Scaled Semivariogram in the Sample Planning of Soils Cultivated With Sugarcane

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Abstract

Sugarcane cultivation has expanded in areas previously occupied by degraded pastures. In the first years of cultivation, besides the physical and chemical restrictions of the soils, other factors can make impossible the maximum productive expression of the crop, like the climatic and edaphic factors. The objective of this work was to evaluate the ideal sampling density and spatial variability of the physical and chemical attributes of soils cultivated with sugarcane. Georeferenced data provided by the Sugarcane Technology Center (STC) of an area of approximately 19,000 hectares located in the northwest region of São Paulo were evaluated. The granulometric fractions of the soils and organic matter contents and base saturation were determined at depths of 0.00-0.25 and 0.25-0.50 m. An index named edaphic environment (ENV) was calculated based on the records of rainfall of the areas and the productivity of the sugarcane, being represented with aptitude scores ranging from 0 (worst condition) to 10 (best condition). The results showed a strong correlation between clay and organic matter attributes with ENV index. Regions with aptitude ≥ 6.65 of ENV index corresponded to sites with clay (CL) and organic matter (OM) content above 335 g kg^{-1} and 30 g kg^{-3}, respectively. Only 10.86% of the area presented base saturation (V%) concentration $\geq 68\%$, correlating positively with CL and ENV. Through the scaled semivariogram it was possible to verify that a density of sampling of a sample to each 18 ha can be used for a mapping in macroscale of the evaluated attributes in the northwest region of the state of São Paulo.

Keywords: geostatistics, spatial variability, production environments, *Saccharum* spp.

1. Introduction

Brazil is among the countries designed to meet the growing demand for food and biofuels in the next four decades (Strassburg et al., 2014). Among the segments of its economy, the production of sugarcane has a relevant socioeconomic role, due to the production of ethanol, as a source of renewable energy, and in natura, for animal feed and sugar and alcohol manufacture.

It is estimated that ethanol production from sugarcane increases from 21 to 61.6 billion liters by 2021, consequently, 6.4 million hectares of planted area will be needed to meet this demand (Goldemberg et al., 2014). Currently, the state of São Paulo is the largest Brazilian producer, with 4558.6 thousand hectares of planted area and average productivity of 77,268 kg ha^{-1} (CONAB, 2017).

The expansion of this crop in recent years has occurred mainly in the northwest region of the state, where small rural properties are leased by sugar and alcohol mills in the region. Such a condition can be justified by the inefficiency in the income transformation of small farmers who practice extensive livestock farming. The poor management of livestock and the low natural fertility of soils do not favor the maximum productive expression of the pastures, which directly infers in the erosive process of the soil that culminates with the degradation (Garbiate et al., 2011). This situation reinforces the need to adopt specific management practices for the production of sugarcane in these areas (Crusciol et al., 2014).

The knowledge of the spatial variability of the physical and chemical attributes of the soils helps in the planning and evaluation of risks for the decision making in the management of the plantations. The so-called edaphic factors are important to define production environments through the soil's agricultural potential (Cavalcante and do Prado, 2010). However, the level of detail and costs of sampling the soil for sugarcane cultivation are high. Tools applied to the study of spatial variability have been presented in an advantageous way to analyze the punctual information of the soil and its spatial dependence with the productivity of the sugarcane (Oliveira et al., 2013).

In the state of São Paulo, the main macro-scale study of soil attributes was carried out by the state environmental agency CETESB (2008, 2015), in which the hydrographic basins of Alto Tietê, Rio Piracicaba, Capivari and Jundiaí were characterized. Although these data were not interpolated, the agency used indexes to estimate soil quality in terms of class, use and occupation. This information can meet some public requirements and assist in agricultural and urban management. However, for agriculture, values that cover spatial variability at a higher level of detail are needed (Liu et al., 2013). Moreover, studies on the ideal sampling density to characterize the spatial variability of soil attributes are extremely important and often scarce (Marques Júnior et al., 2006; Montanari et al., 2012).

This work had the objective of evaluating the ideal sampling density and spatial variability of the physical and chemical attributes of the soils cultivated with sugarcane. In addition, characterize dependence and correlate soil attributes with production environments for sugarcane.

2. Materials and Methods

The work was developed in the northwest region of the State of São Paulo, Brazil, between latitudes 20º20′20″ and 20º45′51″ South and longitudes 51º01′10″ and 51º31′30″ West. The climate of the region, according to the classification of Köppen, is defined as Aw, tropical humid with rainy season in summer and dry in winter and temperature ranging between 26.8 and 21.2 ºC. The average annual rainfall is 1128 mm with the highest occurrence in the period from November to February.

The study area is predominantly on the Bauru Group formations (Adamantina and Santo Anastácio), which presents the sandstone as the main rock. Near the banks of the Paraná, São José dos Dourados and Tietê rivers, there is the outcrop of basalt, belonging to the Serra Geral formation of the São Bento Group (IPT, 1981). The main soils of the region are the eutrophic (base saturation > 50%) and dystrophic (base saturation < 50%) Red Oxisols with texture varying between middle and clayey classes of ferric character near the river banks (Demattê, 1980). It is also observed the occurrence of eutrophic and dystrophic Red Argisols and Red-Yellow Argisols (Ultisols, USDA Soil Taxonomy), with a sandy to medium-clayey texture, respectively (Comissão de Solos, 1960).

Data from the last seven years were collected from an area of 18,693 hectares of the Soil Survey Department of the Sugarcane Technology Center (STC) in the northwest region of the State of São Paulo. The information was extracted from 638 georeferenced sample points belonging to a randomly distributed non-regular grid (Figure 1).
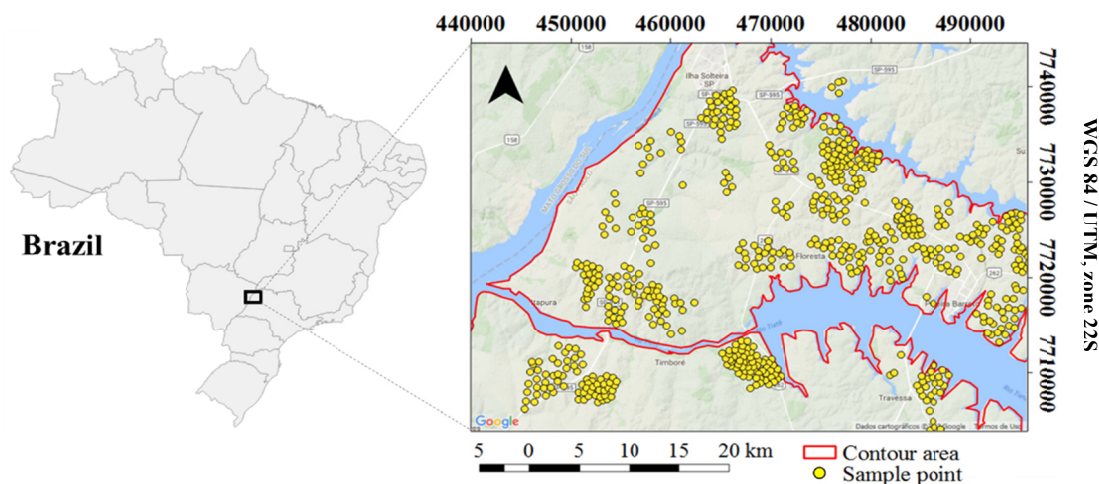

Figure 1. Location of the area and sampling points (adapted from Google Earth)

The collections were made in sugarcane cultivation areas with different ages of cut. The soil was sampled between the rows of the culture in two layers (0.00-0.25 and 0.25-0.50 m), which were submitted separately to chemical and physical analytical determinations. In the laboratory, soil particle fractions were determined: clay (CL), silt (ST) and sand (SD) by pipette method (Embrapa, 2011), and organic matter (OM) and base saturation (V%), by the methods proposed by Van Raij et al. (2001).

With the aid of the Brazilian Soil Classification System (Embrapa, 2013) and agro-environmental zoning for the sugar-alcohol sector proposed by Cavalcante and Prado (2010), it was possible to calculate the edaphic environment index (ENV) for the cultivation of sugarcane, according to the methodology adapted by the STC.

As an example of the framing of the Latosols (Oxisols, USDA Soil Taxonomy) and Argisols in the classes of ENV, we can mention: Latossolos eutróficos of clay texture, classified as environment "A" in which it is attributed scores between 9 and 10 (Figure 2). Those of average texture with clay contents varying between 150 g kg^{-1} at 250 g kg^{-1} and of alic character, are classified as environment "D", scores 3 to 4.99. For the Argisols that presented sandy/medium-clayey binary texture (horizon A + E / horizon B) of dystrophic character, they are also classified as environment "D". However, similar Argisols with higher clay content in depth (medium-clay texture: 150 g kg^{-1} at 250 g kg^{-1}), have a higher potential, classified as "C" environment, with a score between 5 and 6.99.
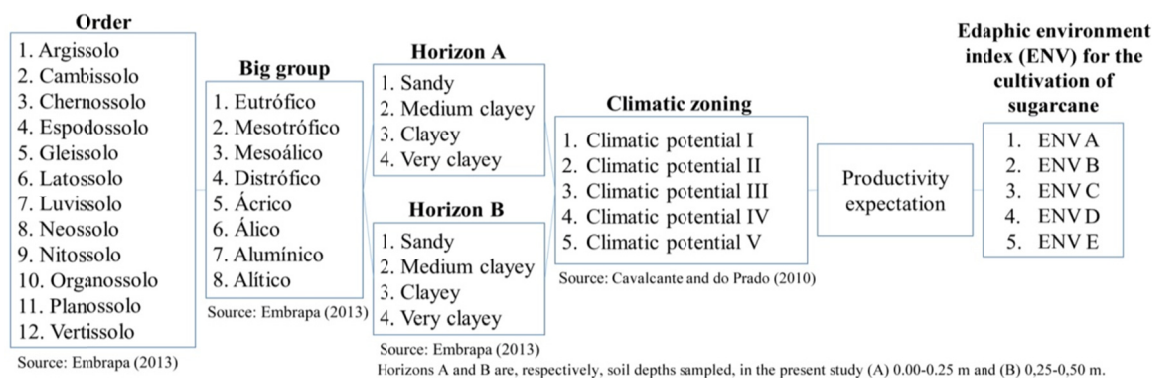

Figure 2. Illustration of the scheme to define the edaphic environment index (ENV) for the cultivation of sugarcane

The water balance and relative water consumption for the sugarcane crop were determined for a period of five years from 2012 to 2016 (totaling four harvests) due to the availability of meteorological data obtained by the Agrometeorological Network of the Northwest region and accessible through the Climate Channel of UNESP Ilha Solteira (http://clima.feis.unesp.br) from the Station.

The edaphic environment for the sugarcane production is also related to the soil water reserve capacity. The high clay content in the soil depth positively influences the availability of water during periods of lower rainfall in the region. The classes of ENV under different climatic conditions as a function of the expected productivity of sugarcane were calculated according to Cavalcante and do Prado (2010). At the end of the scores assignments, the ENV index was calculated by the overall mean of the properties described in Figure 2.

For descriptive statistical analysis of the data, the mean, median, minimum and maximum values, standard deviation, coefficient of variation, kurtosis and asymmetry were calculated. Then, the frequency distribution of the data was verified by evaluating the proximity between the mean and median values and asymmetry and kurtosis coefficients. The coefficient of variation (CV) was classified according to Pimentel-Gomes and Garcia (2002). Subsequently, the Pearson correlation matrix was performed for the two-to-two combinations between the attributes studied.

The spatial dependence of the data was evaluated by the geostatistical analysis, in which the theoretical semivariograms were calculated, according to Equation 1:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(X_i) - Z(X_i + h)]^2 \tag{1}$$

where, γ (h) is the estimated semivariance; N (h) the pairs of values measured by the distance h; Z (Xi) is the value of the variable Z at the point Xi and Z (Xi + h) is the variable value Z at the point Xi + h. The distance vector (h) is given in meters.

The exponential (Equation 2), spherical (Equation 3) and Gaussian (Equation 4) semivariogram models were tested, and the selection criteria were: a) the smallest sum of the squares of the deviations (SQD); b) the highest spatial dependence coefficient (R^2) and c) the highest spatial dependence degree. The final decision of the adjustment model to be considered was based on the cross-validation of the data observed and estimated by the model, as well as the definition of the neighborhood size of points that would provide the best interpolation for ordinary kriging. The analysis of the Spatial Dependence Evaluator (SDE) and its classification was performed according to Montanari et al. (2010).

$$\hat{\gamma}(h) = C_0 + C\left\{1 - \exp\left[-3\left(\tfrac{h}{A_0}\right)\right]\right\}; h > 0 \tag{2}$$

$$\hat{\gamma}(h) = C_0 + C\left[\tfrac{3}{2}\left(\tfrac{h}{A_0}\right) - \tfrac{1}{2}\left(\tfrac{h}{A_0}\right)^3\right]; 0 \leq h \leq A_0 \text{ then } \hat{\gamma}(h) = C_0 + C; h \geq A_0 \tag{3}$$

$$\hat{\gamma}(h) = C_0 + C\left\{1 - \exp\left[-3\left(\tfrac{h^2}{A_0^2}\right)\right]\right\}; 0 < h < d \tag{4}$$

where, $\gamma(h)$ is the estimated semivariance; C_0 is the pure nugget effect; C is the contribution of semivariance; A_0 is the range (m) and h is the distance vector (m); d corresponds to the maximum distance analyzed.

The theoretical semivariograms were scaled by dividing the semivariance by statistical variance (Ceddia et al., 2009; Comegna & Basile, 1994; Ferreyra et al., 2002; Vieira et al., 1981). The choice of the scaled semivariogram model that best fit the data was based on the higher R^2 and the smaller sum of squares of the residues, generated from the observed and estimated data, besides the practical knowledge of the behavior of the assessed attributes. Subsequently the scaled semivariogram served as the basis for calculating the minimum number of soil samples (Oliveira et al., 2014, 2015), according to Equation 5:

$$N = \frac{\alpha}{A_0^2/10000} \tag{5}$$

where, N is the minimum number of samples required for the determination of a sampling mesh in an area α (ha).

3. Results and Discussion

The results showed a high variability of the silt (ST) and clay (CL) in both layers evaluated, with coefficients of variation (CV) above 45% (Table 1). These CV values can be justified by the diversity of soil classes and their particle size distribution present in the northwest region of São Paulo (IPT, 1981). CL ranged from 30 to 730 g kg^{-1} and ST from 10 to 380 g kg^{-1}, considering the two evaluated layers (Table 1).

Table 1. Descriptive analysis of the production environment for the sugarcane crop and the soil attributes analyzed in the 0 to 0.25 and 0.25 to 0.50 m

Atributtes	Average	Median	Value		SD	Coefficient		
			Maximum	Minimum		Var.	Kurtosis	Asym.
Soil depth 0.00-0.25 m								
CL1 (g kg^{-1})	713	749	915	190	125	17.6	2.62	-1.58
ST1 (g kg^{-1})	89	81	380	10	45	50.5	5.69	1.66
SD1 (g kg^{-1})	199	180	650	30	102	51.5	2.45	1.46
OM1 (g kg^{-1})	20	18	81	5	8	41.7	5.84	1.72
V%1	60	61	94	15	16	26.0	-0.56	-0.20
Soil depth 0.25-0.50 m								
CL2 (g kg^{-1})	671	706	877	110	134	20.0	1.87	-1.39
ST2 (g kg^{-1})	89	83	282	10	40	45.2	2.16	1.08
SD2 (g kg^{-1})	241	215	730	26	118	59.0	1.96	1.33
OM2 (g kg^{-1})	13	12	40	4	5	37.2	2.69	1.34
V%2	56	57	90	9	16	28.9	-0.44	-0.25
Edaphic environment								
ENV	5.3	5.0	9.0	1.0	1.8	34.2	0.14	0.33

Note. ENV, SD, ST, CL, OM and V% are respectively the production environment, sand, silt, clay, organic matter and base saturation values in the 0.00-0.25 m layer when followed by the number 1 and in the layer 0.25-0.50 m when followed by the number 2; SD, Var. and Assm. are respectively the standatd deviation and coefficients of variation (%) and asymmetry.

Soil organic matter (OM) was classified as medium in the superficial layer 0-0.25 m (20 g kg^{-1}), and low in the sub-superficial layer 0.25-0.50 m (13 g kg^{-1}) (Table 1). Although these values are unsatisfactory for sugarcane cultivation, the respective CVs of 41.7% and 37.2% indicated the existence of sites with values up to 81 g kg^{-1}, which are classified as very high. The mechanized harvesting of sugarcane provides great deposition of residues on the soil surface, however, Segnini et al. (2013) reported in their studies that the incorporation of straw in the conventional soil preparation does not improve the accumulation of OM, as well as the carbon stocks and its quality. Therefore, conventional management may not be feasible for the maintenance of OM in the superficial layers of the soil, causing high spatial variability.

The sand (SD) and base saturation (V%) contents presented low CV values in comparison to the other attributes, classified as medium < 35% (Table 1). The mean V% was 60% in the 0-0.25 layer and 56% in the 0.25-0.50 m layer, indicating soil profiles with constructed fertility.

In the overall mean, the ENV index was 5.3 and its CV was classified as medium 34%. According to the STC classification methodology, the region would be classified as production environment "C" for sugarcane cultivation, however, it can be inferred the existence of sites with index 1 and 9 according to minimum and maximum values (Table 1). It is evident the existence of sites with production environments "A" and "E" and a local investigation is necessary in order to identify the limiting factors of production, thus defining specific management zones.

All attributes presented average values close to the median, however, only ENV index, V%1 and V%2 presented values of asymmetry and kurtosis close to zero, being considered the only attributes with symmetric frequency distributions (Table 1).

Significant linear correlations of the ENV index with all attributes were observed, being positive with the contents of ST, CL, OM, V%, and negative with SD (Table 2). Among the coefficients obtained, there was a moderate correlation between the CL content and the ENV index in both evaluated layers, being, therefore, the attribute that most influenced the edaphic environment. It is understood that the CL content is directly linked to the inputs of OM and V%, in which the agricultural suitability of the soils favors the use of high technological level in the cultivation of sugarcane. This can be proved by the positive correlations between CL × OM and V%, in which coefficients of 0.52** and 0.26** in the 0-0.25 m layer, and 0.41** and 0.30** in the layer of 0.25-0.50 m, respectively, were found (Table 2).

Table 2. Pearson correlation matrix and respective coefficients between production environment for sugarcane and soil attributes analyzed

Atributtes	ENV	SD1	ST1	CL1	OM1
Soil depth 0.00-0.25 m					
SD1	-0.67**				
ST1	0.42**	-0.65**			
CL1	0.64**	-0.94**	0.36**		
OM1	0.43**	-0.62**	0.54**	0.52**	
V%1	0.40**	-0.32**	0.30**	0.26**	0.44**
Atributtes	ENV	SD2	ST2	CL2	OM2
Soil depth 0.25-0.50 m					
SD2	-0.68**				
ST2	0.37**	-0.53**			
CL2	0.65**	-0.96**	0.27**		
OM2	0.38**	-0.46**	0.32**	0.41**	
V%2	0.55**	-0.35**	0.27**	0.30**	0.32**

Note. ENV, SD, ST, CL, OM and V% are respectively the production environment, sand, silt, clay, organic matter and base saturation values in the 0.00-0.25 m layer when followed by the number 1 and in the layer 0.25-0.50 m when followed by the number 2; ** significant at 1% probability.

As for the SD content, this was negatively correlated with all attributes. It is understood that SD is related to lower water retention (Zhao et al., 2010) and low soil fertility (Souza et al., 2010), consequently lower availability of nutrients to the plants, not favoring the supply of soil OM. Souza et al. (2010), found low

coefficients of linear correlation of the attributes OM and V% with the productivity of the sugarcane cultivated in an Argisol. The authors attributed this fact to the points sampled at lower altitude (< 518.21 m), which was due to the low input of organic matter in the 0.20-0.40 m layer of the soil. In the present study, it was observed that the ENV index was strongly influenced by soil SD content. The highest negative correlation of the index was due to SD content, where -0.67** in the layer of 0.00-0.25 and -0.68** in the layer of 0.20-0.50 m (Table 2).

According to the geostatistical analysis, all variables presented spatial dependence with semivariograms adjusted to the exponential and spherical models (Figure 3). The spatial dependence evaluator (SDE) was classified as moderate for CL1, CL2, SD1, SD2, ST1, ST2, OM1, OM2, V%2, ENV index attributes, and high for V%1, with a representativity of 50.02% to 75.84% of the nugget effect (C_0) in the definition of the threshold of semivariance ($C_0 + C$). The high values of C_0 can be justified by the similarity between points observed at short distances, showing that the spatial distribution of attributes is essentially homogeneous. Vieira et al. (2011) also obtained a high C_0 for the semivariograms of clay and total sand contents, evaluating an Oxisol of the municipality of Angatuba, São Paulo. The authors consider that this behavior is due to the minimum distance between points in the sampling grid, which made it impossible to detect lower variability patterns.
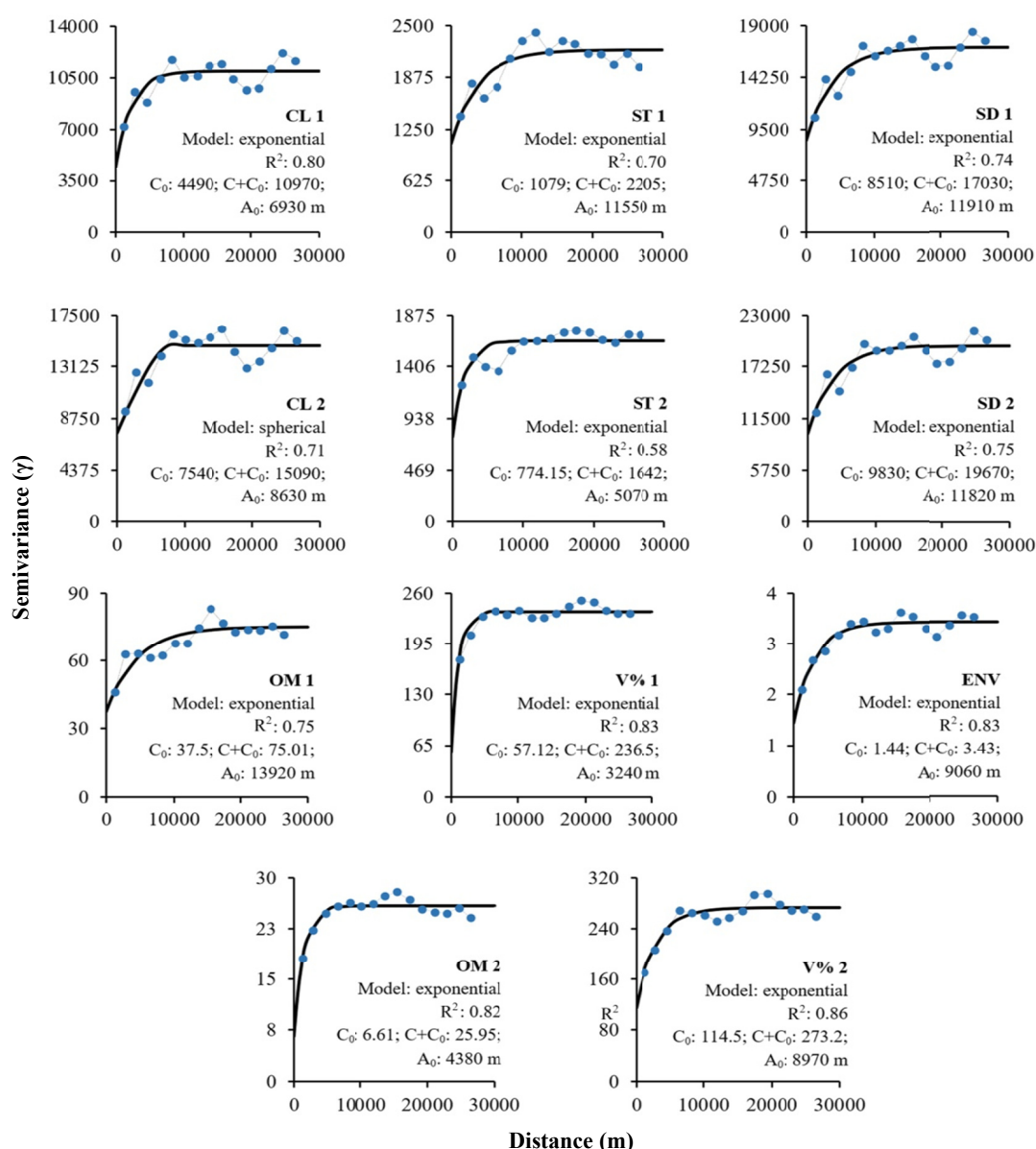

Figure 3. Simple semivariograms and their respective parameters of the clay contents (CL1 and CL2) sand (SD1 and SD2), silt (ST1 and ST2), organic matter (OM1 and OM2), saturation by bases (V%1 and V%2) and environment of production of sugarcane (ENV)

The semivariance stabilizes when the threshold is reached, thereby defining the range (A_0) of the experimental semivariograms (Trevisan et al., 2017). It was observed that the soil attributes of the superficial layer (0.00-0.25 m) presented ranges above 11550 m, except for CL1 and V%1 attributes (Figure 3). These attributes tended to a semivariance structure at short distances, between 3240 and 6930 m, due to the textural variation of soils and the fertility management used in the sugarcane cultivation.

In this region of the São Paulo state, soil pH correction through agricultural correctives, *e.g.*, calcium carbonate, occurs in total area, and the amount usually applied is based on a soil analysis from a single sample (composed of 20 samples randomly collected in an area of homogeneous granulometry). Thus, it is presupposing that soil base saturation does not present high variability in crop areas. Different from that observed in the V%1 semivariogram, it was verified that there is no spatial dependence above 3240 m, which indicates that the conventional sampling of the soil is not appropriate, requiring a greater level of details (Figure 3).

In relation to the 0.25-0.50 m soil layer, A_0 was found between 8630 and 8970 m, for CL2 and V%2, respectively (Figure 3). The soil physical and fertility condition in this layer was more homogeneous, however, it does not deviate from that observed in the soil superficial layer.

Based on the scaled semivariogram, exponential behavior was observed, being similar to most of the soil physical and chemical attributes and the ENV index (Figures 3 and 4). The low spatial dependence, SDE > 46%, was justified by the low contribution of the structural semivariance and the high nugget effect in the fit of the model (Figure 4). This SDE characteristic in the scaled semivariogram was possibly inherited from attributes ST1, ST2, SD1, SD2, OM1 and V%2. The semivariance was stabilized at 10322 m, close to the ranges obtained for A_0 of SD1, SD2, ST1, OM1 and ENV index (Figure 3).

The fit of the exponential model was satisfactory, with coefficient of determination (R^2) of 0.70 and SSE close to zero (Figure 4). Similar results were obtained by Oleiveira et al. (2015) and Marques Júnior et al. (2015), in which they obtained exponential scaled semivariograms with R^2 between 0.50 and 0.91, working with soil physical and chemical attributes of the São Paulo state.
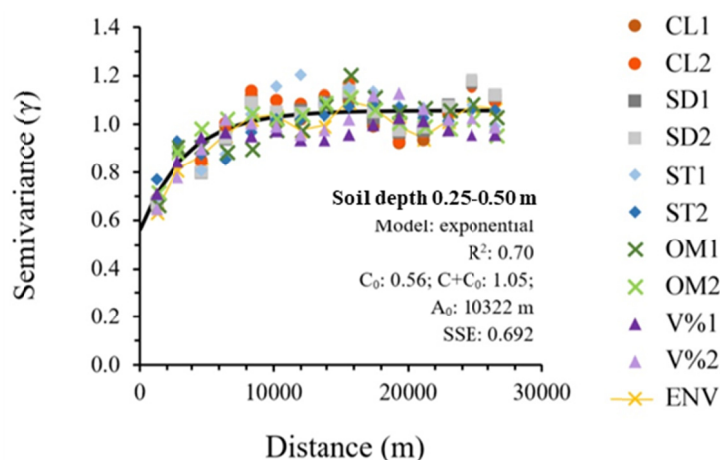

Figure 4. Scaled semivariogram and their respective parameters for the physical and chemical attributes of the soil in the 0-0.50 m layer and environment of production of sugarcane

The minimum number of samples calculated to determine the spatial variability of the investigated attributes in this study was a sample for each 18.12 ha. This sample must be composed of 20 or more sub-samples, representative of an area cultivated with sugarcane, theoretically homogeneous of 18.12 ha. Marques Júnior et al. (2015), evaluating the levels of aluminum and micronutrients in soils of the São Paulo state, found different densities of sampling, much higher than the present study. In Cuesta basaltic regions, a sample in 50,093 ha, Peripheral Depression, a sample in 44,083 ha and, Atlantic plateau, a sample in 43,448 ha. Such variability is attributed especially to geology, the shape of the landscape and the intensity of the weathering of these sites.

From the kriging maps, it was observed that the highest CL contents occurred near the Paraná and Tietê Rivers, represented by classes above 372 g kg^{-1} for CL1 and 335 g kg^{-1} for CL2, in which they corresponded to 12.37 and 50.43% of the area, respectively (Figures 5A ans 5B). The contours of these classes comprise the municipalities of Ilha Solteira, Itapura and west of Pereira Barreto, in which they have the lithology

characterized by basalt spills occurred in the Mesozoic period (IPT, 1980). This layer went through pedogenic processes and formed the soils that today have a clayey or very clayey texture. In a detailed survey of the soils of the "Experimental Campus of Ilha Solteira" conducted by Demattê (1980), it was observed the occurrence in some places with a typical clay dystrophic Red Latosol (Oxisol), reaching values of 620 g kg^{-1} of clay.

It is also observed a spatial correlation between the classes of the ST1 and CL1 maps, in which ST levels between 115 and 43 g kg^{-1} correspond to CL < 272 g kg^{-1}. In the 0.25-0.50 m layer this spatial correspondence occurs to a lesser extent, the ST contents below 107 g kg^{-1} represented the greater part of the area, 72.5%, while the CL contents in this layer were above 225 g kg^{-1}.
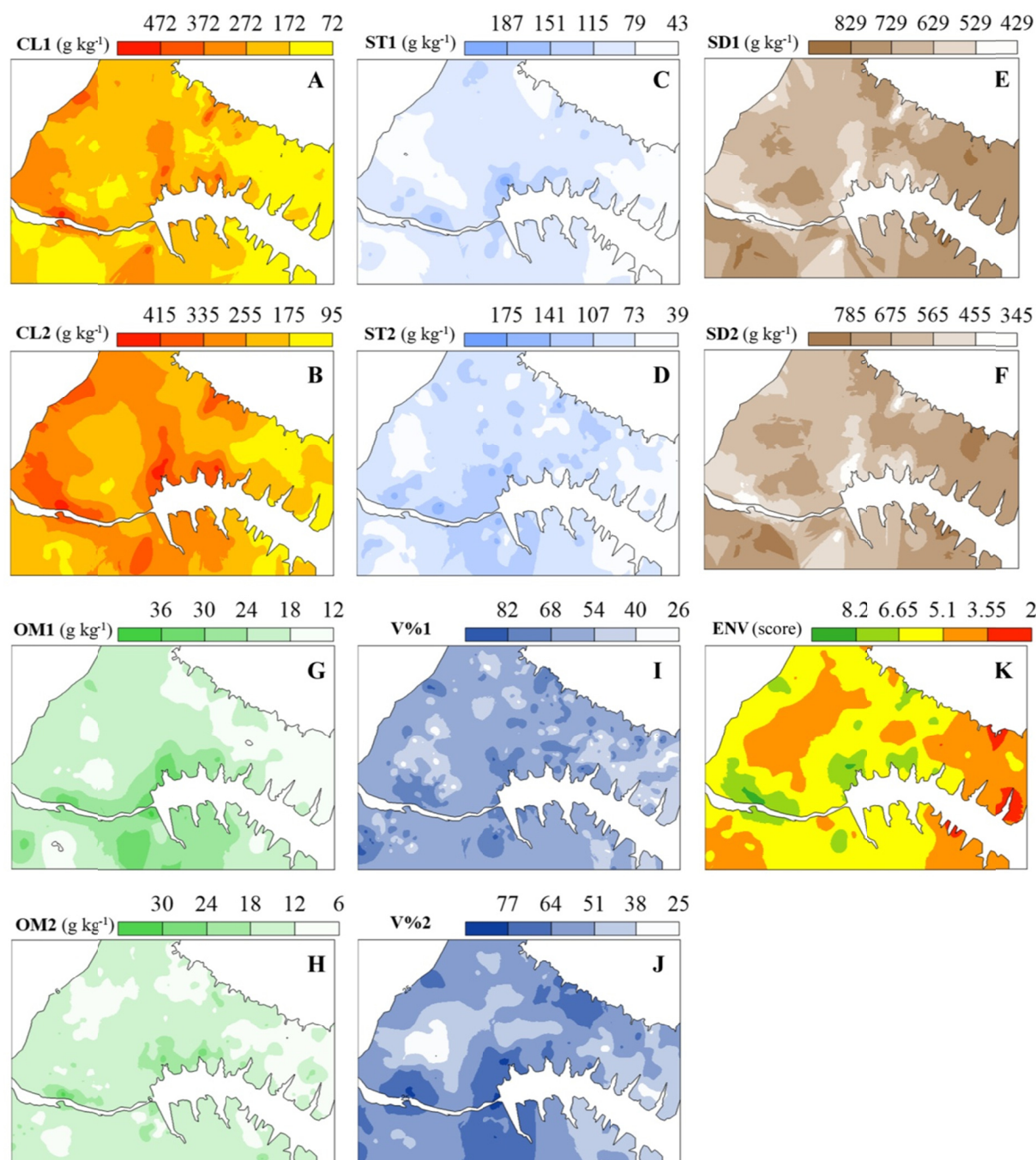

Figure 5. Kriging maps of clay content (A) CL1 and (B) CL2, silt (C) ST1 and (D) ST2, sand (E) SD1 and (F) SD2, soil organic matter (G) OM1 and (H) OM2, and base saturation (I) V%1 and (J) V%2 in the 0.00-0.25 and 0.25-0.50 m layers, and environment of production of sugarcane (K) ENV

The highest SD contents occurred near to the dam of the river that cuts the map, represented by classes above 729 g kg^{-1} in the 0.00-0.25 m layer and above 675 g kg^{-1} in the 0.25-0.50 m layer, occupying 34.11% and 42.61% of the area, respectively (Figures 5E and 5F). This condition suggests the existence of soils with low agricultural ability. Therefore, the contents of CL at these sites do not exceed 180 g kg^{-1}.

High V% levels occurred in the same region, represented by classes above 68% for V%1 and 64% for V%2, corresponding to 10.86% and 19.24% of the total area, respectively (Figures 5I and 5J). These results support the linear correlations obtained between V% × CL and OM, which, although weak, between 0.26** and 0.44**, are justified by spatial distribution. The V%2 map presented spatial distribution similar to the map of CL2, being soils with the best agricultural aptitude (Figures 5B and 5J).

The spatial distribution of OM indicated levels above 30 g kg^{-1} for OM1 and 24 g kg^{-1} for OM2 near the river, which corresponded to 25.69% and 5.43% of the area, respectively. The best OM condition was observed at sites with CL and V% above 272 g kg^{-1} and 54% at 0-0.25 m layer, and above 255 g kg^{-1} and 64% at the 0.25-0.50 m, respectively. Corroborating with the results of the linear correlation between OM × V% and CL, indicating that the contribution of organic matter is influenced by the clay content and base saturation in the layer of 0.25-0.50 m.

The best environments for the sugarcane production were verified in the coastal regions (Figure 5K). It is observed by the spatial distribution of the ENV index by highest occurrence of environments "A", "B" and "C" representing 65.83% of the area. In addition, it was verified that 34.17% of the area presented soils with a score lower than 5, that is, soils with medium to low production potential classified as "D" to "E" environments.

In the comparison between ENV index maps and soil attributes, it can be seen that CL, OM and V% levels follow the distribution of "A" and "B" environments with grades above 6.65 (Figures 5K, 5B, 5G and 5J). The CL content also followed the distribution of the production environments, however in an inverse way, that is, the higher the sand content, the worse the production environment. Similar result to the behavior of the simple linear correlation matrix (Table 2). Souza et al. (2010) affirm that spatial variability of soil attributes should be taken into account in agricultural planning to optimize fertilizer applications and increase sugarcane productivity, thus reducing production costs and environmental problems.

4. Conclusion

Through the scaled semivariogram it was possible to verify that the sampling density of a sample for each 18 ha can be used for a mapping in macroscale in the northwest region of the state of São Paulo.

The semivariance structures of the soil attributes and index of production environments were better fitted to exponential models, with moderate to high spatial dependence classification and ranges up to 13920 m.

The index based on production environments for sugarcane was positively correlated with the contents of silt, clay, organic matter and saturation by bases, and negatively with the sand content.

The best environments for the production of sugarcane were verified in the coastal regions, due to the higher clay content, organic matter and better soil base saturation, considering the two layers evaluated.

Further sample planning studies should be carried out in other regions and soils with different characteristics from those observed in the present study, in order to verify the influence of the spatial variability of the soil attributes in the appropriate sample grid size.

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