; (b) moderate dependence from 25 to 75% and (c) weak dependence > 75%.

Contour maps were constructed according to the classification for interpretation of the soil results (Table 1), according to Prezotti et al. (2007) for the state of Espírito Santo.

### 3 RESULTS AND DISCUSSION

The findings of the descriptive statistics are shown in Table 2. It can be seen that the mean and median values for pH, H+Al, Ca, Mg, OM and liming requirement are close, indicating symmetric distributions. For the variable aluminum, in turn, there is a greater distance between the mean and median values, which is an indication of asymmetric data distribution where the measures of central tendency are dominated by outliers. However, only the calcium and liming requirement showed normal distribution by the Shapiro-Wilk test at 5% probability. The average values of the studied attributes (Tables 1 and 2) were classified, according to Prezotti et al. (2007), into: low level for calcium (<1.5 cmol<sub>c</sub> dm<sup>-3</sup>) and magnesium (<0.5 cmol<sub>c</sub> dm<sup>-3</sup>) and average content for pH level in water (5.0 – 5.9), potential acidity (2.5 – 5.0 cmol<sub>c</sub> dm<sup>-3</sup>), aluminum (0.3 -1.0 cmol<sub>c</sub> dm<sup>-3</sup>) and organic matter (1.5 – 3.0 dag dm<sup>-3</sup>).

**TABLE 1** - Levels for interpretation of analytical results according to the classification of Prezotti et al. (2007).

	Low Level	Medium Level	High Level
pH as an indicator of soil acidity degree	6.0 – 6.9	5.0 – 5.9	< 5.0
H + Al (cmol <sub>c</sub> dm <sup>-3</sup> )	< 2.5	2.5 – 5.0	> 5.0
Al (cmol <sub>c</sub> dm <sup>-3</sup> )	< 0.3	0.3 – 1.0	> 1.0
Ca (cmol <sub>c</sub> dm <sup>-3</sup> )	< 1.5	1.5 – 4.0	> 4.0
Mg (cmol <sub>c</sub> dm <sup>-3</sup> )	< 0.5	0.5 – 1.0	> 1.0
OM (dag dm <sup>-3</sup> )	< 1.5	1.5 – 3.0	> 3.0

pH in water; H+Al – potential acidity; Al – exchangeable aluminium; Ca – exchangeable calcium; Mg – exchangeable magnesium; OM – soil organic matter.

**TABLE 2** - Descriptive statistics of data concerning pH level in water, potential acidity (H+Al), aluminum (Al), calcium (Ca), magnesium (Mg), soil organic matter (OM) and liming requirement (LR) obtained from 60 soil samples.

Descriptive Statistics	pH	H+Al	-----cmol <sub>c</sub> dm <sup>-3</sup> -----			OM dag dm <sup>-3</sup>	LR kg ha <sup>-1</sup>
			Al	Ca	Mg		
Mean	5.22	2.74	0.88	1.39	0.45	1.79	385.79
Median	5.20	2.90	0.30	1.35	0.40	1.90	411.99
SV	0.10	0.33	1.83	0.34	0.02	0.43	42250.03
SD	0.32	0.57	1.35	0.58	0.14	0.65	205.55
CV	6.1	20.8	153.4	41.7	31.1	36.3	53.3
Maximum	5.90	4.00	4.90	3.10	0.8	3.80	794.64
Minimum	4.70	1.70	0.10	0.50	0.2	0.40	0.0
Range	1.20	2.30	4.80	2.60	0.6	3.40	794.64
Skew.	0.0	0.03	1.77	0.36	0.04	0.44	-0.06
Kurt.	-1.05	-0.36	1.56	0.06	-0.37	1.23	-0.90
p-value	0.034 <sup>ns</sup>	0.015 <sup>ns</sup>	3.1 10 <sup>-11</sup> <sup>ns</sup>	0.823*	0.020 <sup>ns</sup>	0.025 <sup>ns</sup>	0.303*

SV – sample variance; SD - standard deviation; CV – coefficient of variation; Skew. – coefficient of skewness; Kurt. – coefficient of kurtosis; <sup>ns</sup> – not significant by the Shapiro-Wilk test at a 5% probability.

Exploratory data analysis using descriptive statistics shows that the variability of the chemical attributes of soil by the coefficient of variation (CV) was 153.4, 53.3, 36.3, 31.1, 20.8 and 6.1% for Al, OM, LR, Ca, H+Al, Mg and pH levels in water, respectively. The coefficient of variation (CV) was considered low for pH, medium for H+Al and OM and high for Al, according to the criteria proposed by Warrick and Nielsen (1980). Similar results were obtained by Zanão Júnior, Lana and Guimarães (2007) for pH, by Silva et al. (2007) for pH, Ca and Mg, by Guedes et al. (2008) for H+Al, by Silva et al. (2010) for H+Al and pH, Barbieri, Marques Júnior and Pereira (2008) for LR and by Marques Júnior et al. (2008) for OM. The high value of the coefficient of variation found

for aluminum can be explained by the anomalous distribution of data. Similar results were reported by Gomes et al. (2008) and Souza, Cogo and Vieira (1997).

The findings of geostatistical analysis (Table 3 and Figure 2) showed that all attributes related to soil acidity and liming requirement had spatial dependence, with cross-validation regression coefficient (c<sub>vr</sub>) varying between 0.263 and 0.898. The model that best fit the semivariograms of the majority of variables was spherical. Similar results were obtained by Oliveira et al. (2009) for pH, Ca, Mg and OM, by Souza et al. (2008) for H+Al, by Barbieri, Marques Júnior and Pereira (2008) for LR and by Lima, Souza and Silva (2010) for pH, Ca, Mg, H+Al and Al.

**TABLE 3** - Estimated parameters of the experimental semivariograms for pH level in water, potential acidity (H+Al), aluminum (Al), calcium (Ca), magnesium (Mg), soil organic matter (OM) and liming requirement (LR) in a conilon coffee plantation.

Parameters	pH	-----cmol <sub>c</sub> dm <sup>-3</sup> -----				MO dag dm <sup>-3</sup>	LR kg ha <sup>-1</sup>
		H+Al	Al	Ca	Mg		
RD	4.59	48.72	0.90	3.15	9.96	2.28	46.06
SSR	1.09 10 <sup>-4</sup>	8.2 10 <sup>-4</sup>	0.017	2.17 10 <sup>-4</sup>	1 10 <sup>-6</sup>	4.54 10 <sup>-4</sup>	1.6 10 <sup>7</sup>
R <sup>2</sup>	0.862	0.947	0.806	0.919	0.923	0.984	0.959
cvr	0.263	0.589	0.729	0.391	0.767	0.695	0.898

RD – Ratio of spatial dependence; SSR - Sum of the squares of residues; R<sup>2</sup>- Coefficient of determination; cvr – Cross-validation regression coefficient.

According to the classification of Cambardella et al. (1994), a moderate degree of dependence is observed for the variable potential acidity and liming requirement, Oliveira et al. (2008) observed the same results about liming requirement. A strong degree of dependence was observed for pH, aluminum, calcium, magnesium and organic matter, Similar results were obtained by Machado et al. (2007) for the variables H+Al, Mg and organic matter and Silva et al. (2008) for pH in water.

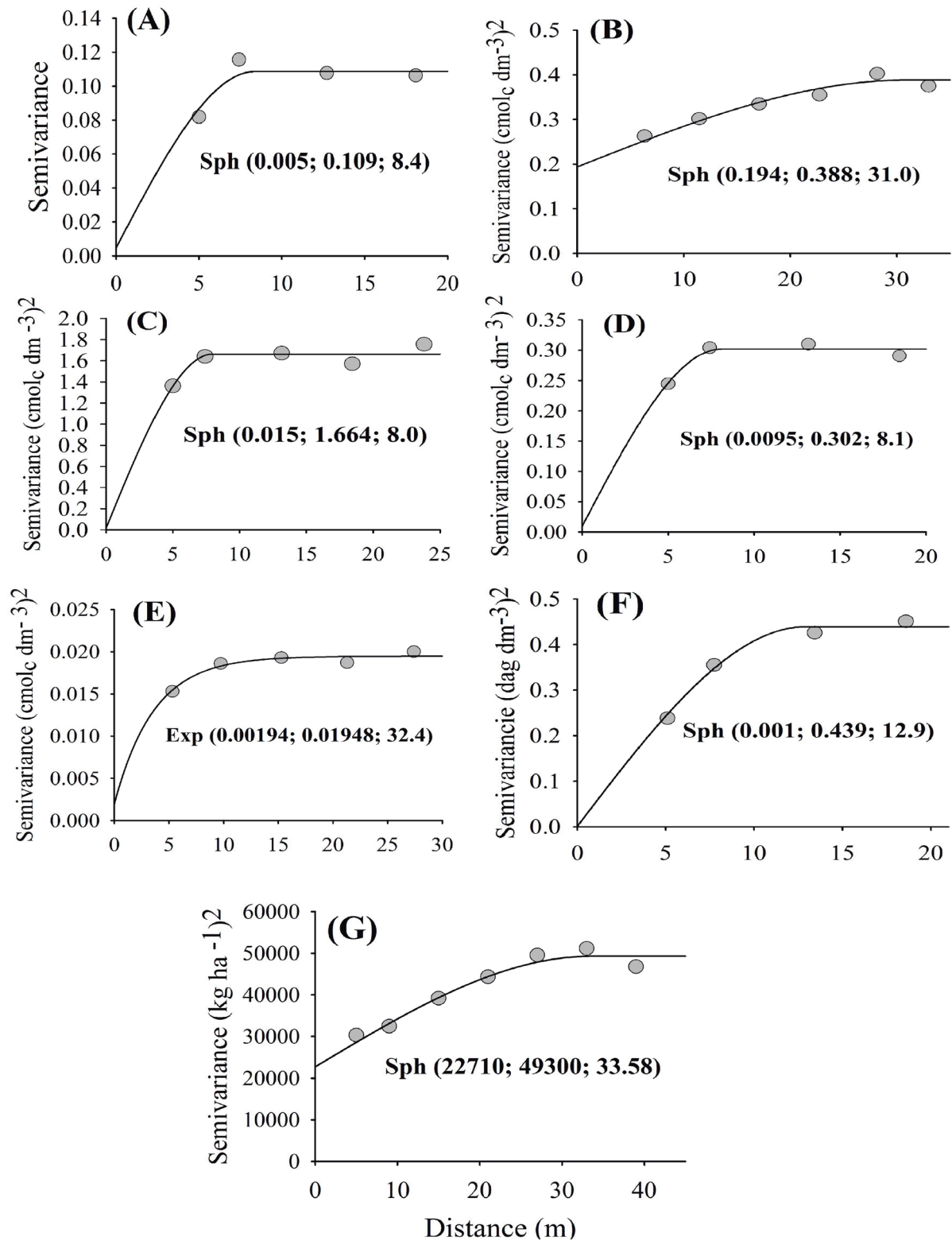
According to the method of interpretation of soil fertility proposed by Prezotti et al. (2007), there is a predominance of medium levels for the variables calcium, pH in water, potential acidity and organic matter, which are well distributed over the conilon coffee crop (Figure 3). Predominated low levels of magnesium in the study area, however mean values was observed on the west side of the experimental area.

In Figure 3, heterogeneity can be seen in the spatial distribution of the levels of aluminum in the study area, and much of the area showing low concentrations and agglomerates with high levels of the referred element, which has also been demonstrated by classical statistics, in the high CV. Thus, different applications of inputs should be adopted in the management of this crop.

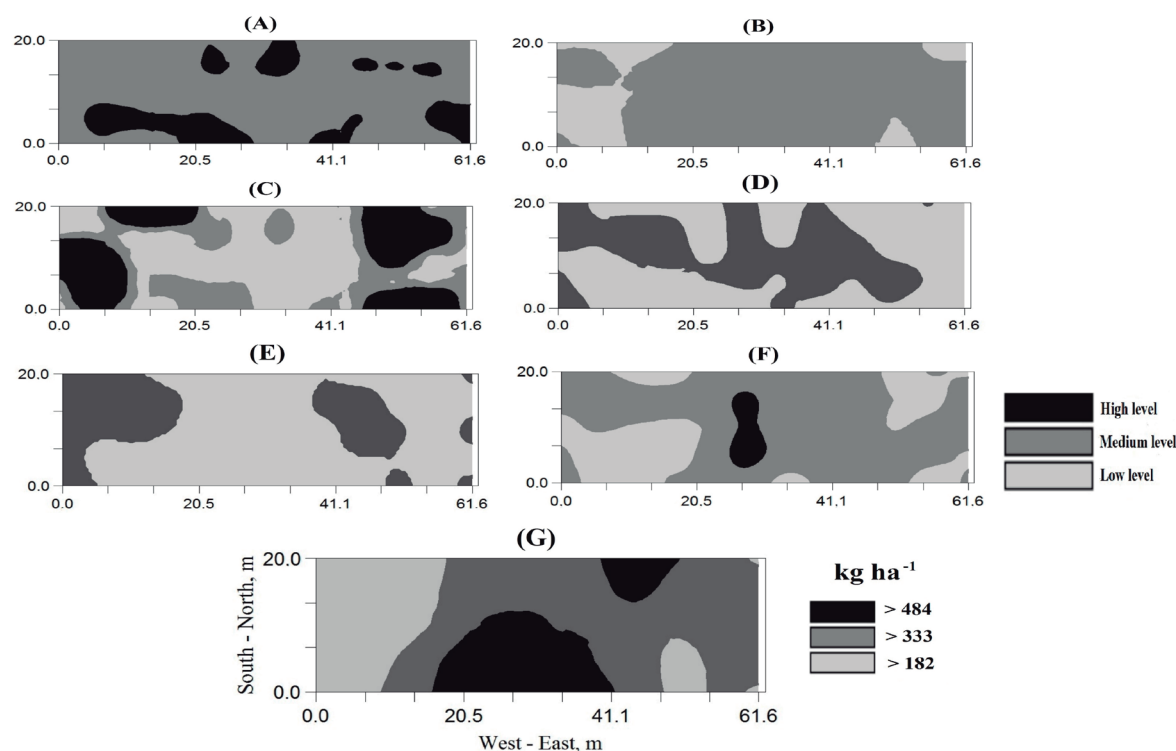
Regarding the liming requirement informed by the map obtained by kriging process (Figure 3), there is a variation from 182 to 794 kg ha<sup>-1</sup>. However, if the conventional method for determination of liming requirement is adopted ignoring the spatial variability of chemical properties of soil acidity, it would be necessary to apply 386 kg ha<sup>-1</sup> (Table 2). Therefore is possible to observe that when considering the spatial distribution of the chemical attributes of soil acidity, it is possible the most efficient liming and reduced the production cost.

Low values of range of spatial structure, varying between 8.0 and 33.58 meters were observed for aluminum and liming requirement, respectively. The range of spatial dependence represents the distance at which the sample points are correlated (JOURNAL; HUIJBREGTS, 1991), i.e., the points located in an area of radius equal to the range are more homogeneous between themselves than with those outside this area. According to Corá et al. (2004), the range values can influence the quality of the estimates, since they determine the number of values used in interpolation. Therefore, estimates made with ordinary kriging for interpolation using higher values tend to be more reliable, with maps that better represent reality.





**FIGURE 2** - Models of semivariograms adjusted for pH level in water (A), potential acidity (B), aluminum (C), calcium (D), magnesium (E), organic matter (F) and liming requirement (G). Values in brackets are nugget effect (Co), level (Co+C) and range (a) in meters, respectively. Sph – spherical model, Exp – exponential model.



**FIGURE 3** - Contour maps of the variables: pH in water (A), potential acidity (B), aluminum (C), calcium (D), magnesium (E) and organic matter (F), according to the classification of Prezotti et al. (2007) and liming requirement (G).

#### 4 CONCLUSIONS

All the studies attributes showed a spatial dependence structure (moderate and strong).

Higher range was found for potential acidity (33.58 m) and lower range for exchangeable aluminum (8.0 m).

The spatial variability of soil chemical properties using geostatistical techniques, proved to be an important tool in order to recommendation of the different rates of inputs along the conilon coffee plantation.

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