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Sampling grids used to characterise the spatial variability of pH, Ca, Mg and V% in Oxisols[1]

Malhas amostrais utilizadas na caracterização da variabilidade espacial de pH, Ca, Mg e V% em Latossolos

Maurício Roberto Cherubin[2]*, Antônio Luis Santi[3], Mateus Tonini Eitelwein[4], Clovis Orlando Da Ros[3] e Mateus Bortoluzi Bisognin[5]

ABSTRACT - Knowledge of spatial variability is an important factor to be considered in planning a program of soil sampling and crop management under precision agriculture (PA). In this context, the aim of this work was to evaluate the efficiency of the dimensions of sampling grids used in the state of Rio Grande do Sul (RS), Brazil to characterise the spatial variability of the attributes pH_{water}, base saturation (V%), calcium (Ca) and magnesium (Mg) levels. The study was carried out on 30 agricultural sites located in the northern region of RS, having soils classified as Oxisols and managed using the tools of PA. The dimensions of the grids under study were: 100 x 100 m (10 areas), 142 x 142 m (10 areas) and 173 x 173 m (10 areas). Soil was collected at a depth of 0.00 to 0.10 m. The data for pH_{water}, V%, Ca and Mg were subjected to exploratory statistical analysis and to geostatistical analysis by means of semivariograms. The areas showed high Ca (>4.0 $cmol_c\ dm^{-3}$) and Mg (>1.0 $cmol_c\ dm^{-3}$) levels and localised problems of soil acidity (pH_{water} <5.5 or V<65%), justifying the carrying out of liming at specific sites. For the geostatistical procedures, the sample grids used at the sites of the Oxisols managed under PA in RS are not efficient in capturing the scales of spatial variability of the attributes pH_{water}, V%, Ca and Mg, which could compromise the accuracy of corrective prescriptions for specific sites.

Key words: Soil acidity. Precision Agriculture. Soil sampling. Geostatistics.

RESUMO - O conhecimento da variabilidade espacial é um importante fator a ser considerado no planejamento de um programa de amostragem de solo e manejo das culturas na agricultura de precisão (AP). Nesse contexto, o objetivo do trabalho foi avaliar a eficiência das dimensões das malhas amostrais utilizadas no Rio Grande do Sul (RS) na caracterização da variabilidade espacial dos atributos $pH_{água}$, saturação por bases (V%), teores de cálcio (Ca) e magnésio (Mg). O estudo foi realizado em 30 áreas agrícolas localizadas na região Norte do RS que apresentam solos classificados como Latossolos Vermelhos e que são manejadas com ferramentas de AP. As dimensões das malhas amostrais estudadas foram: 100 x 100 m (10 áreas), 142 x 142 m (10 áreas) e 173 x 173 m (10 áreas). A profundidade de coleta de solo foi de 0,00-0,10 m. Os dados de $pH_{água}$, V%, Ca e Mg foram submetidos à análise estatística exploratória e à análise geoestatística por meio de semivariogramas. As áreas apresentaram elevados teores de Ca (> 4,0 $cmol_c\ dm^{-3}$) e Mg (> 1,0 $cmol_c\ dm^{-3}$) e problemas localizados de acidez ($pH_{água}$ < 5,5 ou V < 65%), justificando a realização de calagem em sítios específicos. Considerando os procedimentos geoestatísticos, as malhas amostrais utilizadas nas áreas de Latossolos Vermelhos manejados com AP no RS não são eficientes para captar as escalas da variabilidade espacial dos atributos de $pH_{água}$, V%, teores de Ca e Mg, podendo comprometer a acurácia das prescrições de corretivos em sítios específicos.

Palavras-chave: Acidez do solo. Agricultura de precisão. Amostragem de solo. Geoestatística.

*Autor para correspondência
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[2]Programa de Pós-Graduação em Solos e Nutrição de Plantas, Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo-ESALQ/USP, Piracicaba-SP, Brasil, cherubin@usp.br
[3]Departamento de Ciências Agronômicas e Ambientais, Centro de Educação Superior Norte do Rio Grande do Sul, Universidade Federal de Santa Maria, Frederico Westphalen-RS, Brasil, santi_pratica@yahoo.com.br, clovisdaros@smail.ufsm.br
[4]Programa de Pós-Graduação em Engenharia de Sistemas Agrícolas, ESALQ/USP, Piracicaba-SP, Brasil, mateus_eitelwein@outlook.com
[5]Graduando em Agronomia, Centro de Educação Superior Norte do Rio Grande do Sul, Universidade Federal de Santa Maria, Frederico Westphalen-RS, Brasil, mateusbisognin@hotmail.com

INTRODUCTION

Oxisols are widely distributed across almost all regions of Brazil, and make up the predominant taxonomic class, occupying 31.61% of the surface of the country (2.69 million km^2) (ANJOS *et al*., 2012). In the state of Rio Grande do Sul (RS), Oxisols occur mainly in the north, a region located in the geomorphic province of the Plateau, formed by a succession of volcanic flows, followed by cooling on the surface of the earth's crust and the formation of predominantly basaltic rocks (STRECK *et al*., 2008).

These are weathered, deep, well-drained and acidic soils and display high homogeneity in the profile (ANJOS *et al*., 2012; MONTANARI *et al*., 2008; STRECK *et al*., 2008). However, despite being considered homogeneous soils, they may comprise variations in their characteristics over both short and long distances.

Variability of the soil is a result of the interaction of complex pedogenic processes controlled by factors in its formation such as climate, topography, source material and vegetation, and intensified by land-use and management practices (MALLARINO; WITTRY, 2004). Understanding spatial variability in the soil is therefore a factor that should be considered when planning a program of soil sampling and of crop management (KERRY; OLIVER; FROGBROOK, 2010; MALLARINO; WITTRY, 2004; MONTANARI *et al*., 2008; MONTANARI *et al*., 2012; NANNI *et al*., 2011; SOUZA *et al*., 2004; STEPIEN; GOZDOWSKI; SAMBORSKI, 2013).

With the advent of precision agriculture (PA) in Brazil and especially in the South region, where only in RS state, it is estimated that approximately two million hectares are managed using tools of PA (SANTI *et al*., 2009), knowledge of the spatial variability of the soil was made possible through systematic sampling by means of regular grids. However, although the use of sampling grids is officially recommended in the South of Brazil (COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO, 2004), there are still doubts as to the ideal size which would allow capture of the spatial variability of the chemical properties of the soil.

Currently, the sampling grids that are commonly adopted on Brazilian farms have dimensions ranging from 100 to 225 m (NANNI *et al*., 2011). In the South region, samples are collected at somewhat smaller distances, from 100 to175 m. However, the definition of such dimensions for the grids is primarily based on economic and practical reasons and sometimes neglects the geostatistical principles of spatial dependence (VIEIRA, 2000; WEBSTER; OLIVER, 2007).

The influence that the dimensions of the grids used in collecting soil samples have on the accuracy of the generated information is widely discussed in international literature. Studies involve the use of the principles and tools of geostatistics to direct the sampling of soils (KERRY; OLIVER; FROGBROOK, 2010; WEBSTER; LARK, 2012), the influence of the size of the sampling grid on the quality of data interpolation (KRAVCHENKO 2003; FRANZEN, 2011), the reproducibility of the spatial variability (CHANG *et al*., 1999; STEPIEN; GOZDOWSKI; SAMBORSKI, 2013) and the management of nutrients at specific sites (MALLARINO; WITTRY, 2004; STEPIEN; GOZDOWSKI; SAMBORSKI, 2013). However, there are few studies on the conditions of Brazilian soils (MONTANARI *et al*., 2012; NANNI *et al*., 2011) and none for conditions in the South of Brazil.

In this context, the aim of this work was to evaluate the efficiency of the dimensions of sampling grids used in RS in characterising the spatial variability of the attributes pH_{water} and V% and Ca and Mg levels in Oxisols under PA.

MATERIAL AND METHODS

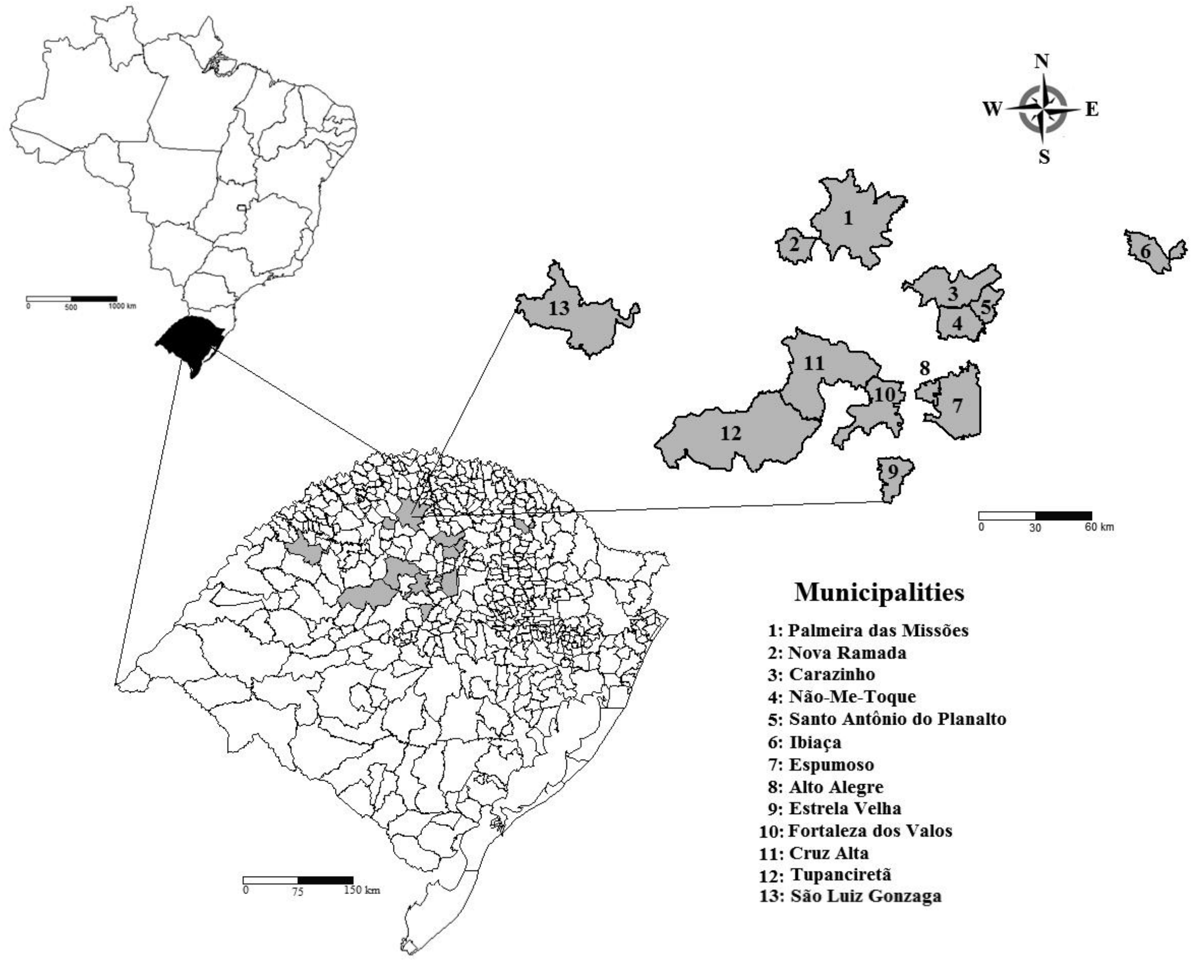
The study was carried out in 30 agricultural areas located in 13 municipalities in the north of Rio Grande do Sul, Brazil (Figure 1), covering 2,467.82 ha. The study area is located in the geomorphic province of the Plateau , and extends to the physiographic regions of the *Alto Uruguai*, *Planalto Médio* and *Missões*. The terrain is gently undulating with the predominant soils classified as Oxisols (*Latossolos Vermelhos* by Brazilian Classification Soil System), having high aluminum and iron levels associated with a low base saturation (alumino ferric, dystroferric or dystrophic) and clayey texture (STRECK *et al*., 2008).

The management system that has been adopted in the area is direct planting (no-tillage), rotating soybean and maize crops in the summer and white oats, black oat and forage turnip in the winter. Fertilization is carried out in the sowing furrow for each crop, and liming over the total area every five years or so.

The areas were sampled from the dimensions of the grids that are commonly used at field level in the south of Brazil, these being: 100 x 100 m (one sample for each ha); 142 x 142 m (one sample for every two ha); and 173 x 173 m (one sample for every three ha). Thus, for each grid 10 areas were studied, giving a total of 1,461 soil samples. The areas being analysed were sampled for the first time by georeferencing, so they did not suffer the effects of previous variable-rate applications of lime and fertilizer.

Each soil sample was composed of 10 subsamples collected within 10 m of the georeferenced point using a automatic screw auger. The collection depth was from 0.00 to 0.10 m, as recommended by the Commission for Chemistry and Soil Fertility

Figure 1 - Location of the study area, highlighting the 13 municipalities where are located the 30 agricultural areas of Oxisols, managed under precision farming



(COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO, 2004) for agricultural areas under consolidated no-tillage systems. The samples were later forwarded to the laboratory where basic chemical analyses were conducted following methodologies recommended by the Commission for Chemistry and Soil Fertility (2004). The following attributes were evaluated in the study: active acidity (pH_{water}, 1:1), base saturation (V%) and the cations related to acidity: calcium (Ca, $cmol_c$ dm^{-3}) and magnesium (Mg, $cmol_c$ dm^{-3}).

Data were subjected to descriptive statistical analysis using the Statistical Analysis System - SAS 8.0 software (SAS Inc, Cary, USA), with the aim of verifying position and dispersion of the data. The statistical parameters determined were; minimum; mean; maximum; standard deviation and coefficients of variation (CV%), precision (CP%), skewness (Cs) and kurtosis (Ck). Based on the CV values obtained, the dispersion of the data was classified as low (CV < 15%), moderate (CV 15-35%) and high (CV > 35%) (WILDING; DREES, 1983). In addition, the existence of a central tendency (normality) in the original data was noted using the W-test ($p<0.05$).

Analysis of the spatial variability of the pH_{water} data, V%, Ca and Mg, was carried out by semivariogram, adjusted by theoretical mathematical models using the Gamma Design Software - GS+. The models for the semivariogram were adjusted based on the best coefficient of determination (r^2) and lowest residual sum of squares (RSS), and were evaluated using cross validation. The parameters of the semivariogram were defined from the adjustment of a mathematical model to the data: nugget effect (C_0), contribution (C_1), sill (C_0 + C1) and range (a). The spatial dependence index (SDI) was calculated using the relationship shown in Equation 1.

$$C_0/(C_0+C_1)*100 \qquad (1)$$

The degree of spatial dependence (DSD), based on the SDI, was classified as strong for SDI ≤ 25%; moderate for an SDI between 25 and 75%, and weak for SDI> 75% (CAMBARDELLA *et al*. 1994).

RESULTS AND DISCUSSION

Exploratory statistical analysis of the attributes for $pH_{água}$ and V% (Table 1) made it possible to verify that 27 areas studied (90.0%) present places with problems of soil acidity, pH <5.5 or V <65.0%, which can restrict normal plant development under no-tillage system (COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO, 2004). This finding is related to the natural acidity characteristic of soils that have undergone intense weathering, and associated with processes of soil acidification triggered by the management practice adopted (ANJOS *et al*., 2012; STRECK *et al*., 2008). In agricultural areas, soil acidity is enhanced by absorption of the base cations by crops and their subsequent export at harvest, by inadequate soil management favouring the erosion and exposure of (more acidic) subsurface horizons, by the use of nitrogen fertilizers and by the oxidation of sulphur and organic matter (SOUZA; MIRANDA; OLIVEIRA, 2007).

The use of smaller sampling grids, allowing for an increase in the number of sampling points, resulted in improvements in the representativeness and accuracy of soil sampling conducted in the study areas (<% CP). However, irrespective of the grid dimensions, it was possible to identify, based on the minimum and maximum values for $pH_{água}$ and V%, a considerable amplitude relative to the mean, demonstrating that the use of georeferenced soil sampling, as recommended under PA, was characterised as an important strategy in identifying places where soil acidity may become a limiting factor. Thus, PA allows an increase in the technical and economic efficiency of the use of limestone, based on interventions located at a specific site.

It was found that for dispersion of the data, based on the coefficient of variation (CV%), the values for pH_{water} showed low dispersion (CV: <15%), with an amplitude of from 2.06 to 7.76%. Whereas the values for %V ranged from 3.92 to 25.18%, classifying the dispersion as from low to moderate (CV: <35%). These results agree with several studies made into Oxisols (BOTTEGA *et al*., 2013; CHERUBIN *et al*., 2011; DALCHIAVON *et al*., 2012; LIMA; SILVA; SILVA, 2013; MONTANARI *et al*., 2008; SANTI *et al*., 2012; SOUZA *et al*., 2004). However, the low CVs seen for the values of pH_{water} are due to its logarithmic scale of expression, requiring caution in comparison with other variables (SOUZA; MIRANDA; OLIVEIRA, 2007).

Although the data for pH_{water} and V% displayed low and moderate dispersion, 56.66 and 26.66% of the areas studied did not follow normal frequency distributions, being confirmed by coefficients of skewness, offset to the left (Cs <0) or to the right (Cs> 0), and by coefficients of kurtosis with platykurtic (Ck <0) and leptokurtic (Ck> 0) distributions. Results like these, that indicate a lack of normality in the data, were also seen in areas of Oxisols by Cavalcante *et al*. (2007), Cherubin *et al*. (2011), Dalchiavon *et al*. (2012) and Montanari *et al*. (2008). However, it is important to note that normality of the data is not a requirement of geostatistics; but the presence of a skewed distribution having many anomalous values should be considered, since kriging is a linear estimator (WEBSTER; OLIVER, 2007). In geostatistics, more important than the normality of the data is whether or not the so-called proportional effect occurs, in which the mean and variance of the data may not be constant, nor be a function of spatial positioning in the study area (CAVALCANTE *et al*., 2007).

For the Ca and Mg cations (Table 2), it was found that the Oxisols studied display on average levels considered as high for both of these macronutrients (Ca > 4.0 $cmol_c\ dm^{-3}$ and Mg > 1.0 $cmol_c\ dm^{-3}$) (COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO, 2004).

In studies conducted by Amado *et al*. (2009), Cherubin *et al*. (2011) and Santi *et al*. (2012) into Oxisol in RS, high levels of Ca and Mg were also found, agreeing with the results of the present work. These high levels are due to the weathering of minerals rich in these elements, such as plagioclase, pyroxene and olivine, in the makeup of the basalt rocks which are the predominant source material of the Oxisol occurring in the study region (STRECK *et al*., 2008). Furthermore, the addition of dolomitic limestone over the years, associated with the low mobility of the Ca and Mg in the soil, may also have significantly contributed to the maintenance and rise in levels of these macronutrients.

Dispersion of the Ca and Mg data was classified as low to moderate, with CV amplitudes that ranged from 11.94 to 34.08% and from 14.86 to 35.00% respectively, agreeing with Amado *et al*. (2009), Bottega *et al*. (2013), Cavalcanti *et al*. (2007), Cherubin *et al*. (2011), Lima, Silva and Silva (2013), Santi *et al*. (2012) and Souza *et al*. (2004). Normal frequency distributions for Ca and Mg were observed in 66.66 and 50.00% of the areas respectively. However, in areas with non-normal distribution, the data showed no discrepant values that could limit the use of geostatistics.

Table 1 - Descriptive statistics of the attributes for pH_{water} and base saturation (V%) in Oxisols areas sampled with different dimensions of sampling grid

Area	Sampling Grid (m)	Statistic Parameters[1]									
		n	Values			SD	Coefficients				W-test[2]
			Minimum	Mean	Maximum		CV	CP	Cs	Ck	
pHwater											
1	100 x 100	89	4.80	5.27	6.30	0.30	5.71	0.61	0.82	0.68	0.93*
2	100 x 100	28	6.00	6.42	6.70	0.18	2.81	0.53	-0.49	-0.06	0.93^{ns}
3	100 x 100	33	5.20	5.56	6.30	0.22	3.99	0.69	1.21	2.85	0.88*
4	100 x 100	40	5.50	6.18	6.60	0.28	4.50	0.71	-0.27	-0.70	0.94*
5	100 x 100	49	5.60	5.94	6.20	0.15	2.52	0.36	0.22	-0.48	0.92*
6	100 x 100	57	6.00	6.42	7.00	0.50	7.76	1.03	0.33	-1.96	0.63*
7	100 x 100	65	4.60	5.50	6.20	0.39	7.07	0.88	-0.35	-0.60	0.97^{ns}
8	100 x 100	47	4.40	4.83	5.40	0.20	4.13	0.60	0.39	0.66	0.96^{ns}
9	100 x 100	46	4.90	5.80	6.90	0.33	5.72	0.84	0.53	2.50	0.94*
10	100 x 100	41	4.90	5.24	5.60	0.21	3.98	0.62	0.20	-1.05	0.94*
1	142 x 142	45	5.50	5.67	5.90	0.11	2.06	0.31	0.23	-0.60	0.91*
2	142 x 142	75	5.50	5.98	6.20	0.15	2.59	0.30	-1.01	1.07	0.89*
3	142 x 142	45	5.10	5.51	5.80	0.14	2.58	0.38	-0.59	0.96	0.93*
4	142 x 142	43	5.20	5.50	5.70	0.12	2.28	0.35	-0.21	-0.39	0.93*
5	142 x 142	59	5.20	5.56	5.90	0.18	3.29	0.43	-0.07	-0.67	0.96^{ns}
6	142 x 142	73	4.80	5.34	5.70	0.18	3.43	0.40	-0.18	0.61	0.95*
7	142 x 142	60	5.00	5.45	5.80	0.14	2.63	0.34	-0.63	2.18	0.91*
8	142 x 142	62	5.00	5.68	6.30	0.23	4.08	0.52	-0.42	1.02	0.96*
9	142 x 142	83	4.80	5.40	6.20	0.26	4.88	0.54	0.15	-0.08	0.98^{ns}
10	142 x 142	91	4.90	5.37	5.80	0.21	3.96	0.42	0.27	-0.52	0.96*
1	173 x 173	34	4.70	5.53	6.20	0.39	6.97	1.20	0.01	-0.38	0.96^{ns}
2	173 x 173	36	4.80	5.36	5.80	0.22	4.11	0.69	0.05	0.15	0.93*
3	173 x 173	51	4.40	5.51	6.20	0.41	7.52	1.05	-0.62	0.37	0.96^{ns}
4	173 x 173	33	4.60	5.48	6.50	0.41	7.45	1.30	0.61	0.69	0.96^{ns}
5	173 x 173	27	5.00	5.54	6.30	0.31	5.56	1.07	0.39	-0.30	0.94^{ns}
6	173 x 173	20	5.00	5.34	5.60	0.14	2.61	0.58	-0.42	0.61	0.94^{ns}
7	173 x 173	24	5.00	5.52	6.00	0.27	4.92	1.00	0.14	-0.53	0.97^{ns}
8	173 x 173	31	4.90	5.57	6.00	0.26	4.62	0.83	-0.36	0.14	0.97^{ns}
9	173 x 173	40	4.70	5.31	6.40	0.29	5.47	0.86	1.02	4.12	0.90*
10	173 x 173	34	4.80	5.54	6.10	0.36	6.50	1.11	0.36	-0.57	0.95^{ns}
Base saturation (V%)											
1	100 x 100	89	29.00	57.18	88.00	11.05	19.33	2.05	0.28	-0.14	0.99^{ns}
2	100 x 100	28	76.00	85.12	89.50	3.34	3.92	0.74	-0.94	0.90	0.93^{ns}
3	100 x 100	33	56.90	66.96	84.80	6.57	9.81	1.71	0.54	0.14	0.97^{ns}
4	100 x 100	40	74.30	81.84	87.80	3.95	4.83	0.76	-0.24	-1.25	0.93*
5	100 x 100	49	66.60	74.31	83.50	4.18	5.62	0.80	0.17	-0.58	0.98^{ns}
6	100 x 100	57	60.00	81.28	91.00	6.82	8.39	1.11	-0.93	0.61	0.93*
7	100 x 100	65	31.60	67.24	87.20	12.21	18.16	2.25	-0.93	0.72	0.94*
8	100 x 100	47	38.10	53.45	66.10	5.91	11.06	1.61	-0.25	-0.23	0.99^{ns}
9	100 x 100	46	29.50	61.11	79.90	9.71	15.89	2.34	-0.67	1.90	0.95^{ns}
10	100 x 100	41	43.20	54.29	70.40	7.31	13.46	2.10	0.22	-0.69	0.96^{ns}

Table 1 continued

1	142 x 142	45	43.00	56.56	69.00	6.36	11.25	1.68	-0.28	-0.58	0.97^{ns}
2	142 x 142	75	45.00	75.12	88.00	6.12	8.15	0.94	-1.65	7.14	0.89*
3	142 x 142	45	35.00	56.80	68.00	8.48	14.94	2.23	-0.72	-0.16	0.93*
4	142 x 142	43	41.00	57.37	69.00	5.36	9.35	1.43	-0.85	1.53	0.95^{ns}
5	142 x 142	59	35.00	58.29	81.00	10.59	18.17	2.37	0.00	-0.39	0.98^{ns}
6	142 x 142	73	42.00	62.04	77.00	6.39	10.30	1.21	-0.19	1.11	0.97^{ns}
7	142 x 142	60	50.00	61.70	73.00	5.28	8.56	1.11	-0.07	-0.19	0.97^{ns}
8	142 x 142	62	61.00	72.03	89.00	5.28	7.32	0.93	0.64	1.45	0.96^{ns}
9	142 x 142	83	38.00	62.49	84.00	10.88	17.41	1.91	-0.31	-0.51	0.98^{ns}
10	142 x 142	91	44.00	59.37	74.00	7.08	11.93	1.25	-0.10	-0.60	0.98^{ns}
1	173 x 173	34	21.70	56.04	77.90	14.11	25.18	4.32	-0.73	0.33	0.95^{ns}
2	173 x 173	36	36.90	59.49	75.40	8.67	14.58	2.43	-0.18	0.27	0.98^{ns}
3	173 x 173	51	16.70	63.47	85.30	14.47	22.79	3.19	-1.32	2.24	0.90*
4	173 x 173	33	35.10	62.71	80.30	10.33	16.48	2.87	-0.56	0.28	0.97^{ns}
5	173 x 173	27	47.30	63.53	83.30	9.54	15.01	2.89	-0.10	-0.74	0.96^{ns}
6	173 x 173	20	37.00	53.80	67.00	9.04	16.81	3.76	-0.31	-0.95	0.95^{ns}
7	173 x 173	24	28.90	57.09	71.80	8.90	15.59	3.18	-1.19	3.23	0.92*
8	173 x 173	31	44.00	61.48	71.70	7.00	11.39	2.05	-0.51	-0.25	0.96^{ns}
9	173 x 173	40	25.80	51.60	77.30	10.17	19.71	3.12	-0.16	0.65	0.99^{ns}
10	173 x 173	34	39.20	64.23	87.80	11.34	17.65	3.03	-0.65	0.19	0.93*

[1]n: number of observations (sampling points); SD: standard deviation; CV(%): coeficient of variation; CP (%): coefficient of precision; Cs: coefficient of skewness; Ck: coefficient of kurtosis; [2]W-test: Shapiro-Wilk test for normal distribution, where: (*) significant at levels of $p<0.05$ and (ns) not significant. When significant, indicates that the normal distribution hypothesis is rejected

Table 2 - Descriptive statistics for the calcium (Ca - $cmol_c\ dm^{-3}$) and magnesium (Mg - $cmol_c\ dm^{-3}$) levels in Oxisols areas sampled with different dimensions of sampling grid

Área	Sampling Grid (m)	Statistic Parameters[1]									
		n	Values			SD	Coefficients				W-test[2]
			Minimum	Mean	Maximum		CV	CP	Cs	Ck	
------ Calcium ------											
1	100 x 100	89	2.70	5.26	9.90	1.15	21.82	2.31	1.01	2.40	0.95*
2	100 x 100	28	5.30	9.07	10.80	1.24	13.71	2.59	-1.34	1.95	0.89*
3	100 x 100	33	6.10	7.62	10.20	0.83	10.88	1.89	0.75	1.59	0.96^{ns}
4	100 x 100	40	5.50	7.94	10.00	1.15	14.46	2.29	0.29	-0.66	0.94*
5	100 x 100	49	4.50	6.91	11.30	1.07	15.50	2.21	1.40	5.12	0.91*
6	100 x 100	57	4.50	7.88	13.50	1.77	22.48	2.98	0.99	1.99	0.93*
7	100 x 100	65	3.60	6.76	10.20	1.20	17.82	2.21	-0.04	1.33	0.97^{ns}
8	100 x 100	47	4.90	6.45	8.30	0.77	11.94	1.74	0.29	-0.10	0.98^{ns}
9	100 x 100	46	1.70	3.34	5.30	0.81	24.31	3.58	0.52	0.17	0.97^{ns}
10	100 x 100	41	2.60	5.11	7.30	0.90	17.53	2.74	0.08	1.23	0.97^{ns}

Table 2 continued

1	142 x 142	45	2.00	3.50	5.40	0.73	20.80	3.10	0.65	0.79	0.95ns
2	142 x 142	75	2.10	5.59	10.50	1.35	24.16	2.79	0.51	1.69	0.98ns
3	142 x 142	45	2.50	5.02	6.70	0.93	18.49	2.76	-0.20	-0.34	0.97ns
4	142 x 142	43	2.70	4.89	6.40	0.72	14.66	2.24	-0.63	0.98	0.97ns
5	142 x 142	59	2.60	4.34	6.90	1.12	25.85	3.37	0.68	-0.19	0.94*
6	142 x 142	73	3.90	5.79	7.60	0.70	12.17	1.42	-0.32	0.86	0.97ns
7	142 x 142	60	3.90	5.99	7.80	0.85	14.24	1.84	-0.23	-0.32	0.99ns
8	142 x 142	62	5.40	6.89	9.40	1.00	14.52	1.84	0.67	-0.01	0.95*
9	142 x 142	83	3.10	5.30	7.50	0.96	18.07	1.98	-0.22	-0.16	0.98ns
10	142 x 142	91	4.10	5.72	8.00	0.84	14.70	1.54	0.54	-0.16	0.97ns
1	173 x 173	34	1.80	4.60	6.90	1.19	25.89	4.44	-0.02	-0.04	0.98ns
2	173 x 173	36	3.00	5.00	7.00	0.83	16.67	2.78	-0.05	0.71	0.98ns
3	173 x 173	51	2.40	6.38	13.30	2.01	31.45	4.40	1.01	2.62	0.94*
4	173 x 173	33	3.80	5.97	9.30	1.35	22.55	3.93	0.75	0.75	0.95ns
5	173 x 173	27	3.70	5.62	9.20	1.28	22.81	4.39	0.69	0.85	0.96ns
6	173 x 173	20	2.50	4.60	6.20	1.23	26.73	5.98	-0.54	-1.10	0.90*
7	173 x 173	24	2.70	4.22	5.40	0.69	16.35	3.34	-0.31	-0.54	0.96ns
8	173 x 173	31	3.60	4.83	6.20	0.70	14.53	2.61	0.07	-0.57	0.97ns
9	173 x 173	40	2.50	4.06	6.00	0.81	20.01	3.16	0.38	0.30	0.96ns
10	173 x 173	34	3.50	6.66	17.60	2.47	34.08	5.84	2.64	11.21	0.77*
------------------------------ Magnesium ------------------------------											
1	100 x 100	89	0.90	2.26	6.00	0.72	31.70	3.36	1.93	7.41	0.86*
2	100 x 100	28	1.50	3.01	3.60	0.50	16.54	3.13	-1.56	2.43	0.84*
3	100 x 100	33	2.40	3.16	4.90	0.49	15.54	2.71	1.31	3.57	0.91*
4	100 x 100	40	2.20	3.46	4.60	0.61	17.66	2.79	-0.01	-0.41	0.96ns
5	100 x 100	49	1.60	2.40	3.70	0.36	14.97	2.14	0.92	2.80	0.94*
6	100 x 100	57	1.60	3.30	4.80	0.63	18.98	2.51	0.24	0.18	0.97ns
7	100 x 100	65	1.00	2.24	3.40	0.53	23.63	2.93	-0.12	-0.16	0.98ns
8	100 x 100	47	1.20	2.12	3.30	0.40	18.91	2.76	0.50	0.82	0.96ns
9	100 x 100	46	0.70	1.55	2.90	0.49	31.71	4.68	0.97	0.87	0.92*
10	100 x 100	41	1.30	2.02	3.00	0.43	21.10	3.30	0.95	0.19	0.89*
1	142 x 142	45	0.90	1.52	2.60	0.36	23.74	3.54	1.19	1.71	0.91*
2	142 x 142	75	1.00	2.68	5.00	0.64	24.01	2.77	0.58	1.75	0.96*
3	142 x 142	45	0.80	1.99	3.20	0.52	26.16	3.90	0.33	0.06	0.97ns
4	142 x 142	43	0.60	1.59	2.30	0.32	20.29	3.09	-0.40	1.36	0.95ns
5	142 x 142	59	1.00	1.86	3.90	0.58	31.13	4.05	1.25	1.74	0.90*
6	142 x 142	73	1.70	2.69	5.90	0.75	27.98	3.27	2.92	9.60	0.65*
7	142 x 142	60	1.50	2.29	3.80	0.41	17.77	2.29	0.81	2.04	0.96*
8	142 x 142	62	1.70	2.81	3.80	0.46	16.19	2.06	-0.08	-0.32	0.99ns
9	142 x 142	83	1.20	2.13	3.20	0.48	22.50	2.47	-0.05	-0.55	0.98ns
10	142 x 142	91	1.30	2.42	3.80	0.47	19.38	2.03	0.23	0.05	0.99ns

Table 2 continued

1	173 x 173	34	1.00	2.38	3.50	0.61	25.78	4.42	-0.12	-0.07	0.97^{ns}
2	173 x 173	36	1.10	2.05	3.40	0.47	22.87	3.81	0.93	1.66	0.91*
3	173 x 173	51	1.10	2.98	5.70	0.90	30.21	4.23	0.69	1.53	0.95*
4	173 x 173	33	1.60	2.82	5.40	0.78	27.75	4.83	1.38	2.61	0.90*
5	173 x 173	27	1.30	2.96	4.70	0.85	28.76	5.53	0.25	-0.33	0.98^{ns}
6	173 x 173	20	0.90	1.76	2.50	0.53	30.03	6.71	-0.16	-1.51	0.91^{ns}
7	173 x 173	24	1.00	1.91	2.70	0.41	21.68	4.43	0.08	-0.01	0.98^{ns}
8	173 x 173	31	1.60	2.11	2.80	0.31	14.86	2.67	0.08	-0.86	0.95^{ns}
9	173 x 173	40	0.80	1.56	2.40	0.36	23.12	3.66	0.15	-0.23	0.98^{ns}
10	173 x 173	34	1.60	3.01	7.00	1.17	35.00	6.00	1.49	2.88	0.88*

[(1)] n: number of observations (sampling points); SD: standard deviation; CV(%): coeficient of variation; CP (%): coefficient of precision; Cs: coefficient of skewness; Ck: coefficient of kurtosis; [(2)]W-test: Shapiro-Wilk test for normal distribution, where: (*) significant at levels of $p<0.05$ and (ns) not significant. When significant, indicates that the normal distribution hypothesis is rejected

The spatial variability of the attributes pH_{water} and V%, and of the bases Ca and Mg, was analysed from the results of the geostatistical analysis (Tables 3 and 4). In the four attributes studied, a large difference in the structure of spatial variability was seen for the areas under study, even when the samples were collected with the same dimensions of sampling grid. This variation can be evidenced by the amplitude observed for the radius of spatial dependence between samples (ranges). For all the grids under study, areas were noted where the values for pH_{water}, V%, Ca and Mg showed no spatial dependence, featuring random distributions (pure nugget effect), and where geostatistics therefore could not be applied (VIEIRA, 2000). Note that there is a trend towards an increase in the occurrence of random distributions as the size of the sampling grid increases, confirming assumptions of Cambardella *et al*. (1994), Vieira (2000) and Webster and Oliver (2007), in which the sampling grid used does not have enough points to detect the dependence, if any, which will be expressed at distances which are smaller than the smallest spacing between samples.

Table 3 - Geostatistical analysis of the attributes for pH_{water} and base saturation (V%) in Oxisols areas sampled with different dimensions of sampling grid

Area	Sampling Grid (m)	n	Nugget Effect	Sill	Contribution	Range	Model	r^2	Spatial Dependence	
									SDI[(1)]	DSD[(2)]
	------------------------- $pH_{água}$ -------------------------									
1	100 x 100	89	PNE[(3)]	PNE	PNE	PNE	-	-	-	-
2	100 x 100	28	0.00	0.06	0.05	636.00	Linear	0.98	8.10	Strong
3	100 x 100	33	0.04	0.05	0.01	422.80	Linear	0.30	78.00	Weak
4	100 x 100	40	0.05	0.11	0.06	1295.00	Spherical	0.74	45.45	Moderate
5	100 x 100	49	PNE	PNE	PNE	PNE	-	-	-	-
6	100 x 100	57	PNE	PNE	PNE	PNE	-	-	-	-
7	100 x 100	65	0.00	0.17	0.17	397.00	Spherical	0.98	1.49	Strong
8	100 x 100	47	0.00	0.04	0.04	246.00	Exponential	0.69	2.50	Strong
9	100 x 100	46	0.04	0.12	0.08	384.00	Exponential	0.77	33.33	Moderate
10	100 x 100	41	0.01	0.04	0.03	442.00	Spherical	0.99	22.32	Strong

Table 3 continued

1	142 x 142	45	0.01	0.03	0.02	2110.00	Spherical	0.72	25.93	Moderate
2	142 x 142	75	0.01	0.04	0.03	2053.00	Spherical	0.81	30.95	Moderate
3	142 x 142	45	0.01	0.03	0.02	2238.00	Spherical	0.67	49.33	Moderate
4	142 x 142	43	0.00	0.02	0.02	319.00	Spherical	0.81	0.06	Strong
5	142 x 142	59	0.02	0.05	0.03	1938.00	Spherical	0.90	38.60	Moderate
6	142 x 142	73	PNE	PNE	PNE	PNE	-	-	-	-
7	142 x 142	60	0.00	0.02	0.02	408.00	Exponential	0.89	20.00	Strong
8	142 x 142	62	PNE	PNE	PNE	PNE	-	-	-	-
9	142 x 142	83	0.00	0.07	0.07	364.00	Spherical	0.83	0.14	Strong
10	142 x 142	91	PNE	PNE	PNE	PNE	-	-	-	-
1	173 x 173	34	PNE	PNE	PNE	PNE	-	-	-	-
2	173 x 173	36	0.01	0.05	0.04	477.00	Exponential	0.76	20.00	Strong
3	173 x 173	51	PNE	PNE	PNE	PNE	-	-	-	-
4	173 x 173	33	0.05	0.39	0.34	2321.00	Spherical	0.87	12.44	Strong
5	173 x 173	27	PNE	PNE	PNE	PNE	-	-	-	-
6	173 x 173	20	PNE	PNE	PNE	PNE	-	-	-	-
7	173 x 173	24	0.00	0.07	0.07	421.00	Spherical	0.82	0.14	Strong
8	173 x 173	31	PNE	PNE	PNE	PNE	-	-	-	-
9	173 x 173	40	0.06	0.13	0.07	2110.00	Spherical	0.45	46.88	Moderate
10	173 x 173	34	0.00	0.14	0.14	475.00	Spherical	0.82	0.07	Strong
---------- Base Saturation (V%) ----------										
1	100 x 100	89	91.90	183.90	92.00	3110.00	Spherical	0.36	49.97	Moderate
2	100 x 100	28	2.49	23.60	21.11	771.00	Gaussian	0.90	10.55	Strong
3	100 x 100	33	6.80	42.28	35.48	302.00	Spherical	0.93	16.08	Strong
4	100 x 100	40	PNE	PNE	PNE	PNE	-	-	-	-
5	100 x 100	49	PNE	PNE	PNE	PNE	-	-	-	-
6	100 x 100	57	38.20	76.41	38.21	1016.00	Linear	0.30	49.99	Moderate
7	100 x 100	65	5.10	175.80	170.70	454.00	Spherical	0.87	2.90	Strong
8	100 x 100	47	PNE	PNE	PNE	PNE	-	-	-	-
9	100 x 100	46	66.00	132.10	66.10	2064.00	Exponential	0.79	49.96	Moderate
10	100 x 100	41	33.50	88.81	55.31	1675.00	Spherical	0.86	37.72	Moderate
1	142 x 142	45	PNE	PNE	PNE	PNE	-	-	-	-
2	142 x 142	75	15.60	92.20	76.60	1767.00	Gaussian	0.93	16.92	Strong
3	142 x 142	45	27.50	262.00	234.50	1250.00	Gaussian	0.97	10.50	Strong
4	142 x 142	43	0.01	28.42	28.41	316.00	Spherical	0.69	0.04	Strong
5	142 x 142	59	25.00	250.90	225.90	1877.00	Spherical	0.99	9.96	Strong
6	142 x 142	73	30.43	60.87	30.44	1540.00	Gaussian	0.93	49.99	Moderate
7	142 x 142	60	PNE	PNE	PNE	PNE	-	-	-	-
8	142 x 142	62	PNE	PNE	PNE	PNE	-	-	-	-
9	142 x 142	83	0.10	123.40	123.30	418.00	Spherical	0.79	0.08	Strong
10	142 x 142	91	PNE	PNE	PNE	PNE	-	-	-	-

Table 3 continued

1	173 x 173	34	PNE	PNE	PNE	PNE	-	-	-	-
2	173 x 173	36	58.00	116.01	58.01	3110.00	Spherical	0.35	50.00	Moderate
3	173 x 173	51	0.10	218.70	218.60	537.00	Exponential	0.61	0.05	Strong
4	173 x 173	33	16.20	233.30	217.10	2083.00	Spherical	0.75	6.94	Strong
5	173 x 173	27	PNE	PNE	PNE	PNE	-	-	-	-
6	173 x 173	20	PNE	PNE	PNE	PNE	-	-	-	-
7	173 x 173	24	PNE	PNE	PNE	PNE	-	-	-	-
8	173 x 173	31	PNE	PNE	PNE	PNE	-	-	-	-
9	173 x 173	40	74.20	148.50	74.30	2110.00	Spherical	0.91	49.97	Moderate
10	173 x 173	34	0.10	129.90	129.80	473.00	Spherical	0.77	0.08	Moderate

(1)SDI: spatial dependence index; (2)DSD: degree of spatial dependence; (3)PNE: pure nugget effect

Table 4 - Geostatistical analysis of calcium (Ca - $cmol_c$ dm^{-3}) and magnesium (Mg - $cmol_c$ dm^{-3}) in Oxisol areas sampled with different dimensions of sampling grid

Área	Sampling Grid (m)	n	Nugget Effect	Sill	Contribution	Range	Model	r^2	Spatial Dependence	
									SDI(1)	DSD(2)
------------------------------------ Calcium ------------------------------------										
1	100 x 100	89	0.98	1.97	0.98	3110.00	Spherical	0.35	49.97	Moderate
2	100 x 100	28	0.46	3.54	3.08	843.50	Gaussian	0.87	12.99	Strong
3	100 x 100	33	0.39	0.79	0.40	683.00	Spherical	0.95	49.68	Moderate
4	100 x 100	40	0.01	1.88	1.87	566.00	Spherical	0.82	0.53	Strong
5	100 x 100	49	PNE(3)	PNE	PNE	PNE	-	-	-	-
6	100 x 100	57	2.46	4.93	2.47	3110.00	Spherical	0.41	49.90	Moderate
7	100 x 100	65	0.01	1.57	1.56	354.00	Exponential	0.77	0.64	Strong
8	100 x 100	47	0.38	0.77	0.39	433.00	Exponential	0.41	49.35	Moderate
9	100 x 100	46	0.45	3.02	2.56	2484.00	Gaussian	0.87	15.04	Strong
10	100 x 100	41	PNE	PNE	PNE	PNE	-	-	-	-
1	142 x 142	45	0.23	0.57	0.34	618.00	Exponential	0.73	40.18	Moderate
2	142 x 142	75	0.28	3.57	3.29	1694.00	Spherical	0.93	7.84	Strong
3	142 x 142	45	0.36	2.72	2.36	2042.00	Gaussian	0.93	13.09	Strong
4	142 x 142	43	0.01	0.52	0.51	372.00	Spherical	0.78	1.92	Strong
5	142 x 142	59	0.58	1.87	1.29	553.00	Gaussian	0.97	31.02	Moderate
6	142 x 142	73	0.36	0.72	0.36	2187.00	Spherical	0.70	49.93	Moderate
7	142 x 142	60	PNE	PNE	PNE	PNE	-	-	-	-
8	142 x 142	62	0.00	1.03	1.03	462.00	Exponential	0.42	0.10	Strong
9	142 x 142	83	0.00	1.02	1.02	563.00	Spherical	0.90	0.10	Strong
10	142 x 142	91	PNE	PNE	PNE	PNE	-	-	-	-

Table 4 continued

1	173 x 173	34	0.00	1.42	1.42	450.00	Exponential	0.46	0.07	Strong
2	173 x 173	36	PNE	PNE	PNE	PNE	-	-	-	-
3	173 x 173	51	2.92	11.85	8.93	3164.00	Gaussian	0.67	24.64	Strong
4	173 x 173	33	PNE	PNE	PNE	PNE	-	-	-	-
5	173 x 173	27	1.27	2.55	1.28	3110.00	Spherical	0.31	49.80	Moderate
6	173 x 173	20	1.17	2.33	1.16	2110.00	Spherical	0.44	50.21	Moderate
7	173 x 173	24	0.00	0.50	0.50	356.00	Spherical	0.60	0.20	Strong
8	173 x 173	31	PNE	PNE	PNE	PNE	-	-	-	-
9	173 x 173	40	0.35	0.75	0.40	1272.00	Exponential	0.93	46.27	Moderate
10	173 x 173	34	0.01	6.09	6.08	442.00	Spherical	0.44	0.16	Strong
------------ Magnesium ------------										
1	100 x 100	89	0.22	0.56	0.34	774.00	Spherical	0.76	38.93	Moderate
2	100 x 100	28	0.02	0.58	0.56	765.57	Gaussian	0.88	3.47	Strong
3	100 x 100	33	0.15	0.30	0.15	1242.00	Spherical	0.81	50.00	Moderate
4	100 x 100	40	0.07	0.48	0.41	512.00	Spherical	0.79	13.57	Strong
5	100 x 100	49	PNE	PNE	PNE	PNE	-	-	-	-
6	100 x 100	57	PNE	PNE	PNE	PNE	-	-	-	-
7	100 x 100	65	0.05	0.32	0.27	422.00	Spherical	0.88	14.78	Strong
8	100 x 100	47	0.02	0.18	0.16	330.00	Exponential	0.53	8.52	Strong
9	100 x 100	46	0.12	0.56	0.44	1968.00	Spherical	0.95	21.21	Strong
10	100 x 100	41	0.08	0.21	0.13	562.00	Spherical	0.88	39.44	Moderate
1	142 x 142	45	0.07	0.21	0.14	1538.00	Spherical	0.92	31.25	Moderate
2	142 x 142	75	0.07	1.17	1.10	2654.00	Spherical	0.94	5.98	Strong
3	142 x 142	45	0.01	1.10	1.09	3110.00	Spherical	0.95	0.91	Strong
4	142 x 142	43	0.00	0.11	0.11	501.00	Spherical	0.79	0.09	Strong
5	142 x 142	59	0.06	0.88	0.82	2110.00	Spherical	0.97	6.83	Strong
6	142 x 142	73	0.41	0.83	0.42	3110.00	Spherical	0.31	49.40	Moderate
7	142 x 142	60	PNE	PNE	PNE	PNE	-	-	-	-
8	142 x 142	62	0.05	0.26	0.21	791.00	Spherical	0.80	17.69	Strong
9	142 x 142	83	0.02	0.28	0.26	890.00	Spherical	0.91	7.04	Strong
10	142 x 142	91	0.03	0.23	0.19	467.00	Spherical	0.47	14.73	Strong
1	173 x 173	34	PNE	PNE	PNE	PNE	-	-	-	-
2	173 x 173	36	0.16	0.32	0.16	2687.00	Spherical	0.61	49.85	Moderate
3	173 x 173	51	0.29	1.84	1.55	3110.00	Spherical	0.90	15.76	Strong
4	173 x 173	33	0.39	0.87	0.48	2223.00	Spherical	0.52	44.94	Moderate
5	173 x 173	27	PNE	PNE	PNE	PNE	-	-	-	-
6	173 x 173	20	PNE	PNE	PNE	PNE	-	-	-	-
7	173 x 173	24	0.00	0.17	0.17	372.00	Exponential	0.35	0.06	Strong
8	173 x 173	31	PNE	PNE	PNE	PNE	-	-	-	-
9	173 x 173	40	0.08	0.19	0.11	1752.00	Spherical	0.88	43.01	Moderate
10	173 x 173	34	0.00	1.53	1.53	632.00	Spherical	0.86	0.07	Strong

(1)SDI: spatial dependence index; (2)DSD: degree of spatial dependence; (3)PNE: pure nugget effect

In areas where the attributes pH_{water}, V%, Ca and Mg present a defined structure of spatial variability, it was generally found that the degree of spatial dependency was moderate to strong, showing that under such conditions, these attributes were more affected by intrinsic properties of the soil (CAMBARDELLA *et al*., 1994). Furthermore, management practices, such as the uniform surface liming carried out over the period of agricultural land use, contribute to the low spatial variability of the attributes of acidity over shorter distances.

These results however warrant caution, since the semivariograms were generated using a limited number of points (n). Webster and Lark (2012) explain that the use of 30 to 50 pairs of points over each distance, as indicated by some authors (LANDIM, 2006), means having less than 50 sampling points in two-dimensional grids and almost inevitably leads to estimates which are only slightly accurate and to semivariograms with high levels of error. According to these authors, for reliable estimates to be generated when the variation is isotropic, at least 100 sampling points are required and ideally 150 to 200.

Moreover, although the number of sampling points is considered to be important in the literature, it is not subject to generalisation for all situations, and may be too small in areas where the variables display their variability on smaller scales (short distances), and too large for areas where their variability is presented on larger scales (long distances) (KERRY; OLIVER; FROGBROOK, 2010).

When larger sampling grids are used therefore, with more widely-spaced points (usually $\geq$ 100 m), together with a reduced size for the areas (a situation commonly seen in the areas under PA in southern Brazil) the comprehension and representation of the different scales of variability for the attributes of acidity and related cations (Ca and Mg) are still limited, even with the use of geostatistics. It can therefore be inferred that the sampling grids used in the Oxisol areas in RS managed under PA are not efficient in capturing the different scales of spatial variability for pH_{water}, V%, Ca and Mg, especially when expressed over short distances. However, it is important to note that the insertion of PA and consequently of soil sampling with grids, even if displaying limited levels of reliability in some situations, has enabled progress to be made in diagnosing soil fertility which is unprecedented in the agriculture of Rio Grande do Sul and in the rest of Brazil, redeeming the role of sampling in the management of soil fertility and agricultural production.

The inefficiency of sampling grids used commercially is also pointed out by Franzen (2011), Kerry and Oliver (2008) and Kerry, Oliver and Frogbrook (2010) in the United States, where generally grids of 100 m (one sample per hectare) are employed in areas under PA. For Brazilian conditions, the results of the present study agree with those obtained by Corá and Beraldo (2006) and Nanni *et al*. (2011) in which the collection of one sample per hectare was not sufficient to capture the spatial variability of V%, with the use of denser grids being necessary in order to make more accurate recommendations for soil correctors possible.

Thus, in the absence of spatial dependence of the data, or with dependencies of limited reliability, it is suggested that users of PA exercise caution when employing kriging interpolation, otherwise the thematic maps of soil attributes, used to determine the variable rates of correctors and fertilizers, will not express the main patterns of spatial variability present in the area (KERRY; OLIVER, 2008). Under such conditions, the use of simple interpolation (linear or polynomial) such as inverse distance, can be just as effective as the kriging method (KRAVCHENKO, 2003; FRANZEN, 2011). According to Corá and Beraldo (2006), map accuracy is dependent on the interpolation method used to estimate the values for non-sampled locations, and in turn, the interpolation method is dependent on the density of sampled points per area.

These results endorse what is currently being practised in the field, where users of PA, during the preparation process for thematic maps, employ computer software available in the market, but which do not take into account the spatial dependence of the attributes being analysed in estimating values at non-sampled locations (CORÁ; BERALDO, 2006). However, it is important to state again that the ability to generate thematic maps for the attributes pH_{water}, V%, Ca and Mg in the absence of any spatial dependence of the data verified by geostatistics, does not exempt the planning of sampling from recommending denser sampling, which would be capable of actually detecting the different scales of spatial variability of the analysed attributes. As good as the interpolation method is, it will never be able to predict values with accuracy, compared to the values obtained by sampling in the field.

Given the results of this exploratory study, the assumptions already outlined by Chang *et al*. (1999) and Stepien, Gozdowski and Samborski (2013) can be confirmed, in which the spatial variability of the attributes pH_{water}, V%, Ca and Mg is unique for each area, being conditioned at different scales by intrinsic and extrinsic soil factors. Therefore, from sampling grids with dimensions $\geq$ 100 m, such as those that have been used in the south of Brazil, it is not possible to generalise a reliable model of the spatial variability of these attributes for Oxisols. However, the study does give an overview of the scale of variation for the soil attributes under study, and becomes an important reference that can assist in planning future soil sampling strategies to be adopted in areas under PA in RS.

A suggestion for the future would be carrying out detailed studies in a microregion, farm or field scale to test different dimensions for sampling grids, with a view to better understanding the variability of the different soil chemical attributes, and the possible definition of more efficient strategies for fertility management.

CONCLUSIONS

1. The sampling grids used in Oxisols under PA in RS, generally employing geostatistical procedures, are not efficient in capturing the scales of spatial variability of the attributes pH_{water}, V%, Ca and Mg, and may lead less accurate liming;
2. Spatial variability over short distances should be taken into consideration in future plans for soil sampling, aiming for the characterization and the site specific management of soil acidity in Oxisols areas managed under PA.

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