SPATIAL VARIABILITY OF THE PRODUCTIVITY AND THE NUTRITIONAL CONDITION OF COFFEE CANEPHORA

Abel Souza da Fonseca[1], Julião Soares de Souza Lima[2], Samuel de Assis Silva[3], Alexandre Candido Xavier[4], Antonio Pereira DrumondNeto[5]

(Recebido: 25 de outubro 2014; aceito: 29 de abril de 2015)

ABSTRACT: Utilizing precision farming techniques along with the Diagnosis and Recommendation Integrated System (DRIS) allows crop management to be improved, thereby making it possible to better control plant nutrition and to assist in reducing fertilizer expenditures. This study aimed to evaluate the spatial variability of the nutritional status of conilon coffee (*Coffea canephora*), using the Nutritional Balance index (NBI). 140 points were georeferenced within a coffee crop, each sampling point contained five plants. Leaf samples were analyzed in order to determine levels of N, P, K, Ca, Mg, S, Fe, B, Zn, Mn and Cu. The crop showed itself to have a nutritional imbalance, as shown by the deficiency and excess variation of some nutrients in the crop. The nutritional balance index (NBI) was not correlated with productivity (Prod), indicating that, when the crop has a high nutritional imbalance IBN is not a good tool for establishing nutritional standards for conilon coffee.

Index terms: Foliar analysis, semivariograms, precision agriculture.

VARIABILIDADE ESPACIAL DA PRODUTIVIDADE E DO ESTADO NUTRICIONAL DO CAFEEIRO CANEPHORA

RESUMO: *O uso das técnicas da agricultura de precisão aliada ao Sistema Integrado de Diagnose e Recomendação (DRIS) permite o aperfeiçoamento do manejo da lavoura, possibilitando melhor controle nutricional da planta e contribuindo para reduzir gastos com fertilizante. Objetivou-se, neste trabalho, avaliar a variabilidade espacial do estado nutricional do cafeeiro conilon (Coffea canephora), utilizando o Índice de Balanço Nutricional (IBN). Em uma lavoura de café foram amostrados 140 pontos georreferenciados, sendo cada ponto amostral constituído de cinco plantas. As amostras foliares foram analisadas para determinação dos teores de N, P, K, Ca, Mg, S, Fe, B, Zn, Mn e Cu. A lavoura apresenta desequilíbrio nutricional mostrado pela variação da deficiência e excesso de alguns nutrientes na lavoura. O índice de balanceamento nutricional (IBN) não apresentou correlação com a produtividade (Prod), indicando que, quando a lavoura apresenta elevado desequilíbrio nutricional o IBN não é uma boa ferramenta para o estabelecimento de um padrão nutricional para o café conilon.*

Termos para indexação: *Análise foliar, semivariogramas, agricultura de precisão.*

1 INTRODUCTION

Conilon coffee (*Coffeea canephora*) is a vital culture for Espírito Santo's economy, a Brazilian state. According to Ribeiro et al. (2014), besides being economically important, the culture is also socially important, due to the fact that it generates employment in the field.

Foliar diagnosis is essential for understanding the crop's nutritional state, and it is also important for recommending fertilizer use in a balanced way and at the lowest possible cost. The Diagnosis and Recommendation Integrated System (DRIS) uses the ratio between nutrients present in the leaf, while comparing these ratios with a high-yield reference population, so as to diagnose deficiency and excess nutrients in the crop.

The DRIS is a tool for interpreting foliar analysis by providing a quick view of the plants nutritional balance, which can guide, jointly with soil analysis, fertilization programs (MARTINEZ et al., 2008). For Partelli, Vieira and Costa (2005) the DRIS is efficient in diagnosing plant nutrition by means of determining the sequence of nutritional limitation. The closer to zero the index is, the closer to equilibrium the culture is.

The DRIS also provides the Nutritional Balance Index (NBI), which is the modular sum of the indices of each chemical element (CANTATUTTI et al., 2007), and enables you to check the nutritional balance of different crops, indicating that the lower the value, the lower the imbalance nutritional (FARNEZI et al., 2010). Elevated NBI values imply that some or many of the nutrient indexes are elevated. The NBI also makes it possible to check whether the limitations in productivity are related to nutrition or not.

[1,5]Universidade Federal do Espírito Santo/UFES - Pós-graduação em Produção Vegetal - Cx. P. 16 - 29500-000 - Alegre-ES abelsouzafonseca@gmail.com, agrodrumond@gmail.com
[2,3,4]Universidade Federal do Espírito Santo/UFES - Departamento de Engenharia Rural - DER/CCA - Cx. P. 16 - 29500-000 Alegre - ES - limajss@yahoo.com.br, alexandre.candido.xavier.ufes@gmail.com

The DRIS index had been used to assess the nutritional status of different crops, such as apple (PARENT, 2011), cotton (SOUZA et al., 2011), orange (DIAS et al., 2013) and other of the agronomic interest. In coffee, several studies have been conducted to define standards and criteria for use of the DRIS on different species, as conilon coffee (PARTELLI; VIEIRA; COSTA, 2005; WADT; DIAS, 2012) or arabic coffee (LANA et al., 2010; MAIA, 2012; SILVA; LIMA; QUEIROZ, 2011).

The application of fertilizers at a variable rate is closely related to precision agriculture concepts, which defends the differential treatment of selected areas of a field of production, based on intra variability of the cultural field and involves a process of investigation and diagnosis (VALENTE et al., 2012). Recent studies have evaluated the spatial relationship between the productivity of coffee and the nutritional status of plants (HAILESLASSIE et al., 2005; SILVA; LIMA; BOTTEGA, 2013; SILVA; LIMA; QUEIROZ, 2011). However, little has been explored spatial analysis of DRIS index and its relationship with coffee productivity, especially for conilon species.

Fertilizer application, based on specific plant deficiencies, as recommended by DRIS, can be improved using precision agriculture concepts, information regarding the spatial distribution of nutrients in the field and best management practices, thereby resulting in a significant increase in profitability for coffee producers.

The aim of this study was to evaluate the spatial variability of conilon coffee's nutritional status and productivity (*Coffea canephora*) through the use of NBI from the DRIS technique.

2 MATERIAL AND METHODS

The experiment was performed at an INCAPER (The Capixaba Institute of Research, Technical Assistance and Rural Education) experimental farm, in the municipality of Cachoeiro de Itapemirim-ES, with *Coffea canephora* var. robusta (L. Linden) A. Chev. 'Encaper 8151` with a 2.9 x 0.9 m spacing, as demarcated by Oliveira (2007). The experimental area (Figure 1) is located at geographical coordinates: 20° 45' 17.31" South Latitude and 41° 17' 8.86" West Longitude, at an altitude of 117 m in 1.0 ha of the culture.

An irregular grid was built in the study area, to collect leafs and fruit. The grid consisted of 140 georeferenced sampling points distanced at approximately 10 m along the of coffee plant rows, and approximately 1,305 m between coffee plant rows, with a point area of 13.05 m^2. Each sample point was made up of five plants, with the final sample of the point, merge result five subsamples.

The data for calculating productivity were collected from the crop in 2011. The collecting was performed in July, 2011. The coffee plants, at each sampling point, were manually striped in sieves and then placed in bags that had been previously labeled. After the samples had been collected, they were taken to the INCAPER laboratory so as to determine the mass of the moist green and unripe coffee beans, cherry and dried coffee. The samples were placed in an artificial drying oven at 105°C (± 3°C) for 24 hours, this in order to determine the moisture at each maturation stage (12 %) in accordance with Campos et al. (2008).

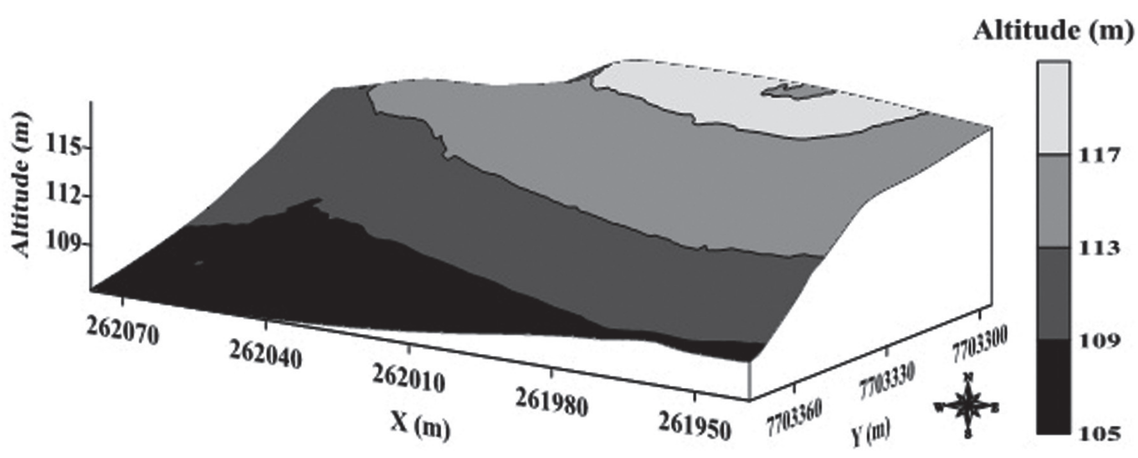

FIGURE 1- Digital elevation model of the experimental area.

Foliar analysis was used to obtain data that makes possible to characterize the nutritional state of each point. In order to obtain these data, two pairs of leaves from the lateral branches (3rd and 4th pairs from the tip to the base) were collected at the plant's average height, from the the 4 cardinal points (OLIVEIRA et al., 2010). The leaves, collected in January/2011, were wrapped in a paper envelope, dried in an oven at 65°C, until they reached a constant mass, grinded and subsequently sent to the analysis laboratory at the Center for Agricultural Sciences – UFES. The samples, after washing, drying at 60 ° C and milling, were subjected to macro and micronutrients analysis using the methods described by Bataglia et al. (1983).

The DRIS index calculations were based on the general formula proposed by Beaufils (1973), according to Barbosa et al. (2006) and Bataglia et al. (2004). The DRIS reference population (standard) was used in accordance with Partelli et al. (2002), who established DRIS standards for the Municipality of Vila Valério-ES. For DRIS application, the functions of the ratios between two DRIS nutrients were calculated according to Jones (1981) (equation 1):

$$f(A/B) = (A/B - a/b).k/s \qquad (1)$$

where: *f (A/B)* is the function of the ratio between the two nutrients A and B from the sample being diagnosed, A/B is the value of the ratio between the two nutrients in leaves under diagnosis, *a/b* is the value of the standard (reference crop), *k* is an arbitrary constant (10) and *s* is the standard deviation of the ratio in the reference population.

Subsequently, the DRIS indexes were calculated:

$$\text{Index A} = \{[f(A/B)+...+f(A/Z)] - [f(B/A)+...+f(Z/A)]\} / (n+m) \qquad (2)$$

where: f (A/B) is the reduced normal function of the direct ratio between the contents of the two nutrients A and B; f (A/Z)is the reduced normal function of the direct ratio between the contents of the two nutrients A e Z;, f (B/A); f (Z/A) is the reduced normal function of the inverse ratio between the concentrations of the two nutrients B and A;Z and A, respectively, n is the number of functions where the nutrient A in analysis appears in the numerator (direct ratios) and m is the number of functions where the nutrient A in analysis appears in the denominator (inverse relationship).

The DRIS also provides the Nutritional Balance Index (NBI) (equation 3). The higher the sum value, the larger the indication of plant nutritional unbalance (MOURÃO FILHO, 2004).

$$NBI = |A\ indexes| + |B\ indexes| + ... + |Z\ indexes| \qquad (3)$$

This index makes possible to verify whether the productivity limitations are related to nutrition or not. Very high NBI values imply that some or many of the nutrients are elevated, i.e. when NBI values are smaller, the crop has a greater nutritional balance.

An exploratory analysis was performed before the descriptive analysis so as to verify the presence of outliers. Data were analyzed by means of position measurements (mean and median); dispersion measurements (maximum and minimum values, upper and lower quartiles, standard deviation, variance and coefficient of variation); dispersion form (coefficient of skewness and kurtosis); and normality verification of the data at a 5% level of significance by way of the Kolmogorov-Smirnov (KS) test, using the software Statistic 7.0.

After determining the NBI and the productivity rate for each sampling point, a geostatistical analysis was performed in order to verify the occurrence of spatial dependence and, if it occurs, to quantify the degree of dependence with theoretical semivariograms fits, based on the intrinsic and stationary assumption(equation 4):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[\left(Z_1(x_i) - Z_2(x_i + h) \right)^2 \right] \qquad (4)$$

where: $\gamma(h)$ is the estimated semivariance; N(h) is the number of pairs of the studied attributes; and $Z(x_i)$ and $Z(x_i + h)$ are the values of the attributes measured at position x_i and $x_i + h$, separated by a h vector (distance between samples).

Were tested the spherical experimental models, Gaussian, exponential, linear with sill. The choice for the adopted model was based on minimizing the residual sum of squares (RSS), in the increased the multiple coefficient of determination (R^2) of the fits from the theoretical models to the experimental semivariograms, and also in the correlation coefficient of cross-validation (r-cv) (observed values versus estimated values).

The existence of the spatial dependence of each attribute was demonstrated by semivariogram defining the parameters: nugget effect (C_0), range (a) and sill (C_0 + C). The index of spatial dependence (ISD) was considered by the ratio $[C_0/(C_0+C)]*100$ and classified in accordance with Zimback (2001), who considers spatial dependency as being strong (ISD>75%), moderate (25% ≤ ISD≤ 75%) and low (ISD <25%).

With the spatial dependency having been confirmed, NBI values and coffee productivity were estimated by ordinary kriging for the non-sampled locations, which spatial distribution maps were built. This geostatistical interpolation uses a linear estimator with minimum variance, and also takes the spatial variability structure into account that was found for the studied variables.

3 RESULTS AND DISCUSSION

3.1 Exploratory and descriptive analysis

During exploratory analysis of the data, the presence of outliers was observed for the K (two observations), Cu (one observation) and Mn (one observation). In the attributes that presented outliers, these were replaced by the average of the closest set of data, according Libardi and Melo Filho (2006). During spatial analysis, according to Nazareno et al. (2013) outliers have a strong impact, especially in the initial stage of the semivariogram. This can cause an erroneous interpretation regarding the nugget effect.

While analyzing the mean of the macronutrients found during the foliar analysis of the coffee plant (Table 1), in accordance with that as described by Bragança, Prezotti and Lani (2007), there were levels of N, P, Ca that are suitable for the coffee crop. The Mg (<0.35 dag kg^{-1}), K (<2.0 dag kg^{-1}), and S (<0.20 dag kg^{-1}) levels were considered low in the crop, the K nutrient being that with the greatest deficiency.

Among the micronutrients, Fe (<120.0 mg kg^{-1}) and Zn (<10.0 mg kg^{-1}) had values that were below those recommended by Bragança, Prezotti and Lani (2007). However, according to Matiello e Garcia (2013), a deficiency of Fe can be extremely critical and yet, the plant is able to continue fruiting satisfactorily, albeit in the short term. According to Oliveira et al. (2010) the deficiency of these nutrients can be related to their low concentration in the soil, because of the soil's original characteristics and/or because continuous farming, being added at low concentrations or not added according to their need.

TABLE 1-Descriptive statistics of the coffee crop foliar nutrients.

Nutrient				Values		Coefficients			Test
	Mean	Md	S	Minimum	Maximum	CV(%)	C_s	C_k	KS
N(dag kg^{-1})	2.88	2.87	0.17	2.52	3.29	5.02	-0.29	1.11	p<0.05*
P (dag kg^{-1})	0.15	0.15	0.03	0.07	0.20	20.59	-0.48	-0.51	p<0.01*
K (dag kg^{-1})	1.02	1.00	0.24	0.50	1.64	23.89	0.47	0.00	$p>0.20^{ns}$
Ca(dag kg^{-1})	1.30	1.32	0.28	0.71	1.99	21.28	-0.09	-0.48	$p>0.20^{ns}$
Mg (dag kg^{-1})	0.33	0.34	0.08	0.15	0.51	22.16	0.41	0.12	$p<0.10^{ns}$
S (dag kg^{-1})	0.15	0.16	0.03	0.08	0.22	19.65	-0.37	-0.18	p<0.05*
B (mg kg^{-1})	105.19	105.1	24.31	65.80	174.00	23.11	0.38	-0.51	$p>0.20^{ns}$
Cu (mg kg^{-1})	15.80	15.81	4.26	6.13	25.18	26.95	0.00	-0.68	$p>0.20^{ns}$
Fe (mg kg^{-1})	48.6	54.0	18.65	2.50	93.00	38.40	-0.46	0.18	p<0.01*
Mn (mg kg^{-1})	203.6	205.5	54.83	89.00	323.00	26.93	0.17	-0.55	$p>0.20^{ns}$
Zn (mg kg^{-1})	6.83	7.54	2.19	1.82	10.87	31.99	-0.60	-0.65	p<0.01*

Md – Median; s – standard deviation ; CV – coefficient of variation ; C_s – asymmetry coefficient; C_k – kurtosis coefficient; ns – normal distribution by Kolmogorov_Smirnov (KS) test 5% probability; and * n-normal distribution.

In contrast to the Fe and Zn deficiencies, very high Mn values were found the mean for the crop is 2.5 times greater than the upper range limit proposed by Bragança, Prezotti and Lani (2007), which is 80 mg kg^{-1}. Silva, Lima and Queiroz (2011), studying the spatial variability in the nutritional status of *Coffea arabica*, based on the DRIS index, also found an excess of production limiting Mn.

Partelli, Vieira and Costa (2005) also observed that the presence of Mn acted as a limiting factor while diagnosing organic and conventional crops in the State of Espírito Santo in the robust coffee culture (conilon). The contrary results found in this study, which coincides with those found by Oliveira (2007), which, according to this author, can be related to soil acidity, which is due to continuous use of acidifying nitrogen fertilizers, which would lead to a greater availability of Mn.

All the nutrients had asymmetry coefficients (C_s) that were close to zero. However, only K, Ca, Mg, B, Cu and Mn showed a normal distribution by means of the Kolmogorov-Smirnov test (KS) ($p<0.05$) and asymmetry to the right. The deviation of the remaining nutrients from normality is due to total amplitude, shown by the lengthening of the distribution tail.

According to Pimentel-Gomes and Garcia (2002), the coefficient of variation (CV), commonly obtained during agricultural field tests for attributes relating to plants, can be classified as: low (CV <10%) as found for N; average (10% < CV < 20%) for S; high (20% < CV < 30%) for P, K, Ca, Mg, B, Cu and Mn; and very high (CV > 30%) for Fe and Zn. Low CV values for N in leaves from conilon coffee plants were also found by Oliveira (2007).

3.2 Nutritional Balance Index (NBI) and Productivity (Prod)

The mean NBI in the crop was 235.32, the minimum value being 122.74 and maximum 390.99 (Table 2). The asymmetry coefficient (C_s) was positive (asymmetry to the right) with the mean greater than the median, thereby indicating value concentrations below the mean. The lower the NBI values, the more balanced the nutrients are in the crop. In this case, the nutrients were not found to be balanced, there were nutrient deficiencies and excesses in the culture, as evidenced by the high NBI values found.

Analyzing the data distribution, there is an absence of normality for the productivity of the processed coffee (sc ha^{-1}) by the K-S test and with asymmetry to the right. Regarding the coefficient of variation, CV of the NBI had a variability with a value between 20% and 30%, and productivity with very high variability and a CV greater than 35%.

3.3 Spatial Analysis of the NBI and Productivity (Prod)

The plant's attributes were fit to the semivariograms with an exponential model with ranges of 15 m and 20 m for the NBI and Prod, respectively. The cross semivariograms for Prod x NBI not present spatial dependence, with random behavior of the samples, characterized by pure nugget effect (Table 3).

The nugget effect (C_0) represents the unexplained variability. The smaller the proportion of the nugget effect in relation to the semivariogram level, the greater the spatial dependence, which in this study showed a moderate ISD of 53 and 55%, respectively, for the NBI and Prod.

Figure 2 shows the exponential semivariograms fitted by the least-squares method to the Prod and NBI data.

The spatial dependence range of one attribute ensures that all sampling points within its action radius present certain similarities and that the values estimated by interpolation for non-sampled locations at distances smaller than the smallest adopted during sampling are more precise. The range is extremely important for evaluating the experiment, as it indicates the distance from which the samples are independent. Measurements, located at distances greater than the range, have random spatial distributions, and the mean is the statistic used to represent the sample field.

As previously mentioned, the NBI and Prod did not present significant linear ($p<0.05$) or even spatial correlation with the construction of the cross-semivariogram. Silva, Lima and Queiroz (2011) observed a significant correlation between the prod and the IBN adjusted for Arabica coffee, attributing this result to higher nutritional balance of the evaluated crops. On this study, the low correlation may be assigned to nutrient values that were taken as a reference for calculating the NBI for the conilon coffee culture, which were mostly in low levels in plant tissue. It is important to remember that the variety under study was the Tropical Robust with propagation by seed, which can differ depending on the reference values being from clonal plantations. Amaral et al. (2007) state that the seminal plant 'Conilon', showed greatly variability morpho-physiological compared to clonal varieties, directly affecting productivity, time of maturity, size and shape of the fruit.

TABLE 2 - Descriptive statistics of the NBI and Productivity of processed conilon coffee.

Attribute	Median	Md	S	Values		Coefficients			Test	r
				Minimum	Maximum	CV(%)	C_s	C_k	KS	
NBI	235.32	231.67	55.5	122.74	390.99	23.59	0.56	0.10	p<0.05*	-
Prod.	54.23	52.32	19.2	15.83	105.29	35.41	0.43	-0.24	p>0.20^{ns}	-0,04

NBI – Nutritional Balance Index; Prod. Processed coffee production (sc ha $^{-1}$); Md – Median; s – standard deviation; CV – coefficient of variation; C_s –symmetrical coefficient; C_k – kurtosis coefficient; ns – normal distribution by the Kolmogorov-Smirnov test (KS) at a 5% probability level; and * non-normal distribution; r – Person`s linear correlation between IBN and Prod.

TABLE 3 - Parameters of the simple and cross semivariograms fitted to the Nutritional Balance Index and conilon coffee productivity.

Attribute	Model	C_0	C_0+C	a (m)	ISD(%)	R^2(%)	RSS	r-vc (%)
NBI	EXP	978	2080	15	53	89	1,86	32
Prod	EXP	161	360	20	55	77	0,73	36
Prod x NBI	EPP	-	-	-	-	-	-	-

Prod x NBI – cross variograms; EXP: exponential model; EPP - pure nugget effect; C_0 - nugget effect; C_0+C -sill; a - range; ISD: index of spatial dependency (%); R^2: coefficient of multiple determination; r-vc: correlation between observed and estimated values by cross-validation.

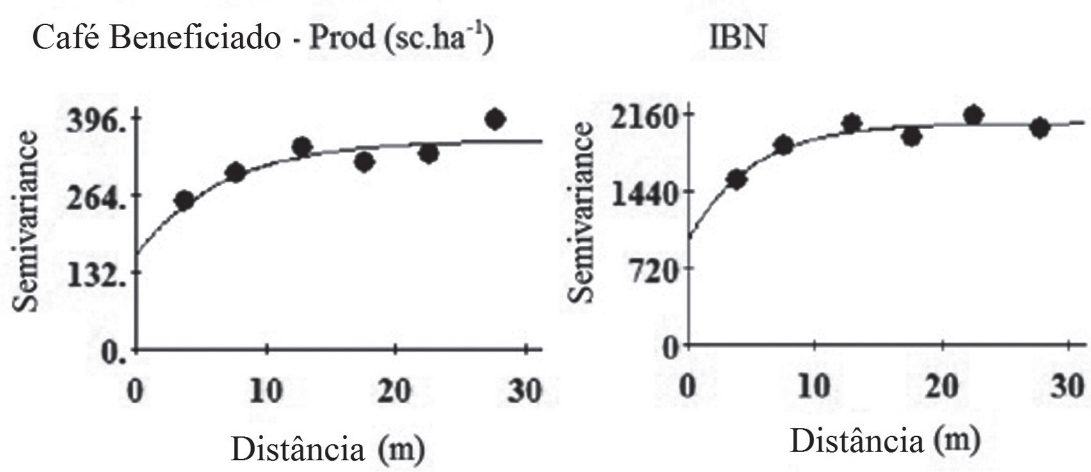

FIGURE 2-Semivariograms of Prod and the NBI, showing the fit of these attributes to the exponential model.

The semivariograms for the two attributes with values of 89% and 77% for the R^2 the NBI and Prod, respectively, and the ones who minimized the RSS values for the models and parameters tested. Silva, Lima and Queiroz (2011) evaluating the spatial variability of productivity and IBN for Arabica coffee showed values similar to those observed in this work. According this authors, both productivity and the nutritional status of plants have high variance depending on the position of the sample points, given the interactions in the soil-plant-atmosphere system.

The r-vc of the crossed validation had an average correlation between the observed and estimated values by cross-validation, however significant, with the a nonzero slope coefficient of the line by the t-test (p<0.05). According to Amado et al. (2007), significant values for the cross validation indicate that the adjusted model is able to represent the spatial variability in production fields.

The productivity map (Prod) built by ordinary kriging shows its spatial distribution in the area (Figure 3). According to Oliveira (2010) this variability may be related to the fact that crop management does not use the application of precision farming variable rate. Another fact that may cause spatial variability in conilon coffee productivity is the number of productive branches (orthotropic) being different for each plant from the sampling point, which has an influence on productivity.

The lowest productivity (Prod) areas, represented by the darker colors on the map (30 to 54 sc/ha), are found in the medium and lower area. The highest Prod values are present in the region to the right of the area, in the lower, medium and higher portion (flat), with values above 54 sc ha^{-1}. Silva, Lima and Queiroz (2011) observed similar behavior of coffee productivity distribution across the landscape in crop arabic coffee. Silva et al. (2007) comment that the crops relief has been an important parameter for defining the spatial behavior of the crop productivity, once this determines the distribution of soil chemical properties across the landscape.

The NBI map (Figure 4) also demonstrates the spatial variability of the index within the crop. The major extents of the area showed NBI values between 200 to 230 and 230 to 260 and are concentrated in upper and lower portions thereof, respectively. A small extension area 200 has lower values and values above 260. Silva, Lima and Queiroz (2011) state that, usually, the lower the NBI value the greater crop yield, however, in this study, throughout the production area the values of this index are considered high, as shown by Wadt and Dias (2012).

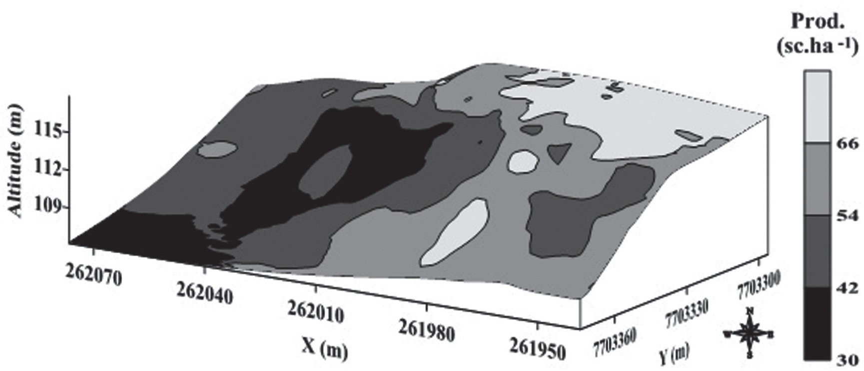

FIGURE 3 - Spatial distribution of productivity (sc ha^{-1}) of conilon coffee, processed variation. Tropical Robust.

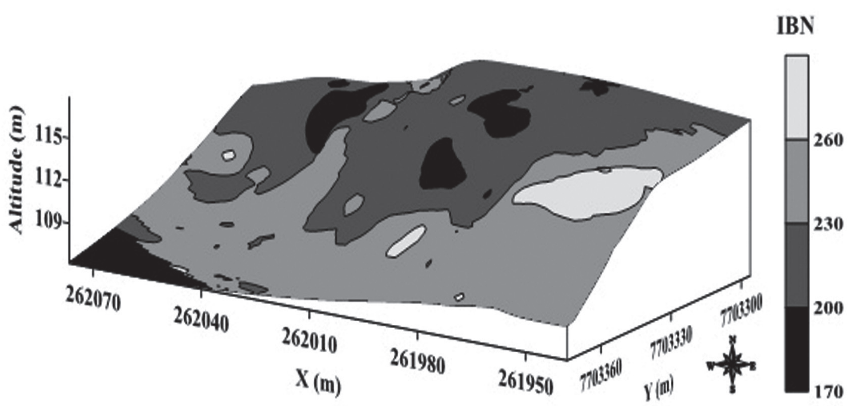

FIGURE 4 - Spatial distribution of the Nutritional Balance index (NBI) of the conilon coffee variety. Tropical Robust.

4 CONCLUSIONS

1. The crop showed itself to have a nutritional imbalance, as shown by the deficiency and excess variation of some nutrients in the crop.

2.The nutritional balance index (NBI) was not correlated with productivity (Prod), indicating that, when the crop has a high nutritional imbalance IBN is not a good tool for establishing nutritional standards for conilon coffee.

5 AKNOWLEDGEMENTS

The authors thank the financial support by FAPES and CNPq in the development of this research.

6 REFERENCES

AMADO, T. J. C. et al. Variabilidade espacial e temporal da produtividade de culturas sob sistema plantio direto. **Pesquisa Agropecuária Brasileira,** Brasília, v. 42, n. 8, p. 1101-1110, ago. 2007.

AMARAL, J. A. T. et al. Crescimento vegetativo e produtividade de cafeeiros conilon propagados por estacas em tubetes. **Ciência e Agrotecnologia**, Lavras, v. 31, n. 6, p. 1624-1629, nov./dez. 2007.

BARBOSA, D. H. S. G. et al. Estabelecimento de normas DRIS e diagnóstico nutricional do cafeeiro arábica na região noroeste do Estado do Rio de Janeiro. **Ciência Rural**, Santa Maria, v. 36, n. 6, p. 1717-1722, nov./dez. 2006.

BATAGLIA, O. C. Resposta à adubação fosfatada na cultura do café. In: YAMADA, T.; ABDALLA, S. R. S. (Ed.). **Fósforo na agricultura brasileira**. Piracicaba: POTAFOS/ANDA, 2004. p. 307-328.

BATAGLIA, O. C. et al. **Métodos de análise química de plantas**. Campinas: Instituto Agronômico, 1983. 48 p. (Boletim Técnico, 78).

BEAUFILS, E. R. Diagnosis and recommendation integrated system (DRIS): a general scheme for experimentation and calibration based on principles developed from research in plant nutrition. **South Africa Soil Science Bulletin**, Pietermararitzburg, v. 1, n. 1, p. 1-132, 1973.

BRAGANÇA, S. M.; PREZOTTI, L. C.; LANI, J. A. Nutrição do cafeeiro Conilon. In: FERRÃO, R. G. et al. (Ed.). **Café Conilon**. Vitória: Incaper, 2007. p. 299-327.

CAMPOS, D. S. et al. Mapeamento da produtividade na cafeicultura de montanha com uso de técnicas de sensoriamento remoto. **Engenharia na Agricultura**, Viçosa, v. 16, p. 39-48, 2008.

CANTARUTTI, R. B. et al. Avaliação da fertilidade do solo e recomendação de fertilizantes. In: NOVAIS, R. F. et al. (Ed.). **Fertilidade do solo**. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2007. p. 769-872.

DIAS, J. R. M et al. Antecipação do período de diagnose foliar em laranjeira 'Pêra' no Amazonas. **Pesquisa Agropecuária Brasileira**, Brasília, v. 48, n. 7, p. 757-764, jul. 2013.

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**, Lavras, v. 34, n. 5, p. 1191-1198, set./out. 2010.

HAILESLASSIEA, A. et al. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. **Agriculture, Ecosystems & Environment**, Amsterdam, v. 108, n. 1/5, p. 1-16, 2005.

JONES, C. A. Proposed modifications of the diagnosis and recommendation integrated system (DRIS) for interpreting plant analyses. **Communications in Soil Science and Plant Analysis**, Philadelphia, v. 12, p. 785-794, 1981.

LANA, R. M. Q. et al. Levantamento do estado nutricional de plantas de *Coffea arabica* L. pelo DRIS, na região do Alto Paranaíba, Minas Gerais. **Revista Brasileira de Ciências do Solo**, Viçosa, v. 34, p. 1147-1156, 2010.

LIBARDI, P. L.; MELO FILHO, J. F. Análise exploratória evariabilidade dos parâmetros da equação da condutividadehidráulica, em um experimento de perfil instantâneo. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 30, n. 2, p. 197-206, 2006.

MAIA, C. E. Fertilization response likelihood for the interpretation of leaf analyses. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 36, p. 437-445, 2012.

MARTINEZ, H. E. P. et al. Diagnose foliar em cafeeiro. In: TOMAZ, M. A. et al. (Ed.). **Seminário para a sustentabilidade da cafeicultura**. Alegre: UFES, 2008. p. 139-166.

MATIELLO, J. B.; GARCIA, A. W. R. **Deficiências de ferro e manganês caminham juntas no cafeeiro**. Varginha: PROCAFÉ, 2013. Disponível em: <http://fundacaoprocafe.com.br/downloads/Folha012FeeMn.pdf>. Acesso em: 19 nov. 2013.

MOURÃO FILHO, F. A. A. DRIS: concepts and applications on nutritional diagnosis in fruit crops. **Scientia Agricola**, Piracicaba, v. 61, n. 5, p. 550-560, 2004.

NAZARENO, A. C. et al. Caracterização do microclima dos diferentes layouts de caixas no transporte de ovos férteis. **Engenharia Agrícola e Ambiental**, Campina Grande, v. 17, n. 3, p. 327-332, 2013.

OLIVEIRA, R. B. **Mapeamento e correlação de atributos do solo e de plantas café conilon para fins de agricultura de precisão**. 2007. 129 p. Dissertação (Mestrado em Produção Vegetal) - Universidade Federal do Espírito Santo, Alegre, 2007.

OLIVEIRA, R. B. et al. Spatial variability of the nutritional condition of canephora coffee aiming specific management. **Coffee Science**, Lavras, v. 5, n. 3, p. 190-196, 2010.

PARENT, L. E. Diagnosis of the nutrient compositional space of fruit crops. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 33, n. 1, p. 321-334, 2011.

PARTELLI, F. L. et al. Normas de referência do DRIS para o cafeeiro conilon (*Coffeacanephora* Pierre exFroehner). In: CONGRESSO BRASILEIRO DE PESQUISAS CAFEEIRAS, 28., 2002, Caxambu. **Anais...** Rio de Janeiro: SARC/PROCAFÉ, 2002. p. 326-328.

PARTELLI, F. L.; VIEIRA, H. D.; COSTA, A. N. Diagnóstico nutricional em cafeeiro conilon orgânico e convencional no Espírito Santo, utilizando o DRIS. **Ciência Rural**, Santa Maria, v. 35, n. 6, p. 1456-1460, nov./dez. 2005.

PIMENTEL-GOMES, F.; GARCIA, C. H. **Estatística aplicada a experimentos agronômicos e florestais:** exposição com exemplos e orientações para uso de aplicativos. Piracicaba: FEALQ, 2002. 309 p.

RIBEIRO, B. B. et al. Avaliação química e sensorial de blends de Coffea canephora e *Coffea arabica* L. **Coffee Science**, Lavras, v. 9, n. 2, p. 178-186, 2014.

SILVA, F. M. et al. Variabilidade espacial de atributos químicos e de produtividade na cultura do café. **Ciência Rural**, Santa Maria, v. 37, n. 2, p. 401-407, mar./abr. 2007.

SILVA, S. A.; LIMA, J. S. S.; BOTTEGA, E. L. Yield mapping of arabic coffee and their relationship with plant nutritional status. **Journal of Soil Science and Plant Nutrition**, Temuco, v. 13, n. 3, p. 556-564, 2013.

SILVA, S. A.; LIMA, J. S. S.; QUEIROZ, D. M. Spatial variability in nutritional status of arabic Coffee based on DRIS index. **Revista Ceres**, Viçosa, v. 58, n. 2, p. 256-261, 2011.

SOUZA, R. F. et al. Diagnose nutricional pelos métodos dris e faixas de concentração para algodoeiro cultivado sob cerrado. **Pesquisa agropecuária Tropical**, Goiânia, v. 41, n. 2, p. 220-228, 2011.

VALENTE, D. S. M. et al. Definition of management zones in coffee production fields based on apparent soil electrical conductivity. **Scientia Agrícola**, São Paulo, v. 69, p. 173-179, 2012.

WADT, P. G. S.; DIAS, J. R. M. Normas DRIS regionais e inter−regionais na avaliação nutricional de café Conilon. **Pesquisa Agropecuária Brasileira**, Brasília, v. 47, n. 6, p. 822-830, 2012.

ZIMBACK, C. R. L. **Análise especial de atributos de solos para fins de mapeamento da fertilidade**. 2001. 114 f. Tese (Livre-Docência em Levantamento do Solo e Fotopedologia) - Universidade Estadual Paulista, Botucatu, 2001.