https://doi.org/10.47456/bjpe.v10i1.42755 ARTIGO ORIGINAL | OPEN ACCESS

Brazilian Journal of Production Engineering
BJPE - Revista Brasileira de Engenharia de Produção
Disponível em: https://periodicos.ufes.br/bjpe
ISSN: 2447-5580

SPATIO-TEMPORAL VARIABILITY OF LEAF MACRONUTRIENTS IN A CONILON COFFEE CROP

VARIABILIDADE ESPAÇO TEMPORAL EM MACRONUTRIENTES FOLIARES EM CULTIVO DE CAFÉ CONILON

VARIABILIDAD ESPACIO-TEMPORAL DE MACRONUTRIENTES FOLIARES EN UN CULTIVO DE CAFÉ CONILON

Diego Capucho Cezana [1], Ivoney Gontijo [2], André Cayô Cavalcanti [3], Marcelo Barreto da Silva [4], Eduardo Oliveira de Jesus Santos [5], & Fábio Luiz Partelli [6*]

[1 2 3 4 5 6] Universidade Federal do Espírito Santo, Centro Universitário Norte do Espírito Santo

[1] capuchoagronomo@gmail.com [2] ivoney.gontijo@ufes.br [3] andrecavalcanti40@yahoo.com.br [4] marcelo.silva@ufes.br [5] eduardoliveira@hotmail.com [6*] partelli@yahoo.com.br

ARTICLE INFO.

Recebido: 25.10.2023
Aprovado: 12.12.2023
Disponibilizado: 14.03.2024

KEYWORDS: Semivariogram; kriging; precision agriculture; Coffea canephora.
PALAVRAS-CHAVE: *Semivariograma; krigagem; agricultura de precisão; Café canéfora.*
PALABRAS CLAVE: *Semivariograma; kriging; agricultura de precisión; Coffea canephora.*

***Autor Correspondente**: **Partelli, F. L.**

ABSTRACT

Studies focusing the understanding of spatio-temporal variability of soil and plant attributes may contribute to the rational use of agricultural inputs, enabling economic and environmental profits. The objective of this work was to determine the spatial and temporal variability of the foliar macronutrients in a Coffea canephora (Conilon coffee) plantation, in two sampling periods (pre-harvest and fruit growth). The study was performed in a Conilon coffee plantation with double spacing of 3.0 x 2.0 x 1.0m (4.000 plat ha^{-1}) under drip irrigation system, in the county of São Mateus, Espírito Santo - Brazil. An irregular mesh with approximately 1.37 ha with 100 points, at a minimum distance of 2 m with each other, was installed. On each sampling point foliar tissue samples were collected in two distinctive periods, during pre-harvest and fruit growth and the levels of foliar macronutrients were determined. Results were submitted to descriptive analysis and geostatistics. A moderate spatial dependence structure was observed and verified for foliar contents of nitrogen, phosphorus, potassium and calcium in both sampling periods.

RESUMO

Estudos voltados para a compreensão da variabilidade espaço-temporal dos atributos do solo e das plantas poderão contribuir para o uso racional dos insumos agrícolas, possibilitando lucros econômicos e ambientais. O objetivo deste trabalho foi determinar a variabilidade espacial e temporal dos macronutrientes foliares em uma plantação de Coffea canephora (café Conilon), em dois períodos de amostragem (pré-colheita e crescimento dos frutos). O estudo foi realizado em um cafezal Conilon com espaçamento duplo de 3,0 x 2,0 x 1,0m (4.000 plat ha-1) sob sistema de irrigação por gotejamento, no município de São Mateus, Espírito Santo - Brasil. Foi instalada uma malha irregular com aproximadamente 1,37 ha com 100 pontos, com distância mínima de 2 m entre si. Em cada ponto amostral foram coletadas amostras de tecido foliar em dois períodos distintos, durante a pré-colheita e crescimento dos frutos e determinados os teores de macronutrientes foliares. Os resultados foram submetidos à análise descritiva e geoestatística. Foi observada e verificada uma estrutura de dependência espacial moderada para os teores foliares de nitrogênio, fósforo, potássio e cálcio em ambos os períodos de amostragem.

RESUMEN

Los estudios centrados en la comprensión de la variabilidad espacio-temporal de los atributos del suelo y las plantas pueden contribuir al uso racional de los insumos agrícolas, permitiendo obtener beneficios económicos y ambientales. El objetivo de este trabajo fue determinar la variabilidad espacial y temporal de los macronutrientes foliares en una plantación de Coffea canephora (café Conilon), en dos periodos de muestreo (precosecha y crecimiento del fruto). El estudio se realizó en un cafetal Conilon con doble espaciamiento de 3,0 x 2,0 x 1,0 m (4.000 plat ha-1) bajo sistema de riego por goteo, en el municipio de São Mateus, Espírito Santo - Brasil. Se instaló una malla irregular de aproximadamente 1,37 ha con 100 puntos, a una distancia mínima de 2 m entre sí. En cada punto de muestreo se recolectaron muestras de tejido foliar en dos períodos distintos, durante la precosecha y el crecimiento del fruto, y se determinaron los niveles de macronutrientes foliares. Los resultados fueron sometidos a análisis descriptivo y geoestadístico. Se observó y verificó una estructura de dependencia espacial moderada para los contenidos foliares de nitrógeno, fósforo, potasio y calcio en ambos períodos de muestreo.

INTRODUCTION

More than 150 million bags of coffee were harvested worldwide in 2016, being 95 millions of *Coffea arabica* and 56 millions of *C. canephora*, with the major producers being Brazil, Vietnam, Colombia, Indonesia, Ethiopia, Honduras and India (ICO, 2022). According van der Vossen (2016) coffee generates 175 billion dollars and is being produced by more than 25 million families. Brazil is a global leader in coffee (*Coffea* sp.) production, having produced 51.4 million bags in 2016, being 43.38 millions of *C. arabica* and 7.99 millions of *C. canephora* (ICO, 2022).

Determination of the foliar nutrients enables the determination of responses from coffee plants to management systems, genotypes planted and periods of the year, allowing to understand relations between nutrients in the plant and to interfere in the nutritional management of crops, thus increasing the probabilities of higher yields (Partelli et al., 2007, Farnezi et al., 2010, Gomes et al., 2016). Knowledge of the spatial variability of plant's foliar contents, in addition to a higher coffee yield, may assist in decisions regarding the best nutritional design and management to be adopted in the plantation.

Knowledge of the maturation cycle in coffee crops (concerning the period from blooming to grain maturation) is fundamental for the agricultural planning aiming the forecasting of harvest, commercialization and to estimate product quality (Bardin-Camparotto et al., 2012, Partelli et al., 2014, Marré et al., 2015; Covre et al., 2018), as well as estimating the nutritional demand required for a complete fruit formation (Covre et al., 2016b; Covre et al., 2018) and vegetative growth (Covre et al. 2016a). However, the extent of each stage of the cycle is variable and may affect the dry weight and the accumulation rate of nutrients in the coffee bean (Laviola et al., 2007, 2008, Partelli et al., 2014, Marré et al., 2015). Thus, knowledge of the dynamics in coffee fruit formation is important to recognize periods of increment in nutritional demand and definition of the best strategies to fertilize coffee plantations.

Coffee farming occurs in environments with a great diversity of soil, topography, plant physiology characteristics, disease and pest management, irrigation systems, mechanization and fertilization systems, among other characteristics. The influence of these factors may strongly affect coffee productivity, once if these variations are not considered and the crop is managed homogenously, profits may decrease. Therefore, spatial analyses which consider productivity associated to attributes of the soil and the plant may tent to support an efficient management of the production process (Alves et al., 2009, Santos et al., 2017, Mota et al., 2020, Santos et al. 2020 e Silva et al 2020).

The hypothesis of the present work was that there is spatial and temporal variation of foliar nutrients in Conilon coffee produced by the fertilization management system and soil origin. The objective was to describe spatial and temporal variability of foliar macronutrients (N, P, K and Ca) in a Conilon coffee plantation, in two sampling periods.

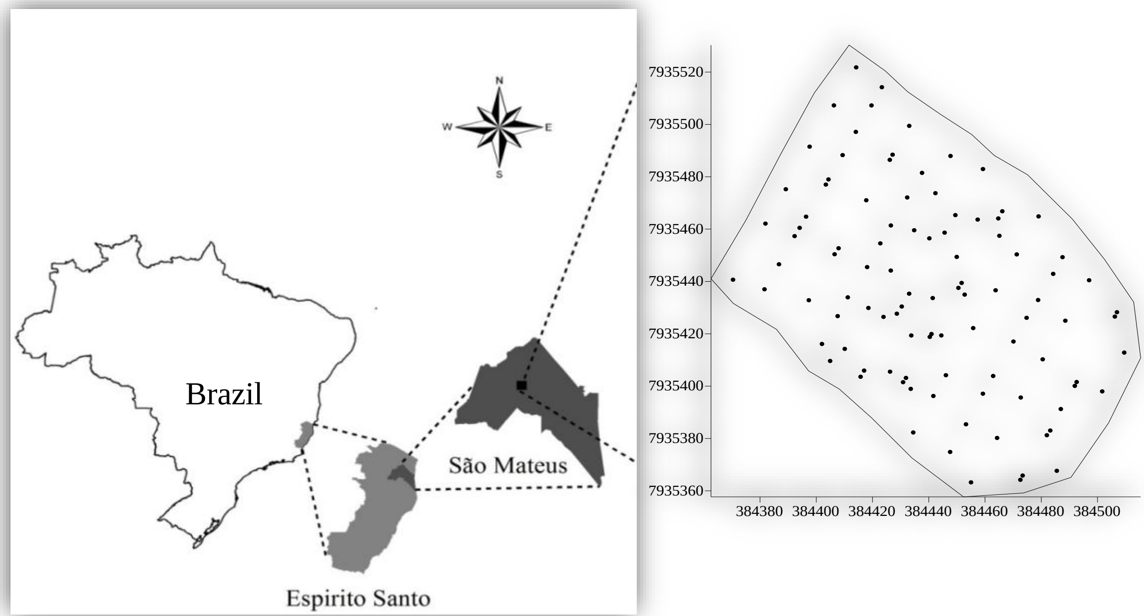
MATERIALS AND METHODS

The experiment was performed in a commercial plantation in the county of São Mateus, northern region in the state of Espírito Santo - Brazil, coordinates UTM 7935440 m South latitude and 384440 m West longitude, with mean altitude of 81 m, zone 24 K *datum* WGS 1984. According to EMBRAPA (2013), the soil was classified as dystrophic yellow Latosol (Oxisol), with Loam Sandy Clay texture and contests of total clay, silt and sand of 231, 150 and 619 g kg^{-1}, respectively. The regional climate was classified as Aw, according Köppen's classification, characterized by a humid tropical climate, with dry winter and maximum rainfall in the summer (Alvares et al., 2013).

The experimental area, planted with Conilon coffee (*Coffea canephora* Pierre ex A. Froehner), genotype Bamburral, variety Tributun (MAPA, 2018), was implemented in a flat topography area, using an area previously planted with papaya crop, where double spacing between plants with 3.0 x 2.0 x 1.0 m (4.000 plants ha^{-1}) and drip irrigation system were used. When the crop was implemented the soil was amended with 1.500 kg ha^{-1} of dolomitic limestone in grooves in the whole area. While sowing, 5 kg of chicken manure were applied in topdressing, in addition to 100 g of simple superphosphate in the pit. After removing the papaya crop in 2012, when Conilon coffee was two years old, fertirrigation was applied. Fertilization and liming were performed based on the results obtained from the soil analysis.

Evaluations were completed when plants were three years old. To study and analyze the spatial dependence of foliar attributes an irregular mesh with approximately 1.37 ha and 100 points and a minimum distance of 2 m from each other was used (FIGURE 1). For georeferencing of the area, a pair of GPS TechGeo® receptors, geodesic model GTR G2 were used, and the data was processed by the Continue Monitoring Net form IBGE, showing a precision of 10 mm + 1 ppm.

Figure 1. Map of the experimental area with the spatial distribution of the sampling points (*datum* WGS 1984, zone UTM 24 K south).



Foliar tissue samples were obtained in two different periods: the first one on May 3rd (pre-harvest) and the second one in December 18th (fruit growth). Harvest was completed on July 3rd of the same year. For each sampling point, a foliar sample was collected, composed by 20 leaves, collected from the third and fourth pair of leaves from productive branches localized in the superior third portion of the plant. Samples were processed and analyzed in laboratory to determine contents of N, P, K and Ca according Silva (2009).

Initially, the results concerning foliar macronutrients were submitted to descriptive statistical analysis, obtaining the following measures: arithmetic mean, median and coefficients of variation, asymmetry and Kurtoses, and normality was verified by the Shapiro-Wilk test, at 5% probability, using the statistical software Action v. 2.3 (Action Development Core Team, 2012).

To determine the spatial dependence structure of foliar contents, a geostatistical analysis was performed through semivariogram fitting, with the aid of the software GS+ Version 7® (Gamma Design Software, 2004), which executes calculation of sample semivariances, according to the expression registered in Vieira et al. (1983):

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

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

Scaling of semivariograms was performed in order to standardize semivariogram values from variables under study. Scaling of semivariograms was performed by dividing the semivariance values by the sample variance (Vieira et al., 1997).

Subsequently, interpolation of foliar macronutrient values (N, P, K and Ca) was completed by means of an ordinary kriging, in order to obtain the spatial variability maps for variables under study. The isocline maps were elaborated using the software ArcGIS 10.2.2 (Esri Corp, 2014).

Semivariograms were tested to fit theoretical models such as the spherical model, exponential model and Gaussian model which have their parameters well defined: nugget effect (C_o), sill (C_o+C) and range of the spatial dependence (a). When uncertain about more than one model for the same semivariogram, the highest correlation (r-VC) was considered, obtained by the method of cross validation (Amado et al., 2007). The spatial dependence index (IDE) was determined, which is the proportion of the nugget effect (C_o) in percentage, in relation to the sill (C_o+C), given by the equation 2:

$$\mathrm{IDE} = \frac{\mathrm{Co}}{\mathrm{Co} + \mathrm{C}} 100 \quad (2)$$

The spatial dependence index was classified according Cambardella et al. (1994): (a) Strong IDE forte ≤ 25%; (b) Moderate IDE from 25 to 75% and (c) Weak IDE ≥ 75%.

RESULTS AND DISCUSION

The results of descriptive statistics (Table 1) showed data followed a normal distribution, by the Shapiro-Wilk test at 5% probability, for all macronutrients in both periods with the exception of P and K during the fruit growth period, which can be confirmed by the proximity of values to the mean and median values and low values of the asymmetry and kurtosis, showing the occurrence of a platykurtic (Silva et al., 2010) and positive asymmetric distribution (Guimarães, 2000).

Table 1. Descriptive statistics for foliar macronutrient contents data obtained from 100 sampling points, during pre-harvest and fruit growth periods, expressed in g kg^{-1}, in a Conilon coffee plantation.

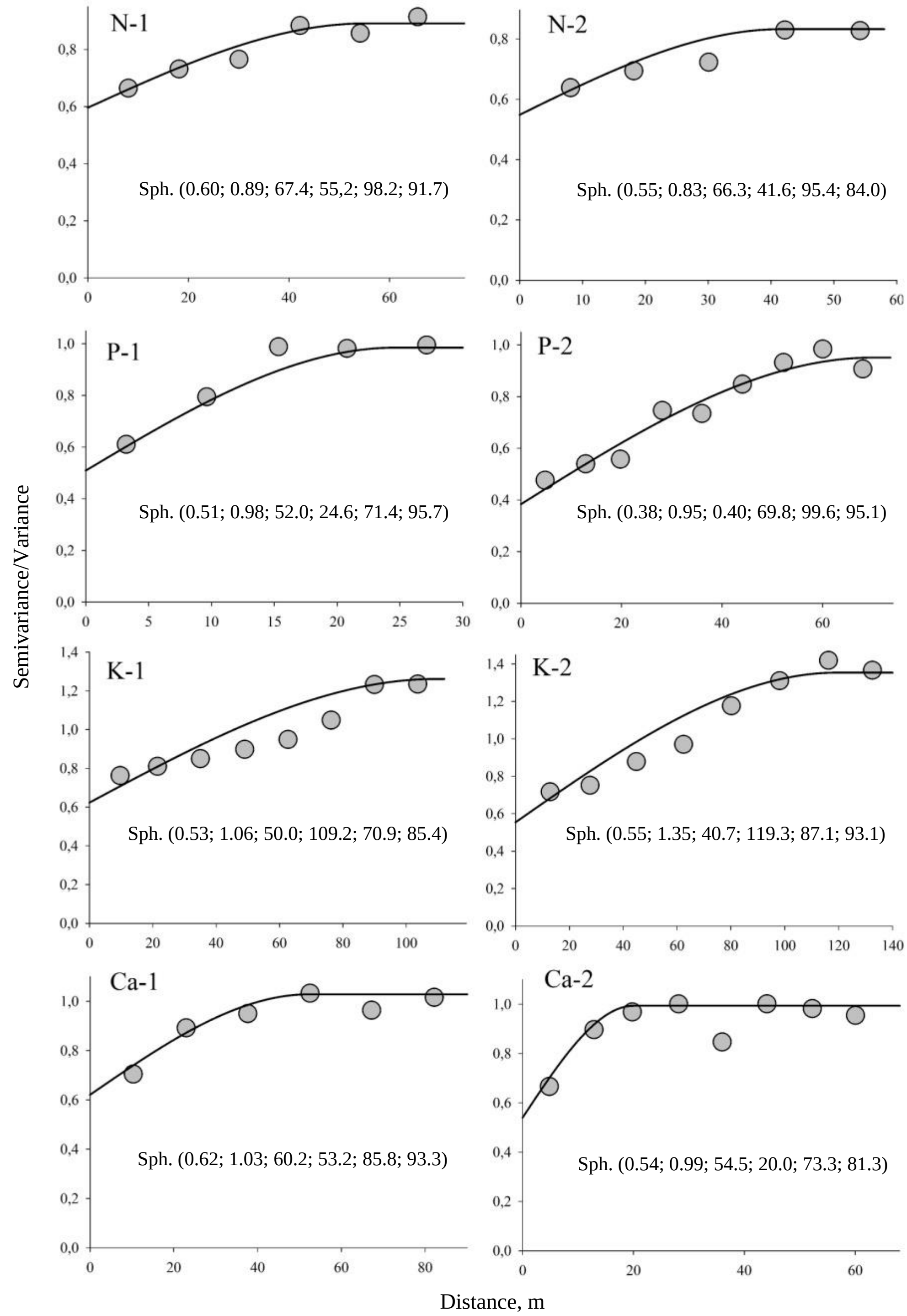
Measures	N	P	K	Ca	N	P	K	Ca
	-------------- pre-harvest -------------				-------- fruit growth ---------			
Mean	30.2	1.75	12.8	16.8	31.3	1.49	14.9	20.7
Median	30.2	1.75	13.1	16.7	31.1	1.48	14.4	20.8
CV	9.1	10.1	13.0	22.5	10.0	14.1	11.8	13.3
Ass.	0.02	0.13	0.14	0.11	-0.02	0.37	0.04	-0.47
Kurt.	-0.64	-0.24	-0.42	-0.35	0.34	-0.51	-0.51	0.57
p-value	0.72*	0.07*	0.19*	0.61*	0.14*	0.03	0.04	0.06*

CV – Coefficient of variation; Ass. – Coefficient of asymmetry; Kurt. – Coefficient of Kurtosis; * – normal distribution by the Shapiro-Wilk test, at 5% probability.

The coefficient of variation was considered low (CV < 12%) for N and P during the pre-harvest period, as well as for N and K during the fruit growth period, and moderate (12% < CV < 62%) for all other variables, according to the classification proposed by Warrick and Nielsen (1980). Similar classification was observed by Fonseca et al. (2015) but only for Ca in a Conilon coffee plantation, variety robusta and by Silva et al. (2011) for Ca and N during fruit growth period in Arabica coffee plantation. However, Silva and Lima (2014) observed low values of CV for foliar P sampled during the fruit growth period.

Mathematical models, adjusted to the scaled semivariograms through geostadistics, showed the variables under study had a spatial dependence structure (Figure 2). The spherical model was the best fitted to the scaled semivariograms. Similar fitting was observed by Silva et al. (2013) for Ca and K in Arabica coffee during fructification period and by Oliveira et al. (2010) for Ca during the same period in Conilon coffee plantation.

Figure 2. Parameters and models of scaled semivariograms fitted to the contents of nitrogen, phosphorus, potassium and calcium, during the pre-harvest and fruit growth periods. Values in parenthesis are the nugget effect (C_o), sill (C_o+C), IDE, range (a), r-VC and R^2, respectively. Sph. – Spherical model.

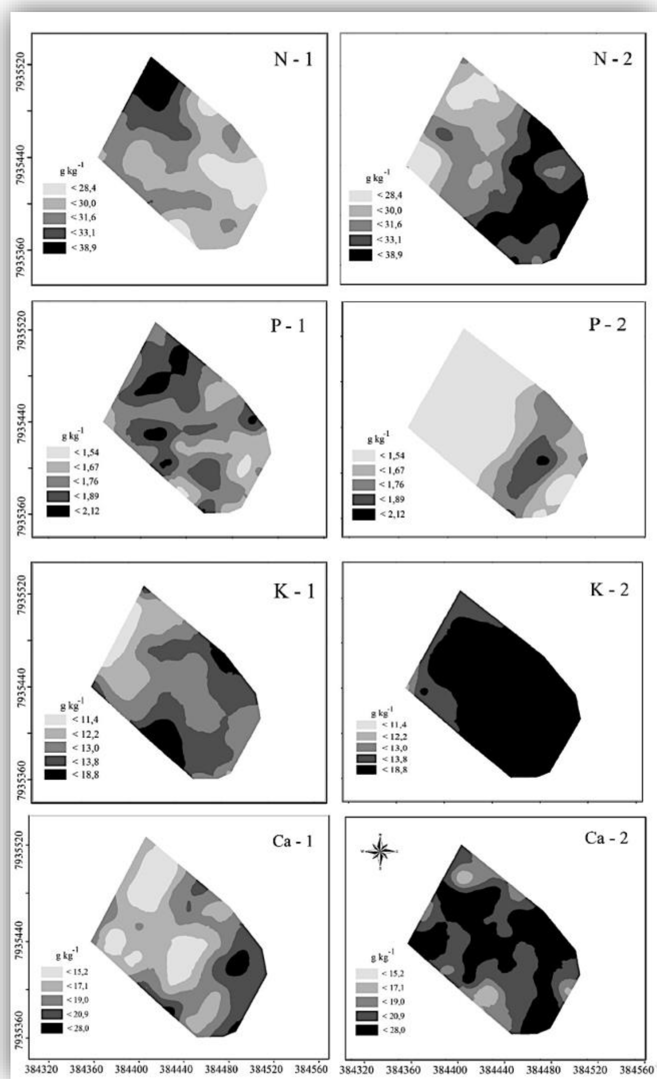


According to the spatial dependence index (IDE) proposed by Cambardella et al. (1994), macronutrients under study for both periods were classified as being of a moderate spatial dependence (IDE varying from 25 to 75%). Similar classification was observed by Silva et al. (2009) for foliar nitrogen and phosphorus collected in the second period in Arabica coffee plantation and by Armindo et al. (2012) for foliar macronutrients in citrus.

In the present study, the performance of semivariograms analyzed by the values of the determination coefficient (R^2) varied from 81.3 to 95.7%, which means that more than 81.3% of the variability existing in the estimated semi-variance values is explained by the fitted models. Adequate r-CV fitting was verified for all attributes under study, with values between 70.9 and 99.6%, for K during pre-harvest and P during fruit growth, respectively.

Regarding the spatial dependence range (a), values varied from 24.6 to 109.2 m for P and K, respectively during pre-harvest (Figure 2). During fruit growth the range values varied from 20.0 to 119.3 m for Ca and K, respectively. Comparing the range values of foliar macronutrient contents with regard to the periods, higher values of calcium and nitrogen were observed during pre-harvest and higher values of potassium and phosphorus during the period of fruit growth. Attributes showing higher values of range tent to be more spatial homogeneous, as observed when comparing foliar macronutrient contents maps in both studied periods (Figures 3 and 4). On the other hand, low values of range may negatively influence in the estimative quality, once few points are used to perform the interpolation (Corá et al., 2004).

Figure 3. Spatial variability maps for contents of macronutrients: nitrogen, phosphorus, potassium and calcium in a Conilon coffee plantation, during the pre-harvest and fruit growth periods.



In a general way, the variation of N content in both periods was small, increased 4 % during the fruit growth period (Table 1). However, when analyzing the distribution of this nutrient spatially (Figure 3), a clear inversion of values is observed in regions with lower contents in pre-harvest, which showed higher values during fruit growth period. Similar behavior was observed for the foliar phosphorus content

Foliar contents of N and P in pre-harvest showed a regular spatial distribution, delimiting distinct regions with higher values localized in the north-center of the plantation (FIGURE 3). During the fruit growth period contents of nitrogen and phosphorus showed an inversion (Figure 3), being this an important period to notice, when comparing maps of both periods. During pre-harvest (May) the demand for nutrients is higher, especially in genotypes of delayed maturation (Partelli et al., 2014) and, these nutrients (N and P) have intense translocation for fruits and tissues in the plant, having a higher demand when compared to the month of December, which generally receives more fertilizations. These differences may also be justified by the adoption of a conventional fertilization management, that is to say, where spatial variability is not considered.

Concerning to the contents of potassium and calcium, higher concentration was verified during fruit growth period, when compared to pre-harvest (Figure 3). An increment of 16 and 23 % was observed, respectively (Table 1). It is suggested that during May the demand for these nutrients for fruits is higher when compared to December, especially for delayed genotypes (Partelli et al., 2014). Therefore, in May and before the coffee harvest, it is understandable that foliar concentration is lower when compared to December.

Analyzing maps where foliar contents of K are represented, higher spatial variability of this nutrient was verified during the first period when visually compared with the second period. A predominance of ranges with contents between 13.9 and 18.8 g kg^{-1} was observed in the area under study (Figure 3).

When comparing maps of foliar contents of Ca, is possible to observe a lower spatial variability for sampling during the fruit growth period, in addition to the map showing some spots with values above 19.0 g kg^{-1}. During the first period the map shows higher variability with the occurrence of values under 19.0 g kg^{-1} (Figure 3). The mean value for Ca-1 contents were inferior to Ca-2, showing an increase of Ca levels in the plant (Table 1).

CONCLUSION

Moderate spatial dependence structure was verified for foliar contents of calcium, potassium, nitrogen and phosphorus in both sampling periods.

The spherical model was the best fitted for all foliar macronutrients evaluated, in both sampling periods.

The geostatistical analysis provided a practical localized fertilization aiming the reduction of agricultural inputs and increasing productivity.

Spatial variability and dependence allow to hypothesize provable effects of biennially of Conilon coffee, requiring further studies on this subject.

REFERENCES

Action development core team. (2012). *Action 2.3*: ESTATCAMP. São Carlos.

Amado, T. J. C. et al. (2007). Variabilidade espacial e temporal da produtividade de culturas sob sistema de plantio direto. *Pesquisa Agropecuária Brasileira*, Brasília, 42(8), 1101-1110.

Alvares, C. A. Et al. (2013). Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift,* Stuttgart, 22(6), 711-728.

Alves, M. C. et al. (2009). Geostatistical analysis of the spatial variation of the berry borer and leaf miner in a coffee agroecosystem. *Precision Agriculture*, Dordrecht, 10(12), 1-14.

Armindo, R. A. et al. Spatial variability of leaf nutrient contents in a drip irrigated citrus orchard. *Engenharia Agrícola*, Jaboticabal, 32(3), 479-489.

Bardin-Camparotto, L., camargo, M. B. P., & Moraes, J. F. L. (2012) Época provável de maturação para diferentes cultivares de café arábica para o Estado de São Paulo. *Ciência Rural*, Santa Maria, 42(4),.594-599.

Cambardella, C. A. et al (1994). Field-scale variability of soil properties in Central Iowa Soils. *Soil Science Society of America Journal,* Madison, 58(5), 1501-1511

Corá, J. E. et al. (2004) Variabilidade espacial de atributos do solo para adoção do sistema de agricultura de precisão na cultura de cana-de-açúcar. *Revista Brasileira de Ciência do Solo*, Viçosa, 28(6), 1013-1021.

Covre, A. M., Partelli, F. L., Bonomo, R., Braun, H., & Ronchi, C. P. (2016). Vegetative growth of Conilon coffee plants under two water conditions in the Atlantic region of Bahia State, Brazil. *Acta Scientiarum. Agronomy*, 38(4), 535-545.

Covre, A. M. Partelli, F. L. Bonomo, R., & Gontijo, I. (2018). Micronutrients in the fruits and leaves of irrigated and non-irrigated coffee plants. *Journal of Plant Nutrition*, (41). 1-11.

Covre, A. M., Rodrigues, W. P., Vieira, H. D., Braun, H., Ramalho, J. C. & Partelli, F. L. (2016). Nutrient accumulation in bean and fruit from irrigated and non-irrigated *Coffea canephora* cv. Conilon. *Emirates Journal of Food and Agriculture*, 28(6): 402-409. https://doi.org/10.9755/ejfa.2016-04-341

Empresa Brasileira de Pesquisa Agropecuária. *Sistema brasileiro de classificação de solos.* 3.ed. rev. ampl. Rio de Janeiro: Embrapa Solos, 2013. 353 p.

Esri Corp (2014). ArcGIS 10.2.2. Available from http://www.esri.com/software/arcgis

Farnezi, M. M. M. et al. Levantamento da qualidade da bebida do café e avaliação do estado nutricional dos cafeeiros do Alto Jequitinhonha, Minas Gerais, através do DRIS. *Ciência e Agrotecnologia*, (2010). Lavras,34(5), 1191-1198

Fonseca, A. S. et al. (2015). Spatial variability of the productivity and the nutritional condition of *Coffee canephora*. *Coffee Science*, Lavras, 10(4), 420-428.

Gamma Design Software (2004). *Geoestatistics for the environmental science.* Version 7.0. Michigan. 1CD-ROM.

Gomes, W.R.; Rodrigues, W.P.; Vieira, H.D.; Oliveira, M.G.; Dias, J.R.M.; Partelli, F.L. Genetic diversity of standard leaf nutrients in *Coffea canephora* genotypes during phenological phases. *Genetics and Molecular Research*, 15(4). https://doi.org/p.gmr.15048839

Guimarães, E. C.(2000) *Variabilidade espacial de atributos de um Latossolo Vermelho-escuro textura argilosa da região do cerrado, submetido ao plantio direto e ao plantio convencional* [tese]. Campinas: Universidade Estadual de Campinas.

ICO - International Coffee Organization. (2022). Trade Statistics. Available from http://www.ico.org/trade_statistics.asp

Laviola, B. G. et al. (2008). Acúmulo em frutos e variação na concentração foliar de NPK em cafeeiro cultivado em quatro altitudes. *Bioscience Journal,* Uberlândia, 24(1), 19-31.

Laviola, B. G. et al. (2007). Acúmulo de nutrientes em frutos de cafeeiro em quatro altitudes de cultivo: cálcio, magnésio e enxofre. *Revista Brasileira de Ciência do Solo,* Viçosa, 31(6), p.1451-1462.

MAPA - Ministério da Agricultura, Pecuária e Abastecimento. (2018). Registro Nacional de Cultivares - RNC. Available from http://sistemas.agricultura.gov.br/snpc/cultivarweb/cultivares_registradas.php

Marré, W. B., Partelli, F. L., Espindula, M. C., Dias, J. R. M., Gontijo, I., & Vieira, H. D. (2015). Micronutrient accumulation in conilon coffee berries with different maturation cycles. *Revista Brasileira de Ciência do Solo*, (39), 1456-1462.

Oliveira, R. B. et al. (2010). Spatial variability of the nutritional condition of canephora coffee aiming specific management. *Coffee Science*, Lavras, 5(3), 190-196.

Partelli, F. L., Espindula, M. C., Marré, W. B., & Vieira, H. D. (2014) Dry matter and macronutrient accumulation in fruits of conilon coffee with different ripening cycles. *Revista Brasileira de Ciência do Solo*, v. 38(1) 214-222.

Mota, F. M., Partelli. F. L., Santos, A. R., Ferrari, J. L., & Peluzio, J. B. E. (2020). Relação entre variáveis meteorológicas e Índices de Vegetação em lavouras cafeeiras. *Brazilian Journal of Animal and Environmental Research*, (3). 4287-4209.

Partelli, F. L., Vieira, H. D., Carvalho, V. B., de, & Mourão Filho, F. de A. A. (2007). Diagnosis and recommendation integrated system norms, sufficiency range, and nutritional evaluation of Arabian coffee in two sampling periods. *Journal of Plant Nutrition*, (30) 1651-1667.

Santos, M M., Silva, C. A., Oza, E. F., Gontijo, I., Amaral, J. F. T., & Partelli, F. L. (2021). Concentration of Nutrients in Leaves, Flowers, and Fruits of Genotypes of Coffea canephora. *Plants*, (10), 2661-2680.

Santos, E. O. J., Gontijo, I., Silva, M. B., & Partelli, F. L. (2017). Sampling design of soil physical properties in a conilon coffee field. *Revista Brasileira de Ciência do Solo*, Viçosa, (41). https://doi.org/10.1590/18069657rbcs20160426

Silva, S. A. et al (2010). Variabilidade espacial de atributos químicos de um Latossolo Vermelho-amarelo húmico cultivado com café. *Revista Brasileira de Ciência do Solo*, Viçosa, 34(1), 15-22.

Silva, S. A., Lima, J. S. S., & Bottega, E. L. (2013). Yield mapping of arabic coffee and their relationship with plant nutritional status. *Journal of Soil Science and Plant Nutrition*, 13(3), 556-564.

Silva, S. A., Lima, J. S. S., & Queiroz, D. M. (2011). Spatial variability in nutritional status of arabic coffee based on dris index. *Revista Ceres*, Viçosa, 58(2) 256-261.

Silva, S. A., Lima, J. S. S., & Teixeira, M. M. (2009). Variabilidade espacial da produtividade e teores de macronutrientes nas folhas de duas variedades de café arábica. *Engenharia na agricultura*, Viçosa, 17(5) 337-345

Silva, S. A. & Lima, J. S. S. (2014). Spatial estimation of foliar phosphorus in different species of the genus *Coffea* based on soil properties. *Revista Brasileira de Ciência do Solo*, 38(5), 1439-1447.

Silva, M. B., Partelli. F. L., Gontijo, I., & Caldas, M. M. (2020). Nutritional balance and its relationship to yield in a coffee field: Inferences from geospatial analysis. *Revista Brasileira de Engenharia Agricola e Ambiental*, (24)1, 834-839.

Van der Vossen, H. (2016) Narrowing the yield gap of smallholder coffee production as sustainable strategy to meet rising demand for quality coffees. *The 26th International Conference on Coffee Science.* Kunming (2).

Vieira, S. R. et al. (1983). Geostatistical theory and application to variability of some agronomical properties. *Hilgardia*, Berkeley, 51(1), 1-15.

Vieira, S. R. et al. (1997). Scaling of semivariograms and the kriging estimation of field-measured properties. *Revista Brasileira de Ciência do Solo*, Viçosa, 21(4). 525-533.

Warrick, A.W., Nielsen, D.R (1980). Spatial variability of soil physical properties in the field. In: HILLEL, D., ed. Applications of soil physics. New York, Academic, (1)1,.319-344