SPATIAL ESTIMATION OF FOLIAR PHOSPHORUS IN DIFFERENT SPECIES OF THE GENUS *Coffea* BASED ON SOIL PROPERTIES[1]

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SUMMARY

Information underlying analyses of coffee fertilization systems should consider both the soil and the nutritional status of plants. This study investigated the spatial relationship between phosphorus (P) levels in coffee plant tissues and soil chemical and physical properties. The study was performed using two arabica and one canephora coffee variety. Sampling grids were established in the areas, and the points georeferenced. The assessed properties of the soil were levels of available phosphorus (P-Mehlich), remaining phosphorus (P-rem) and particle size, and of the plant tissue, phosphorus levels (foliar P). The data were subjected to descriptive statistical analysis, correlation analysis, cluster analysis, and probability tests. Geostatistical and trend analyses were only performed for pairs of variables with significant linear correlation. The spatial variability for foliar P content was high for the variety Catuai and medium for the other evaluated plants. Unlike P-Mehlich, the variability in P-rem of the soil indicated the nutritional status of this nutrient in the plant.

Index terms: coffee, remaining P, cokriging, geostatistics.

RESUMO: *ESTIMATIVA ESPACIAL DO FÓSFORO FOLIAR EM DIFERENTES ESPÉCIES DO GÊNERO COFFEA, COM BASE NAS PROPRIEDADES DO SOLO*

A análise dos sistemas de fertilização do cafeeiro deve envolver informações conjuntas de solo e do estado nutricional das plantas. Este trabalho objetivou estudar a relação espacial entre os teores de P do tecido vegetal de cafeeiros e os atributos químicos e físicos do solo. Este estudo foi realizado com duas variedades de café arábica e uma variedade de café conilon.

[1] Received for publication on April 30, 2013 and approved on June 2, 2014.

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Foram construídas grades amostrais nas áreas, sendo os pontos georreferenciados. Avaliaram-se, do solo, os teores de P disponível (P-Mehlich) e de P remanescente (P-rem) e a granulometria, enquanto do tecido vegetal, os teores de P (P foliar). Os dados foram submetidos a: análise estatística descritiva, de correlação, análise de agrupamentos e testes de probabilidade. As análises de tendência e as geoestatísticas foram realizadas apenas para os pares de variáveis que apresentaram correlação linear significativa. A variabilidade espacial dos teores foliares de P é alta para a variedade Catuaí, sendo média para os demais cultivares avaliados. A variabilidade do P-rem do solo refletiu o estado nutricional quanto a esse nutriente na planta, o que não ocorreu com o P-Mehlich.

Termos de indexação: café, P remanescente, cokrigagem, geoestatística.

INTRODUCTION

Phosphorus (P) is an essential nutrient for the development and productivity of all plant species, and its demand is particularly critical for crops of agricultural interest, given the need for high yields. With regard to coffee, Reis Jr & Martinez (2002) claimed that this nutrient is the most crucial in the plantation of new crops, given its importance for the initial plant development.

The importance of P for coffee cultivation is not only restricted to the early development stages of the plants, because, according to Silva & Lima (2012), insufficient levels of this nutrient in the plant tissue affect the absorption of other essential elements that are important protectors during other phases of crop growth and development. Interactions between P and other elements in the plant can occur during both absorption and radial transport over long distances, and in the metabolism of the element within the metabolic chains of coffee (Amaral et al., 2006).

The P availability in solution is dependent on several factors that govern mainly the adsorption and desorption processes of this element; the soil can be a source or a drain of this nutrient (Silva et al., 2010). Although there is a dynamic equilibrium between the soil solid and solution phases, P retention is favored in the solid phase by the high weathering degree of soils, resulting in insufficient P concentrations in solution to meet plant requirements (Gichangi et al., 2008).

Gichangi et al. (2008) stated that P amount available to plants has a close relationship with the P intensity factor and also with the soil replenishing or buffering capacity, which is represented by the remaining phosphorus (P-rem). Remaining P measures the amount of P that remains in the equilibrium solution in response to a P concentration added to the soil (Donagemma et al., 2008). Thus, the higher the concentration of P-rem, the lower is phosphate adsorption, and consequently, the higher is its concentration in the solution.

Studies have confirmed that analyses of coffee fertilization systems must involve joint information of both the soil, and the nutritional status of plants (Farnezi et al., 2010; Silva & Lima, 2012). For Silva & Lima (2012), the success of coffee management programs depends, in addition to the above-mentioned factors, on the existence of spatial variation of the elements that control and, or, influence the productivity of the crop.

In addition to the importance of studying soil fertility and the plant nutritional status, the way in which information is obtained is decisive for understanding the processes of interaction between physical and biological systems and to guide decision-making in agricultural management processes. Spatial studies, which consider a nonstochastic variation for the various factors that define crop production, are an important orientation in the adoption of more reliable methods and techniques for crop fertilization management (Lima et al., 2013). Silva et al. (2010) claimed that the use of spatial analysis techniques that consider the joint variation of two variables can bring significant advantages in the process of evaluating and understanding their variability, but mainly to assist the understanding of the interactions existing in production systems, and in particular, in the soil-plant system.

Given the above, the objective of this study was to investigate the spatial relationship between the P levels in plant tissues of two coffee species, and the chemical and physical properties of the underlying soil.

MATERIAL AND METHODS

The study was performed in southeastern Brazil, in two of the largest coffee producing regions in Brazil. Two *Coffea arabica* L. varieties were used (Catuai and Catucai), grown in the eastern region of the State of Minas Gerais, and one variety of *Coffea canephora* Pierre (Conilon), grown in the southern region of the State of Espirito Santo.

The two *Coffea arabica* l. plantations are located on the same farm (20º 45' 45.4" S and 41º 32' 9.75" W, on average 860 m asl), and the soil in the region is classified as humic Red Latosol, with a fairly thick A horizon. The soil of the *Coffea canephora* Pierre plantation (20º 45' 17.31" S and 41º 17' 8.86" W, on average 115 m asl) was classified as a dystrophic Red-

Yellow Latosol with a clayey texture. The size of the three areas was approximately 1 ha each.

According to the Köppen climate classification, the two regions addressed in this study are included in class Am (Tropical monsoon), with an average temperature of >18 °C during the coldest month of the year, with no winter season and a rainfall index higher than the annual potential evapotranspiration.

For soil and leaf sampling, regular grids were constructed in the study areas, and the sampling points georeferenced using the Global Positioning System (GPS). A 100-point sample density was used for the areas cultivated with arabica coffee, with a distance of 20 m between points in the row and 5 m between rows. A sample density of 110 points was used for the area cultivated with conilon coffee, with a distance of 10 m between points in the row and 3 m between rows.

The sampling points consisted of five plants in the planting row. A representative composite samples for each point was formed from the individual samples of each of the five plants. Soil was collected from under the tree canopies, from North to South, in the 0-0.20 m layer. Leaves were sampled, according to Ribeiro et al. (1999), in the median portion of the four plantation quadrants (North-South, East-West projection), taking leaves from the third or fourth pair from the apex of the plagiotropic branches, totaling eight leaves per plant and 40 leaves per sampling point.

In the soil, the levels of available P were assessed, by the Mehlich-1 method (P-Mehlich), as well as the remaining P (P-rem) and particle size. In the plant tissue, the P content (foliar P) was determined. The levels of P and P-rem in the soil and foliar P were determined as proposed by Embrapa (1997). The soil particle size was determined using the pipette method, with sedimentation in aqueous medium, according to Stokes' Law.

In the exploratory data analysis, the presence of discrepant data (outliers) was assessed as well as their influence on the results of descriptive analysis. To this end, an interquartile ratio was used to define these values. The data were subjected to descriptive statistical analyses so as to determine their position and dispersion measures as well as the form of the dispersion (asymmetry and kurtosis). Normality was tested by the Shapiro-Wilk test at 5 % (W). Pearson's correlation analysis was used to evaluate the relationship between foliar levels of P and the soil chemical and physical properties of this study.

Trend and geostatistical analyses were only performed for pairs of variables that had a significant Pearson linear correlation, the others were discarded for being unsuited for using multivariate estimation methods.

The trend distribution was analyzed by the data dispersion behavior in relation to the x and y geographical coordinates, considering ±2 standard deviations, as proposed by Kerry & Oliver (2008). For the variables with no detectable trend, the original data were used, and for those with a trend, residues were used in the geostatistical analysis, as described by Lima et al. (2010).

The data were subsequently subjected to geostatistical analysis, to verify the existence of, and to quantify, the degree of spatial dependence, from adjusting theoretical functions to experimental variogram models, both univariate and multivariate, based on the assumption of stationarity from the intrinsic hypothesis, according to equations 1 (variogram) and 2 (cross-variogram):

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

$$\gamma_{12}^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z_1(x_{1i}) - z_1(x_{i1} + h)][z_2(x_{2i}) - z_2(x_{2i} + h)] \quad (2)$$

where, *N (h)* = is the number of pairs of experimental observations and *Z (xi), Z (xi + h)*, separated by a h vector, and Z1 and Z2 are spatially correlated variables. In the fitting of theoretical models to experimental variograms, the coefficients, nugget effect (C_0), sill (C_0+C_1), structural variance (C_1) and range (a) were determined. The models tested for fitting were spherical, exponential, Gaussian and linear. The models were chosen based on least squares, selecting those with highest R^2 value, lowest SQR (square sum of residues) and highest R^2 value in the cross-validation.

To determine the spatial dependence index (SDI), the relationship $C_0/(C_0+C_1)$ was used, according to the criteria established by Cambardella et al. (1994), which considered a weak (SDI > 75%) moderate (25 % ≤ SDI ≤ 75 %) and strong (SDI < 25 %) spatial dependence.

In order to estimate values of the variables for the sites that were not sampled, and to produce thematic maps, ordinary *kriging* was used. In order to spatialize foliar P in relation to the soil physical and chemical properties, a multivariate extension of *kriging*, known as *cokriging,* was used. This estimation can be more accurate than the *kriging* of a simple variable, when the cross-variogram shows a dependency between the two variables (Vieira et al., 2009).

Geostatistical analyses, as well as the interpolations, were performed using GS+ software for Windows, version 7.0 and the maps with Surfer software, version 10.0.

Cluster analysis was performed in order to divide the distribution of both the foliar P as well as P-rem in three distinct class levels: low, medium and high, using the Euclidean distance as a criterion for separation between the classes. This analysis was individually performed for each variety, species (by joining the two varieties of Arabica coffee) and finally by considering the two species together.

From the number of classes, the “K - means” method was used to determine the members of each of these. Thereafter, the likelihood of coinciding levels of foliar P and P-rem was estimated, i.e. the likelihood of finding low foliar P levels in the low P-rem class, repeating the procedure for the other classes.

In order to verify the best possibility when using a table to estimate plant-absorbed P, based on the distribution of P-rem in the soil, the different grouping arrangements were compared by the Student’s t test at 1 %.

RESULTS AND DISCUSSION

The presence of discrepant data (outliers) was observed in only the granulometric fractions and their influence on the distribution of these fractions, so the decision was taken to remove them from the data set. Vieira et al. (2009) argued that, when the data volume is significant, removing the outliers tends to make the statistical summary more reliable, in addition to contributing to reducing the tails of the normal distribution.

After detecting the presence of discrepant data (outliers) and their withdrawal, the data were subjected to a Pearson linear correlation analysis (Table 1). This analysis was performed after the removal of outliers and previously to the others, since the latter, as mentioned in item 2, would only be applied to sets with a significant correlation, regardless of the type of relationship.

Only P-rem was significantly correlated with the foliar P levels, in a positive correlation for all species and varieties, indicating that at points where the P-rem levels are higher, the foliar P levels are as well. Shen et al. (2011) claim that the relationship between soil and plant properties is not always observed since the interactions in the two systems can change the distribution behavior of these properties.

As a significant correlation of foliar P levels was only observed with P-rem, the other analyses will focus only on these two properties. Silva et al. (2010) commented that the absence of correlation between properties undermines the use of geostatistical multivariate methods, since the capacity of the covariate is practically nil in the estimation of the main variable.

Table 1. Pearson’s linear correlation and its levels of significance

Foliar nutrient	P	P-rem	Sand	Silt	Clay
P-Conilon	0.19	0.42**	0.09	-0.22	0.13
P-Catuaí	-0.13	0.79**	-0.05	0.19	-0.13
P-Catucaí	0.05	0.49**	-0.22	0.07	0.19

** Correlation significant at 1 %.

With the exception of data from the area with the variety Catuai, the other variables showed normal distribution, according to the normality test results (Table 2). For this variety, the absence of normality was justified by the asymmetry and kurtosis values which were slightly different from zero and negative, with asymmetric distribution on the left and with platykurtic behavior, but without extremely long tails. Data normality is only a requirement for geostatistics when using probabilistic estimation models, as is the case with indicative kriging, in other cases it is only expected that the tails of the normal distribution are not very long (Silva & Lima, 2012).

When analyzing the average values, it was observed that the levels of foliar P and also the concentrations of P-rem are similar for all soils, varieties and species of the study, differing from the results of Paul & Furlani Jr. (2010). These authors reported evident differences in foliar nutrient levels among coffee varieties, mainly due to the genetic variability, which results in greater or lesser nutrient uptake, translocation and efficiency of use. In the study in question, this genetic influence was not confirmed, i.e., this fact must have been more related to pure management issues and, or, to some similarities between the physiological mechanisms of the plants in the process of P uptake and utilization.

Although the averages were similar, foliar phosphorus levels were within the appropriate limits, though close to the lower limit of the class with some values below this, both for conilon as well as the arabica coffee, according to Ribeiro et al. (1999) and Prezotti et al. (2007). Both authors reported that adequate foliar levels for both species are between 1.20 to 2.00 g kg^{-1}.

In the case of P-rem, which represents an estimator of the soil capacity factor in relation to P (Donagemma et al., 2008), the average values obtained for all soils under study can be classified as intermediate, according to Novais & Smyth (1999).

However, the variables presented a coefficient of variation (CV) between 16 and 28 % (Table 2), which, according to Frogbrook et al. (2002) strongly indicates the existence of spatial variability in the data distribution. These authors state that coefficients of less than 10 % indicate uniformity in the data distribution, while higher values are linked to spatial variation and cannot be regarded as independent.

The variograms showed (Table 3) that all properties had spatial dependence, with well-defined levels, assuming, in this case, an intrinsic stationarity, since there was no trend to variation in the properties with the directions. The non-occurrence of a proportional effect is favorable for geostatistical analysis, i.e. when the average and variability are constant in the study area, the results of the analysis are more reliable and

Table 2. Descriptive statistics of data of foliar phosphorus and remaining phosphorus in the soil

Property	Mean	Median	Min	Max	CV	C_s	C_k	W *p*
					%			
				Coffea canephora Pierre				
P	1.50	1.50	1.20	1.90	21.78	0.42	-0.36	0.008
P-rem	19.17	19.53	12.30	24.10	16.03	-0.34	-0.15	0.001
				Coffea arabica L. cv Catuaí				
P	1.40	1.50	0.80	2.30	23.34	-0.57	-0.57	0.132
P-rem	20.32	20.60	11.30	29.00	27.84	-0.24	-0.53	0.446
				Coffea arabica L. cv Catucaí				
P	1.20	1.20	0.80	1.70	17.73	0.60	0.34	0.025
P-rem	19.05	19.45	10.60	22.60	25.12	1.00	-0.38	0.000

P: foliar phosphorus (g kg^{-1}); P-rem: remaining phosphorus (mg L^{-1}); CV: coefficient of variation C_s: asymmetry; C_k: kurtosis; W *p*: level of significance by the Shapiro-Wilk normality test (p>0.05).

Table 3. Models, parameters and results of the cross-validation for the univariate variograms (P, P-rem) and cross-variograms (P/P-rem) fitted to the data

Property	Model	C_0	C_0+C	A	RSS	R^2	SDI	R^2 (VC)	p-valor
				Coffea canephora Pierre					
P	Exponential	0.14	1.01	28	4.71	96.8	14	30.0	0.000
P-rem	Exponential	0.45	1.17	60	1.97	91.7	38	34.0	0.000
P/P-rem	Exponential	0.39	1.15	89	3.54	88.9	34	36.3	0.000
				Coffea arabica L. cv Catuaí					
P	Spherical	0.16	1.29	78	4.16	74.5	13	31.7	0.000
P-rem	Spherical	0.44	1.76	90	2.6	95.8	25	41.2	0.000
P/P-rem	Spherical	0.11	1.08	62	3.83	81.1	10	38.8	0.000
				Coffea arabica L. cv Catucaí					
P	Spherical	0.07	0.92	17	1.42	84.0	07	32.1	0.000
P-rem	Spherical	0.10	0.87	14	4.7	67.0	11	34.4	0.000
P/P-rem	Gaussian	0.53	1.32	22	3.05	80.3	40	40.1	0.000

P: foliar phosphorus; P-rem: remaining phosphorus; P/P-rem: foliar phosphorus/remaining phosphorous.

the discontinuity at the graph origin is reduced (Vieira et al., 2009).

P-rem was fitted to the P variograms and to the cross variogram between P/P-rem and the exponential model for conilon coffee, and to the spherical model for species Catucaí. For variety Catuai, the model that fit the univariate variograms best was the spherical, while the Gaussian model fit the cross-variogram best.

The range of the variograms varied from 14 m (P-rem of variety Catucai) to 90 m (P-rem of variety Catuai). The cross-variograms showed intermediate range values, however in all analyzed situations the values were higher than those of the main variable, in the case of foliar P. This behavior was most evident for the species conilon, where the range increased by 61 m. These results corroborate those found by Bottega et al. (2011) and Silva et al. (2010), who claimed that the cross-variogram range values tend to rise in circumstances where the spatial continuity of the auxiliary variable is greater than the main variable.

Table 4 shows the distribution classes of foliar P contents and the concentration of P-rem in the soils under study. The class values are similar for species in association and for the two varieties of arabica coffee, indicating the possibility of using a single table to estimate P absorbed by the plant based on soil P-rem. Mattiello et al. (2008) stated that appropriate levels of P in coffee leaves can range from 1.2 to 2.2 g kg^{-1}, and that levels lower than these can significantly affect crop productivity and the quality of the harvested products.

Tables 5 and 6 show the likelihood of coinciding levels of foliar P and P-rem. It was observed that in all cases, the likelihood of coinciding classes is high and significant at a 1 % level by the Student's test. These results indicate that, in areas where the levels

Table 4. Classes and limits as defined by cluster analysis for foliar phosphorus and remaining phosphorus (P-rem)

Class	Foliar P		P-rem	
	Minimum	Maximum	Minimum	Maximum
	g kg^{-1}		mg L^{-1}	
		Coffea canephora Pierre		
Low	1.2	1.3	12.30	16.47
Intermediate	1.4	1.5	17.23	20.57
High	1.6	1.9	20.69	24.10
		Coffea arabica L. cv Catuaí		
Low	0.8	1.0	10.60	12.70
Intermediate	1.1	1.3	13.60	16.70
High	1.4	1.7	17.70	22.60
		Coffea arabica L. cv Catucaí		
Low	0.8	1.2	11.30	17.70
Intermediate	1.3	1.6	18.60	22.60
High	0.17	2.3	23.60	29.00
		Coffea arabica L. (Catuaí and Catucaí)		
Low	0.8	1.2	10.60	15.27
Intermediate	1.3	1.4	15.43	20.18
High	1.5	2.3	20.30	29.00
		All species		
Low	0.8	1.0	10.60	15.80
Intermediate	1.1	1.3	16.10	21.60
High	1.4	2.3	22.60	29.00

Table 5. Occurrence probability of foliar phosphorus groups (low, medium and high) within the remaining phosphorus groups (low, medium and high)

P-rem	Probability - Foliar P		
	Low	Intermediate	High
	Coffea canephora Pierre		
Low	0.62 a	0.23 b	0.15 c
Intermediate	0.22 b	0.72 a	0.08 c
High	0.07 c	0.26 b	0.67 a
	Coffea arabica L. cv Catuaí		
Low	0.63 a	0.25 b	0.13 c
Intermediate	0.19 b	0.67 a	0.14 b
High	0.00 c	0.23 b	0.77 a
	Coffea arabica L. cv Catucaí		
Low	0.67 a	0.33 b	0.00 c
Intermediate	0.00 c	0.78 a	0.22 b
High	0.00 c	0.27 b	0.73 a
	Coffea arabica L. (Catuaí and Catucaí)		
Low	0.62 a	0.31 b	0.07 c
Intermediate	0.05 c	0.65 a	0.30 b
High	0.00	0.17	0.83
	All species		
Low	0.82 a	0.14 b	0.04 c
Intermediate	0.18 b	0.61 a	0.20 b
High	0.00 c	0.33 b	0.67 a

Average probabilities followed by the same letter in the column did not differ using the "t" test at 5 %.

of P-rem are low, the chance that the foliar P content is the same for the canephora, Catuai arabica coffee and Catucai variety arabica coffee is 62, 63, and 67 %, respectively. In the case of the other arrangements (medium-medium and high-high) the significant behavior is repeated with a slight positive variation in the probability values.

When the species were analyzed together, the probability values were higher only for the low-low arrangement, and were inferior to others obtained during individual analyses. Therefore, it is evident that estimating foliar P, while using the information from the P-rem concentration, can provide better results when performed individually, i.e. separately for each species as well as for each variety.

By comparison, the probability values for the medium-medium and low-low arrangements were statistically higher when the species were analyzed individually, indicating their use in detriment of the definition of a single table. Prezotti et al. (2007) stated that arabica have a higher demand for P than conilon coffee plants, confirming the use of individual rather than a single table for all species.

The figures 1, 2 and 3 show the spatial distribution maps of foliar P and P-rem values, as estimated by ordinary kriging, as well as the foliar P maps which were estimated with additional spatial information from P-rem (P/P-rem) using the cokriging method. The mean square error values between the P and P/P-rem estimates are also presented.

In the case of conilon coffee, the spatial variability observed for foliar P was considerable (Figure 1), since the value of the semivariance range was only 28 m, resulting in several spots of different sizes across the area. This fact is shown in the greater variation between the nutritional content among the plants. The same behavior was observed for P-rem, with the highest spatial continuity, allowing a better delimitation of the concentration classes.

Table 6. Probability comparison of overlapping groups for foliar phosphorus and remaining phosphorus for the different combinations used in the cluster analysis

Variety	Probability		
	Low	Intermediate	High
		Coffea canephora Pierre	
Conilon	0.62 b	0.72 a	0.67 a
All species[(1)]	0.82 a	0.61 b	0.67 a
		Coffea arabica L.	
Catuaí	0.63 b	0.67 b	0.77 b
Catucaí	0.67 b	0.78 a	0.73 b
Arábica[(2)]	0.62 b	0.65 b	0.83 a
All species	0.82 a	0.61 c	0.67 c

Average probabilities followed by the same letter in the column did not differ by the "t" test at 5 %. [(1)] *Coffea canephora* Pierre and *Coffea arabica* L. (cv. Catucai and cv Catuai); [(2)] *Coffea arabica* L. cv. Catuai and cv Catucai.

The limits of the map resulting from cokriging were better defined and, consequently, the spatial continuity was greater. Silva et al. (2010) stated that when the auxiliary variable has greater continuity than the main variable, the resulting cokriging map tends to have this characteristic, contributing to a smoothing of the variability. However, this outcome did however not result in elevated mean square error values between the foliar P and P/P-rem maps, and the error values were lower than 1 % in most of the study area.

A similar behavior was observed for the Catucai variety (Figure 2), with considerable variability in foliar P. In most part of the study area the plants had foliar P contents between 0.85 and 1.15 g kg^{-1}.

The spatial variability of P-rem had lower spatial continuity than foliar P, characterized by the smallest range value and also the highest map discontinuity, which significantly influenced the result of the cokriging map, thereby resulting in mean square errors of around 1 to 2 %. Han et al. (2003) suggested that the cokriging technique provides better estimates than the ordinary kriging method, since cross-variogram functions are precisely defined, and also that the greatest variability is observed for the main and not for a secondary or auxiliary variable.

Different from the earlier maps, the foliar P and P-rem values for variety Catuai (Figure 3) had greater continuity and, consequently, the cokriging map reflects the real P distribution better. Mean square errors were concentrated between 0 and 1 % in almost the entire study area.

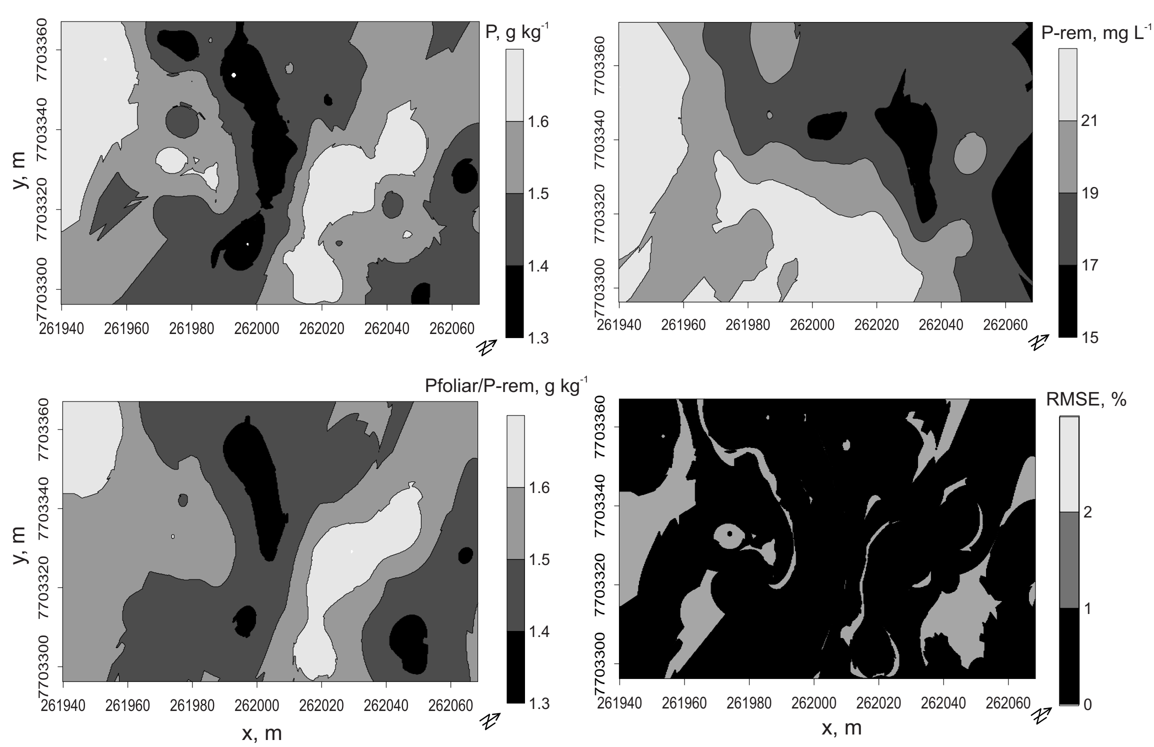

Figure 1. Spatial distribution maps obtained by ordinary kriging (foliar P and P-rem), cokriging (Pfoliar/P-rem) and root mean square error (RMSE) for the *Coffea canephora* Pierre cv Conilon.

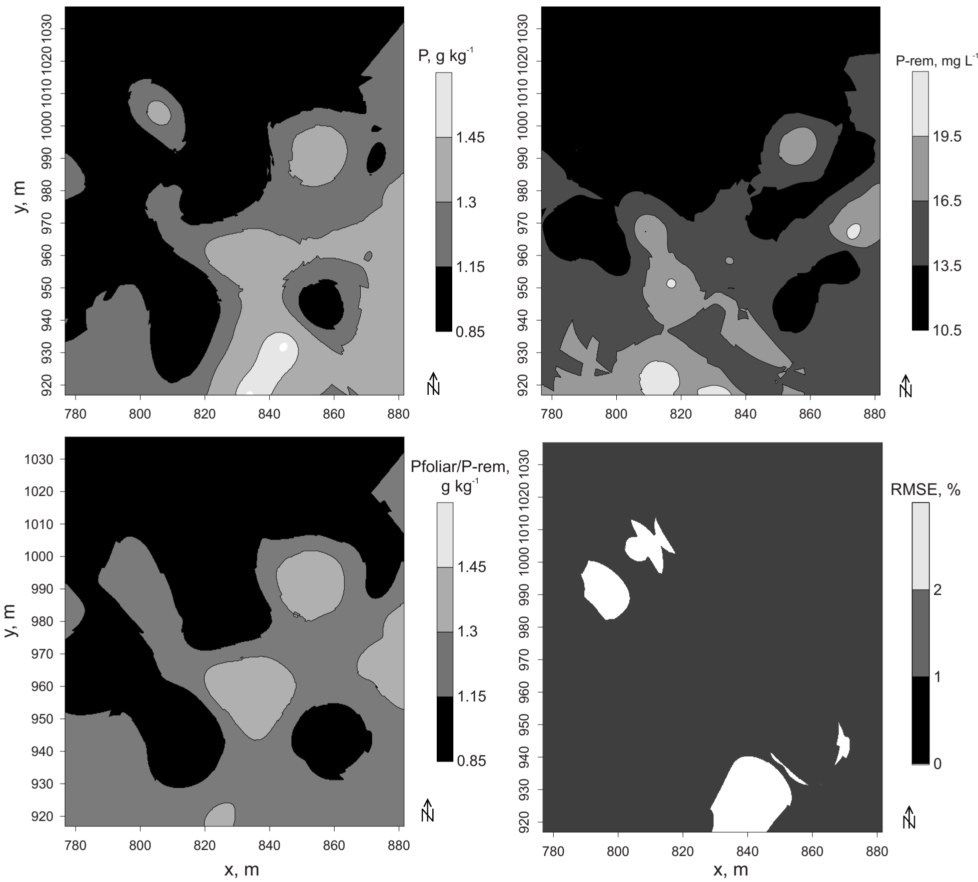

Figure 2. Spatial distribution maps obtained by ordinary kriging (foliar P and P-rem), cokriging (Pfoliar/P-rem) and root mean square error (RMSE) for *Coffea arabica* L. cv Catucai.

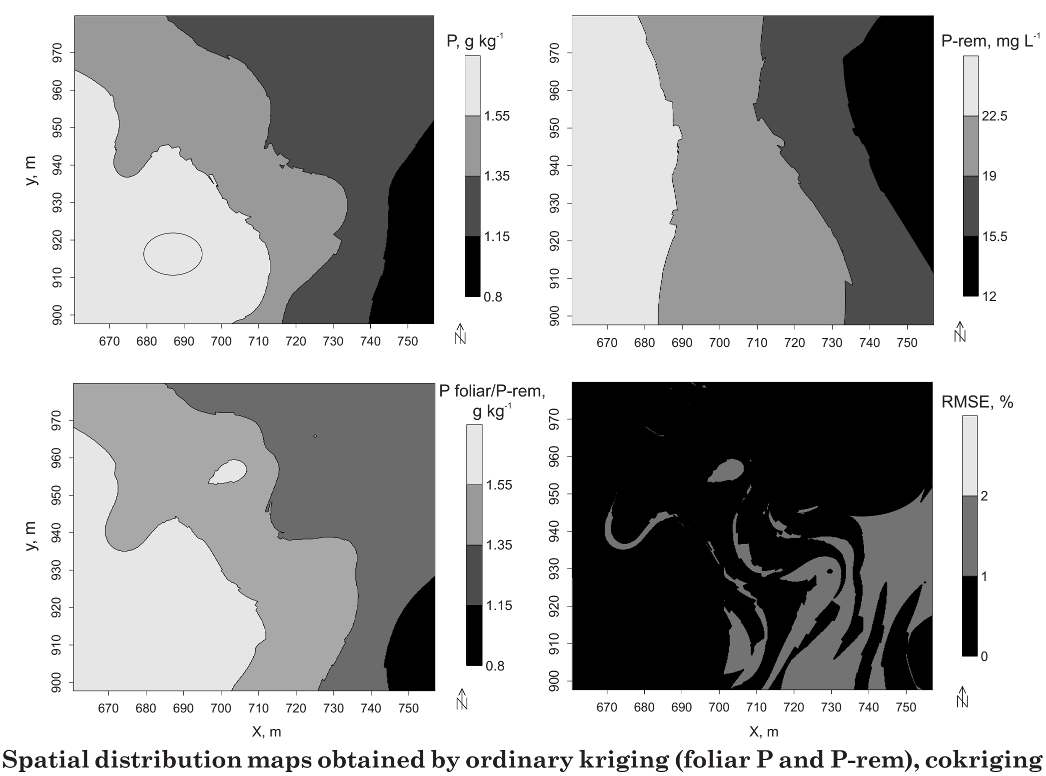

Figure 3. Spatial distribution maps obtained by ordinary kriging (foliar P and P-rem), cokriging (Pfoliar/P-rem) and root mean square error (RMSE) *Coffea arabica* L. cv. Catuai.

CONCLUSIONS

1. The spatial variability for the foliar P content is high for variety Catuai and average for the other evaluated coffee varieties.

2. Unlike P-Mehlich, the variability in P-rem of the soil indicated the nutritional status of this nutrient in the plant.

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