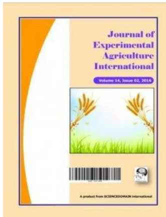

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Spacial Variability of Balanced Indexes of Kenworthy(BIK) for Macro and Micronutrients on the Coffee Canephora

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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. Authors JSSL and SAS managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

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 Balanced Indexes of Kenworthy (BIK). The experiment in southern Espírito Santo, in an area planted with seminal conilon coffee (Lat 20°37'31''S e 41°05'22''W). 140 points were georeferenced within a coffee crop, each sampling point contained three plants. Leaf samples were analyzed in order to determine levels of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Boron (B), Manganese (Mn), Zinc (Zn) and Copper (Cu), and the BIK it was determined for all nutrients. The indexes and the yield (Prod) were analyzed by means of geostatistics. The diagnosis presented in this study indicated a higher nutritional limitation due to the deficiency for K, Zn, Fe and B for excess for Cu, showing the nutritional imbalance of the crop. With the exception of BIK for P, all variables presented spatial dependence adjusted to the spherical and exponential models.

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Keywords: Coffea canephora; foliar analysis; nutritional balance; DRIS; nutrients.

1. 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 varieties commercially cultivated 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 increase productivity with quality and sustainability. For Fonseca, Lima e 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 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 [2].

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. 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 [3]. 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 Balanced Indexes of Kenworthy (BIK) 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 [4].

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

2. MATERIALS 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 "W). According to the Koppen and Geiger climatic classification [5], Cachoeiro region has categorizations Cwa, Cwb and Aw, being the prevalent climate of the typical Tropical Cwa region.

According to the EMBRAPA methodology [6], 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 10m 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 was 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 on a digital scale and taken to the UFES laboratory (LHRG / UFES-CCAE). This sub-sample was placed in an oven at 45ºC (± 2ºC) and dried to a humidity of 11-12ºC. 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:

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

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-CCAE. 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 Manual Protocol Analysis [6]. The samples were analyzed to obtain the concentrations in dry matter.

The Balanced Indexes of Kenworthy 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 <Cref,

$$IK = P + I \quad (2)$$

in which: IK = Balanced Indexes of Kenworthy Nutrient; P = (C/Cref) * 100, i.e., C% Cref; I = (100 - P)*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> Cref (equation 3),

$$IK = P - I \quad (3)$$

in which: IK = Balanced Indexes of Kenworthy Nutrient; P = (C / Cref) * 100, i.e., C% Cref; I = (P - 100)*CV/100, that is, variance influence; CV = coefficient of variation of nutrient in the standard population.

The classification suggested empirically to interpret the balanced indexes for the nutrients of the sample [7], 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 the standard in the BIK calculation (Table 1), was calculated by the average of three concentrations used as the standard for coffee cultivation [8,9,10].

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

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

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

Theoretical models such as spherical, exponential and Gaussian were tested for the adjustment of the staggered semivariogram by the data variance, defining the parameters: nugget effect (C_0), the baseline (C_0 +C) and the spatial dependence range (a). In order to choose the best fit model, it was used the smallest sum of the square of the residuals (SQR) and the

Table 1. Standard concentration values for BIK 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

Source: data calculated by the author

highest coefficient of determination (R^2). The spatial dependence index (SDI) was classified which considers spatial dependence as low (SDI> 75%), moderate (25% ≤IDE≤ 75%) and strong (SDI <25%) [11]. With the confirmed spatial dependence, the spatial distribution maps for the BIK values and coffee conilon productivity were made by ordinary kriging.

3. RESULTS AND DISCUSSION

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

The ordering of the values of the Balanced Indexes of Kenworthyallows 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 BIK.

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} [12]. 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, the 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 platicuric 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 [13] 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 BIK for N, K and Mg presented low variation, with CV <12%. The other variables presented CV between 12 and 60%, is considered of average variation according to Warrick and Nielsen [14]. This demonstrates the variability of these variables around the mean, justifying the importance of their spatial study.

Table 2. Descriptive statistics of the balanced indexes of Kenworthy for macronutrients and micronutrients in the field

BIK	Mean	Md	S	Values		Coefficients			Test
				Min	Max	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; Min - minimum; max- Maximum;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*

Table 3 shows the BIK frequencies (macronutrients) of the 80 sampled points 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, plant 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 [15], therefore it is extremely important to supply it to the culture.

The presence of potassium in the coffee straw is high, and its return to the crop is important, aiming to reduce its export from the soil reservoir [16]. 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 BIK frequencies (micronutrients) of the 80 sampled points 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.

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 demonstrates 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. Inadequate micronutrient contents have a direct effect on crop development, and also reduce the efficiency of macronutrient-containing fertilizers [17].

The micro-nutrient deficiency in a crop can cause an 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 [18]. In the coffee crop, the lack of micronutrients can cause

Table 3. The frequency of leaf samples of conilon coffee, in the different ranges, according to the Balanced Indexes of Kenworthy for macronutrients

Range	BIK (%)	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

a decrease in plant growth and a decrease in production [19].

In Table 5 it can be observed that the P did not present spatial dependence for the distances sampled, thus presenting a random behavior in the study area (pure nugget effect), a fact that according to [20] probably the lower distance in the mesh was not enough to determine spatial dependence.

Two models were most appropriate to explain the structure of the spatial variability of the BIK, the exponential model fitting the BIK for K and Zn and the spherical model for the other indexes, ranging from 10 to 95 m. The range (a) of spatial dependence is an important parameter in the spatial variability study, it indicates the zone of influence of a sample, that is, it defines the maximum distance to where the value of a variable presents spatial dependence relation with its neighbor [21].

The spatial dependence index, which measures the relationship between the nugget effect and the baseline, was considered strong for the BIKCa according to the classification proposed by [11], while the other indexes had moderate spatial dependence.

Given the increased cost of input management in agriculture, accurate nutrient management is the solution to increase the efficiency of its use [22]. Once the spatial dependence was established by interpolation by ordinary kriging the spatial distribution maps for each attribute.

Fig. 2 demontrates 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 BIK 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. This micronutrient has compromised the Brazilian coffee productivity production, since our soils are generally poor in this element [23]. The deficiency of this micro is one of the most generalized and limiting for the coffee crop, causing the death of the pointers, super broke [24] and limitation of shoot growth [25]. Severe disturbances, such as: lower flowering glue and smaller fruits are results of Zn deficiency in coffee culture [24].

Table 4. The frequency of leaf samples of conilon coffee in the different ranges, according to the balanced indexes of Kenworthy for micronutrients

Range	BIK (%)	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

Table 5. Parameters and model of graded semivariograms adjusted for BIK and coffee 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

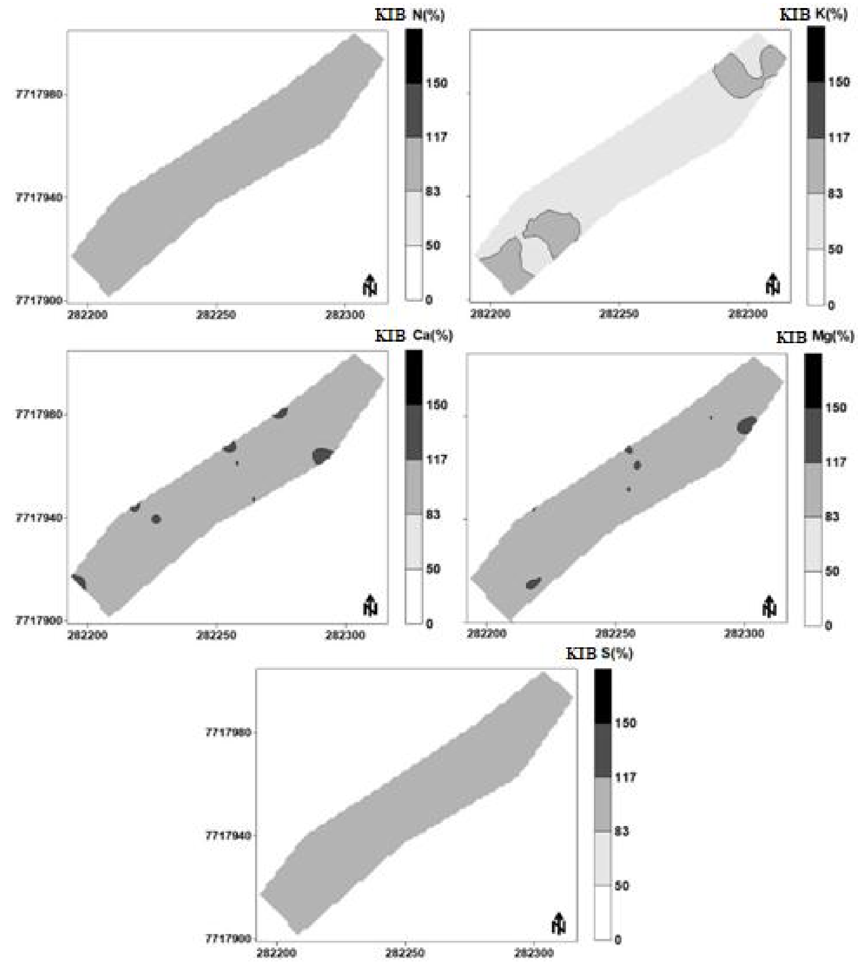

Fig. 1. Spatial distribution of the BIKof the macronutrients
Source: Author data

Fe deficiency confirms the studies of [26] 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, the lack of Fe can be very critical and even so, in the short term, the plant will continue to fruit well [27].

The Zn and Fe micronutrients deficiency in conilon coffee crops in different harvests [28,29]. The low concentration of these nutrients in the soil solution may be related to this deficiency, as well as the non-fulfilment of this need in previous crops.

B, which is also deficient in the crop, participates in cell growth, biosynthesis of cell wall components, the phenols metabolism, nucleic acids, carbohydrates and indoleacetic acid(IAA), as well as conferring stability and structure to the cell wall [30,31,32]. Like other micronutrients, B is essential to the crop, and it is necessary to provide it in fertilizers to improve the nutritional status of the crop, thus affecting a plant that is more resistant to attack by pests and diseases and with good productivity.

The productivity map (Prod) shows its spatial distribution in the area (Fig. 3). As 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) is not the same in each plant of the sampling point [28]. It should be noted that the climate conditions, too, cause great influences on crop yield.

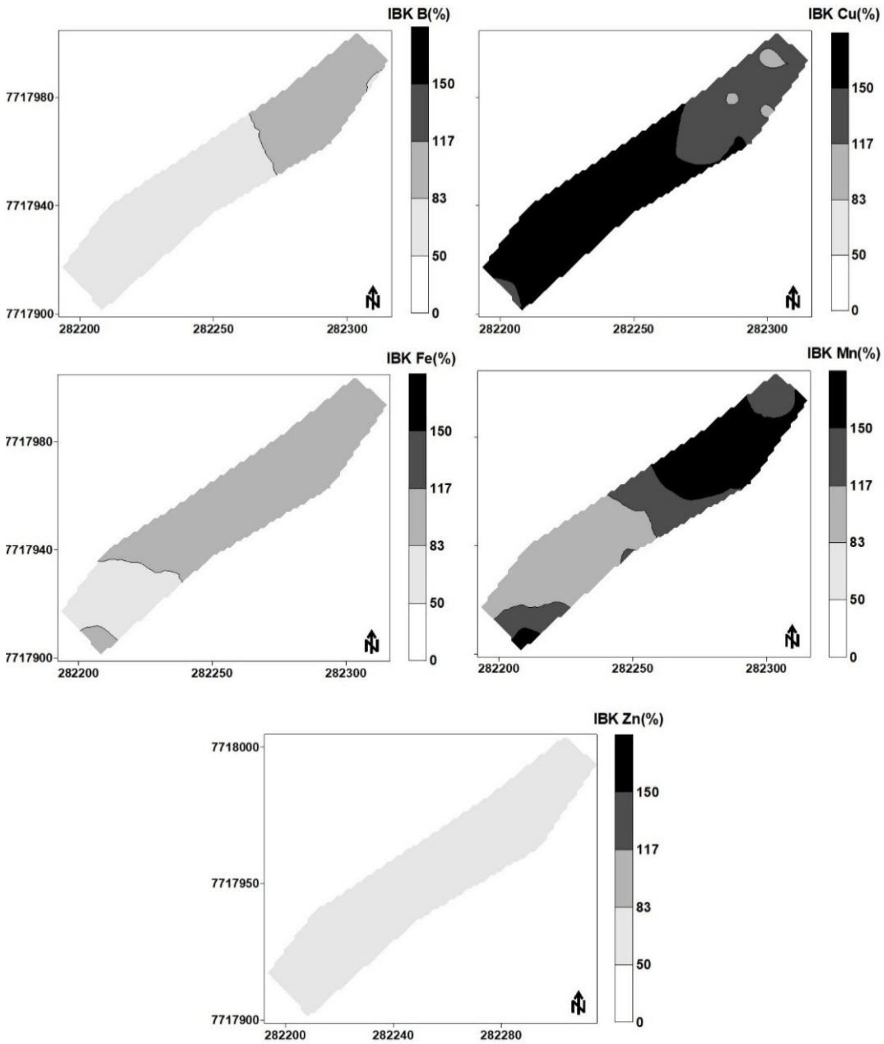

Fig. 2. Spatial distribution of BIK of micronutrients
Source: Author data

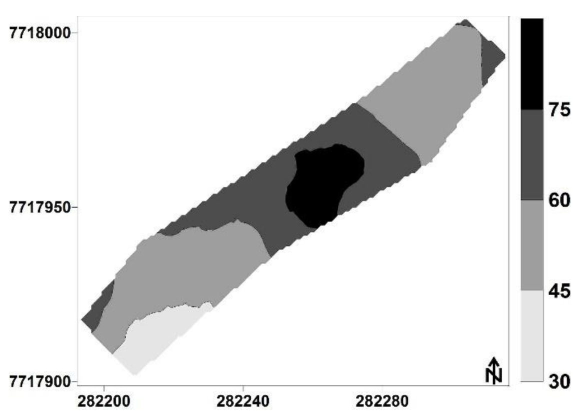

Fig. 3. Spatial distribution of conilon coffee productivity (sc ha^{-1})
Source: Author data

4. 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 BIK 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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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