LIMING INFLUENCE ON THE SPATIAL VARIABILITY OF THE LEAF CHEMICAL COMPOSITION AND IN THE INITIAL GROWTH OF THE EUCALYPTUS

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ABSTRACT: The correct nutrition by the occasion of implantation is essential for the increasing and maintaining the productivity of the planted forests and one of the management options used to minimize the effects of variability in productivity is the precision agriculture, which with the use of geostatistical tools aid in the management of the crop and represents an important factor in the economy and more rational employment of agricultural inputs. The aim of this study was to evaluate the influence of liming on the spatial variability of leaf chemical composition (N, P, K, Ca, Mg and S) and at the height of the spontaneous hybrid of Eucalyptus urophylla clone I 144, at six months after planting, in a Quartzarenic Neosol in a low altitude cerrado zone. The experiment was conducted in an area belonging to the Bom Retiro Farm, property of Eldorado Brazil Celulose, between the months of March to September 2014, located in the city of Água Clara, MS. The geostatistical mesh installed in a regular grid for data collection was comprised of 50 points with a sample spacing of 9.0 x 7.5 m. The studied attributes were the plant height and leaf nutrient content (N, P, K, Ca, Mg and S) of the eucalyptus. The data were analyzed by descriptive statistics and spatial variability was determined by geostatistical methods such as calculating the semivariogram and use of interpolated maps by ordinary kriging. The liming had influenced the leaf content of nitrogen, phosphorus, calcium and magnesium of Eucalyptus urophylla clone I 144 and the leaf magnesium was the only attribute that presented spatial dependence, which enables the management located at an early stage.
Key words: geostatistics, eucalyptus nutrition, limestone, precision agriculture.

INFLUÊNCIA DA CALAGEM NA VARIABILIDADE ESPACIAL DA COMPOSIÇÃO QUÍMICA FOLIAR E NO CRESCIMENTO INICIAL DO EUCALIPTO

RESUMO: A correta nutrição por ocasião da implantação é essencial para o aumento e manutenção da produtividade das florestas implantadas e uma das opções de manejo utilizadas para minimizar os efeitos da variabilidade na produtividade é a agricultura de precisão, que com o uso de ferramentas geoestatísticas auxiliam no manejo da lavoura e representa fator importante na economia e emprego mais racional dos insumos agrícolas. O objetivo deste trabalho foi avaliar a influência da calagem na variabilidade espacial da composição química foliar (N, P, K, Ca, Mg e S) e na altura do híbrido espontâneo de Eucalyptus urophylla clone I 144, aos seis meses após o plantio, num Neossolo Quartzarênico em área de cerrado de baixa altitude. O experimento foi conduzido em área pertencente à Fazenda Bom Retiro, propriedade da Eldorado Brasil Celulose, entre os meses de março a setembro de 2014, localizada no munícipio de Água Clara, MS. A malha geoestatística instalada em grade regular para coleta dos dados foi constituída de 50 pontos com espaçamento amostral de 9,0 x 7,5 m. Os atributos estudados foram a altura de planta e os teores foliares de nutrientes (N, P, K, Ca, Mg e S) do eucalipto. Os dados foram analisados pela estatística descritiva e variabilidade espacial foi determinada por métodos geoestatísticos como cálculo do semivariograma e uso de mapas interpolados por krigagem ordinária. A calagem influenciou os teores de nitrogênio, fósforo, cálcio e magnésio foliar do Eucalyptus urophylla clone I 144 e o magnésio foliar foi o único atributo que apresentou dependência espacial, o que possibilita o manejo localizado em estádio inicial.
Palavras-chave: geoestatística, nutrição de eucalipto, calcário, agricultura de precisão.

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1. INTRODUCTION

The eucalyptus plantations occupy 5.56 million hectares of planted forest area in Brazil, and according to data from the Brazilian Industry of trees, this represents 71.9% of the total cultivated forests (IBA, 2016). Mato Grosso do Sul has been highlighting on the national scene in the forest sector in the last 10 years, and in the year 2016, the State is already the third largest producer of eucalyptus in area in Brazil with 804 million hectares, exceeded only by Minas Gerais and São Paulo (Mendes et al., 2016).

In Mato Grosso do Sul (Brazil), the regions of Três Lagoas and Água Clara are the largest growing culture in the state and this expansion is sometimes carried out in low natural fertility soils, as is the case of Quartzarenic Neosols (Correa et al., 2015). These soils have low particles aggregation and clay content, followed by an accelerated decomposition of organic matter, resulting in reduced water retention and a limited supply of nutrients for the plants (Correia et al., 2004; Albuquerque et al., 2011; Prado, 2013).

The correct nutrition by the occasion of implantation is essential for the increasing and maintaining the productivity of the implanted forests and the analysis of leaf nutrient content is one of the most efficient methods to evaluate the nutritional status (Bassaco & Walczak, 2014). Despite the tolerance of Eucalyptus species to soil acidity and interchangeable aluminum, the availability of calcium and magnesium should be adequate, because it is of the greater accumulation nutrients in the aerial part, which justifies the need to carry the liming with the goal of providing these nutrients to the culture (Leite et al., 2011; Maeda & Bognola, 2012).

One of the management options used to minimize the effects of the variability in cultures productivity is the precision agriculture, which represents a set of techniques and procedures used in order to the agricultural production systems be optimized, with the main objective the management of spatial variability using as tool the geostatistical analysis (Da Silva et al., 2015).

The geostatistical analysis aids to study the spatial variability of leaf nutrient contents and its use provides information concerning the planning and management of agricultural areas (Vieira et al., 2010). Despite the importance of the spatial description of the leaf nutrient content as a tool to characterize the soil fertility through geostatistical calculations, few studies were conducted in this sense, mainly in the initial period of the initial development of eucalyptus culture.

In the face of the exposed, this study was carried out in order to evaluate the influence of liming on the spatial variability of leaf chemical composition (N, P, K, Ca, Mg and S) and at the height of the spontaneous hybrid of *Eucalyptus urophylla* clone I 144, at six months after the planting, in a Quartzarenic Neosol in a low altitude of cerrado zone.

2. MATERIAL AND METHODS

This experiment was developed in an area belonging to the Bom Retiro Farm, property of Eldorado Brazil Celulose, between the months of March to September 2014, located in the city of Água Clara, MS. The experimental area has 5.5 ha (110 x 50 m), average slope of 2 % and relative altitude of 319 m with geographic coordinates 20°26'52" S and 52°52'40" W.

The soil was classified as Quartzarenic Neosol (Santos et al., 2013), and according to the area usage history, was being cultivated with pasture for 50 years. The regional climate, according to the Köppen classification, is Aw (Nimer, 1989), characterized as humid tropical, with the rainy season in summer and dry in winter. The region presents as climate feature an annual average of the maximum temperature 29.2 °C and a minimum annual average of 18.7 °C, with annual average rainfall of 1271 mm, abundant from November to March. In Figure 1 is recorded the climatic conditions during the experiment (INMET, 2016).

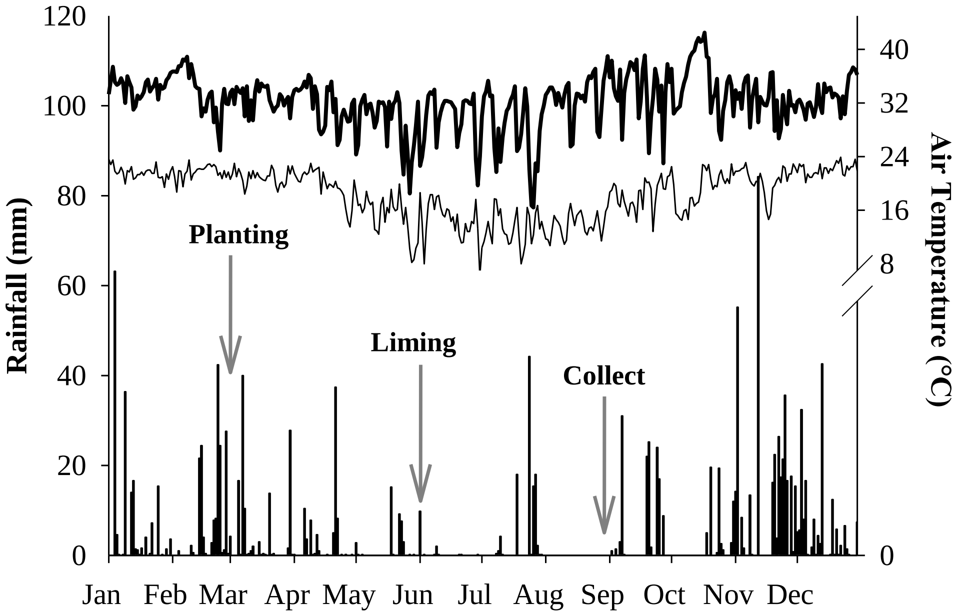

Figure 1. Rainfall data, maximum and a minimum temperature of the experimental area. Bom Retiro farm, Água Clara, MS, Brazil, 2014.

For the chemical and textural characterization of the soil before experiment installation, on 24.01.2014 was collected a composite sample, originated of 20 single samples deformed of all experimental area, in the stratified layers of 0.00 - 0.20 and 0.20 - 0.40 m, whose the results are presented in Table 1 (Raij et al., 2001; Donagema et al., 2011).

Table 1. Soil chemical and granulometric characterization, in the layer of 0.00 - 0.20 to 0.20 - 0.40 m, before the experiment implementation, Água Clara, MS, Brazil, 2014.

Layer	OM	pH	P	K^+	Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$	Al^{3+}	SB	CTC	V	Sand	Silt	Clay
m	g dm^{-3}	$CaCl_2$	mg dm^{-3}	mmol$_c$ dm^{-3}							%	g kg^{-1}		
0.00-0.20	12	4.1	8	0.9	1	2	36	8	3.9	39.9	10	857	29	114
0.20-0.40	14	4.1	4	0.9	2	0	26	12	2.9	20.9	10	854	32	114

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The seedling planting of spontaneous hybrid of *Eucalyptus urophylla* clone I 144 was carried on 10.03.2014 and for acidity, the correction was applied 2 Mg ha^{-1} of dolomitic limestone. The adopted spacing was 3.0 m between rows and 2.5 m between plants in single rows, with a population of 1333 plants ha-1. As mineral fertilizer planting, was used 230 g pit^{-1} of the formulated 05-23-06 + 5% sulfur, 0.3% boron and 0.6 % copper and zinc, while, the cover fertilization, carried out at day 90, constituted of an application of 156 g pit^{-1} of the formulation 11-00-22 + 10% sulfur and 0.8% boron. The other cultural practices were carried out according to the established for culture.

In this study are being analyzed the data from leaf content and the eucalyptus height. The treatment was constituted of an application of 2 Mg ha^{-1} of dolomitic limestone (88% PRNT, 30% CaO and 12% MgO) applied to a haul, held on 6/25/2014.

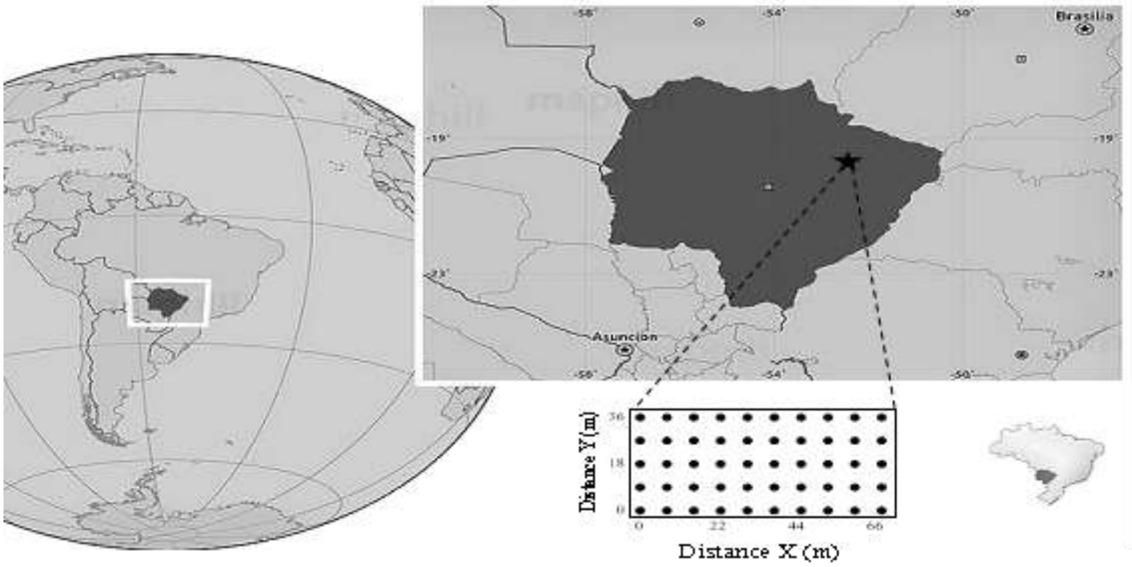

Figure 2. Identification of the study location and sampling mesh sketch. Bom Retiro Farm, Água Clara, MS, Brazil, 2014.

To collect the plant data, a geostatistical mesh in the regular grid using a GPS navigation was allocated. The sampling mesh was constituted of 50 points, with a sample spacing of 9.0 x 7.5 m, distributed in order to cover the entire experimental area (Figure 2). The eucalyptus height (HEI) was estimated with the aid of a graduated rule and, for quantification of leaf nutrient contents, was sampled a newly -mature leaf of each cardinal point of the upper third of the crown, in the third to last launching of leaves of the branches, in September, the end of winter, six months after the planting of culture. The collected material was dried in a forced air circulation in oven at 65 °C for 72 hours and then milled to the determination of leaf nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) content following the methodology proposed by Malavolta (2006).

For each analyzed attribute, was carried out a descriptive analysis with the aid of classical statistics, using SAS software, which was calculated the average, median, minimum and maximum values, standard deviation, the coefficient of variation, kurtosis, and skewness, which allowed to verify the existence of central tendency and dispersion. The adjustment of the data to the distribution of the normal type was evaluated by Shapiro & Wilk test at 5 %.

To evaluate the degree of correlation between the studied attributes used the Pearson correlation coefficient (R), calculated using the Excel software and to characterize the spatial variability, geostatistical methods were used, through simple semivariograms calculation with use of Gamma Design Software 7.0 package (GS+, 2004).

To define the best semivariographic model was taken into consideration the smallest sum of squared of the residues (RSS), the highest coefficient of determination (r2) and the largest evaluator of spatial dependence (DSE). The final decision of the model that represented the adjustment was attested by cross-validation, as well as to define the size of the neighborhood that provided the best mesh kriging.

To express the spatial dependence of the attributes was used the Evaluator of spatial dependence (DSE), which measures the proportion of the structured variance (C_1) in relation to the level (C_0 + C_1), and was calculated according to equation 1:

$$DSE = \left(\frac{C_1}{C_0+C_1}\right).100 \quad (1)$$

3. RESULTS AND DISCUSSION

Only for nitrogen, phosphorus and calcium content was observed a normal frequency distribution. For the remaining leaf content, the distribution was classified as indeterminate (Table 2). According to Vieira et al. (2010) the geostatistical analysis does not demand that the data present frequency distribution of the normal type, but the identification of the occurrence of very skewed distributions is interesting in the sense that the ordinary kriging can be considered an estimate based on weighted moving averages, with weights calculated from semivariograms.

Regarding the coefficient of variation (CV, %) and according to the classification proposed by Pimentel Gomes & Garcia (2002), only the leaf content of nitrogen and sulfur presented the CV classified as low (<10

%). The phosphorus and potassium content presented an average coefficient of variation (between 10% and 20%), while the plant height at six months after the planting and the leaf content of calcium and magnesium presented high coefficients of variation (>20 %).

In the present study, the maximum and minimum values of foliar calcium and magnesium content indicate high variability for these elements, which may affect the plant height and, consequently, the wood productivity and the uniformity of production in the area. In the case of the calcium content in the leaves (2.6 to 6.9 g kg^{-1}) are classified as low to medium according to Raij (2011) and found below the values considered adequate by Silveira et al. (2004), whose the appropriate range is 7,1 to 11 g kg^{-1}. The low Ca and Mg contents in the leaf may be related to the fact of the liming had been made by haul on the surface and the low solubility and mobility of the limestone in the soil profile. Studies conducted by Scarbi et al. (1999) showed that the calcium deficiency considerably reduced the fiber length and the lignin concentration in the Eucalyptus wood. Is emphasized that the calcium at not very high concentrations increases the cations and anions absorption by their role in maintaining the functional integrity of the plasma membrane (Epstein & Bloom, 2006; Malavolta, 2006).

Table 2. Parameters of the descriptive statistics of the height and leaf nutrient content of *Eucalyptos urophylla*, at 6 months after planting, after application of 2 Mg ha^{-1} of dolomitic limestone in a Quartzarenic Neosol, in Água Clara, MS, Brazil, 2014.

Attribute	Average	Median	Value		Standart deviation	Coefficient			Test probability	
			Minimum	Maximum		Variation (%)	Kurtosis	Skewness	Pr<w	FD
HEI (m)	3.40	3.50	1.90	4.40	0.69	20.14	-0.60	-0.50	0.009	IN
N (g kg^{-1})	28.8	28.9	24.2	34.3	2.00	8.300	-0.33	0.21	0.750	NO
P (g kg^{-1})	1.70	1.80	1.20	2.50	0.27	15.60	0.27	0.29	0.310	NO
K (g kg^{-1})	9.80	10.0	6.00	14.0	1.73	17.50	-0.14	0.31	0.001	IN
Ca (g kg^{-1})	4.20	4.10	2.60	6.90	1.07	25.19	-0.20	0.53	0.105	NO
Mg (g kg^{-1})	2.60	2.50	1.40	4.70	0.78	29.31	0.25	0.84	0.006	IN
S (g kg^{-1})	1.40	1.50	1.30	1.80	0.14	9.440	-0.71	0.38	0.002	IN

Hei: plant height; N: leaf nitrogen; P: leaf phosphorous; K: leaf potassium; Ca: leaf calcium; Mg: leaf magnesium; S: Leaf sulfur; FD: frequency distribution, being NO and IN Respectively of the normal and indeterminate type.

Leite et al. (2011) studying the nutritional relations during a cycle of eucalyptus cultivation in different population densities verified that 64 % of the demand of calcium is required in the first two years. Being that in the first year 55.6% of the calcium is found in the leaves and in the following year, this value decreases to 11%. As the calcium is still in the phloem, after the dehiscence of the leaves, this nutrient stay stored in the litter (40 %), so the mineralization has great importance in the cycling and maintenance of the supply of the element for the culture.

According to Silveira et al. (2001) The amount of limestone applied must be based on the calcium content (Ca) present in the biomass, at the age of seven years, which normally ranges from 150 to 400 kg Ca ha^{-1}, in function of the genetic material and soil type. Thus, although the calcium content found in the leaf in the first year of age is low, the applied dose of dolomitic limestone in this experiment is enough for the development of the culture. Barros et al. (1985) Studied the effect of the application of three doses of dolomitic limestone to haul, in the furrow and in the planting pit of *Eucalypto urophylla* sp, was established that the best growth was obtained in the dose of 4 t ha-1 of limestone applied to the haul, the same was conducted in this experiment.

Table 3. Correlation matrix between the plant height and leaf content of *Eucalyptos urophylla*, at 6 months after planting, after application of 2 Mg ha^{-1} of dolomitic limestone in a Quartzarenic Neosol, in Água Clara, MS, Brazil, 2014.

	HEI	N	P	K	Ca	Mg
N	0.10	1.00	-	-	-	-
P	-0.02	**0.30***	1.00	-	-	-
K	0.13	0.01	0.14	1.00	-	-
Ca	-0.03	**0.29***	0.02	-0.06	1.00	-
Mg	**-0.33***	0.25	0.15	-0.14	**0.71****	1.00
S	0.07	**0.39****	**0.30***	**0.34***	**0.41****	0.24

HEI: plant height; N: leaf nitrogen; P: leaf phosphorus; K: leaf potassium; Ca: leaf calcium; Mg: leaf magnesium; S: leaf sulfur; * and ** Significant at 5 and 1%, respectively, by t Student's test.

The magnesium presented levels classified as low and medium, whose the adequate range is of 3.5 to 5.0 g kg^{-1} (Raij, 2011), which can also significantly affect the culture productivity, because besides being an enzymatic activator it presents structural function, taking part in the constitution of the chlorophyll and aiding several physiological vital processes to plants, such as photosynthesis (Epstein & Bloom, 2006).

Guimarães et al. (2015) studying the limitations to the initial growth of *E. saligna* in sandy soils was verified that the exchangeable magnesium content was one of the soil chemical attributes that presented greater correlation with the variables of plant growth, concluding that, when adjusting the contents of this variable to the requirements of the culture, the growth gains could be elevated. One of the few studies in forests with severe visual deficiency symptoms was carried out by Silveira (2012) and showed that magnesium deficiency can limit 10-20 % of final productivity. In relation to the nutrient demand, magnesium presents a similar behavior to calcium, with 56.1 % of the demand required in the first two years being the leaves the main source of the elements drain (82.9% in the first year and 20.6 % in the second year).

The observed levels of nitrogen in the leaves (24.2 to 34.3 g kg^{-1}) are above the values considered adequate for eucalyptus (13.5 to 18 g kg^{-1}) according to Raij (2011), however, within the appropriate ranges of 22 to 27 g kg^{-1} by Silveira et al. (2004). Silveira et al. (2004) reached the maximum productivity of *E. grandis*, two years old, with a content of 24.8 g kg-1 of nitrogen in the leaves, a similar value to that found in this work. Therefore, the elevation of this nutrient content may be contributing to the increase of eucalyptus growth.

The same was observed for the phosphorus in the experiment, whose contents are classified as medium to high (Table 2). The observed increase of N and P contents in the leaves should be related to the mineralization of the organic matter favored by liming (Rocha et al., 2008). It can be emphasized that the phosphorus contents should not have contributed to the variations observed in the height because besides the nutrient presents adequate levels in the leaves, the fertilizations conducted in the planting are enough for the great development of the culture.

The potassium presented levels classified as low to high (6 to 14 g kg^{-1}) according to Raij (2011). The high amplitude observed in the contents, together with the elevated speed of absorption of the nutrient by the plant and ionic competition by the same site of absorption with calcium and magnesium can lead to the induction of deficiency of these divalent nutrients and affect the height and consequently the productivity of wood (Epstein & Bloom, 2006).

By analyzing the K/Ca ratio in the diagnostic leaves, it is verified that the value found of 2.30 is above of the appropriate range (1.3 to 1.8 K/Ca) by Silveira et al. (1999). This can be explained due to potassium by having greater mobility and absorption in the plant (monovalent K+), the cover fertilization had been carried out at the same time of collecting of the diagnosis leaves and the source of the fertilizer had been the chloride that has high solubility when compared to Limestone (divalent Ca2+ and Mg2+). According to Prado (2014), the average leaf content of K provides an acceptable decrease of leaf Ca and Mg with satisfactory production. However, higher levels of K can lead to the decreased of leaf contents of Ca and Mg, in a way that should be avoided the fertilization management of potassium. While the increase in Mg concentration in the solution does not affect the absorption of K.

For Carvalho et al. (2010), the best suite instrument to demonstrate the estimative of the dependence between the samples is the autocorrelation analysis, being that the semivariogram is a function that translates the semivariance in function of the distances between sample points. Magnesium was the only attribute that presented significant correlation ($p < 0.01$) with eucalyptus height (Table 3) and produced semivariogram that adjusted to the theoretical models (Figure 3). The other attributes did not present a spatial dependence structure, characterizing is called as "*pure nugget effect*".

The spherical model was the one that best fit the semivariogram, with spatial dependence, R^2 0.75 and range of 17.8 m. The range is an important parameter in the study of the semivariogram because it represents the maximum distance in which there is a spatial correlation between the points of the same attribute (Mion et al., 2012; Matias et al., 2013). Low range values can negatively influence the quality of the estimates because some points are used to execute the interpolation in order to estimate values in unmeasured locations (Cruz et al., 2010).

It can be observed, by the kriging map, for the magnesium content in the leaf (Figure 4), that only 3.4% of the area is within the appropriate ranges (3.5 to 5.0 g kg^{-1}) by Raij (2011). In this way, the localized management helps to avoid the application of overestimated doses in certain areas and insufficient in others that can lead to a differentiated state of nutrition in the plants, increasing the variation in the production, considering the relation between the nutrient content in the vegetal tissue and the plant growth and development.

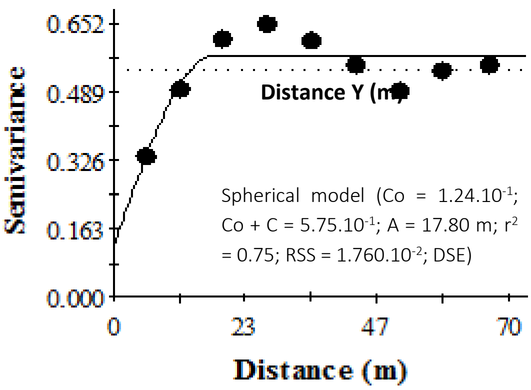

Figure 3. Semivariogram for leaf Magnesium in *Eucalyptus urophylla.*

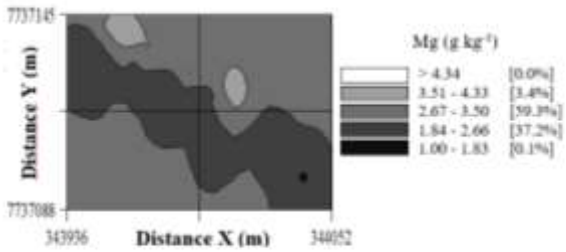

Figure 4. Kriging map for leaf magnesium in *Eucalyptus urophylla*.

For being a recent planting and liming conducted to haul, is expected that in the following years, with the development of the root system and the decline of the limestone in the soil profile, eucalyptus may present better relations between the soil nutrient availability and its growth, Since this fact is more observed in the early stages of tree development (Silveira et al., 2004).

4. CONCLUSION

The liming influenced the leaf nitrogen, phosphorus, calcium and magnesium contents of *Eucalyptus urophylla* clone I 144 and the leaf magnesium was the only attribute that presented spatial dependence, which allows the management located in the initial stage.

5. ACKNOWLEDGEMENTS

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