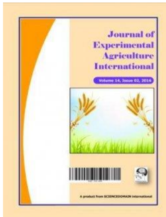

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Spatial Variability of Deviation from Optimum Percentage in Conilon Coffee

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Authors' contributions

This work was carried out in collaboration between all authors. Author ASF did the data acquisition, data analysis, writing and editing. Author MLJ participated in the writing. Authors JSSL and SAS managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this work was to identify the structure of the spatial dependence of the percentage deviation of the optimum (DOP) and its correlation with the productivity in the conilon coffee crop. The data were collected at the experimental farm of INCAPER, county of Cachoeiro de Itapemirim-ES. Leaves were collected in the middle third of each plant, two pairs of leaves of lateral branches, at the 4 cardinal points. The leaves were sent to the laboratory to determine the contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn. To evaluate the nutritional status, the DOP indexes of macro and micronutrients were classified as optimal (DOP = 0), deficiency (DOP <0) or excess (DOP> 0). The nutritional balance index (ΣDOP) was calculated showing a nutritional imbalance in the crop. The order of nutrient limitation (Fe> K> Zn> S> Mg> N> Ca> Cu> P> B> Mn) shows deficiency for Fe, K, Zn and S and excess for Mn. The nutritional balance evaluated through the DOP indexes presented spatial variability with a defined structure adjusted to the exponential and spherical semivariogram models.

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1. INTRODUCTION

Due to its economic and social importance, coffee cultivation contributes significantly to the Brazilian agricultural sector, being the main agricultural culture in the states of Minas Gerais and Espírito Santo. Due to its expressiveness, the knowledge of mineral nutrition has been of great importance in recommending the specific amount of fertilizers for the development of coffee with high productivity. For Fonseca, Lima and Silva [1], knowing the nutritional conditions of the crop is an important factor to understand its development, indicating the leaf nutrient contents and making it possible to correlate with the productivity in order to equate the presented variations.

The use of soil chemical analysis and leaf analysis have contributed significantly to the increase in the production of conilon coffee [2,3,4]. For Fonseca et al. [5] the mineral nutrition of the plant demands great attention in the coffee cycle, where the foliar diagnosis is essential to understand the nutritional status of the crop of interest.

The diagnosis of the nutritional status of the coffee tree is to know and evaluate the nutritional aspect of the plant through visual analysis and dry matter of the leaf tissue. Fertilizer management, in order to increase coffee productivity, should take into account the high nutrient exportation of the plant as a whole at high harvest, fertilizer prices and nutritional status monitoring Bataglia et al. [6].

Fonseca et al. [7] studying the spatial variability of nutritional status of the conilon coffee tree, observed that foliar diagnosis is essential not only for the understanding of the nutritional status of a crop but also for the recommendation of a balanced fertilization with the lowest possible cost.

The Deviation from Optimum Percentage (DOP) is a methodology for interpreting the nutritional status alternative to the sufficiency range and the Integrated Diagnosis and Recommendation System (IDRS), which is still little used, even though it has the potential in the evaluation of the nutritional status. It is a method of analysis that quantifies the difference between a single concentration of nutrients and its reference value using a percentage expression, classifying the individual nutrient indexes according to the order of limitation Montañes et al. [8].

The individual DOP indexes report on high priority nutrients in a management program Romero et al. [9]. The DOP index is easy to apply and interpret and generates positive indexes indicating the excess or negative indicating deficiency for each nutrient. The index equal to zero indicates optimum concentration. These indexes allow the order of nutritional limitation in the crop to be obtained, and the modular sum of its values allows the evaluation of the nutritional balance index (ΣDOP), which compares the nutritional status of the crop under study with a crop considered ideal in nutritional terms. The interpretation of the nutritional status of a coffee crop helps to understand the dynamics of nutrients in the process of their nutritional balance.

Considering the importance of evaluating the nutritional status of the coffee tree and the potential of the DOP index, the objective of this paper was to identify the spatial dependence structure of the Deviation from Optimum Percentage (DOP) according to leaf diagnosis and its correlation with productivity of the conilon coffee crop, facilitating interpretation and assisting in crop management.

2. MATERIALS AND METHODS

Data collection was performed at the INCAPER experimental farm located in the county of Cachoeiro de Itapemirim-ES. The crop is cultivated with the species *Coffea canephora* Pierre ex Froehner (Robusta Tropical variety - "Emcaper 8151") in spacing 2.9 x 0.9m. The experimental area is located in the geographic coordinates: 20º45'17,31 "S and 41º1'8,86" W, with an average elevation of 117 m.

The cultural maintenance of the area has been carried out by chemical and manual methods for the control of weeds, for the phytosanitary control of the coffee plant and for the harvest. It was also carried out the sowing of the coffee, avoiding that non productive branches competed for water and nutrients with the productive branches. The management of the fertilization with 0.13 kg by plants of the formulation 20-00-20 (% N-P-K) and an application of 0.08 kg by plants of super simple (SS) with doses varying according to the soil analysis.

In the study area, an irregular mesh of 1.0 hectare was constructed, being 140 georeferenced sample points spaced in approximately 10 m in the coffee line. Each sampling point was composed of five coffee plants, totaling an area of 13.05 m² per point.

The data for calculation of productivity were collected in the harvest of 2013, by means of manual melting. At the end of the harvest the samples were taken to the INCAPER laboratory, where they were placed in an oven for drying at 105°C (± 3°C) for 24 hours to determine the humidity at each stage of maturation (12% h.b.) according to Campos et al. [10].

The foliar analysis was used to obtain the data for the characterization of each sampling point as to its nutritional status. In order to obtain these data, two pairs of leaves of the lateral branches (3^hrd and 4^{th} pairs counting from the tip to the base, at the 4 cardinal points) were removed in the middle third of each plant in the months of January and February 2013. The collected leaves were packed in a paper envelope, oven dried at 65° C to constant mass, ground and then sent to the laboratory for analysis. The samples were analyzed according to EMBRAPA [11] to obtain the dry matter concentrations of the macronutrients: N, P, K, Ca, Mg and S; and micronutrients: Fe, B, Zn, Mn and Cu.

Knowing the nutrient concentration at each sampling point was tested the normality of each data using the test Kolmogorov-Smirnov - KS (≤0,05) and the presence of discrepant values. Descriptive analysis was performed, determining the position measurements, dispersion (mean, median, maximum and minimum values, standard deviation, coefficients of variation, asymmetry and kurtosis).

The DOP was calculated using equation 1:

$$DOP = [(C * 100) / Cref] -100 \quad (1)$$

where: C is the concentration for each nutrient in the sample; Cref is the nutrient concentration recommended by the norm for the same sampling conditions, where the critical values established for the conilon coffee in the region, proposed by Bragança, Prezotti and Lani [12] (Table 1).

Using the DOP index values for each sampling point, the nutritional balance index (ΣDOP) was calculated by summing the index module obtained for each nutrient, making it possible to verify if the production limitations are of nutritional order.

Table 1. Critical levels of nutrients in the conilon coffee crop used as reference for calculating the DOP

Critical Level			
Macronutrients (dag kg^{-1})		Micronutrients (mg kg^{-1})	
N	3.00	Fe	130.00
P	0.12	Zn	12.00
K	2.10	Mn	69.00
Ca	1.40	B	48.00
Mg	0.32	Cu	11.00
S	0.24	-	-

A correlation analysis of Spearman ($p \leq 0.05$) between nutrient DOP indexes and ΣDOP and productivity was performed, considering the classification proposed by Kitamura, Morel and Lima [13]. Subsequently, the geostatistical analysis of the DOP and ΣDOP indexes was performed to quantify the degree of spatial dependence between the samples and the characteristics necessary for the estimation of values for non sampled sites. The degree of dependence was quantified by adjusting the theoretical semivariograms to the data, based on the assumption of intrinsic stationarity (equation 2):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[\left(Z_1(x_i) - Z_2(x_i + h) \right)^2 \right] \quad (2)$$

where: γ (h) is the estimated semivariance; N (h) is the number of pairs of the studied attribute; and Z (xi), Z (xi + h) are the values of the attributes measured at position xi and xi + h, separated by a vector h (distance between samples).In the semivariogram adjustments the theoretical models were tested: spherical, exponential and Gaussian. The model was chosen by minimizing the sum of the residual squares (SRQ) and by the multiple determination coefficient (R^2), resulting from the adjustment to the experimental semivariograms. The spatial dependence indexes (SDI) was considered by the $[C_0 / (C_0 + C)]* 100$ ratio and classified according to Cambardella et al. [14], which considers spatial dependence as weak (SDI> 75%), moderate 25% ≤SDI≤75%) and strong (SDI <25%). With the confirmed spatial dependence, the spatial distribution maps for the values of the DOP index, ΣDOP and the coffee conilon productivity were made by ordinary kriging.

3. RESULTS AND DISCUSSION

For each leaf nutrient studied, its averages and medians were close (Table 2). The DOP indexes of N, P, S, Fe and Zn were not normal, due to the high values of the asymmetry and / or kurtosis coefficient. Although normality is not a requirement of geostatistics, it is convenient that the data do not present distribution with very elongated tails, as it may compromise the analysis [15].

It is observed that the Ob / NC ratio less than one unit indicates nutrient deficiency and the inverse indicates the concentration in the foliar tissue higher than that recommended in the literature. According to Martinez et al. [16] nutrients K, Mg, S and Zn are extremely important for the vegetative growth and the development of coffee fruits, the imbalance of these elements leads to significant losses in crop productivity. Once it is known the spatial variability of these nutrients, it allows to reach areas in the crop with deficiencies, without promoting excesses in other regions and has the consequence of improving the nutritional conditions of the crop, allowing greater productivity with economy.

The analysis of data variability by the coefficient of variation (CV), according to Warrick and Nielsen [17] was classified as low for N (CV <12%), and the average for other variables (12% <CV <60%).

When considering the average of the 140 points sampled, the mean negative indexes were: Fe (-64.03), K (-54.71), Zn (-45.33), S (-31.17), Mg (- 9.56) and N (-6.23). The negative DOP indexes indicate the nutrient deficiency in relation to the standard, showing the percentage in which the concentrations of these nutrients are outside the desired value. Positive DOP indexes indicate nutrient excess in the crop; these were: Mn (190.83), B (91.26), P (5.71), Cu (5.35) and Ca (4.09). According to the values found for the DOP indexes, the order of nutrient deficiency limitation in the crop was Fe> K> Zn> S> Mg> N> Ca> Cu> P> B> Mn, where N is the last limiting nutrient deficit, from which all the nutrients are in excess.

Mirabdulbaghi [18], studying pear trees, obtained DOP indexes for macronutrients DOP macro positive and DOP micro negative. The results found in the conilon coffee plantation differ from the previous study, being negative for macronutrients (K, S, Mg and Ca), micronutrients (Fe, Zn) and positive indexes for the macronutrients Ca and P, and the micronutrients Cu, B and Mn.

Analyzing Table 3, significant Spearman correlations ($p \leq 0.05$) with ΣDOP were classified as: positive high with the DOP index of Mn ($0.6 \leq r < 0.8$); moderate positive with B ($0.4 \leq r < 0.6$); low negative for the DOP index of P, K, S and Zn ($0.2 \leq r < 0.4$). Productivity had a low positive correlation with S and negative correlation with K.

Table 2. Descriptive statistics of leaf nutrient contents for conilon coffee

Nutrients	Median	Ob/NC	Md	S	Values		Coefficients			Test KS
					Min	Max	CV(%)	C_s	C_k	
N(dag kg^{-1})	2.88	0.96	2.87	0.17	2.52	3.29	5.02	-0.29	1.11	*
P (dag kg^{-1})	0.15	1.25	0.15	0.03	0.07	0.20	20.59	-0.48	-0.51	*
K (dag kg^{-1})	1.02	0.49	1.00	0.24	0.50	1.64	23.89	0.47	0.00	ns
Ca (dag kg^{-1})	1.30	0.93	1.32	0.28	0.71	1.99	21.28	-0.09	-0.48	ns
Mg (dag kg^{-1})	0.33	1.03	0.34	0.08	0.15	0.51	22.16	0.41	0.12	ns
S (dag kg^{-1})	0.15	0.63	0.16	0.03	0.08	0.22	19.65	-0.37	-0.18	*
B (mg kg^{-1})	105.19	2.19	105.1	24.31	65.80	174.00	23.11	0.38	-0.51	ns
Cu (mg kg^{-1})	15.80	1.44	15.81	4.26	6.13	25.18	26.95	0.00	-0.68	ns
Fe (mg kg^{-1})	48.6	0.37	54.0	18.65	2.50	93.00	38.40	-0.46	0.18	*
Mn (mg kg^{-1})	203.6	2.95	205.5	54.83	89.00	323.00	26.93	0.17	-0.55	ns
Zn (mg kg^{-1})	6.83	0.57	7.54	2.19	1.82	10.87	31.99	-0.60	-0.65	*
∑DOP	564.78	-	568.25	96.09	306.41	802.97	17.01	0.04	0.03	ns
Prod (sc ha^{-1})	55.49	-	52.32	20.99	15.83	113.03	37.82	0.61	0.07	ns

*Ob / NC - relationship between observed value and critical level; Md - Median; S - standard deviation; CV - coefficient of variation; Cs - Asymmetry coefficient; Ck - kurtosis coefficient; ns - normal distribution by Kolmogorov-mirnov test (KS) ($p \leq 0.05$); * non-normal distribution*

Table 3. Spearman correlation analysis, significant at the 5% probability level, between ΣDOP, Prod and DOP indexes of each evaluated nutrient

	DOP											∑DOP
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	
∑DOP	-0.01	**-0.21**	**-0.34**	-0.05	0.14	-0.10	**0.55**	0.05	-0.07	**0.61**	**-0.27**	1.00
Prod.	0.11	-0.03	**-0.21**	0.16	0.04	**0.23**	0.12	-0.06	0.10	-0.12	0.08	-0.11

Bold: significant by the Spearman test (p ≤ 0.05)

According to the Spermam correlation, the nutritional imbalance occurred due to the excess of Mn and B and the K deficiency in the leaves of the evaluated coffee tree. The application with antagonistic nutrients is a solution to reduce effects of toxicity of the micros and even its absorption. Veloso et al. [19] discusses the difficulty of studying the effects of Mn toxicity alone because of interactions between it and other elements, such as Fe, Al, Si and Ca. These interactions may be responsible for the diversity of symptoms and different degrees of growth reduction in different species and cultivars [20]. Its toxicity is corrected by liming which, by raising the pH, precipitates the excess of available Mn, reducing its absorption by the plant [21]. This fact can be observed with the foliar Ca concentration below the critical level.

Application of N-ammonia (ammonium sulfate) may help reduce the concentration of Mn, for example. The Ca: Mg ratio may help reduce the absorption of B. Moreira et al. [22] reported a decrease in the absorption of B when applied 7,800 kg h^{-1} of limestone in the Ca: Mg ratio of 3: 1. In the present study, the Ca: Mg reaction is 3.94.

Since it is not possible to reduce nutrients in the short term, it is recommended the localized fertilization at variable rates with K, S and Zn, aiming at the improvement of ΣDOP, since they present a negative correlation with ΣDOP (r = -0.35, -0.19 and -0.34, respectively). In order to do this, it is necessary to know the spatial distribution of each nutrient in the area, to avoid the use of fertilizers or products that offer Mn and B, avoiding to increase the nutrient contents even further.

All variables analyzed presented spatial dependence (Table 4) with R^2 values of semivariogram adjustments greater than 80% for 92.3% of the variables, except for Mn DOP indexes (79.9%). The variables were adjusted to the exponential and spherical models for the experimental semivariogram.

The scope evidences distance the extent of spatial dependence in function of the sampling performed. For B, for example, that the range value is 50.0 m, a smaller number of samples will be collected than for the P (a = 10.0 m). The values of the ranges follow the order: B> Prod> N> ΣDOP> Mn> K > Fe = Zn = Ca = Mg = S = Cu = P. The Ca, Fe, Mg and Cu contents,

Table 4. Models and parameters of the graduated semivariograms adjusted for the PDO Index of each nutrient and the Nutritional Balance Index (ΣDOP).

Indexes DOP	Model	C_0	C_0+C	a (m)	GDE(%)	R^2(%)
N	EXP	0.45	1.03	22.00	43	81.6
P	ESF	0.05	1.04	10.00	4	88.0
K	EXP	0.03	1.04	13.77	3	82.7
Ca	EXP	0.22	0.95	10.00	23	84.8
Mg	EXP	0.01	0.93	10.00	1	86.1
S	ESF	0.40	0.98	10.00	40	92.2
B	EXP	0.03	0.99	50.00	3	93.8
Cu	EXP	0.10	1.01	10.00	10	92.8
Fe	EXP	0.01	0.93	10.00	1	81.0
Mn	EXP	0.38	1.07	15.00	36	79.9
Zn	EXP	0.01	1.04	10.00	1	92.0
∑DOP	EXP	0.22	1.01	21.42	22	88.4
Prod	EXP	0.53	1.07	49.00	50	50.0

ΣDOP: nutritional balance index; EXP: exponential model; ESF: spherical model; GDE: degree of spatial dependence (%); R2: coefficient of multiple determination as of S and Zn, had the same range and fit the same theoretical model, presenting the same spatial distribution pattern. The classification of spatial dependence, according to Cambardella et al. [14], shows strong SDI for most DOP indexes (SDI <25%), with the exception of N, S, Mn and Prod, whose spatial dependence was moderate (25% ≤SDI≤75%). The maps of the DOP indexes of Fe and K generated by interpolation by ordinary kriging after adjustment of the semivariograms (Fig. 1) show the nutrient deficiency in the whole area.

Fig. 1 (a) shows the DOP Index variation from -70 to -60 for Fe, while in Fig. 1 (b) the dominant range for the DOP Index is -65 to -50. These high negative values of the DOP index indicate that these nutrients are far below the concentration considered ideal for the good development and productivity of the coffee.

Potassium (K) requirements are very close to those of N, being the highest proportion found in grains, particularly in coffee mucilage [23]. The K has great importance in coffee, influencing the characteristics of reproductive growth, production, number of cherry grains and size of plagiotropic branches Clemente et al. [24]. According to the same authors, potassium nutrition may influence the production of large or small coffee beans, also influenced by genotypes, climatic and health characteristics.

Zn is the third most limiting nutrient by crop failure, followed by S. The DOP distribution of these nutrients in the area ranges from -60 to -40 and -45 to -30, for Zn and S, respectively (Fig. 2).

The DOP index of Zn affected the nutritional balance of the crop more than the values obtained from the DOP index of S, as evidenced by its negative correlation with ΣDOP (r = -0.27). The correction of these nutrients in the crop will have the consequence of increasing the DOP indexes, approaching them to zero, increasing the nutritional balance. Zn-deficient plants have a lower activity of the enzyme superoxide dismutase (SOD), which results in the loss of cellular compartmentation, causing chlorosis and necrosis, degradation of indoleacetic acid (IAA) and, consequently, inhibition of growth of new shoots and internodes [25].

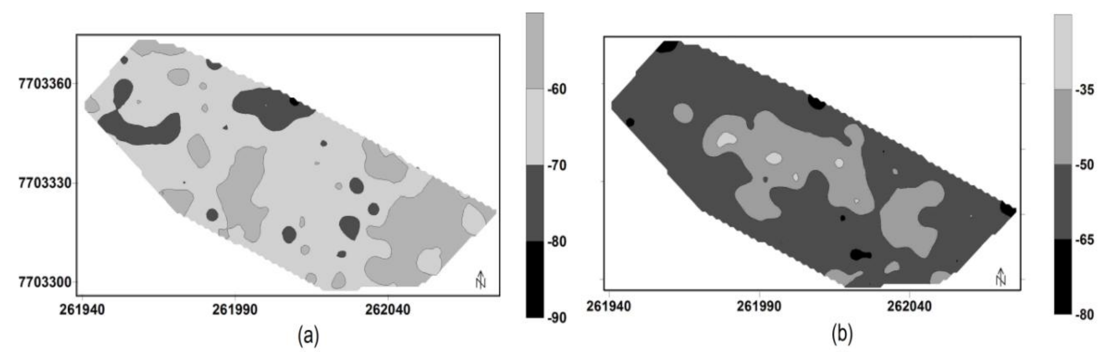

Fig. 1. Map of the DOP index for Fe (a) and K (b)

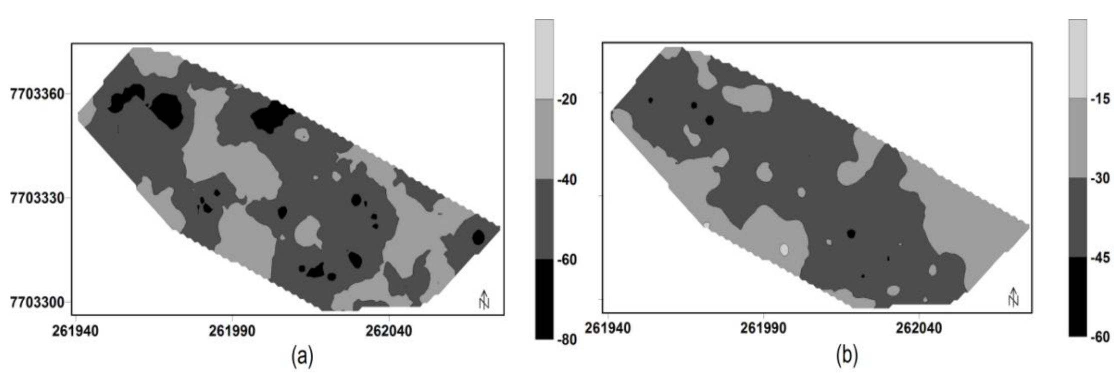

Fig. 2. Map of the DOP index for Zn (a) and S (b)

Fertilization with S, besides contributing to the reduction of the values of ΣDOP, which is desired, contributes to a significant increase in productivity, since it showed a significant positive correlation with it (r=0.23). The S is a fundamental nutrient in the formation of chlorophyll due to its participation in the metabolism of carbohydrates, reducing the photosynthesis in the crop with deficiency of this nutrient [26].

The negative values of DOP index for the micronutrients Fe (Fig. 1a) and Zn (Fig. 2a) in the crop can be justified by the successive application of NPK formulations, neglecting the application of these micronutrients and allowing them to be depleted in the plant.

The DOP indexes of Mg and N were the last in the order of limitation, which presented negative values, that is, these are the last limiting nutrients due to crop failure by this methodology. Due to the variability within the area, darker color regions in which the Mg presents high negative values of DOP Index (-60 to -30) (Fig. 3a). Considering Figs. 3a and 3b, positive values of DOP for Mg are observed in the upper part of the map, which corresponds to the low part of the crop. In the case of N, higher concentrations occur in the upper part of the crop.

In coffee production, the greatest needs are for N, which is the nutrient that most elevates crop production, followed by K [27], being the second most exported by coffee beans. Fig. 3b shows the variability in the DOP index for N, where the index values are all higher than -15.

For the DOP indexes of Ca and Cu (Fig. 4), most of the area presents minimum values of -20 and -10, respectively. The two nutrients, although not equal to zero, do not influence the nutritional balance, as evidenced by Spearman's non-significant correlation with ΣDOP (Table 3).

The Cu, although required in less quantity by plants, is essential to complete the vegetative cycle [28]. Its equilibrium is of extreme importance for the coffee crop since Cu deficiency can limit plant growth and production even when all other essential nutrients are present in adequate quantities [29,30].

The DOP Index of P (Fig. 5a) is close to 0, with most of the area ranging from 0 to 20. The high values of the DOP Index of B (Fig. 5b) show that it is in excess in the crop , with the lowest index being equal to 40, with the highest concentration in the upper region of the map corresponding to the low and lateral part of the crop area (Fig. 3b).

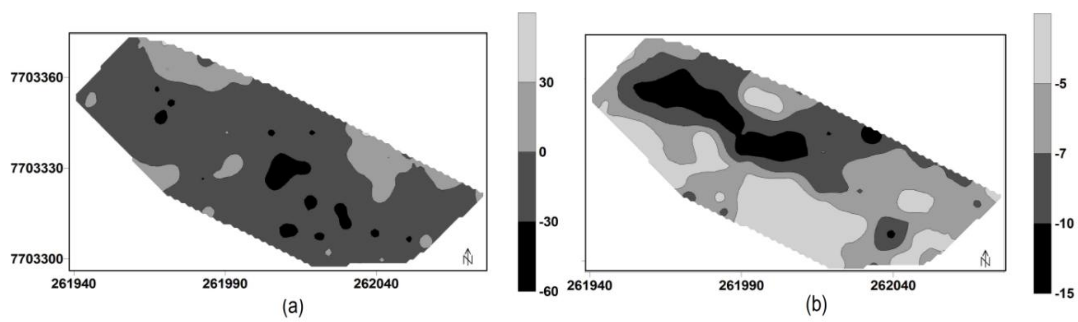

Fig. 3. Map of the DOP index for Mg (a) and N (b)

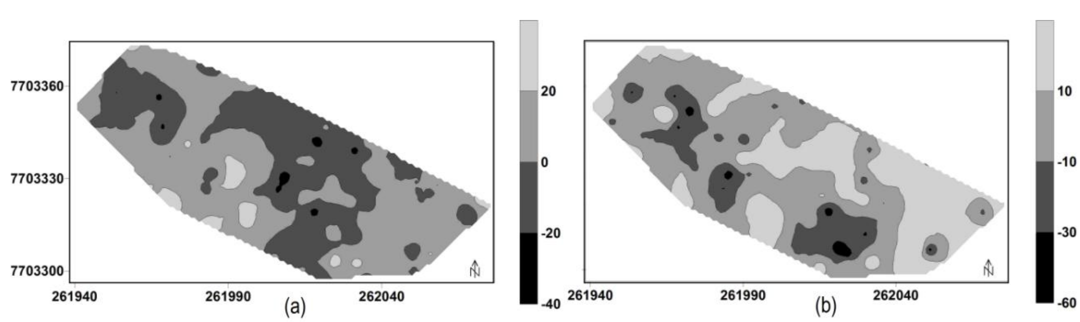

Fig. 4. Map of the DOP index for Ca (a) and Cu (b)

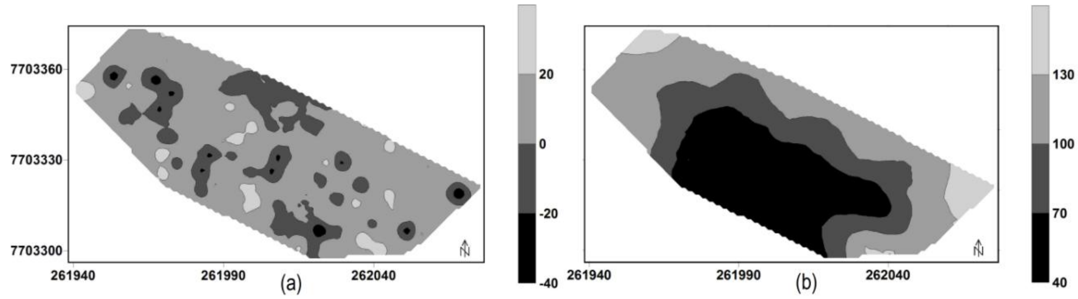

Fig. 5. Map of the DOP index for P (a) and B (b)

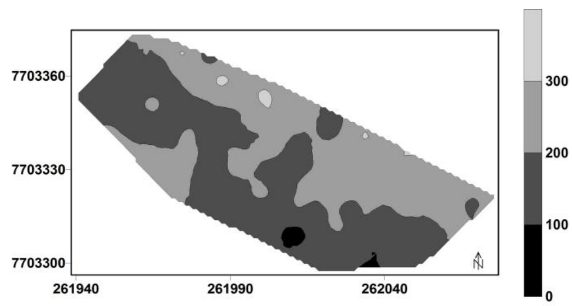

Fig. 6. Map of the DOP Index for Mn

The DOP index maps of Mn (Fig. 6) and ΣDOP (Fig. 7) show similarities due to the high positive correlation between them (r=0.61). Approximately 50% of the area present Mn DOP index above 200. The Mn concentration of the crop (203.6 mg kg^{-1}) is 2.95 times higher than the critical level proposed by Bragança, Prezotti and Lani [12] which is 69 mg kg^{-1}. Silva, Lima and Queiroz [31], studying the spatial variability of the nutritional status of Arabica coffee based on the DRIS index, also find an excess of Mn limiting the production.

The excess of Mn may have induced Fe and Mg deficiency by inhibition of absorption or competition at the cellular level, and Ca deficiency due to the indirect effect on transport to the new leaves [32].

The mapping of the DOP Index for each nutrient allowed to evaluate the nutritional status of the crop with respect to each nutrient. It was possible to identify regions with excess and deficiency for the same nutrient within the same area. For Romero et al. [33], when this nutritional imbalance is identified based on the DOP index, a corrective fertilization plan or a nutrient reduction in the fertilization plans is necessary.

No correlation was found between ΣDOP and productivity, there being no similarity between the maps (Fig. 7) and the shape. This lack of correlation may be due to the genotype being the Robusta Tropical with seed propagation, which may differ according to the reference values used from clonal genotype crops.

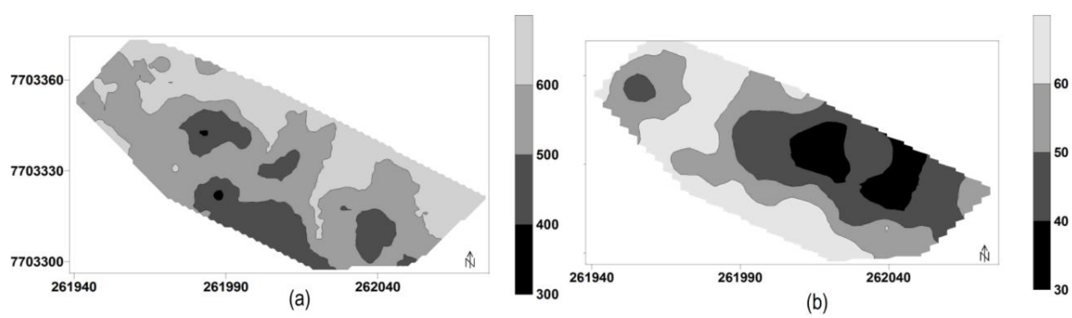

Fig. 7. Map of ΣDOP (a) and Prod (b)

The nutritional monitoring of the plants is essential for the construction and maintenance of efficient production systems since it brings several contributions to coffee cultivation, it allows to consider the spatial variation present in the productions [34]. The spatial variability of ΣDOP in the crop is related to the variation of the DOP indexes of each sampled nutrient. The high values of the DOP indexes show that the crop is in imbalance and, even if this imbalance does not correlate with the productivity of the harvested crop, it is necessary a different management in the fertilization for nutrients that are affecting these values, so that the problem is not aggravated. It should be noted that the ΣDOP presents regions with higher values exactly where it is observed in the maps of the DOP of the B and Mn. This fact can lead to erroneous interpretation of the nutritional status of a coffee crop, that is, disregarding the nutrients that are deficient.

4. CONCLUSION

The nutritional balance according to DOP index presented variability in the whole area with defined spatial structure and adjusted to the exponential and spherical semivariogram models.

The DOP method classified the nutrients in the order in which they are limiting (Fe> K> Zn> S> Mg> N> Ca> Cu> P> B> Mn), as well as the identification of deficiency and excess limitations.

Only the DOP indexes of K and S showed a significant correlation with productivity.

The excess of Mn and B was the one that most influenced the nutritional imbalance of the crop, being necessary to avoid the availability of this nutrient in the plans of fertilization or the application of antagonistic nutrients.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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