ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 11, pp. 51438-51442, November, 2021
https://doi.org/10.37118/ijdr.23107.11.2021

RESEARCH ARTICLE OPEN ACCESS

SPATIAL VARIABILITY OF HUMIC SUBSTANCES IN A LATOSOL UNDER COFFEE CULTIVATION IN THE CERRADO OF MINAS GERAIS

Danilo Ferreira Mendes*[1], Cinara Xavier de Almeida[2], Ricardo Falqueto Jorge[2], Beno Wendling[2], Edmar Isaías de Melo[2] and Stella Rabelo Rocha[3]

[1]Doctoral student in agronomy at the Federal University of Uberlândia;[2] Doctor and professor at the Federal University of Uberlândia; [3] Undergraduate in agronomy at the Federal University of Uberlândia

ARTICLE INFO

Article History:
Received 06th August, 2021
Received in revised form
17th September, 2021
Accepted 09th October, 2021
Published online 23rd November, 2021

Key Words:
Soil, Spatial Dependence, Semivariogram, Geostatistics.

Corresponding author:
Danilo Ferreira Mendes

ABSTRACT

Coffee growing in Brazil is an important agribusiness specialty, as it is one of the crops that moves the country's economy the most, being responsible for about one third of the world coffee production. Organic matter is an indispensable attribute for high yields and, associated with precision agriculture, it becomes a tool with high accuracy for identifying areas with different organic matter contents. The objective of the study was to analyze the spatial variability of organic matter fractions in a clayey red latosol. Soil sampling was carried out in a regular grid with 112 points in a 14-hectare area, cultivated with Coffea arabica L, for the quantification of carbon contents. A geostatistical study was carried out, aiming to characterize the probabilistic distribution and verify the variability of the data. It was found that the area under study showed moderate spatial dependence for the organic matter compartments. Thus, the management employed can alter the organic matter content in the soil, and the use of geostatistics together with the maps generated can be useful to help the producer in making decisions related to soil management in areas with coffee plantations.

Citation: ***Danilo Ferreira Mendes, Cinara Xavier de Almeida, Ricardo Falqueto Jorge, Beno Wendling et al.*** "Spatial variability of humic substances in a latosol under coffee cultivation in the cerrado of minas gerais", *International Journal of Development Research*, 11, (11), 51438-51442.

INTRODUCTION

Brazil is the world's largest coffee producer and exporter. The Brazilian coffee industry plays an active role in the country's economic growth, especially in the main producing regions (CONAB, 2021).Coffee is a shrub of the Rubiacea family and produces a fruit with sweet, edible pulp whose exterior is initially green and, when ripe, turns red or yellow. A perennial plant, the coffee tree can produce for 20 to 30 years, depending on the conditions of planting and management. There are dozens of coffee species and the most common ones for cultivation are *Coffea arabica* and *Coffea canephora*. The arabica species has white flowers and light seeds, while the robusta/conilon species has bicolor flowers (white and brown stripes) and brown seeds. Economically, the two most important species are *Coffea arabica* (Arabica coffee), which accounts for more than 60% of world production, and *Coffea canephora* (Robusta coffee). The world's largest coffee producer, Brazil has predominantly arabica plantations.

According to the National Supply Company (CONAB, 2021), the area cultivated with arabica coffee is estimated to be 1,778.6 thousand hectares for the 2021 harvest, which corresponds to about 81% of the total area destined for national coffee growing. Minas Gerais concentrates the largest area with the species, 1,262.6 thousand hectares, corresponding, in this harvest season, to almost 71% of the area occupied with arabica coffee in the country. Soil fertility is one of the most impacting factors for the coffee plant to express its full productive potential. Therefore, knowledge of this information is fundamental for the definition of sustainable management practices to be adopted in coffee plantations. According to Vaz (2006), soil is considered a living system in continuous evolution and presents organisms that are dependent on organic matter, which provides them with nutrients primordial to their survival and energy. Soil organic matter is considered a relevant indicator of the quality of this medium, due to its ability to modulate the chemical, physical and biological conditions of the soil and, thus, its nutritional efficiency (COSTA *et al.*, 2013). It is found in soils, sediments, and natural waters, and can be divided into two classes of compounds: the nonhumic substances (such as proteins, polysaccharides, nucleic acids, sugars, and amino acids) and the humic substances (FONTANA, 2009; ATIYEH *et al*., 2002). According to authors Whitby and Van der Berg (2015), humic substances are considered an energy source for beneficial soil organisms such as algae, fungi, bacteria and small animals and these organisms do not have photosynthetic apparatus to capture energy from the sun, therefore surviving on substances on or in the soil containing residual carbon. Oliveira (2011) points out that the different functional groups present in humic substances, such as carbonyls and phenolic hydroxyls, make them assume a polyelectrolytic behavior, acting as complexing agents of various metal ions, and are also able to adsorb various organic pollutants such as pesticides, thus decreasing the concentrations of these materials in the environment. The study of precision farming is essential for crop monitoring. Additionally, the map generation helps the producer to make decisions regarding fertilization management by identifying different management zones. According to the Brazilian Association of Precision Agriculture (AsBraAP 2021), the technology is a great investment attraction for agriculture, as well as a great alternative for soil management.

Therefore, integrating spatial variability with organic matter is an excellent combination. Geostatistical analysis technology is widely used to assess the spatial variability of soil properties in agroeco systems (Bogunovic *et al*. 2014). The knowledge of the variability of the compartments of organic matter in the soil is fundamental since these elements determine the physical and chemical quality of the soil, which directly implies the productivity of the crops. In addition, studies of organic matter compartments allow quantification of the percentage of carbon in each organic matter fraction. In the analysis of soil attributes, the presence of spatial variability is a fact, which leads to irregular productivity over the same area. Seeking to maximize crop management and rationalize agricultural inputs, precision agriculture is a tool that optimizes cultural tracts and identifies different management zones. A clear example is organic matter, where the carbon fraction can vary by diverse factors such as pedogenetics, climate and anthropogenics. Precision agriculture, combined with spatial variation and the study of soil attributes, becomes a very useful and attractive tool for farmers, since it provides savings, increases productivity and environmental quality of the soil. To understand the distribution and spatial dependence of organic matter, quantification of humic acid and fulvic acid was done by chemical fractionation followed by the making of maps. Thus, the assessment of spatial variability and the mapping of soil properties are fundamental prerequisites for soil and crop management. In this context, the present study aimed to explore the spatial variability of the compartments of organic matter in a latosol under coffee cultivation in the Cerrado region of Minas Gerais. Thus, the use of geostatistics can be a powerful technique to map different areas related to soil quality, allowing more efficient crop management, thus justifying the importance of this study.

MATERIALS AND METHODS

The experiment was conducted in an agricultural area, being cultivated in recent years with Coffea arabica L. and is located near the coordinates 18°42'28.9 "S 47°33'27.0 "W, in a clayey RED LATOSSOLO (EMBRAPA, 2013). In january 2012 the plantation was renewed with planting of coffee in the spacing of 3.8 x 0.7 m. From March 2018 the characterization of the area of approximately 14 hectares (ha) was carried out, to define the regular sampling mesh, with 112 points distanced of 25 x 50 m (Figure 1).

Determination of the position of the field samples: A Hipper dual frequency L1/L2 GNSS (Global Navigation Satellite System) receiver was used to collect the coordinates of the points. One of the receivers was used to serve as a base for GNSS tracking, performing a static relative positioning. Subsequently, the data were processed in the Topcon Tools 8.2.3 software, adopting as reference stations for post-processing the Uberlândia/MG and Rio Paranaíba/MG stations of the Brazilian Continuous Monitoring Network (BCMN).

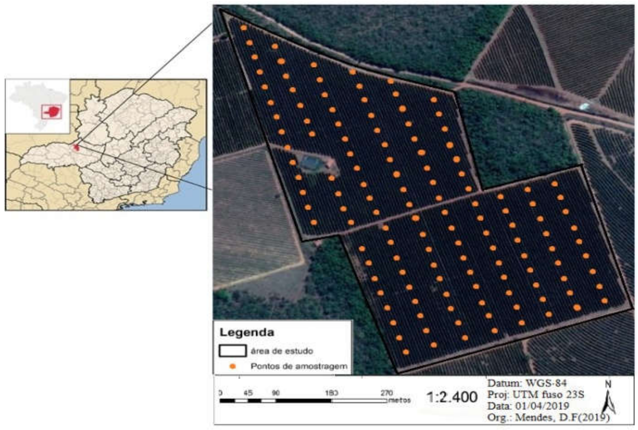

Figure 1. Sketch study area Juliana Farm, Monte Carmelo-MG

Sampling of Soil: To sample the study area, soil samples were collected in the 0 to 0.1 m and 0.1 to 0.2 m layers at all grid points. These samples were used in the determination of the organic matter compartments, being humic acid and fulvic acid.

Quantification of organic matter compartments: The chemical fractioning of humic substances was performed based on the differential solubility characteristics, obtaining as products the following fractions: fulvic acids (FA) - soluble in acid and alkali; humic acids (HA) - soluble in alkali and insoluble in acid (SCHNITZER, 1982; MENDONÇA; MATOS, 2017). Extraction was determined according to Embrapa (2009) with modifications. We used 0.0625 g of TFSA, which was passed through a 0.3 mm sieve and placed in 1.5 mL *Eppendorf*. 1.0 mL of 0.1 mol/L NaOH solution was added, shaken manually, and left to stand for 24 hours. After resting, the extraction set was centrifuged at 5,000g for 10 minutes, and the supernatant was transferred to *Eppendorf* of the same capacity (1.5 mL) and reserved. The *Eppendorf* containing the supernatant (AH and AF) received 25 µL of concentrated sulfuric acid ($H2SO^{-4}$) and left to stand for 18 hours, after resting the sample was again centrifuged at 5,000 g for 10 minutes.After centrifugation, the supernatant (AF) and the precipitate (AH) were obtained, and the supernatant was transferred to another *Eppendorf* with a volume of 1.5 mL.In the *Eppendorf* containing the precipitate (AH), 1.0 mL of 0.1 mol/L NaOH solution was added. In the *Eppendorf* containing the precipitate (AH), 1.0 mL of 0.1 mol/L NaOH solution was added. The organic carbon of the fractions (AF) and (AH) was quantified using a 1 mL aliquot of the extract being the result of the previous process, 1 mL of potassium dichromate 0.042 mol L^{-1} and 1 mL of concentrated H_2SO^4 where it was placed in a 10 mL volume test tube. Subsequently, the sample was heated in a preheated digester block at 150°C for 30 minutes. In conjunction, a calibration curve was made with different sucrose concentrations for the quantification of carbon in each organic matter compartment. A spectrophotometer adjusted to a wavelength of 450 nm was used to read the samples.

Statistical Analysis: For each variable obtained, a statistical study of the main moments was carried out through descriptive statistics, aiming to characterize the probabilistic distribution and verify data variability. The statistical moments used in this methodology are:

Average (μ):

$$\mu = \Sigma Z_i/n \quad (1)$$

Variance (σ^2):

$$\sigma^2 = \Sigma(Z_i-\mu)^2/(n-1) \quad (2)$$

Coefficient of variation (C.V.):

$$C.V. = 100\ \sigma/\mu \quad (3)$$

Coefficient of asymmetry (g1):

$g_1 = M_3/(\sigma^2)^{1.5}$ (4)

in which:

$M_3 = \Sigma((Z_i)^3/n) - 3\mu\Sigma((Z_i)^2/n) + 2\mu^3$ (5)

Kurtosis coefficient (g2):

$g_2 = M_4/(\sigma^2)^2$ (6)

in which:

$M_4 = \Sigma((Z_i)^4/n) - 4\mu\Sigma((Z_i)^3/n) + 6\mu^2\Sigma((Z_i)^2/n) - 3\mu^4$ (7)

Where n is the number of samples.

The minimum, maximum and amplitude values of the observed data were also analyzed. The geostatistical methodology was used with the objective of defining the model of spatial variability of the soil organic matter compartments.

Variographic analysis and kriging: The variographic analysis was performed through semivariograms.In addition, semivariances were calculated and, soon after, a graph of the semivariance $\gamma(h)$ *versus* distance (h) was elaborated.This graphic was used to define the semivariogram model adjusted to experimental data.The semivariances calculation and the choice of the semivariogram model were elaborated through the geostatistical software GS+ (ROBERTSON, 1998). After the definition of the semivariogram model, an interpolation was performed using the kriging method and the kriging estimation according to the equation:

$$Z^*(x) = \Sigma\lambda_i Z(x_i);$$

Where:λ are the weights of each measured value, Z is measured value and Z* and the value estimated by the kriging method. The weightsλ that are obtained through the Lagrange multipliers method, associated with the estimation equation, and the method's requirement that the hope of the errors be equal to zero and the estimation variance be minimal, make the kriging variance the smallest variance among all the interpolation processes. For the adjustment of the mathematical models to the semivariograms the "*Jack-knifing*" validation method was applied, in which the mean and variance values of the reduced errors are analyzed (SOUZA *et al*., 1997), which were considered the models: spherical, exponential, linear and gausian.

RESULTS AND DISCUSSION

Statistical Analysis: The descriptive analysis of the soil organic matter compartments are shown in Table 1, where the different carbon contents in each compartment can be seen. The contents of humic and fulvic acid carbon decreased in depth, with the lowest contents verified in the 0.10-0.20 m layer. These results agree with those obtained by Zanão *et al*. (2007). Adopting the coefficient of variation (CV) classification proposed by Warrick and Nielsen (1980) where its limits are: low for CV < 12%; average of 12% < CV < 60% and high for CV > 60%, it was found that the organic matter fractions present an average coefficient of variation in the two layers between 13.77% and 36.94%. The coefficient of asymmetry (Cs) is used to characterize how and how much the frequency distribution deviates from symmetry: if Cs > 0, you have right-symmetric distribution; if Cs < 0, the distribution is left-symmetric; and if Cs = 0, the distribution is symmetric (Guimarães, 2004).Positive asymmetry values, as observed in the C-AH fraction and in the upper layer of the C-AF fraction, indicate asymmetrical distribution to the right; therefore, in the lower layer of the C-AF fraction the distribution of values is to the left, because it has negative (Cs). According to WEBSTER (2001), asymmetry values up to 0.5 indicate normal distribution. In this study, the C-AF fraction had normal behavior, whereas the C-AH fraction in both layers indicated abnormal distribution for the analyzed data set. According to the results, it can be seen that there is variation in the carbon content throughout the area, therefore, only with the statistical data it is not possible to identify such variations, demonstrating the importance of making the maps.

Geostatistical Analysis: Through the geostatistical analysis data, all the soil attributes under study presented spatial dependence, therefore no variable presented random distribution in space, as shown in Table 2. The organic matter fractions presented moderate spatial variability with values from 45.05% to 49.70% according to the classification of Cambardella *et al*. (1994). These results clearly indicate that the sampled and georeferenced points are more similar to the value of the neighboring points than the rest of the sample space, thus demonstrating the accuracy and precision of the data. An important parameter in the study of semivariograms is the range, which means the maximum distance that a variable is spatially correlated (DAVIS, 1986). According to the results, the humic acid carbon fraction in the lower layer presented the greatest distance, 532.40 meters, and the smallest distance corresponded to the fulvic acid carbon fraction in the lower layer, with 80.50 meters.

Table 1. Descriptive statistics of variables: humic acid carbon fraction (C-AH, in mg g-1 soil),fulvic acid carbon fraction (C-AF, in mg g-1 soil) in different layers (0-0.10 and 0.10-0.20 m) in the crop year 2018/19.

Variable	Descriptive statistic							
	Min	Max	Amp	Mean	Me	As	CV	Kurt
C-AH 0-0,10m	1,39	4,74	3,35	2,57	2,44	0,60	26,69	0,09
C-AH 0,10-0,20m	0,70	5,16	4,45	2,03	1,85	0,71	36,94	3,19
C-AF 0-0,10m	1,94	5,35	3,40	2,89	2,84	0,39	13,77	12,04
C-AF 0,10-0,20m	1,64	4,11	2,46	2,80	2,80	-0,002	16,18	0,42

Min - Minimum value; Max - Maximum value; Amp – Amplitude; Mean - Average; Me - Median; As - Asymmetry; CV – Coefficient of variation; Kurt - Kurtosis.

Table 2. Parameters of the fitted semivariograms for: Humic acid carbon fraction (C-AH, in mg g^{-1} soil), Fulvic acid carbon fraction (C-AF, in mg g^{-1} soil) in different layers (0-0.10 and 0.10-0.20 m) in the crop year 2018/19

Variable	Parameters					
	Model	Co	Co + C1	$Co/(Co+C1)^2$	a	r^2
C-AH 0-0,10m	Exponential	0,28700	0,63700	45,05	268,70	0,864
C-AH 0,10-0,20m	Spherical	0,38600	0,79000	48,86	532,40	0,804
C-AF 0-0,10m	Exponential	0,07140	0,14380	49,65	444,00	0,507
C-AF 0,10-0,20m	Exponential	0,08290	0,16680	49,70	80,50	0,719

Co = nugget effect; Co+C1= level; $Co/(Co+C1)^2$Degree of spatial in percentage, being classified as: <25% = strong; between 25 e75 % = moderateand> 75% = weak (Cambardella et al, 1994); a = range.

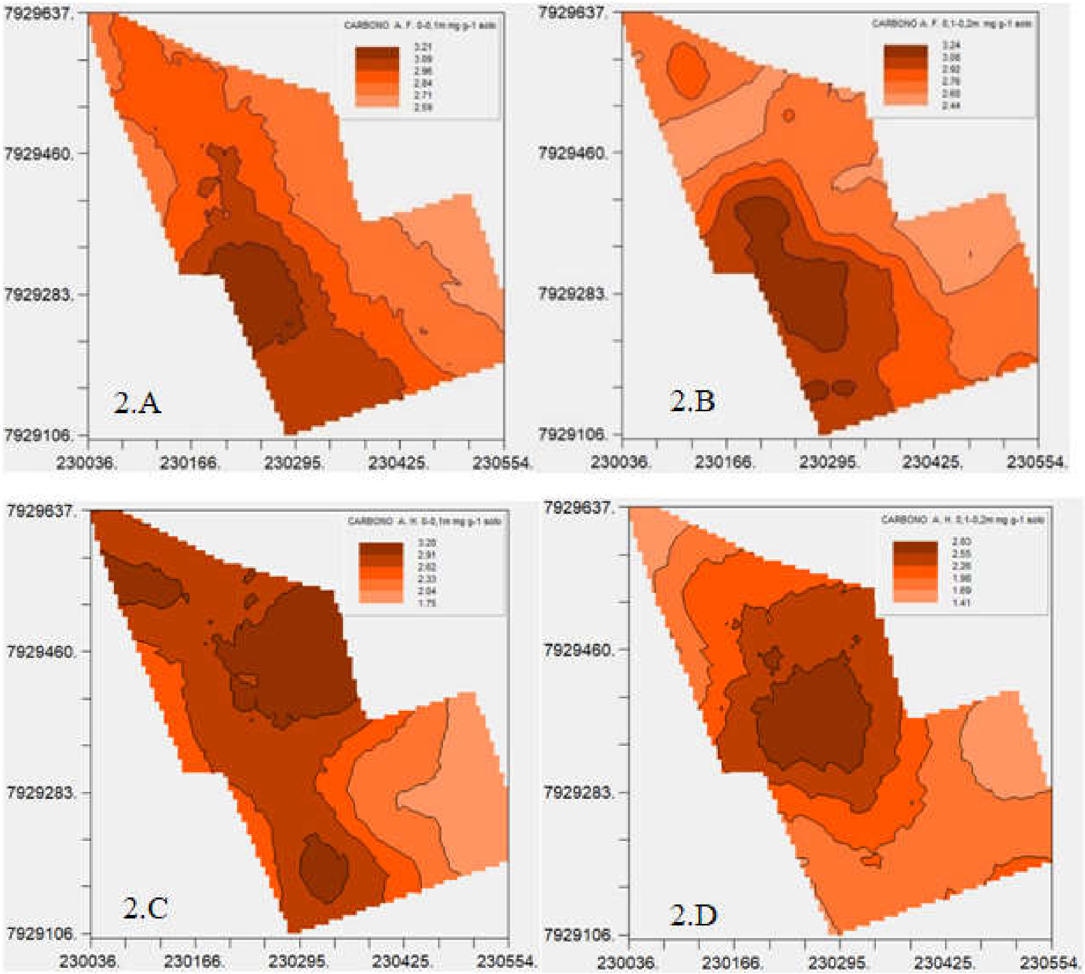

Figure 2. Spatial distribution of the humic acid carbon fraction in the layer 0 - 0.1 m (2.a) and 0.1-0.2 m (2.b) and spatial distribution of the fulvic acid carbon fraction in the layer 0 - 0.1 m (2.c) and 0.1-0.2 m (2.d) resulting from ordinary kriging. Juliana Farm, Monte Carmelo-MG

One of the great difficulties encountered in studies of spatial variability is the determination of adequate spacings to accurately characterize spatial variations, optimizing resources and maximizing time (LIMA *et al*., 2010). Note that if geostatistics are adopted in the sampling scheme, the number of samples to be collected will be reduced, due to the higher range values presented by the variables. Therefore, in addition to vertical variability, there is also horizontal variability, since the range was different between humic acid and fulvic acid at different depths.

Spatial distribution of humic acid and fulvic acid: The semivariograms adjusted for the compartments of organic matter were exponential and spherical. In the spatial distribution maps generated for the fractions C-FAH; C-FAF it was observed that there is a homogeneous pattern as to the distribution for the humic acid carbon fraction, and the highest levels were concentrated in the center of the area, while for fulvic acid the highest levels were concentrated in the lower left part of the area. According to Burak *et al*(2015), the main contribution of organic material comes from vegetable remains of the production pruning left in the soil and from the senescence of the coffee leaves.

CONCLUSIONS

- With the proposed sampling grid, it was possible to create the thematic maps to observe the spatial distribution of the variables in the experimental area.
- Higher levels of organic matter were found in the topsoil layer.
- The coefficient of variation indicated medium variability for the attributes under analysis at all depths evaluated.
- The attributes showed spatial dependence, classified as moderate, with ranges varying from 80.50 to 532.40 m.
- Most of the data fitted the exponential model semivariogram followed by the spherical model.

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