SOIL SAMPLING INTENSITY AND SPATIAL DISTRIBUTION PATTERN OF SOILS ATTRIBUTES AND CORN YIELD IN NO-TILLAGE SYSTEM

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ABSTRACT: Taking into account that the sampling intensity of soil attributes is a determining factor for applying of concepts of precision agriculture, this study aims to determine the spatial distribution pattern of soil attributes and corn yield at four soil sampling intensities and verify how sampling intensity affects cause-effect relationship between soil attributes and corn yield. A 100-referenced point sample grid was imposed on the experimental site. Thus, each sampling cell encompassed an area of 45 m^2 and was composed of five 10-m long crop rows, where referenced points were considered the center of the cell. Samples were taken from at 0 to 0.1 m and 0.1 to 0.2 m depths. Soil chemical attributes and clay content were evaluated. Sampling intensities were established by initial 100-point sampling, resulting data sets of 100; 75; 50 and 25 points. The data were submitted to descriptive statistical and geostatistics analyses. The best sampling intensity to know the spatial distribution pattern was dependent on the soil attribute being studied. The attributes P and K^+ content showed higher spatial variability; while the clay content, Ca^{2+}, Mg^{2+} and base saturation values (V) showed lesser spatial variability. The spatial distribution pattern of clay content and V at the 100-point sampling were the ones which best explained the spatial distribution pattern of corn yield.

KEYWORDS: geostatistics, precision agriculture, *Zea mays*.

INTENSIDADE AMOSTRAL E DEFINIÇÃO DA DISTRIBUIÇÃO ESPACIAL DE ATRIBUTOS DO SOLO E DA PRODUTIVIDADE DE MILHO SOB SEMEADURA DIRETA

RESUMO: Tendo em vista ser a intensidade amostral de atributos do solo um fator determinante para a aplicação dos conceitos de agricultura de precisão, este trabalho foi conduzido para determinar o padrão de distribuição espacial de atributos do solo e da produtividade de milho em quatro intensidades de amostragem de solo e verificar a influência da intensidade amostral na compreensão da relação de causa e efeito entre atributos do solo e produtividade. Para isto, utilizou-se uma malha amostral de 100 pontos referenciados, na qual cada célula amostral de 45 m^2 era composta por cinco linhas de 10 m da cultura, onde o ponto referenciado foi considerado o centro da célula. As amostras foram realizadas nas profundidades de 0-0,1 e 0,1-0,2 m para avaliar atributos químicos e a textura do solo. A partir dos 100 pontos, obtiveram-se conjuntos de dados com 100; 75; 50 e 25 pontos amostrais. Os dados foram submetidos à análise estatística descritiva e à geoestatística. A melhor intensidade amostral para determinação do padrão de distribuição espacial foi dependente do atributo do solo estudado. Os teores de P e K^+ no solo apresentaram maior variabilidade espacial, enquanto os teores de argila, Ca^{2+}, Mg^{2+} e valores de saturação por base (V) apresentaram menor variabilidade. Os teores de argila e os valores de V, na intensidade amostral com 100 pontos, foram os que melhor se correlacionaram com a produtividade.

PALAVRAS-CHAVE: geoestatística, agricultura de precisão, *Zea mays*.

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INTRODUCTION

One of the determining factors for the practical application of the concepts of precision agriculture (PA) is related to the number of samples necessary to know, with accuracy, the spatial distribution pattern of soil attributes (CORÁ & BERALDO, 2006). However, a large number of samples can raise costs relating to the analysis of soil attributes, thereby undermining the benefits of implementing the concepts of PA (KRAVCHENKO, 2003).

The accuracy of the maps of soil attributes is dependent on several factors, but primarily the spatial structure of the analyzed variables (MUELLER et al., 2001), therefore, is dependent on the sampling intensity used to be captured correctly. In this sense, THOMPSON et al. (2004) found that the spatial structure of the soil K^+ and P content were changed when the sampling intensity was modified. The authors noted that the sampling intensity of 0.20 samples per hectare the adjusted model for K^+ and P was the exponential, reaching values of 485 and 228 m, respectively, whereas for the sample intensity of 0.40 samples per hectare the spherical model was adjusted and the ranges were 301 and 299 m for K^+ and P, respectively.

The definition of sample intensity might depend on the evaluated attribute, since different soil properties may require different sampling intensities. This happens because some attributes suffer greater change in its spatial distribution pattern than others, mainly due to soil management. For example, the spatial variability of of soil P and K^+ content is most affected by soil management in relation to other chemical attributes, mainly due to those fertilizer nutrients contained in the lines seeding.

MALLARINO & WITTRY (2004), when studying strategies for more efficient soil sampling approach in eight fields of agricultural production in the U.S., found that for all the strategies investigated, lower efficiency in the samples was for P and K^+ as compared with pH and organic matter (OM). In agreement with these results, SOUZA et al. (2006) found that it would be necessary a larger sample size to determine the spatial distribution patterns for P and K^+ compared to those required for pH, organic matter and eutroferric Red Latosol clay under cultivation of sugar cane.

However, the definition of sampling intensity, based on knowledge of the spatial variability of soil attributes, is not sufficient for the decision making in the planning of crops. It is also necessary to verify that the data related to soil properties, obtained in a given intensity, were correlated with data from crop yield; therefore, to carry out the planning and commercial fields of scientific experiments it is necessary to know both the spatial variability of soil and plant attributes (REICHERT et al., 2008).

Based on the foregoing, the hypothesis of this study is that the spatial distribution of soil attributes change with the intensity of soil sampling and consequently affects the understanding of cause and effect relationships between the spatial distribution of crop productivity and the soil properties. Therefore, the study aimed to determine the spatial distribution of soil attributes, using four soil sampling intensity and corn yield, and see how the intensity of soil sampling interfere in understanding the relationship of cause and effect between soil properties and corn yield.

MATERIAL AND METHODS

The experiment was conducted in Jaboticabal, state of São Paulo (SP), in Brazil (21º14'05"S, 48º17'09"W and altitude of 613 m). Climatologically the area belongs to the tropical zone/megatermal or Köeppen Aw (tropical climate with dry winter and average temperature of the warmest month above 18 ºC). The average annual rainfall is 1,417 mm, with annual distribution concentration in the period from October to March and on the dry period from April to September. The experimental area is classified as Rhodic Hapludox, clayey texture, soft wavy relief, with an average slope of 5%.

For 10 years, the experimental area has a corn crop in the summer using the no-tillage system and it remains fallow during the winter. Before sowing of the summer crop, a spontaneous vegetation desiccation is performed with non-selective herbicides.

In crop year 2007/2008, it was seeded the Syngent triple hybrid Master on 12/05/2007, aiming a density of 65,000 plants ha^{-1}. The recommendations of fertilizers and sowing coverage were based on the results of chemical analysis of soil, according to RAIJ et al. (1997). At the time of sowing, it was applied 30 kg of N, 70 kg of P_2O_5 and 50 kg of K_2O per ha. In coverage, it was applied 100 kg ha^{-1} of N when the plants presented four to six pairs of fully developed leaves. Fertilization was performed conventionally, i.e., considering the average need of even input application in the area.

Data were collected following a sampling grid containing 100 points referenced according to coordinates X and Y. The points were arranged at equidistant intervals, from 10 m in the direction of the rows of the crop (Y coordinate), along with four 250 m-long parallel transects, spaced 4.5 m (X coordinate), forming a rectangle with four columns and 25 rows. The cell sample was composed of five lines of 10 m, totalizing 45 m^2 each, considering the point referenced as the center of the cell (Figure 1).

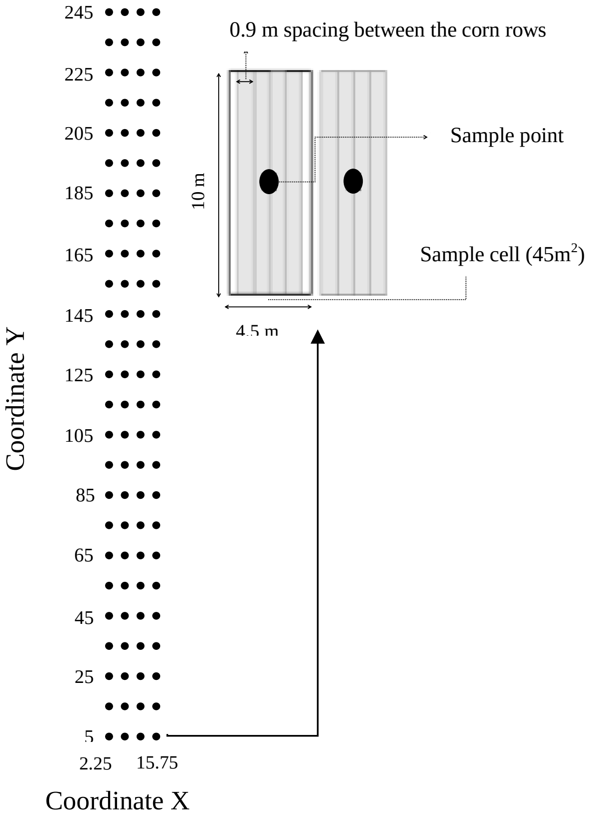


FIGURE 1. Sampling scheme of soil attributes and corn yield in a Rhodic Hapludox under no-tillage system.

The corn harvest was performed 151 days after sowing, using a mechanical harvester of plots, which allows the harvest of a row of corn at a time. Thus, in each cell sample was harvested five lines of 10 m of corn plants, and the mass of grains was considered as the productivity of the cell. The grain moisture was standardized at 13% to estimate the yield (Mg ha^{-1}).

After the corn harvest, the soil sampling was performed, using a Dutch auger, in the layers 0 to 0.1 and 0.1 to 0.2 m deep, collecting five soil sub-samples to compose a representative composite sample, one sub-sample collected in the center of the cell (referenced point) and the other in the four cardinal points, spaced 2 m from the midpoint. It was measured the clay content (CAMARGO et al., 1986), pH, P, K^+, Ca^{2+}, Mg^{2+} and OM in the samples, according to the procedures described by RAIJ et al. (2001). Then, it was calculated the soil cation exchange capacity (CEC) and percent of soil bases saturation (V).

The sampling intensities were established by elimination of intermediate sample points, starting from the highest intensity of the sampling grid, i.e., the sample grid with 100 points spaced 10 meters as Y coordinate and 4.5 meters as X coordinate. Thus, obtaining data sets with 100; 75; 50 and 25 sampling points (Figure 2). Regarding the intensity of 75 points, it was taken points every 40 meters in Y direction, starting with the distance 25 in coordinate Y. Thus forming seven sets of points spaced 20 m apart according to the coordinate Y. In the sample grids of 50 and 25 points, the sampling points were spaced 20 to 40 m in Y direction, respectively (Figure 2).

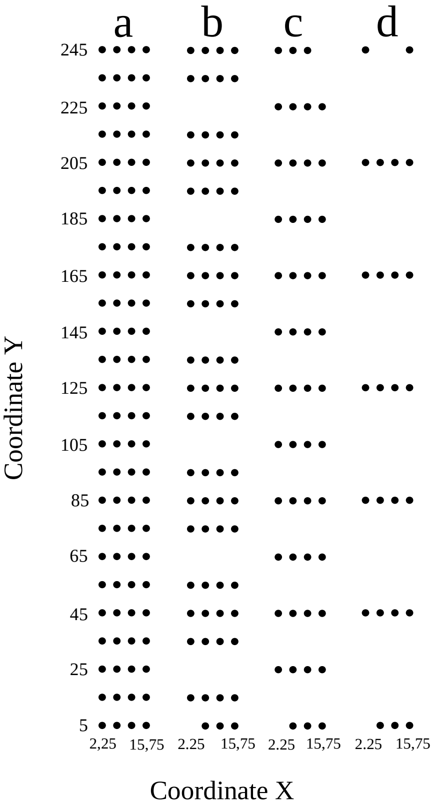


FIGURE 2. Model of sampling distribution for different sampling intensities: a (100 points), b (75 points), c (50 points) and d (25 points).

The data set, obtained from each sampling plan, was submitted to descriptive statistical analysis to determine the average, maximum and minimum values, coefficient of variation (C.V.), asymmetry and kurtosis coefficients and data frequency distribution. To test the hypothesis of normality of the data, it was used the SHAPIRO & WILK (1965) test.

To estimate the spatial dependence between samples, as well as identify whether the changes were systematic or random, it was used semivariogram models. The selection of models was based on the smallest residual sum of squares (RSS) and better coefficient of determination (R^2). The semivariograms were validated by the cross validation method, noting isotropy in all adjusted models, indicating that the pattern of spatial variability structure is the same in all directions.

To analyze the degree of spatial dependence it was used the classification of CAMBARDELLA et al. (1994), which considers the strong spatial dependence semivariograms having nugget effect equal to 25% of the sill; moderate spatial dependence when the nugget effect is between 25 and 75% and low spatial dependence when the nugget effect is greater than 75%.

Seeking to spatially correlate corn yield and soil attributes, it was estimated the crossed semivariogram. It was used the corn yield as a dependent variable and soil attributes as a covariate. The soil variables were used to estimate the cross semivariogram only when presented simple semivariograms, i.e., presented spatial dependence (VIEIRA, 2000). It was selected the cross semivariogram which presented its series of points distributed only in one quadrant, denoting thus a reliable aspect between yield and soil attributes (MEGDA et al., 2008), since the cross semivariogram presenting their number of points in more than one quadrant are considered spatial correlation indefinite (CAMARGO et al., 2008).

RESULTS AND DISCUSSION

The results show that average values for clay were similar between different sampling intensities (Table 1). Based on the C.V. classification, suggested by PIMENTEL-GOMEZ & GARCIA (2002), we observed a low variability (C.V. < 10%) for clay depths 0 to 0.1 and 0.1 to 0.2 m for all sample intensities studied (Table 1). Similar results were obtained by KITAMURA et al. (2007) to study the variability of attributes of a Rhodic Hapludox under no-tillage system. However, MELLO et al. (2006) found average variability for clay in a Eutroferric red latosol under cultivation of sugar cane.

TABLE 1. Results of the descriptive statistics and semivariogram parameters of clay content (g kg^{-1}), from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1 m				0.1 to 0.2 m			
Average	333	333	333	333	355	355	354	354
Medium	335	335	334	334	356	356	356	356
Minimum	288	288	288	304	314	314	316	316
Maximum	373	366	373	359	391	387	391	387
C.V.	6	5	6	4	6	5	6	6
Asymmetry coefficient	-0.17	-0.18	-0.18	-0.29	-0.12	-0.08	0.04	0.05
Kurtosis coefficient	-0.53	-0.61	-0.15	0.12	-0.87	-0.91	-0.91	-0.92
P<W	0.287	0.340	0.791	0.801	0.047	0.073	0.152	0.216
Normality	N	N	N	N	N	N	N	N
Model	Gau	Exp	Exp		Sph	Exp	Gau	
C_0	159.0	111.8	150.5		229.6	236.4	269.7	
C_0 +C	356.0	355.3	348.3		459.3	435.7	545.8	
Range (m)	49	120	87		121	148	121	
SDD	M	M	M		M	M	M	
R^2	0.908	0.738	0.842		0.824	0.599	0.793	
RSS	6462	24903	6371		18292	42980	35051	

C.V.= Coefficient of variation (%); P<W= normality test result; N = Normal distribution (P<M > 0.01); Sph = Spherical; Exp = Exponential; Gau = Gaussian; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; RSS = Residual sum of squares.

The values of the average and medium to the clay are close. Additionally, the coefficients of asymmetry and kurtosis are close to zero, indicating symmetric distributions (Table 1). Similar results were obtained by AMARO FILHO et al. (2007) in an Oxisol on a sampling grid of 100 points spaced 10 m. The normality of the data for these attributes (Table 1) is confirmed by the result of the SHAPIRO & WILK (1965) test.

The clay attribute showed spatial dependence for all sample intensities, with the exception of sampling intensity with 25 points. This happened because the spacing adopted in intensity with 25 points was not enough to capture the spatial dependence of clay. The Gaussian model was adjusted for the clay data at the depth of 0 to 0.1 m in the sampling intensity with 100 points, and the exponential model was adjusted with 75 and 50 sampling points. For the depth of 0.1 to 0.2 m, it was fitted the spherical model for the sample intensity with 100 points, exponential for the one with 75 points and Gaussian to the one with 50 points (Table 1). KITAMURA et al. (2007), working with Rhodic Hapludox under no-tillage system and with a sample grid of 75 points spaced 10 m, adjusted the spherical model for clay depths 0 to 0.1 and 0.1 to 0.2 m.

It was observed that, with the change in sample intensity, the clay showed variation in the value range from 49 m in the intensity of sampling with 100 points to 120 m when using 75 points, to the depth of 0 to 0.1 m (Table 1). This indicates that the choice of sampling intensity can alter the results of the spatial structure of the attribute clay and that the choice of sampling intensity is crucial for understanding the spatial distribution pattern of clay. According to the classification of CAMBARDELLA et al. (1994), the clay showed moderate spatial dependence (Table 1) for the sample intensities studied. Therefore, the sampling intensity did not alter the spatial dependence degree of clay. KITAMURA et al. (2007) observed moderate spatial dependence for clay while MELLO et al. (2006) found strong spatial dependence.

Based on the classification by the C.V., the attribute phosphorus showed high variability in all sample intensities and depths studied (Table 2). In sample intensities of 100 and 75 points, data did not present normality, while the intensities 50 and 25 data presented normality. This may have occurred because the withdrawal of points is possible if you have eliminated extreme points, but real, that influenced the data normality.

TABLE 2. Results of the descriptive statistics and semivariogram parameters of soil phosphorus content (mg dm^{-3}), from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0-0.1 m				0.1-0.2 m			
Average	33	33	32	30	21	21	20	20
Medium	31	30	31	27	20	19	19	16
Minimum	8	8	8	8	7	8	7	8
Maximum	67	67	64	60	46	46	42	42
C.V.	48	46	50	47	45	47	45	52
Asymmetry coefficient	0.46	0.51	0.33	0.32	0.73	0.86	0.58	0.76
Kurtosis coefficient	-0.78	-0.67	-0.97	-0.83	-0.04	0.00	-0.55	-0.61
P<W	0.001	0.007	0.044	0.512	0.000	0.000	0.024	0.014
Normality	N-N	N-N	N	N	N-N	N-N	N	N
Model	Exp	Exp			Exp	Exp		Gau
C_0	117.7	116.8			60.5	53.5		60.4
C_0 +C	255.3	246.9			92.123	107.1		120.9
Range (m)	20	16			36	47		22
SDD	M	M			M	M		M
R^2	0.579	0.480			0.503	0.768		0.584
RSS	2006	2835			358	347		1195

C.V.= Coefficient of variation (%); P<W= normality test result; N = Normal distribution (P<M > 0.01); N-N = Non-normal distribution (P<M < 0.01); Exp = Exponential; Gau = Gaussian; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; RSS = Residual sum of squares.

The exponential model was fitted for the P levels at depths from 0 to 0.1 and 0.1 to 0.2 m in the sample intensities with 100 and 75 points. At depth of 0.1 to 0.2 m, the Gaussian model was adjusted when using 25 points (Table 2). Similar results were obtained by CAVALCANTE et al. (2007a), working with Hipodystrophic red latosol under no-tillage system and sampling grid of 64 points spaced 2 m when fitted to the exponential model for P at depth 0 to 0.1 m and spherical for the depth of 0.1 to 0.2 m. In the present study, the range of values for P across the with sampling intensity, with the largest variation observed when using the sampling intensity with 75 points (47 m) compared with that one with 25 points (22 m) at depth of 0.1 to 0.2 m (Table 3).

As for P, high variability was also observed in the K^+ contents (Table 3). High variability for the soil K^+ were also found by CORÁ et al. (2004) in an Eutroferric red latosol under cultivation of sugar cane and by MACHADO et al. (2007) in an Red Latosol under conventional tillage.

TABLE 3. Results of the descriptive statistics and semivariogram parameters of soil potassium content (mmol$_c$ dm^{-3}) from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1m				01 to 0.2m			
Average	1.90	1.92	1.96	1.94	1.39	1.37	1.37	1.38
Medium	1.90	1.80	1.90	1.80	1.30	1.30	1.30	1.30
Minimum	0.90	0.90	1.00	1.30	0.80	0.80	0.80	0.80
Maximum	3.60	3.60	3.60	3.50	2.40	2.20	2.10	2.00
C.V.	30	30	30	28	26	26	24	24
Asymmetry coefficient	0.81	0.67	1.19	1.38	0.41	0.34	0.31	0.38
Kurtosis coefficient	0.79	0.45	1.48	1.79	-0.39	-0.69	-0.64	-0.57
P<W	N-N	N-N	N-N	N-N	N-N	N-N	N-N	N-N
Normality	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Model		Sph			Exp	Exp		
C_0		0.145			0.051	0.046		
C_0 +C		0.265			0.118	0.118		
Range (m)		9			18	17		
SDD		M			M	M		
R^2		0.234			0.478	0.301		
RSS		3.16E-03			6.76E-04	2.02E-03		

C.V.= Coefficient of variation (%); P<W= normality test result; N-N = Non-normal distribution (P<M < 0.01); Sph = Spherical; Exp = Exponential; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; RSS = Residual sum of squares.

The high variability for the soil P content may be related to their low mobility in soil (MACHADO et al., 2007). On the other hand, the variability of the K^+ in soil due to not only to lines fertilization, but also the location of the plants because the K^+ does not form organic compounds in the plant tissue and is easily transported from shoots to soil after a rain. Thus, theoretically, K^+ tends to concentrate near the stem of each plant, decreasing concentration as it move away (CARVALHO et al., 2002).

The spherical model was adjusted for the K in the soil at the depth of 0 to 0.1 m and the sampling intensity with 75 points. At the depth of 0.1 to 0.2 m, it was fitted the exponential model to the sample intensities with 100 and 75 points (Table 3). CAVALCANTE et al. (2007b), working with a sample grid of 64 points spaced 2 m, fitted the spherical model for the soil K^+ content at depths of 0 to 0.1 and 0.1 to 0.2 m. CORÁ et al. (2004), in a sample grid of 421 points spaced 50 m, set the exponential model for soil K^+ content at depths of 0.1 to 0.2 m and 0.6 to 0.8 m.

The results obtained with the adjusting of the data to clay, P and K^+ contents semivariograms models indicate that the choice of the experimental model of semivariogram is dependent not only of the evaluated attribute, but also the sampling rate, i.e., to the same attribute you can adjust different experimental models and obtain different values of the range varying the sampling intensity. These results are accordingly to those reported by THOMPSON et al. (2004) who also observed that, when used 0.2 samples per ha, the data for P and K^+ content were adjusted to the exponential model, and when used 0.4 samples per ha, the data were adjusted to the spherical model.

The content of soil organic matter (OM) showed C.V. values between 13 and 16% for sample intensities and depths studied, classified as medium variability (Table 4), in accordance with the results obtained by CORÁ et al. (2004). The data presented normality in all intensities and depths studied (Table 4) and no spatial dependence. One hypothesis for this fact is that the continuous deposition of plant residues on the soil of the experimental area during the 10 years that the soil has been used under tillage provided certain homogenization of the levels of soil OM, causing a random pattern of distribution spatial levels of soil OM.

TABLE 4. Results of the descriptive statistics of soil organic matter content (g dm^{-3}), from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1m				0.1 to 0.2 m			
Average	17	17	17	17	14	14	14	14
Medium	17	17	17	17	14	14	14	14
Minimum	11	11	11	11	8	8	8	11
Maximum	22	22	22	22	18	18	18	18
C.V.	13	14	15	16	15	15	14	14
Asymmetry coefficient	0.10	0.22	-0.04	-0.03	-0.32	-0.34	-0.14	0.12
Kurtosis coefficient	0.28	0.13	0.23	-0.12	0.11	-0.27	0.31	-0.91
P<W	0.043	0.108	0.242	0.779	0.018	0.038	0.145	0.251
Normality	N	N	N	N	N	N	N	N

C.V.= Coefficient of variation (%); P<W= normality test result; N-N = Non-normal distribution (P<M < 0.01).

Among the soil chemical properties, the lowest value of CV was found for pH (between 10 and 13%) in the sample intensities and depths studied, getting close to the limit of the class of low variability (C.V. < 10%) (Table 5). Similar results were obtained by CORÁ et al. (2004), when worked with an eutroferric red Latosol under cultivation of sugar cane. It is expected the occurrence of lower value of CV for pH, since their values vary within a narrow range (GOMES et al., 2008). Agreeing with COELHO et al. (2003), the C.V. of pH can not be compared with those of other attributes because it is measured in logarithmic scale.

A tendency was observed in the data for soil pH at both depths studied, because the semivariogram, when fitted with the original data, grew without limits for all calculated values of h (distance of samples), indicating that the size of the field sampled was not enough to display all the variance (VIEIRA, 2000). The tendency has been removed by the method of trend surface proposed by DAVIS (1973).

TABLE 5. Results of the descriptive statistics and semivariogram parameters of soil pH, from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1m				0.1 to 0.2m			
Average	4.8	4.8	4.8	4.8	4.8	4.8	4.7	4.8
Medium	4.7	4.7	4.7	4.7	4.6	4.7	4.5	4.6
Minimum	3.9	3.9	3.9	3.9	4.0	4.0	4.0	4.0
Maximum	6.4	6.4	6.4	6.4	6.3	6.3	6.3	6.3
CV	11	11	10	12	11	12	11	13
Asymmetry coefficient	1.01	1.06	1.17	1.49	1.13	1.17	1.28	1.39
Kurtosis coefficient	1.20	1.23	2.50	2.88	1.02	1.01	1.88	1.54
P<W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normality	N-N	N-N	N-N	N-N	N-N	N-N	N-N	N-N
Model	Gau	Gau	Gau	Gau	Gau	Gau	Gau	Gau
C_0	0.039	0.038	0.032	0.018	0.025	0.025	0.052	0.034
$C_0 + C$	0.120	0.098	0.100	0.218	0.144	0.144	0.182	0.284
Range (m)	12	10	10	15	13	14	12	13
SDD	M	M	M	F	F	F	M	F
R^2	0.445	0.552	0.312	0.686	0.683	0.620	0.453	0.603
RSS	2.35E-03	9.67E-04	2.37E-03	8.67E-03	2.31E-03	3.71E-03	7.05E-03	0.0175

C.V.= Coefficient of variation (%); P<W= normality test result; N-N = Non-normal distribution (P<M < 0.01); Gau = Gaussian; C_0 = Nugget effect; $C_0 + C$ = Sill; SDD = Spatial dependence degree; M = Moderate; F = Strong; RSS = Residual sum of squares.

For soil pH, it was adjusted linear trend surfaces in Y in sampling intensity with 100 points and at both depths studied. In sampling intensity with 75 points, it was adjusted linear trend surfaces in Y and X, at the depth of 0.0 to 0.1 m and linear in the Y at the depth of 0.1 to 0.2 m. In sampling intensity with 50 points, it was adjusted the linear trend surface in X and Y to the depth of 0.0 to 0.1m and linear straight in Y at the depth of 0.1 to 0.2 m. For the intensity with 25 points there was no need to adjust trend surface. After removal of the trend, it was possible to adjust the pH to the Gaussian model for depths and the soil sample intensities studied (Table 5). Contrary results were obtained by CORÁ et al. (2004) that fitted the spherical model for soil pH.

The levels of Ca^{2+} (Table 6), Mg^{2+} (Table 7) and V (base saturation) (Table 8) were considered with high variability according to the classification by C.V. This occurs because of the non-uniform distribution of lime in the surface, which probably led to greater variability of these attributes in the experimental area.

Noting the variability of soil properties studied in this study, based on the C.V., it is possible to see that it is similar to the different tested sample intensities. These results are in accordance with those obtained by THOMPSON et al. (2004) that, by studying an area with predominant Red Alfisol under no-tillage system and with rotation of peanut-wheat-corn crops, it was found that the variability of the levels of P, K^{+}, Ca^{2+} and Mg^{2+} did not change when the intensity of sampling was 0.2, 0.4 and 1.0 sample per ha.

TABLE 6. Results of the descriptive statistics and semivariogram parameters of soil calcium content ($mmol_c\ dm^{-3}$) from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1 m				0.1 to 0.2 m			
Average	22	23	20	25	20	20	18	23
Medium	15	15	14	11	12	13	10	12
Minimum	3	3	4	5	3	3	3	4
Maximum	152	152	152	152	150	129	129	129
C.V.	125	123	133	142	126	118	135	142
Asymmetry coefficient	3.17	2.89	3.82	2.69	3.17	2.62	3.55	2.56
Kurtosis coefficient	10.35	8.71	15.51	6.83	11.08	7.07	12.95	5.68
P<W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normality	N-N	N-N	N-N	N-N	N-N	N-N	N-N	N-N
Model	Gau	Gau	Gau	Gau	Gau	Gau	Gau	
C_0	77.2	111.1	2.0	1.0	2.8	5.0	1.0	
$C_0 + C$	413.1	428.8	582.4	1240.0	322.4	289.9	433.1	
Range (m)	12	13	15	14	14	14	13	
SDD	F	M	F	F	F	F	F	
R^2	0.495	0.285	0.650	0.666	0.736	0.496	0.600	
RSS	41606	66272	112983	472368	25234	48549	102992	

C.V.= Coefficient of variation (%); P<W= normality test result; N-N = Non-normal distribution (P<M < 0.01); Gau = Gaussian; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; F = Strong; RSS = Residual sum of squares.

As for pH values, there was a trend in the data for Ca^{2+} and Mg^{2+} and V values and corn yield at both depths studied. In sampling intensity with 100 points, linear trend surfaces were adjusted in Y to V, at a depth of 0.1 to 0.2 m; linear and quadratic trends in the levels of Y for Ca^{2+} and Mg^{2+} at both depths; linear in X and in Y for values of V and corn yield, 0 to 0.1 m depth. For a sampling rate of 75 points, it was adjusted the linear trend surface in the values of Y to V at the depth of 0.1 to 0.2 m; linear and quadratic Y for Ca^{2+} and Mg^{2+} in both depths; linear in X and Y for values of V at the depths of 0 to 0.1 m. For the intensity with 25 points there was no need to adjust trend surface.

TABLE 7. Results of the descriptive statistics and semivariogram parameters of soil magnesium content (mmol$_c$ dm^{-3}), from 0 to 0.1 and from 0.1 to 0.2 m depths, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1m				0.1 to 0.2m			
Average	11	12	10	13	10	10	8	12
Medium	7	7	7	6	5	5	4	5
Minimum	2	2	2	3	1	1	1	1
Maximum	69	69	69	69	68	68	68	68
C.V.	126	128	141	148	146	143	165	163
Asymmetry coefficient	2.78	2.53	3.55	2.44	2.82	2.55	3.57	2.47
Kurtosis coefficient	7.07	5.54	11.97	4.57	7.25	5.66	12.12	4.73
P<W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normality	N-N	N-N	N-N	N-N	N-N	N-N	N-N	N-N
Model	Gau	Gau	Gau	Gau	Gau	Gau	Gau	
C_0	21.2	32.9	0.1	1.0	1.5	1.0	0.1	
C_0 +C	113.0	124.2	164.1	329.6	114.2	123.3	153.1	
Range (m)	12	12	14	14	14	14	14	
SDD	F	M	F	F	F	F	F	
R^2	0.490	0.351	0.695	0.699	0.692	0.597	0.619	
RSS	3267	5299	10286	40626	3979	6672	12236	

C.V.= Variation coefficient (%); P<W= normality test result; N-N = Non-normal distribution (P<W <0.01); Gau = Gaussian; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; F = Strong; RSS = Residual sum of squares.

TABLE 8. Results of the descriptive statistics and semivariogram parameters of soil base saturation (%), from 0 to 0.1 and from 0.1 to 0.2 m depth, for four sampling intensities in a Rhodic Hapludox under no-tillage system.

	Number of Sampling Points							
	100	75	50	25	100	75	50	25
Statistics	0 to 0.1 m				0.1 to 0.2 m			
Average	44	44	42	45	40	41	37	40
Medium	41	41	39	38	34	36	32	35
Minimum	16	16	19	22	11	11	12	12
Maximum	96	96	96	96	94	94	94	94
C.V.	44	45	42	45	55	55	55	58
Asymmetry coefficient	1.02	1.03	1.16	1.37	1.02	1.01	1.22	1.33
Kurtosis coefficient	0.59	0.53	1.33	1.42	0.32	0.21	1.31	1.28
P<W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normality	N-N	N-N	N-N	N-N	N-N	N-N	N-N	N-N
Model	Gau	Gau	Gau	Gau	Gau	Gau	Gau	Gau
C_0	31.4	45.7	0.1	10.0	40.2	36.0	51.1	20.0
C_0 +C	138.6	130.9	236.8	298.1	228.1	210.4	308.7	410.9
Range (m)	12	12	13	14	12	13	14	14
SDD	F	M	F	F	F	F	F	F
R^2	0.675	0.645	0.537	0.714	0.769	0.649	0.577	0.566
RSS	1971	1369	24490	17158	4180	6755	20724	53882

C.V.= Coefficient of variation (%); P<W= normality test result; N-N = Non-normal distribution (P<W <0.01); Gau = Gaussian; C_0 = Nugget effect; C_0 +C = Sill; SDD = Spatial dependence degree; M = Moderate; F = Strong; RSS = Residual sum of squares.

After removing the trend, it was possible to adjust the Gaussian model for Ca^{+2} (Table 6), Mg^{2+} (Table 7) and V values (Table 8), at depths and sample intensities studied. Similar results were obtained by REICHERT et al. (2008), working with a Planosol and sample grid of 240 points spaced 8 m.

The range of values for attributes pH, Ca^{2+}, Mg^{2+} and V were similar to the sample intensities studied (100; 75; 50 and 25 points). The greatest change in the value range was observed for pH values (Table 5), which increased from 10 to 50 m in intensity points 15 to 25 m in intensity points.

It is expected similarity in the pattern of spatial distribution of soil Ca^{2+} and Mg^{2+} and pH and V values since these variables are correlated.

It was observed that, although the Gaussian model has been adjusted for pH, Ca^{2+}, Mg^{2+} and V in all sample intensities and, even the range values being similar among sampling intensities, the effect nugget and sill had a significant variation among the sampling intensities (Tables 5; 6; 7 and 8). The greatest variation in the values of the nugget effect and the sill was observed for Ca^{2+}, the value of nugget effect is 111.1 in sampling intensity with 75 points and 1.0 in intensity with 25 points. The sill values were from 413.1 in the sample intensity with 100 points to 1,240.0 when using 25 points (Table 6).

This fact meant that the variables presented classification of the degree of spatial dependence in function of different sampling intensities. The degree of spatial dependence for the Ca^{2+}, Mg^{2+} and V values, was classified as moderate using 75 points for the depth 0 to 0.1 m, while, for the remaining sample intensities, it was classified as strong (Tables 6; 7 and 8). The change in the degree of spatial dependence of soil attributes can generate changes in the accuracy of isoline maps, since the accuracy of these maps is closely related to the degree of spatial dependence of the measured attribute (KRAVCHENKO, 2003).

It was found that the spatial distribution of soil attributes was different depending on the sampling intensity. It can be noted that the soil P and K^+ values presented the greatest variations in spatial distribution, being possible to verify the spatial dependence only when it was used the sample intensities with 100 and 75 points.

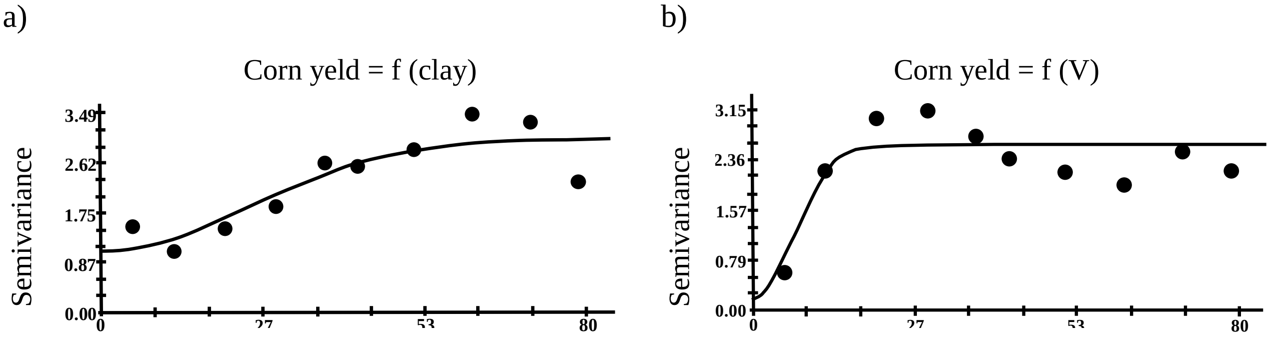
These results are in accordance with those obtained by MALLARINO & WITTRY (2004), when they studied strategies to perform the sampling of soil more efficiently in eight fields of agricultural production in the USA. The authors found that for all the strategies investigated the sampling efficiency was lower for the attributes P and K^+ in comparison with pH and OM. Likewise, SOUZA et al. (2006) noted the need to collect a larger number of samples for the determination of the spatial distribution of the levels of P and K^+ in an Eutroferric red latosol under cultivation of sugar cane. This occurs due to constant fertilization with P and K^+ in the areas of agricultural production (CORÁ & BERALDO, 2006), which affects the spatial distribution pattern, particularly those attributes.

Observing the results of this study, it was possible to separate the soil attributes into two groups according to their spatial variability. The first group, with greater spatial variability, was formed by the variables P and K^+, and a second group, with less variability, was formed by varying amounts of clay, Ca^{2+}, Mg^{2+} and V values. To define the spatial distribution pattern for the first group, the minimum sampling rate was 75 points, while for the second group, 50 sampling points were sufficient. However, to verify correlation with the productivity of maize, only the sample intensity with 100 points was efficient.

The use of single sample intensity for all attributes studied was not adequate, therefore, the soil characteristics showed different patterns of spatial distribution. This reinforces the importance of knowledge of the spatial variability of soil attributes for proper soil management and, consequently, the crop management. It also demonstrates that, for each attribute or group of attributes soil, it is necessary different sample intensities. However, in practice, it is usually used one sample intensity for studies related to the determination of the soil distribution patterns. Thus, it is necessary to use a sampling intensity capable of determining the spatial distribution of attribute that presents the lowest range. For the present study, the sampling intensity that allowed defining the spatial distribution pattern for the K^+ and P, which had the lowest range, was the one with 75 points.

The model adjusted to the data of corn yield was spherical with nugget effect (C_0) = 0.139; sill = 0.445 and range = 22 m (R^2 = 0.672 and RSS = 0.0186). This result differs from that obtained by FREDDI et al. (2006) that has adjusted the exponential model to the data of corn yield under conventional tillage, using a sampling grid with 66 points, spaced 10 m.

To verify the spatial correlation between soil properties and corn yield it was estimated crossed semivariogram. It was selected cross semivariogram using corn yield data, clay contents (Figure 3a) and V values (Figure 3b), at depth 0 to 0.1 m and sampling intensity with 100 points. The Gaussian model was set with a range of 60 m for clay contents and 14 m for V values. Unlike simple semivariograms, the value of cross semivariogram range indicates how far the variables are spatially correlated (VIEIRA, 2000). It is important to note that the fitted model for the values of corn (Gaussian) was the same as that which were adjusted for levels of clays and V values. This indicates that the spatial distribution of corn yield was dependent on the clay and V values.



Gau (C_0 = 1.064; C_0+C = 3.071; A = 60 m; R^2 = 0.80; RSS = 1.23) Gau (C_0 = 0.140; C_0+C = 2.616; A = 16 m; R^2 = 0.71; RSS = 1.35)

V = Base saturation; Gau = Gaussian; C_0 = Nugget effect; C_0+C = Sill; A = Range; RSS = Residual sum of squares.

FIGURE 3. Cross semivariogram between corn yield and clay content (a) and V values (b) for 100-points sampling intensity in a Rhodic Hapludox under no-tillage system.

Observing the results obtained with the cross semivariogram, it appears that the data set relating to the attributes of the soil, obtained by sampling intensity with 100 points, was the best spatially correlated with corn yield. It confirmed the hypothesis that reducing the sampling intensity affects negatively the understanding of the spatial correlation between soil properties and yield of corn for this study.

CONCLUSIONS

It was confirmed the hypothesis of the study that the spatial distribution of soil attributes changes according to the sampling intensity, affecting the understanding of cause and effect relationships between the spatial distribution of crop yield and soil properties.

Soil P and K^+ values showed greater spatial variability, while the clay, Ca^{2+}, Mg^{2+} and V had the lowest spatial variability, indicating that the sampling intensity to determine the spatial distribution pattern is dependent on the soil attribute studied.

The clay and V values obtained with the sampling intensity with 100 points were the soil attributes that best correlated to corn yield data, providing better understanding of cause and effect relationships between corn yield and soil attributes.

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