SCAP
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Spatial variability of nutrients in *Crotalaria juncea* grown in an eroded soil

Variabilidade espacial de nutrientes em plantas de *Crotalaria juncea* em área erodida

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ABSTRACT

The aim of this work was to characterize the spatial variability of the attributes of soil and plants in severely-eroded areas. The experimental plot had dimensions of 45 by 65 m, and was divided up into a grid with regular spacing of 5 m between points, making up a rectangle of 10 columns and 14 lines, totaling 140 points. The contents of macro and micronutrients were determined in the plants, plus dry matter and height of the *Crotalaria juncea.* The attributes of plants and soil thickness were distributed over the area in a well-defined spatial structure, with an adjustment of the spherical and Gaussian models, making an exception for calcium. Soil thickness demonstrated the locations with an accelerated process of erosion and displayed a clear spatial relationship with plant height and dry matter of the *C. juncea* and with the foliar macro and micronutrients.

Keywords: Geostatistics, green manure, soil thickness

RESUMO

O objetivo desse trabalho foi caracterizar a variabilidade espacial de atributos de solo e de plantas em áreas severamente erodidas. A parcela experimental teve a dimensão de 45 por 65 m e foi dividida em uma malha com espaçamento regular de 5 m entre pontos, sendo um retângulo de 10 colunas e 14 linhas, totalizando 140 pontos. Foram determinados os teores de macro e micronutrientes nas plantas, matéria seca e altura da C*rotalaria juncea* L. Os atributos das plantas e a espessura do solo distribuem-se na área em estudo com uma estrutura espacial bem definida, com ajuste dos modelos esférico e gaussiano com exceção para o cálcio. A espessura do solo demonstrou os locais com o processo de erosão acelerado e apresentou forte relação espacial com a altura de planta e matéria seca da *C. juncea* e, com os macros e micronutrientes foliares.

Palavras-chave: Geoestatística, adubo verde, espessura do solo

Introduction

Given the importance of the soil in the productive system, its conservation is of fundamental importance to guarantee the sustainability of agriculture (Cruz *et al*., 2008). The constant reduction in soil productivity has been attributed principally to hydric erosion and unsuitable handling of the soil. Another aspect of major importance is that the input of sediments from areas suffering from erosion leads to the silting-up of rivers and lakes, compromising the quality of the water and affecting aquatic life, mainly through the eutrophization of waters (Hernani *et al*., 1999). Soil resistance to hydric erosion displays wide amplitude, resulting from climatic variability, which influences the rains' capacity to cause erosion and the variation of classes of soil with differentiated attributes and handling.

The accelerated erosion of the soil is a factor that may contribute to increase the spatial variability of soil attributes, interfering in the development of agricultural plantations and plant nutrition (Campos *et al*., 2008), In this way, geostatistics can help to understand how erosion adversely affects the productivity of crops. Therefore, the adoption of geostatistics in modeling the variability of plant and soil attributes is fundamental, since at present the vast majority of agricultural producers consider the soil in their farming areas to be uniform. However, each borehole may have considerable variations in its attributes, such as variability of the class of soil, productivity, declivity, the need for nutrient and loss of soil (Campos *et al.,* 2009).

Studies have demonstrated the spatial variability of attributes of the soil (Salviano *et al.,* 1998; Abreu *et al*., 2003; Souza *et al.,* 2004; Montanari *et al.,* 2005; Oliveira *et al.,* 2009) of soil erosion in agricultural areas (Souza *et al*., 2003; Campos *et al*., 2008) of soil thickness (Albuquerque *et al*., 1996; Bertolani & Vieira, 2001; Abreu *et al.,* 2003) and of plants (Albuquerque *et al.,* 1996; Abreu *et al*., 2003; Roque *et al*., 2008; Oliveira *et al*., 2009).

The soil attributes, after undergoing successive changes caused by agricultural activities, and consequently by the erosive processes, behave in a highly-differentiated manner over the countryside (Bertolani & Vieira, 2001). Therefore, the spatial variation of soil thickness is not only attributed to the processes of formation of the soil, but also to the techniques of soil preparation, e.g. soil mobilization, as these originate losses of soil in the surface layer, causing in the different classes of soil a reduction of the A+B horizons and imposing differentiated variability of this attribute along the slope.

This history of use of the soil shows that change does not always give rise to a new ecological system, either of crops or grazing lands. The appraisal of degraded areas is a highly-important process for laying down strategies for soil conservation. Therefore, the objective of this work was to characterize the spatial variability of plant and soil attributes in severely eroded areas.

Material and Methods

The experiment was conducted in an area of commercial production of sugar cane in the district of Piracicaba (São Paulo State) located at coordinates 22º 22′ South and 47º 30′ West. The local climate, according to Köppen's classification, is of the subtropical humid mesothermal type, with dry winters. The soil was classified as an association of Red-Yellow Argissol, alic or dystrophic, Tb, moderate sandy/medium texture + Litholic soil (Salviano *et al.,* 1998). The land is undulated with 8% average declivity. The existence of deep erosion furrows in the area was noted. Cultivation of sugar cane has been carried out in this area for over thirty years. The system of cultivation adopted in the area, especially renewal of the canebrakes, has proved to be of poor efficiency in controlling erosion.

The experimental plot had dimensions of 45 by 65 m, and was divided up into a grid with regular spacing of 5.0 m between points, making up a rectangle of 10 columns and 14 lines, totaling 140 points. The thickness of the soil defined as the layer of soil above horizon C was determined by means of boring down to 1.20 m. In the erosion furrows, in which horizon C was exposed, soil thickness was considered as zero, irrespective of the eroded layer of horizon C.

Installation of the experiment occurred after plowing and boring the soil and application and incorporation of 4.0 Mg ha^{-1} of dolomite lime, as recommended by the base saturation method. Broadcast seeding was done 10 days after preparation of the soil, using 30 kg ha^{-1} of crotalaria seeds (*Crotalaria juncea* L.). Germination was adversely affected by lack of rainfall, for which reason new seeding was carried out fifteen days later, using the same procedure. Five hundred kg per ha of formula 17.7.21 manure was applied.

The contents of macro and micronutrients in crotalaria were determined in the following way: the plant material was dried and ground and then underwent digestion with nitric-perchloric solutions in a digester block, 0.50 g of dry mass, 4 mL of concentrated HNO_3 + 1 mL of concentrated $HCIO_4$, completing the volume to 50 mL with de-ionized water (Malavolta *et al.,* 1997). Micronutrients were analysed by atomic emission spectroscopy with plasma (ICP-AES).

The above-ground biomass of crotalaria was sampled to determine dry matter ("MS"), considering mini-portions of 2.0 by 2.5 m, with the plants cut just above the soil, dried at 65º C for 48-h and weighed. To determine average height ("ALT") three plants were taken from each plot. Four leaves per plant, fully expanded, a total of ten plants, was sampled out in the period of blossoming for determine foliar macronutrients (N, P, K, Ca, Mg and S) and micronutrients (Fe, Zn, Cu and Mn).

The macro and micronutrients, dry matter, plant height and soil thickness were assessed by means of descriptive statistical analysis, calculating the mean, median, standard deviation, maximum and minimum values, coefficient of variation, coefficient of asymmetry and curtosis coefficient. The hypothesis of normality of the data was tested by the *Kolmogorov-Smirnov* test, using the computer program SAS (Schlotzhaver & Littell, 1997). The values of the attributes above the mean plus four standard deviations were discarded (Cahn *et al*., 1994). The number of data discarded was always below 1.5% of each set of 140 data.

Spatial dependence was analyzed by means of adjustments of semivariograms (Vieira, 2000), based on the premise of the stationary nature of the intrinsic hypothesis, which is estimated by:

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

in which N (h) is the number of pairs of experimental observations $Z(x_i)$ e $Z(x_i + h)$ separated by distance h. The semivariogram is represented by the graph $\hat{\gamma}(h)$ versus h. By adjusting a mathematical model to the calculated values of $\hat{\gamma}(h)$, we estimated the coefficients of the theoretical model for the semivariogram (the nugget effect, $\mathbf{C_0}$; sill, $\mathbf{C_0+C_1}$; and range, **a**). To analyze the degree of spatial dependence of the attributes under examination, the classification of Cambardella *et al*. (1994) was used, which considers as strong the spatial variation of the semivariograms that have a nugget effect <25% of the sill, moderate when this is between 25 and 75% and weak, > 75%.

The semivariogram models considered were the spherical, exponential, linear and Gaussian, these adjusted by the GS^+ program (version 7.0) (Gamma Design Software, 2004). Subsequently, these models were used in the development of isolines (Kriging). In the event of doubt between more than one model for the same semivariogram, we considered the greatest value of the coefficient of correlation obtained by the method of cross-validation. For preparation of the maps of spatial distribution of the variables, the Surfer 8.0 program was used (Golden Software, 1999).

Results and Discussion

The results of the Kolmogorov-Smirnov test indicated normality for the variables soil thickness, plant height, potassium and copper concentrations (Table 1). The measures of position, mean and median, displayed similar values, indicating that the sets of values tend towards normal distribution, a fact in harmony with curtosis and asymmetry values close to zero. The normality of the data is not a requirement of geostatistics; it is merely convenient that distribution should not display very long tails, which could compromise the estimates from Kriging, based on the mean values (Isaaks & Srivastava, 1989).

According to the classification by Warrick & Nielsen (1980), the values of the coefficient of variation were high for soil thickness, dry matter, P, K, S, Cu and Mn (Table 1). Variables N, Ca, Mg, Fe and Zn displayed average variation and the variable height of the crotalaria plant displayed a low CV. Bertolani & Vieira (2001), studying the spatial variability of the rate of infiltration of water and thickness of horizon A in a Red-Yellow Argissol, noted a low CV for soil thickness, although (Abreu *et al.*, 2003), researching the spatial variability of the physical-hydric proper-

Table 1 – Descriptive statistics for the variables dry matter (kg ha^{-1}), height of the *Crotolaria juncea* L. plants (m), soil thickness (m), foliar macronutrients N, P. K, Ca, Mg and S (g kg^{-1}) and foliar micronutrients Fe, Zn, Cu and Mg (mg kg^{-1}).

Attribute	Mean	Median	Minimum	Maximum	DP[1]	CV[2]	Asymmetry	Curtosis	d[3]
Thickness	85.00	85.00	15.00	120.00	28.47	35	0.57	-0.58	0.04^{ns}
Dry matter	8.87	8.87	3.40	13.09	2.11	25	-0.33	-0.13	0.13
Height	2.53	2.53	1.94	2.96	0.23	9	-0.35	-0.36	0.04^{ns}
Nitrogen	15.22	15.12	11.20	19.25	1.86	12	0.16	-0.58	0.12
Phosphorus	1.28	1.28	0.49	2.21	0.39	31	0.03	-0.69	0.14
Potassium	5.08	5.08	2.68	8.14	1.36	26	0.36	0.98	0.05^{ns}
Calcium	6.82	6.82	4.92	9.24	0.96	14	0.30	-0.58	0.14
Magnesium	3.20	3.20	2.02	4.46	0.61	19	0.19	-0.59	0.13
Sulfur	1.41	1.41	0.51	2.37	0.38	27	-0.01	-0.22	0.14
Iron	92.00	92.00	44.00	145.00	20.64	22	0.30	-0.39	0.12
Zinc	11.00	11.00	7.00	15.00	2.06	19	0.07	-0.85	0.12
Copper	3.00	3.00	1.00	6.00	1.43	47	0.32	-0.80	0.06^{ns}
Manganese	41.00	41.00	12.00	105.00	24.11	51	0.65	-0.60	0.13

[1]DP = standard deviation; [2]CV = coefficient of variation; [3]d= Statistic of the Kolmogorov-Smirnov test, ^{ns} negligible to 5% of probability.

ties of the soil in a Argissol, verified a high CV for soil thickness.

Montezano *et al.* (2008), studying the variability of nutrients in corn plants in a Red-Yellow Latossol, found that the concentrations of macronutrients in the indicative leaf of the corn plants showed little variability and the concentrations of micronutrients displayed average variability. Berndtsson & Bahri (1995) found that the contents of nutrients in the soil showed greater variation than the concentrations of nutrients in the plant. The same authors argued that other factors, besides the influence of the chemical attributes of the soil, significantly affect chemical variability in the plant, as do the type of plant, genetic properties and attributes of the soil.

The results of the geostatistic analysis showed that all the variables analyzed displayed spatial dependence at the two depths studied, with the exception of Ca (Table 2). All the data on the attributes under examination adjusted to the spherical model, with the exception of variables soil thickness and sulfur, which adjusted to the Gaussian model. Analysis of the relationship $C_0/(C_0+C_1)$ showed that the plant variables displayed a strong degree of spatial dependence, and moderate spatial dependence for all the plant's macro and micronutrients, with the exception of P and Cu which showed a strong degree of spatial dependence. The distribution of soil and plant attributes in space was not random, as all the attributes of the soil displayed a degree of spatial dependence, as established by the relation $C_0/(C_0+C_1)$. This demonstrates that the semivariograms explained the greater part of the variance of the experimental data.

Calcium did not display spatial dependence for the conditions of this experiment, or rather, a pure nugget effect, and thus all the variability estimated by the semivariogram was associated to the random nature of the data (Table 2 and Figures 1 and 2).

In this case there was an indication of spatial independence of the attribute, or that the distance of the sample used was greater than necessary to reveal spatial dependence. The lime applied just before planting probably contributed to this result. The reach of spatial dependence, which means the maximum distance over which a variable is spatially correlated, ranged from 15 m for soil thickness to 64 m for N and Cu in the plant (Table 2 and Figure 1 and 2). The micronutrients in the plant had such ranges varying from 26m for Zn to 64 m for Cu; in the macronutrients the ranges varied from 20 m for S to 64 m for N.

The variation of thickness of horizon A+B is a sign of erosion in this class of soil, as the smaller the thickness of the surface horizon, the quicker its saturation at the time of heavy rains, increasing soil runoff (Figure 3).

Although hardly representative an area was mapped with less than 20 cm of soil thickness, while stressing that this soil was originally over 120 cm in thickness. The shallowest soil was located to the right of the landscape. Similar results were observed by

Table 2 – Models and estimated parameters of the experimental semivariograms for the variables dry matter (kg ha^{-1}), height of the *Crotalaria juncea* L. plants (m), soil thickness (m), foliar macronutrients N, P. K. Ca, Mg and S (g kg^{-1}) and foliar micronutrients Fe, Zn, Cu and Mn (mg kg^{-1}). Trients Fe, Zn, Cu and Mn (mg kg^{-1}).

Attribute	Model	Nugget effect	Sill	Range	$C_0/(C_0+C_1)$[1]	VC[2]
Thickness	Gaussian	331	854	15	36	0.90
Dry matter	Spherical	0.51	4.81	21	11	0.95
Height	Spherical	0.01	0.06	22	17	0.98
Nitrogen	Spherical	2.03	4.28	64	47	0.88
Phosphorus	Spherical	0.03	0.16	37	16	0.92
Potassium	Spherical	0.91	2.06	26	44	0.90
Calcium	EPP[3]	-	-	-	-	-
Magnesium	Spherical	0.18	0.37	23	50	0.89
Sulfur	Gaussian	0.07	0.16	20	42	0.90
Iron	Spherical	239	480	45	50	0.90
Zinc	Spherical	2.07	4.45	26	46	0.93
Copper	Spherical	0.70	3.01	64	23	0.90
Manganese	Spherical	289	678	52	43	0.91

[1]$C_0/(C_0+C_1)$ = degree of spatial dependence; [2]VC = coefficient of determination of the cross-validation test; [3]EPP = Pure nugget effect.

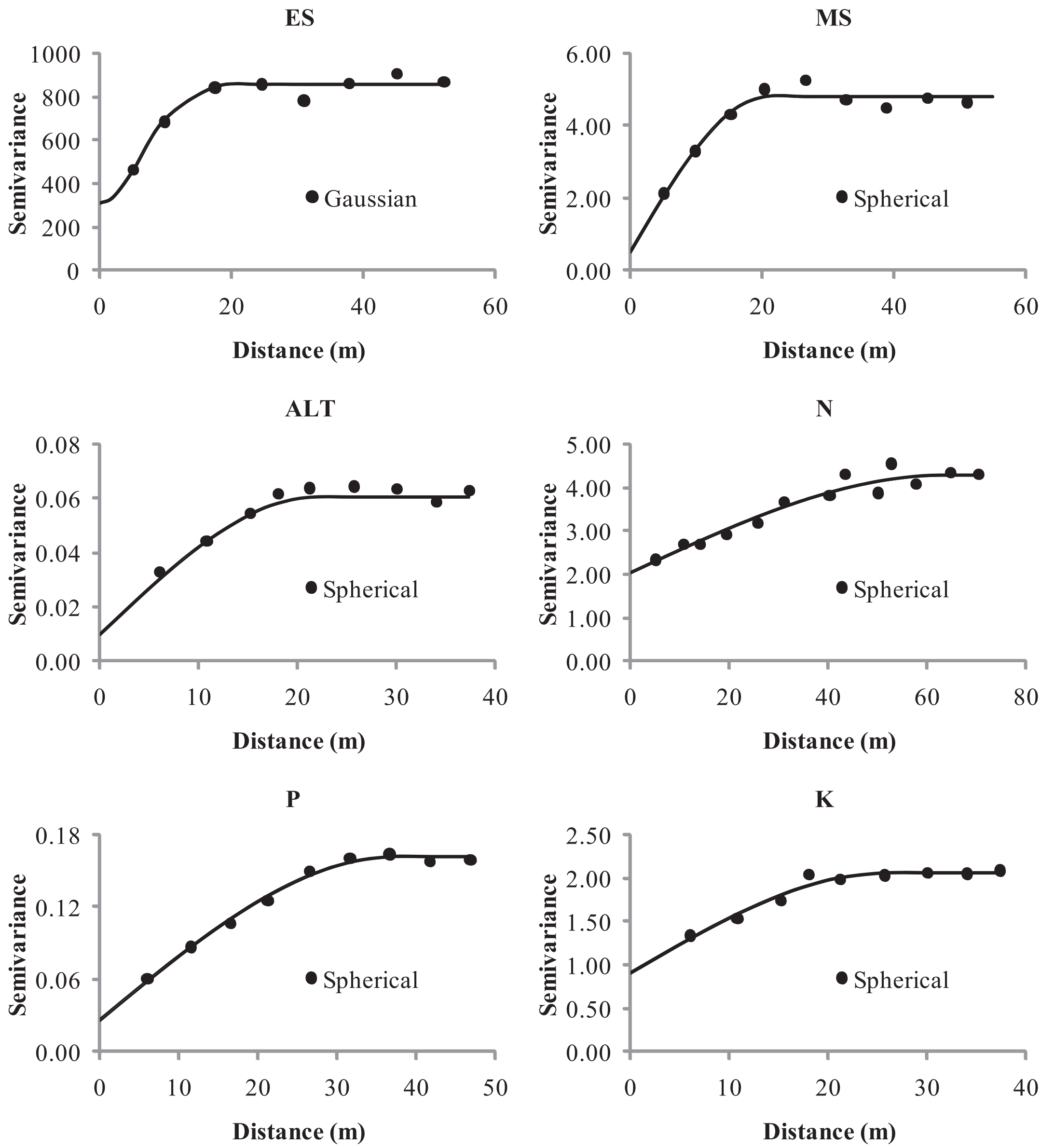

Figure 1 – Semivariogram of attributes soil thickness (ES), dry matter (MS), plant height (ALT), nitrogen (N), potassium (K) and phosphorus (P).

Bertolani & Vieira (2001). Studying the spatial variability of the thickness of horizon A in a Red-Yellow Argissol, they verified the presence of deeper erosion furrows in the most degraded areas, going as far as horizon Bt, compromising the productivity of crops.

The comparison between the standard of thickness of the soil and production of dry matter and the height of the crotolaria plant (Figure 3) showed similarities suggesting, that the variables were correlated principally when the soil was up to 0.60 m in thickness. This fact is justified by erosion exposing the layers that are poorer in nutrients and richer in toxic elements, such as Al, besides reducing the depth reached by the roots. Albuquerque *et al.* (1996) found a direct relationship between the thickness of horizon A and the productivity of grains of corn; the productivity of corn was reduced by 42.9 kg ha^{-1} for each centimeter less in the thickness of horizon A.

We found a strong relation between the thickness of the soil and the foliar macro and micronutrients in crotalaria (Figures 3 and 4). In the regions with thinner soil, the greatest concentrations of macro and micronutrients were found, with the exception of K. The explanation for this fact is that areas that underwent a smaller process of erosion are richer in

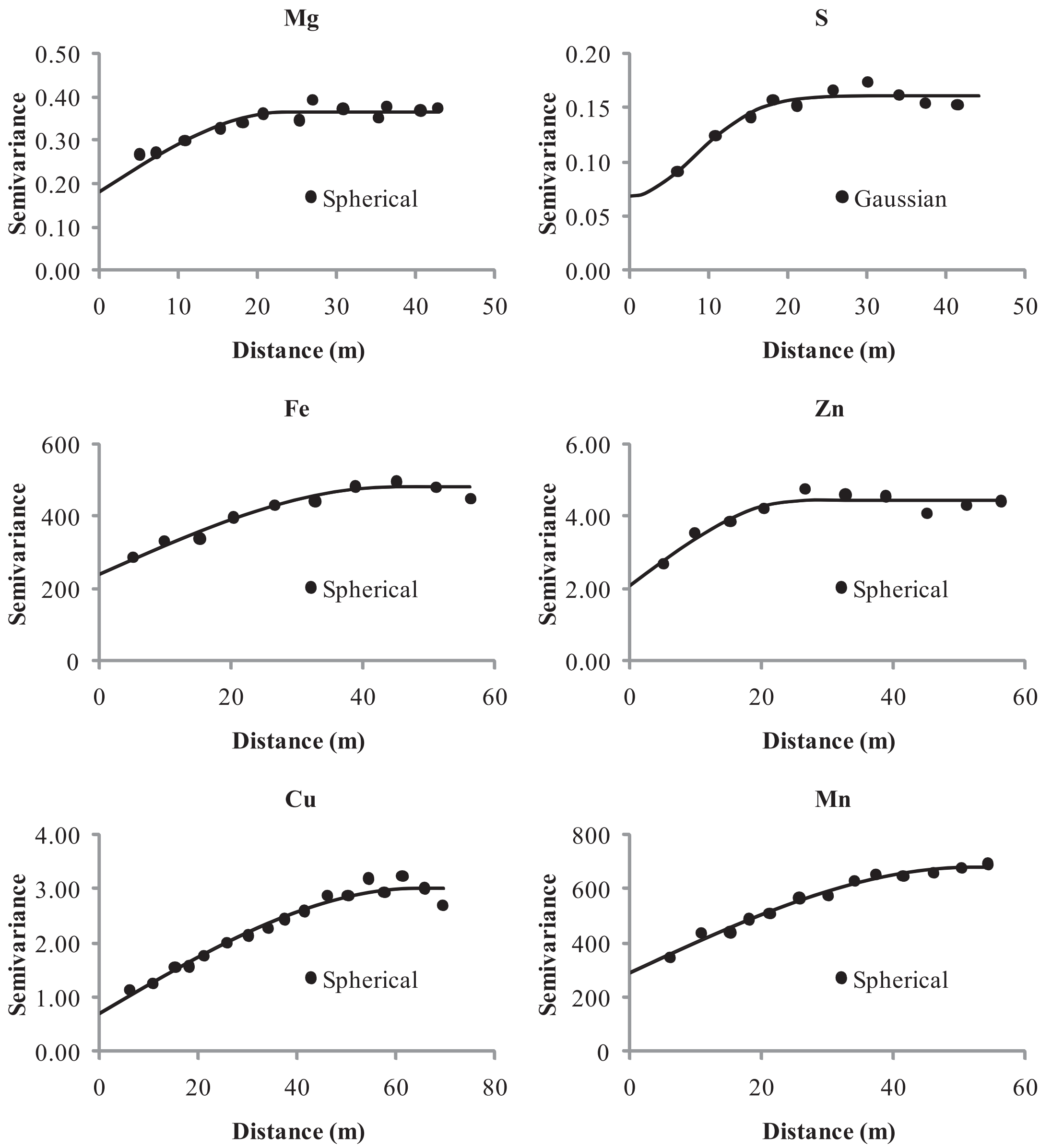

Figure 2 – Semivariogram of attributes soil magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn)

plant nutrients, which therefore allows the plant to absorb a greater quantity of these elements. Silveira & Cunha (2002), studying the spatial variability of micronutrients in different cultivation systems, observed that the systems that turned the soil over more intensive showed less availability of micronutrients in comparison with the conservation systems.

The relation between the spatial variability of the attributes of the soil and variability of the plant's attributes can help to identify the cause-and-effect relationship of these attributes. We observed that the loss of soil directly reflected on the growth of crotalaria (Figures 3 and 4). Silva *et al.* (2006), studying the accumulation of nutrients in cover crops in a system of no-tillage, observed that the crotalaria accumulated a greater quantity of macro and micronutrients than in succession to millet and soil left fallow. However, in areas that displayed loss of soil, that is to say, a reduction of thickness of the soil this was reflected on the growth of this crop.

With regard to soil handling and conservation, it should be noted that the areas in which processes of erosion do not allow proper growth of the plants, these consequently do not provide good coverage for the soil, in this way creating a vicious circle that tends to increase erosion in areas in which erosion is already occurring.

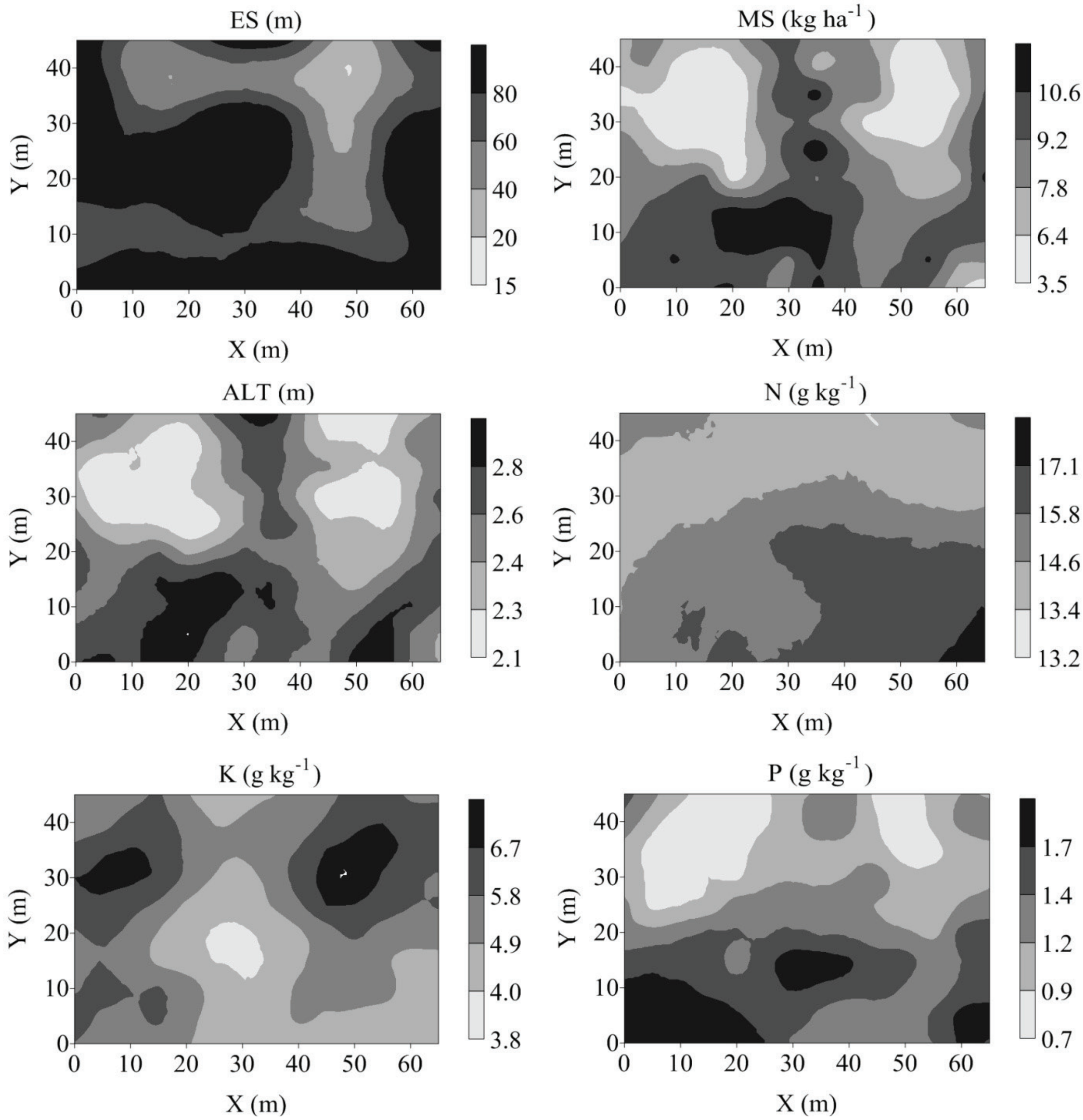

Figure 3 – Maps of spatial distribution of the variables soil thickness (ES), dry matter (MS), plant height (ALT), nitrogen (N), potassium (K) and phosphorus (P).

Conclusions

The plant attributes and soil thickness were distributed over the study area with a well-defined spatial structure, with adjustment of the spherical and Gaussian models, with the exception of calcium.

Soil thickness showed places with an accelerated process of erosion and displayed a strong spatial relation with the height of the plant and dry matter of *Crotalaria juncea,* and with the foliar macro and micronutrients.

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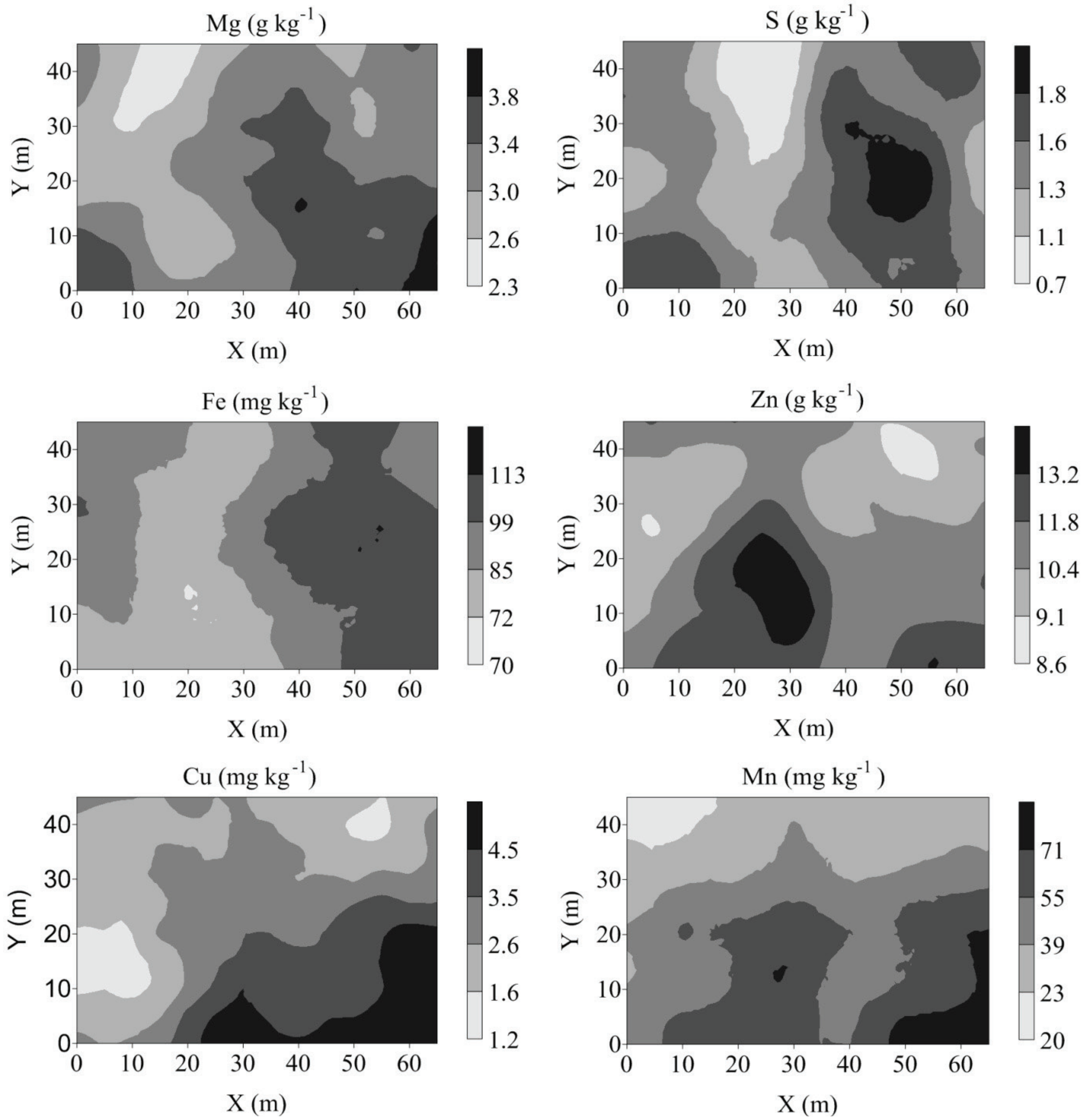

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