

SPACIAL VARIABILITY OF KENWORTHY BALANCED INDEXES (KBI) FOR MACRO AND MICRONUTRIENTS ON THE COFFEE CANEPHORA

SUMMARY

The nutritional monitoring of coffee is essential for the construction and maintenance of efficient production systems, since it brings several contributions to coffee cultivation and allows to consider the spatial variation present in the productions. The objective of this paper was to analyze and describe the spatial behavior of the coffee nutritional status based on the Kenworthy balanced indexes (KBI). The experiment in southern Espírito Santo, in an area planted with seminal conilon coffee. It was determined the Kenworthy balanced indexes for Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Boron (B), Manganese (Mn), Zinc (Zn) and Copper (Cu) and yield (Prod) obtained by the crop, being the data analyzed by means of geostatistics. The diagnosis presented in this study indicated a higher nutritional limitation due to deficiency for K, Zn, Fe and B and for excess for Cu, showing the nutritional imbalance of the crop. With the exception of KBI for P, all variables presented spatial dependence adjusted to the spherical and exponential models.

Key words: *Coffea canephora*, foliar analysis, nutritional balance, DRIS, nutrients

RESUMO

O monitoramento nutricional do cafeeiro é essencial para a construção e manutenção de sistemas de produção eficiente, pois traz diversas contribuições a cafeicultura e permite considerar a variação espacial presente nas produções. O objetivo do trabalho foi analisar e descrever o comportamento espacial do estado nutricional do cafeeiro com base nos índices balanceados de Kenworthy (IBK). O experimento no sul do Espírito Santo, em uma área cultivada com café conilon seminal. Determinou-se os índices balanceados de Kenworthy para Nitrogênio (N), Fósforo (P), Potássio (K), Cálcio, Magnésio (Mg), Enxofre (S), Boro (B), Manganês (Mn), Ferro (Fe), Zinco (Zn) e Cobre (Cu) e a produtividade (Prod) obtida pela cultura, sendo os dados analisados por meio da geoestatística. O diagnóstico apresentado neste trabalho apontou maior limitação nutricional por deficiência para o K, Zn, Fe e B e por excesso para o Cu, mostrando o desequilíbrio nutricional da lavoura. Com exceção do IBK para o P, todas as variáveis apresentaram dependência espacial ajustada aos modelos esférico e exponencial.

Palavras chave: *Coffea canephora*, análise foliar, equilíbrio nutricional, DRIS, nutrientes

INTRODUCTION

Agriculture is part of the primary sector of the economy, with important participation in the country's GDP, with coffee farming as one of the main activities contributing

economically and socially. Coffee conilon (*Coffea canephora*) is one of the two main kinds cultivated commercially in Brazil and has been studied for being of great contribution to the sector. The understanding of the factors influencing coffee production is of great importance for this reality, allowing the producer an productivity increase with quality and sustainability.

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. The detailed knowledge of the spatial variability makes possible the optimization of fertilizer applications, improving the control of the crop production system. One of the ways to maximize the efficiency of fertilizer recommendation in high yielding crop areas is to include the use of tools that quantify nutrient availability during the crop cycle (GOTT et al., 2014).

Precision Agriculture (PA) aims to reduce production costs, reduce the contamination of nature by the pesticides used and logically increase productivity. That is, it is all interference practice in order to establish ideal conditions for the kinds cultivated in agriculture, be it chemical, physical or biological. For Almeida and Guimarães (2016) the PA can bring possible environmental benefits, as it allows the rational use of natural resources and avoids applications of excess products that could lead to contamination of the soil and water by leaching resources processes and also surface runoff . In this way, it aims to improve the economic return by prioritizing the allocation of inputs in the places with the highest probability of response and the elimination of factors limiting productivity as nutrient contents below the critical level.

The Kenworthy Balanced Indices (KBI) method allows a methodology to evaluate the nutritional status of cultivated plants with the purpose of guiding the decision on the recommendation of fertilization for agricultural crops.

This information about the nutritional balance can then be used in the decision making of the management of the fertilization. The diagnosis method addresses the nutritional balance aspect by analyzing each nutrient in isolation from the others, giving an idea of the balance between what was effectively absorbed and what was needed by the plant (Kenworthy, 1961).

The objective of this paper was to analyze and describe the spatial behavior of the coffee nutritional status based on the Kenworthy balanced indexes.

MATERIAL AND METHODS

The paper was carried out in a commercial crop of coffee conilon (*Coffea canephora*) of seminal propagation, located in the county of Cachoeiro de Itapemirim -ES, in the Boa Vista community, São Vicente District (Lat 20°37'31 "S and 41°05'22 "O). According to the Koppen-Geiger climatic classification (1928), Cachoeiro region has categorizations Cwa, Cwb and Aw, being the prevalent climate of the typical Tropical Cwa region.

According to the EMBRAPA methodology (2011), the soil of the property has a medium clayey textural feature and was classified as Cambisol. The maximum and minimum temperatures in the 2016 harvest were 33.23 ° C and 15.8 ° C, respectively, with an annual rainfall of 911 mm. Fertilizers are recommended by chemical analysis of soil and plant tissue soon after harvest (August to September).

In the study area, an irregular mesh was constructed, being georeferenced 80 sample points spaced in approximately 10 m in the coffee line. Each sampling point was composed of three coffee plants in the spacing of 1.50 x 1.50, totaling an area of 6.75 m² per point.

The data for calculating productivity were collected in the 2016 crop. The coffee fruits were manually harvested from the 3 plants in July, being bagged and their mass determined, defining the point of production (PP). From the total coffee of the point, a wet sub-sample (SU) was collected, weighed in a digital scale and taken to the UFES laboratory (LHRG /

UFES-CCAIE). This sub-sample was placed in an oven at 45° C (± 2°C) and dried to a humidity of 11-12°C. After the dry subsample (SS) it was reweighed and benefited (pounded for removal of the bark and the parchment). After the processing, the productivity of the point was calculated, according to equation 1:

$$\text{Prod} = (10000 * \text{PP} * \text{AP-1} * \text{SB} * \text{SU-1}) / 60 \quad (1)$$

In what: Prod = point productivity (sc ha-1); PP = production at the point (kg); AP = area of the point (m²); SP = beneficiary sub-sample (kg); SU = wet sub-sample (kg).

The foliar analysis was used to obtain data that allow the characterization of each point as to its nutritional status. To obtain these data, two pairs of leaves of the lateral branches (3rd and 4th pairs counting from the tip to the base) were removed in the middle third of each plant, in the 4 points in the month of February, 2016.

The collected leaves were wrapped in a paper envelope and identified, dried in an oven at 65 ° C until constant mass in the Laboratory of Hydraulics, Water Resources and Geoprocessing of the Federal University of Espírito Santo, Center of Agricultural Sciences and Engineering Campus - LHRG / UFES- CCAIE. Afterwards, they were sent to a laboratory accredited by the MAPA for the determination of the macronutrients dry matter concentrations: N, P, K, Ca, Mg and S; and the micronutrients: Fe, B, Zn, Mn and Cu, according to the Methods of Analysis Manual Protocol of EMBRAPA (EMBRAPA, 2011). The samples were analyzed to obtain the concentrations in dry matter.

The Kenworthy Balanced Indices were calculated using a Microsoft Excel spreadsheet, as follows:

1) if the value of the nutrient concentration in the sample (C) is lower than that of the standard (Cref), the influence of the variability (I) is added to the percentage value to obtain the balanced index (equation 2). Therefore, if $C < C_{ref}$,

$$\text{IK} = \text{P} + \text{I} \quad (2)$$

in which: IK = Nutrient Kenworthy balanced index; $\text{P} = (\text{C} / \text{C}_{ref}) * 100$, i.e., C% Cref; $\text{I} = (100 - \text{P}) * \text{CV} / 100$, that is, variance influence; CV = variation coefficient of nutrient in the standard population.

2) if the value of the nutrient concentration in the sample (C) is higher than that of the standard (Cref), the influence of the variability (I) is subtracted from the percentage value to obtain the value of the balanced index. Therefore, if $C > C_{ref}$ (equation 3),

$$\text{IK} = \text{P} - \text{I} \quad (3)$$

in which: IK = Nutrient Kenworthy balanced index; $\text{P} = (\text{C} / \text{C}_{ref}) * 100$, i.e., C% Cref; $\text{I} = (\text{P} - 100) * \text{CV} / 100$, that is, variance influence; CV = coefficient of variation of nutrient in the standard population.

The classification suggested empirically by (Malavolta et al., 1997) can interpret the balanced indexes for the nutrients of the sample, classes below:

- a) Range of deficiency: 17 to 50%.
- b) Range below normal: 50 to 83%.
- c) Normal range: 83 to 117%.
- d) Range above normal: 117 to 150%.
- e) Excess range: 150 to 183%

The value used as standard in the KBI calculation (Table 1), was calculated by the average of three concentrations used as standard for coffee cultivation (Braga et al., 2006).

144 Table 1. Standard Concentration Values for KBI Calculation

Nutrient	Standard Concentration Values	s	CV
N	2,90	0,13	4,51
P	0,14	0,02	14,18
K	2,07	0,14	6,88
Ca	1,29	0,12	8,90
Mg	0,34	0,04	11,60
S	0,22	0,03	14,01
B	50,92	8,42	16,55
Cu	11,22	3,35	29,86
Fe	122,00	17,16	14,07
Mn	77,88	33,09	42,49
Zn	13,08	2,32	17,74

145 Source: data calculated by the author

146
147 The degree of dependence was quantified by means of the adjustment of theoretical
148 semivariograms, based on the assumption of intrinsic stationarity (equation 4):

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

(4)

150
151 where: $\gamma(h)$ is the estimated semivariance; $N(h)$ is the number of pairs of the studied
152 attribute; and $Z(x_i)$, $Z(x_i + h)$ are the values of the attributes measured at position x_i e $x_i + h$,
153 separated by a vector h (distance between samples).

154 Theoretical models such as spherical, exponential and Gaussian were tested for the
155 adjustment of the staggered semivariogram by the data variance, defining the parameters:
156 nugget effect (C_0), the baseline ($C_0 + C$) and the spatial dependence range (a). In order to
157 choose the best fit model, it was used the smallest sum of the square of the residuals (SQR)
158 and the highest coefficient of determination (R^2). The spatial dependence index (SDI) was
159 classified according to Cambardella et al. (1994), which considers spatial dependence as low
160 (SDI > 75%), moderate ($25\% \leq IDE \leq 75\%$) and strong (SDI < 25%). With the confirmed
161 spatial dependence, the spatial distribution maps for the KBI values and coffee conilon
162 productivity were made by ordinary kriging.

163 RESULTS AND DISCUSSION

164
165 Evaluating the the crop nutritional status, according to the average of the 80 evaluated
166 points (Table 2), Zn is the most deficient nutrient in the crop (66.76%). Like B (81.38%) and
167 K (80.67%), Zn is in the range considered below normal, which includes 50-83% indexes.
168 Opposite to these nutrients, in the above normal range (117-150%) we have P (130.69%) and
169 Mn (130.89%). The nutrient that was in the most extreme range was Cu (187.06%), which
170 occupies the excess range.

171
172
173 Table 2. Descriptive statistics of the Keyworthy Balance Indices for macronutrients and
174 micronutrients in the field

KBI	Mean	Md	S	Values		Coefficients			Test
				Min	Msx	CV(%)	C_s	C_k	KS
N (%)	99,54	96,86	7,50	87,85	118,75	7,53	0,59	-0,45	ns
P (%)	130,69	129,60	18,12	96,82	171,89	13,87	0,34	-0,48	*
K (%)	80,67	82,10	7,46	69,94	96,96	9,25	0,23	-0,82	ns

Ca (%)	105,45	104,84	14,44	79,38	131,81	13,69	0,10	-0,98	ns
Mg (%)	109,78	108,52	10,30	88,75	128,00	9,38	-0,06	-0,91	ns
S (%)	101,23	100,00	16,02	80,46	141,46	15,83	0,81	-0,15	ns
Fe (%)	90,95	90,79	14,34	60,27	125,29	15,77	0,06	-0,39	ns
Zn (%)	66,76	64,59	9,14	49,82	89,12	13,69	0,55	-0,15	ns
Mn (%)	130,89	122,18	49,05	63,31	259,41	37,47	0,88	0,25	ns
B (%)	81,38	80,85	10,23	60,13	108,78	12,57	0,39	-0,32	ns
Cu (%)	187,06	169,46	72,86	74,55	380,93	38,95	0,77	0,03	ns
Prod (sc ha ⁻¹)	58,30	55,29	21,75	20,37	102,60	37,30	0,27	-0,95	ns

Md - Median; s - standard deviation; CV - coefficient of variation; Cs - Coefficient of symmetry; Ck - kurtosis coefficient; ns - normal distribution by Kolmogorov-Smirnov test (KS) at 5% probability; and * Non-normal distribution.

The ordering of the values of the Kenworthy balance indexes allows nutrients to be placed according to the order of nutritional limitation in the crop, which in order of deficiency is Z> N> K> B> Fe> N> S> Ca> Mg> P > Mn> Cu. Knowing that from Fe to Mg, are the nutrients that are in the range considered normal for coffee cultivation according to the standard established for the KBI.

The average productivity of the crop was 58,30 sc ha⁻¹ (Table 2), well above than the state average productivity in the previous year, which was 27.41 sc ha⁻¹ (CONAB, 2015). The harvest of 2015 suffered from prolonged drought and water deficit in the months of December 2014 and January and February 2015, which resulted in poor grain formation and lower fruit yield being smaller and lighter. It was possible to find In the crop, maximum yield of 102,60 sc ha-1 and minimum of 20,37 sc ha-1 , showing great variability of the same in the area.

The Mg was the only variable that presented a negative asymmetry coefficient, indicating a trend of higher values than the mean. With the exception of Cu, all the variables presented a negative kurtosis coefficient, that is, the platycuric frequency distribution.

The mean and median values for the attributes under study were similar, indicating the normality of the data, as evidenced by the Kolmogorov-Smirnov (KS) test. P was the only variable that did not present a non-normal distribution. Paz-Gonzalez, Taboada and Vieira (2001) state that, when the normality of the data is satisfied, the estimation of values in unmeasured locations using the kriging method in interpolation has its efficiency increased, presenting better results in relation to other methods.

The CV values of the KBI for N, K and Mg presented low variation, with CV <12%. The other variables presented CV between 12 and 60%, being considered of average variation according to Warrick and Nielsen (1980). This demonstrates the variability of these variables around the mean, justifying the importance of their spatial study.

Table 3 shows the KBI frequencies (macronutrients) of the 80 sampled points sampled in the crop. N is the nutrient that has the highest sample frequency within the normal range. Among the macronutrients, K is the nutrient that deserves more attention, with 52.5% of samples below normal. This nutrient has importance in the photosynthesis, respiration and circulation of sap in the plant, with effect on the starch formation in the leaves and contribution in the granulation phase of the fruits, easily translocating the adjacent leaves to the fruits (SANTOS, 2005), therefore it is extremely important to supply it to the culture.

Table 3. Frequency of leaf samples of conilon coffee, in the different ranges, according to the Kenworthy Balanced Index for macronutrients

Range	KBI (%)	N	P	K	Ca	Mg	S
Range of disability	<50	0	0	0	0	0	0
Below normal range	50-83	0	0	52,5	6,25	0	3,75

Normal range	83-117	98,75	18,75	47,5	71,25	70	80
Range above normal	117-150	1,25	63,75	0	22,5	30	16,25
Excess range	>150	0	17,5	0	0	0	0

Source: Author data.

The presence of potassium in coffee straw is high, and its return to the crop is important, aiming to reduce its export from the soil reservoir (GUARÇONI, 2011). Besides that, raising the K content in the applied formulation may be another way of making this nutrient available to the plant.

All phosphorus samples are in the normal range or above, showing that the amount of phosphorus available for the plant absorption is in agreement with what is necessary for the coffee.

In Table 4 are the KBI frequencies (micronutrients) of the 80 sampled points sampled in the crop. Fe is the nutrient that presents the highest frequency of the samples in the below normal range (95,0%). B is the second most deficient nutrient, with 58,75% of samples below the normal range.

Table 4. Frequency of leaf samples of conilon coffee in the different ranges, according to the Kenworthy Balanced Index for micronutrients

Range	KBI (%)	B	Cu	Fe	Mn	Zn
Range of disability	<50	0	0	0	0	1,25
Below normal range	50-83	58,75	1,25	31,25	18,75	93,75
Normal range	83-117	41,25	15	66,25	27,5	5
Range above normal	117-150	0	20	2,5	23,75	0
Excess range	>150	0	63,75	0	30	0

Source: Author data.

The average Fe and Mn are within the normal range, but it is observed that there are 31,25% of Fe samples in the below-normal range, this value is 18,75% for the Mn. This shows the importance of using geostatistics to define management zones. With the construction of the maps it is possible to verify the area where these samples are concentrated. For Tomaz et al. (2009), inadequate micronutrient contents have a direct effect on crop development, and also reduce the efficiency of macronutrient-containing fertilizers.

The micro-nutrient deficiency in a crop can cause imbalance in the plant metabolism, making the plants more susceptible to pests and diseases, causing an increase in the expenses with pesticides and costing the crop (TOMAZ et al., 2011). In the coffee crop, the lack of micronutrients can cause a decrease in plant growth and a decrease in production (MALAVOLTA, 1986)

In Table 5 it can be observed that the P did not presented spatial dependence for the distances sampled, thus presenting a random behavior in the study area (pure nugget effect), a fact that according to Lima, Souza e Silva (2010) may be due to lower distance mesh was not sufficient to determine spatial dependence.

248 Table 5. Parameters and model of graded semivariograms adjusted for KBI and coffee
249 productivity

Attribute	Model	C ₀	C ₀ +C	a	R ²	GDE
N	ESF	0,43	1,00	19	82	43
P	EPP	-	-	-	-	-
K	EXP	0,52	1,04	52	70	50
Ca	ESF	0,24	1,01	16	76	24
Mg	ESF	0,25	0,92	10	87	27
S	ESF	0,55	1,16	156	91	48
B	ESF	0,49	1,17	115	78	42
Cu	ESF	0,20	1,06	82	99	19
Fe	ESF	0,43	1,15	132	88	38
Mn	ESF	0,48	1,15	95	96	41
Zn	EXP	0,46	0,96	19	94	48
Prod	ESF	0,59	1,17	54	94	36

250

251 Two models were more adequate to explain the structure of the spatial variability of
252 the KBI, the exponential model fitting the KBI for K and Zn and the spherical model for the
253 other indexes, ranging from 10 to 95 m. The range (a) of spatial dependence is an important
254 parameter in the spatial variability study, it indicates the zone of influence of a sample, that
255 is, it defines the maximum distance to where the value of a variable presents spatial
256 dependence relation with its neighbor (Silva et al., 2010).

257 The spatial dependence index, which measures the relationship between the nugget
258 effect and the baseline, was considered strong for the KBICa according to the classification
259 proposed by Cambardella (1984), while the other indexes had moderate spatial dependence.

260 Given the increased cost of input management in agriculture, accurate nutrient
261 management is the solution to increase the efficiency of its use (VASU et al., 2017). Once the
262 spatial dependence was established by interpolation by ordinary kriging the spatial
263 distribution maps for each attribute.

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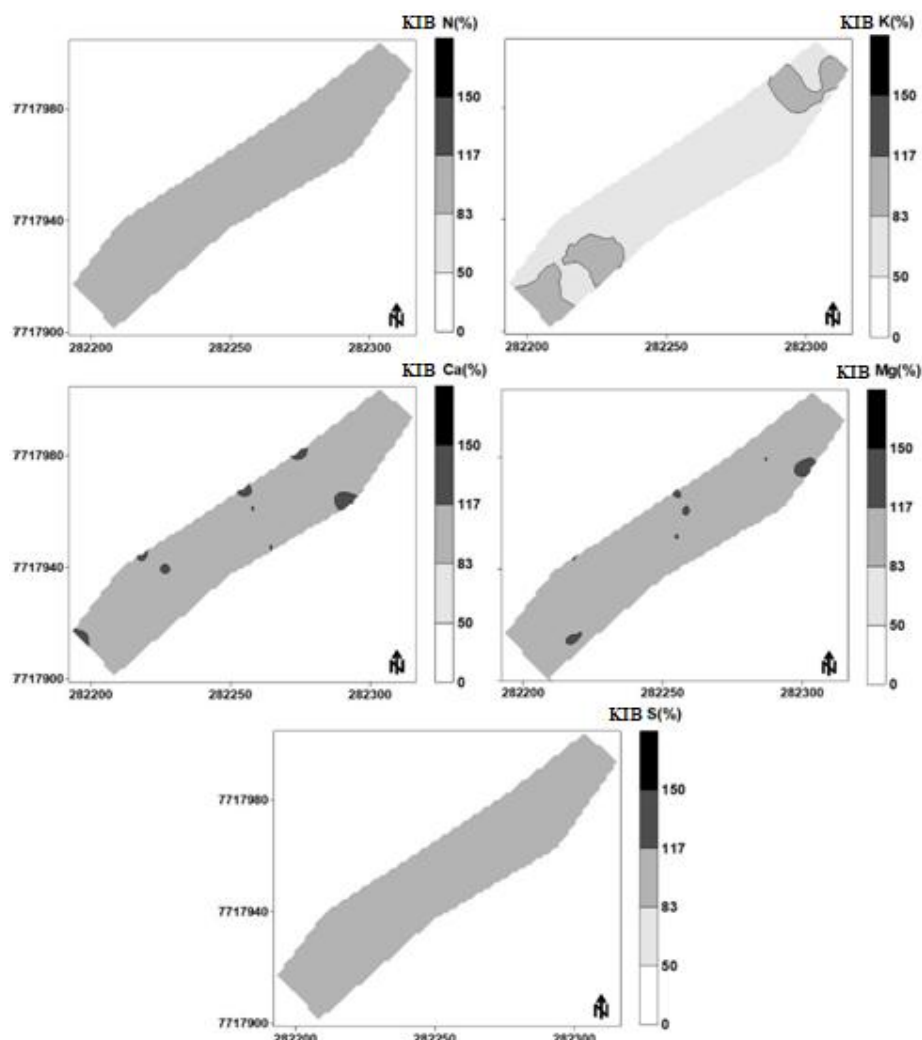


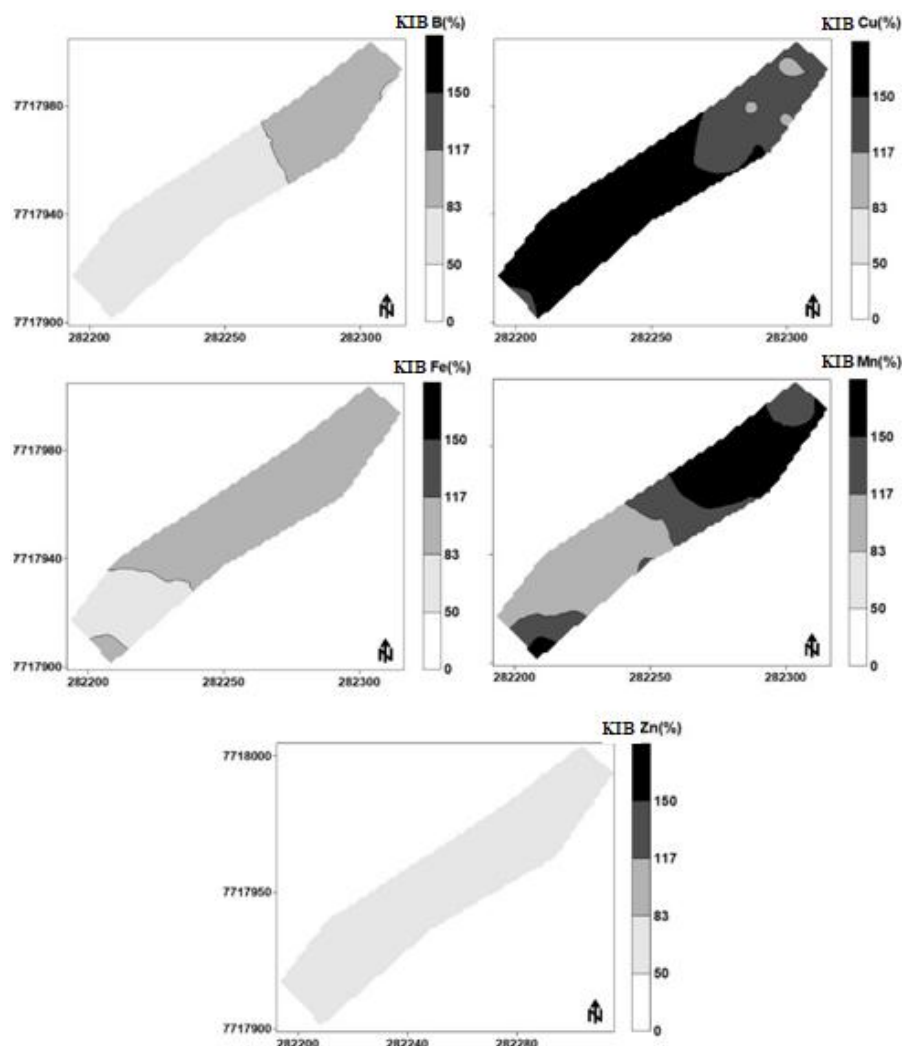
Figure 1. Spatial distribution of the KBI (KBI) of the macronutrients.
Source: Author data.

Figure 2 shows the deficiency of Zn, B and Fe in the area. It is possible to verify that the bottom area is the part that is deficient for the three micronutrients, being the zone that needs more attention. The KBI of the Zn is in the zone below the normal in the whole area, which is the most limiting micronutrient in the crop.

Zinc deficiency is common in coffee plantations. According to Reis Jr and Martinez (2002), this micronutrient has compromised the Brazilian coffee productivity production, since our soils are generally poor in this element. The deficiency of this micro is one of the most generalized and limiting for the coffee crop, causing the death of the pointers, superbroke (MALAVOLTA, FERNANDES & ROMERO, 1993) and limitation of shoot growth (IBC, 1985). Severe disturbances, such as: lower flowering glue and smaller fruits are results of Zn deficiency in coffee culture (MALAVOLTA, FERNANDES & ROMERO, 1993).

Fe deficiency confirms the studies of Costa, Bragança and Lani (2000), who, through a diagnosis in conilon coffee plantations in the state of Espírito Santo, concluded that, in a large number of crops, Fe is a limiting factor for fruit production. However, for Matiello and

285 Garcia (2015) the lack of Fe can be very critical and even so, in the short term, the plant will
 286 continue to fruit well.
 287



288
 289 Figure 2. Spatial distribution of KBI of micronutrients.
 290 Source: Author data.
 291

292 Studies by Fonseca et al. (2015) and Oliveira et al. (2010) also show Zn and Fe
 293 micronutrients deficiency in conilon coffee crops in different harvests. The low concentration
 294 of these nutrients in the soil solution may be related to this deficiency, as well as the non-
 295 fulfillment of this need in previous crops.

296 B, which is also deficient in the crop, participates in cell growth, the cell wall
 297 components biosynthesis, the phenols metabolism, nucleic acids, carbohydrates and AIA, as
 298 well as conferring stability and structure to the cell wall (BUCHANAN, GRUISSEN and
 299 JONES, 2000, MARSCHNER, 1995, TAIZ and ZEIGER, 2002). Like other micronutrients,
 300 B is essential to the crop, and it is necessary to provide it in fertilizers to improve the
 301 nutritional status of the crop, thus affecting a plant that is more resistant to attack by pests and
 302 diseases and with good productivity.

303 The productivity map (Prod) shows its spatial distribution in the area (Figure 3). As
 304 the crop does not have localized management (application at the varied rate), it is normal to

find this variability in the crop. Another fact that can cause the spatial variability of productivity in conilon coffee is the number of productive branches (orthropeans) not be the same in each plant of the sampling point (FONSECA et al., 2015). It should be noted that the climate conditions, too, cause great influences on crop yield.

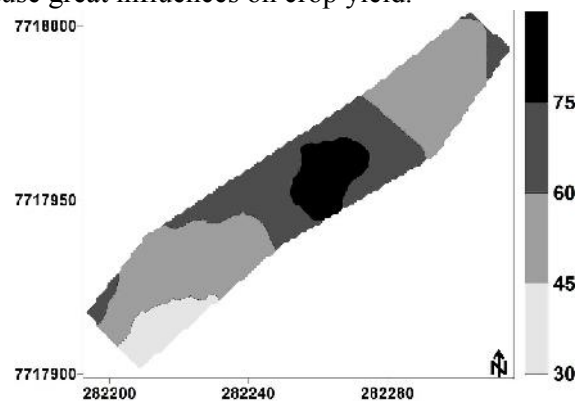


Figure 3. Spatial distribution of conilon coffee productivity (sc ha⁻¹).

Source: Author data.

CONCLUSION

The diagnosis presented in this paper showed a higher nutritional limitation due to Potassium (K), Zinc (Zn), Iron (Fe) and Boron (B) deficiency and for Copper (Cu) excess showing the nutritional imbalance of the crop.

With the exception of IBK for P, all Kenworthy equilibrium indexes presented spatial dependence, with spherical and exponential model fit.

The coffee conilon productivity showed spatial dependence.

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