SPATIAL VARIABILITY ANALYSE AND CORRELATION BETWEEN PHYSICAL CHEMICAL SOIL ATTRIBUTES AND SUGARCANE QUALITY PARAMETERS

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ABSTRACT

With the high increment in the ethanol demand, the trend is that the planted area with sugar cane in Brazil will increase from the actual 7 million ha up to 12 million ha in 15 years. The sugar cane expansion demands, beyond the enlargement of the boundaries with the installation of new industrial units, better use of the production areas and improvement of the yield and quality, together with production costs reduction. In such a way, the adoption of Precision Agriculture (PA) can be an important tool in the management of the sugar cane industries. The objective of this work was to study the Pearson's correlation between physical and chemical soil attributes with sugarcane quality parameters, as well as verifying the spatial variability of these attributes. This work was carried out in an area of 10 ha located in Araras/SP - Brazil, in November 2008. A grid of 30x30 m was made totalizing 117 sample points. To measure sugar cane juice quality samples were taken from each point, constituted by 10 plants in the same row, just before harvesting. Laboratory analyzes of Brix, Pol, Purity and Total Reduction Sugar (TRS) were made. Soil samples were collected immediately after harvesting in the same grid points. The chemical soil attributes analyzed were macro and micro nutrients and soil physical attributes were the soil texture. The correlation obtained between sugarcane quality parameters and soil physical attributes ranged from -0.28 to 0.27 and for soil chemical attributes between 0.21 to 0.30. Spatial dependence was detected for the majority of the attributes in studied.

Key-words: precision agriculture, linear correlation, geostatistics.

INTRODUCTION

Brazil is the biggest sugarcane producer in the world and this crop is among the three more important to the country. The Brazilian sugarcane production in the 2009/10 season was of 612 million tons (89.5% in the centre-south). Of the total of the production for the industry, 276 million tons were used in sugar production, reaching 34.6 million tons (30.1 million in the centre-south) and 336.2 million tons for alcohol production, resulting in a production about 25.8 billion liters (23.7 billion in the centre-south). These numbers represent a 6.7% increase in production comparing with last season (CONAB, 2010).

With the high demand for increased ethanol production, the trend is that the planted area with sugar cane continues to rise. In such a way, the adoption of precision agriculture (PA) may be an important contribution to increasing sugarcane yield and quality of raw material.

The quality of the raw material is defined as the group of characteristics that the product should present assisting the demands of the industry for occasion of processing. The parameter used to express sugar cane quality there is juice Brix, pol, purity index, and fiber content (Netafilm, 2010). The occurrence of restraining factors for the development of the sugar cane can result in damages for its quality, with direct and indirect reflexes on the industrial processing of the biomass (MUTTON, 2008). Kunert (2000) defines this restraining factor as stress, characterizing as resultant of crop development in conditions below the ideal, including among others, climate conditions (hydro stress), nutrients limitations and biological competition.

Among the factors related to the crop yield are the soil physical and chemical attributes, which besides having a spatial variability, can vary in time for a given position (BERNOUX, 1998a and 1998b). Those variations, due to the natural agents' action, as well as of the human action, can manifest with larger intensity in some properties more than in others (BRAGATO & SPRING, 1998, BURKE et al., 1999, SLOT et al., 2001). The variability of soil properties has been approached by several authors being attributed to several factors, such as characteristics of the origin material and the formation factors, which do not act on time, but second a certain pattern.

Johnson & Richard Jr. (2005) analyzed the correlation of soil chemical attributes (P, K, Ca, Mg, soil pH, soil OM, soil estimated N release (ENR), soil cation exchange capacity (CEC), soil buffer pH, Ca/Mg and S), yield and sugar cane quality parameters for three years. A high degree of variability and spatial correlation was observed in both soil properties and sugar yield and quality, suggesting that PA approach can be justified. The author concluded that correlations between soil properties and cane and sugar yield did occur but were marginal and further studies should include micronutrients.

The objective of this paper is to present the correlation analyze between soil physical and chemical attributes and parameters of sugar cane quality (juice Brix, pol, purity and TRS) obtained by laboratorial analysis, as well as verifying the spatial variability of all the attributes in study.

MATERIAL AND METHODS

The experiment was conducted in a 10 ha sugar cane field at the sugarcane mill “Usina São João Açúcar e Álcool” in Araras in November 2008. The area is located 166 km north of the city of São Paulo in the southeast region of Brazil at

22º 23’ 38” S latitude and 47º 18’ 04” W longitude. The field is 657 m above sea level and with a slope of 1.2%. The sugar cane variety planted in 2007 (first cut) is SP80-3280 and was mechanically green harvested.

A total of 117 sample points was established on a 30x30 m grid for sampling the physical chemical soil attributes and sugarcane quality parameters. Each point contained 10 plants random distributed in 2 linear meters, of the same row, sampled in the area just before harvesting. Laboratory analyzes was conducted at UFSCAR (Araras, SP) for Brix, pol, purity and total recovery sugar (TRS) where Brix was determined by refractometer, pol was determined by using a polarimeter, purity % refers to the percentage of sucrose present in the total solids content in the juice. A higher purity indicates the presence of higher sucrose content out of the total solids present in juice. The purity percentage along with sucrose percent aids in determining maturity time and TRS refers to the total recoverable sugar percent in the sugarcane, it is function of the sucrose and Brix. Soil samples (0 – 0.2 m) were collected immediately after harvesting in the same grid points. The chemical soil attributes analyzed were macro and micronutrients (SOM, soil pH, P, K, Ca, Mg, H+Al, CEC, B, Cu, Fe, Mn, Zn) that were extracted using the ion exchange resin method proposed by Raij et al. (1987), and soil physical attributes Clay, Silt, Sand content. The particle-size analysis was performed using the hydrometric method (EMBRAPA, 1979).

Exploratory and descriptive analyses were performed using the methodology proposed by Johnson and Richard Jr. (2005) by first calculating univariate statistics using Minitab 15 software. The Kolmogorov-Smirnov statistic was also calculated for the data to test for the presence of a normal distribution. If the calculated statistic p-value was significant at $p \leq 0.05$, the distribution was considered nonnormal. To test for the presence of anisotropy, variogram analysis was performed (ESRI - Environmental Systems Research Institute, Inc. 2006. ArcGIS 9.2).

As pointed out by Warrick and Nielsen (1980) in treating of data obtained in the nature, the adjustment to a theoretical distribution is just approximate. In agreement with Cressie (1991) the normality of the data is not mandatory in geostatistics, it is convenient just that the distribution does not presents prolonged tails (values of kurtosis too low or to high), what could compromise the analyses.

Before variogram analysis, three-dimensional surface plots and semi-variance surfaces were constructed for each variable. This information was used to determine the strategy for variogram analysis.

Pearson’s correlation analysis was performed between physical chemical soil attributes and sugarcane quality parameters on the combined data set using Minitab 15 software. Correlation results were considered significant if the probability was significant at $p \leq 0.05$.

The attributes were submitted to the geostatistics analysis through the software “Geostatistical Analyst of ArcGis 9.2”. For all the attributes, variograms were adjusted considering the distribution as being isotropic and anisotropic. The choice of which variogram was better fitted to the data, preceding kriging, was based on the Space Dependence Index (SDI) (Cambardella *et al.*, 1994), which supplies a percentage of how much the variogram explained the event, and with the statistics of prediction errors of the cross validation. With the cross validation, it is possible to identify areas that there was no spatial dependence and indicates the robustness of the chosen model in the estimation of unknown values (Isaaks and Srivastava, 1989).

The Kriging interpolation allows, by a cross validation, to check the data, or at least a comparison between the errors. According to Jakob and Young (2006) for this method the ideal would be to have a Mean Standardized error (MSE) of the values predicted close to "0", a Root Mean Square (RMS) lower as possible, an Average Standard Error (ASE) close of the Root Mean Square, and a Root Mean Square Standardized (RMSS) close to "1". Finally, maps were constructed by ordinary kriging in ArcMap v. 9.2 (ESRI, 2006) utilizing the previously determined variograms.

RESULTS AND DISCUSSION

Exploratory statistical analysis

The exploratory and descriptive analyses of the soil physical and chemical attributes and sugarcane quality parameters are presented in Table 1.

Table 1. Descriptive analysis for the values of data

	min.	med	max.	mean	SD	CV	sk	k	p-value
Brix	20.1	21.6	22.7	21.6	0.6	2.6	-0.4	-0.2	>0.150
pol	15.2	16.6	17.8	16.5	0.5	3.1	-0.2	-0.2	>0.150
purity	87.7	90.9	92.3	90.7	0.9	1.0	-0.9	0.8	<0.010
TRS	16.5	17.9	19.1	17.9	0.5	2.9	-0.2	-0.3	>0.150
sand	588.0	678.0	768.0	677.7	41.3	6.1	0.03	-0.3	>0.121
clay	160.5	235.5	310.5	232.5	32.6	14.0	-0.06	-0.1	>0.150
silte	61.0	87.5	128.5	89.7	13.6	15.2	0.3	-0.1	>0.150
SOM	13.0	20.0	25.0	19.6	2.3	12.1	-0.2	-0.1	<0.010
pH	4.8	5.5	6.7	5.5	0.4	7.3	0.6	-0.04	<0.010
P	13.0	51.0	538.0	65.2	67.5	103.6	5.4	34.6	<0.010
K	0.4	1.0	2.4	1.1	0.3	31.8	1.5	3.3	<0.010
Ca	20.0	37.0	125.0	39.4	15.9	40.4	2.4	9.4	<0.010
Mg	6.0	12.0	48.0	13.4	6.1	45.7	2.3	8.7	<0.010
H+Al	9.0	16.0	31.0	17.3	4.5	26.0	0.4	0.1	<0.010
CEC.	46.8	68.1	162.9	71.4	18.7	26.1	2.4	8.6	<0.010
B	0.04	0.1	0.2	0.1	0.03	24.2	0.06	0.5	<0.010
Cu	0.5	0.9	2.7	0.9	0.2	29.0	2.5	11.7	<0.010
Fe	14.0	34.0	79.0	34.4	11.5	33.4	0.8	1.6	<0.050
Mn	1.1	2.9	6.0	2.9	1.0	34.0	0.6	0.03	<0.032
Zn	0.2	0.4	1.7	0.4	0.2	43.4	3.7	21.2	<0.010

where: min – minimum; med; median; max – maximum; SD – standard deviation; CV – coefficient of variation; sk – skewness; k – kurtosis; p-value for normality test. Brix, pol, putity, TRS in (%); sand, clay and silt in (g.kg^{-1}); SOM – soil organic matter in (g.dm^{3}); P, B, Cu, Fe, Mn, Zn in (mg.dm^{3}); K, Ca, Mg, H+Al, CEC in (mmolc.dm^{3}).

All parameters with the exception of P and CEC in the 117 sampled points present a distribution where means and medians were similar, revealing distributions that were only slightly asymmetrical. This conclusion is also supported by the negative values and near zero values of skewness coefficients with exception for P, K, Ca, Mg, CEC, Cu e Zn which presents high values of skewness. Johnson & Richard Jr. (2005) detected significant positive skew with the mean greater than the median, for the majority of these properties, with K, Mg, CEC, and S not significantly skewed. All distributions are considered as nonnormal for the Kolmogorov-Smirnov statistic at 5% of significance with exception of Brix, pol, TRS, sand, clay, silt and Fe. The coefficients of variation show that only Brix, pol, purity, TRS, sand and pH had low variation ($CV \leq 10\%$), in agreement with the Gomes and Garcia (2002) criterion.

Correlation between soil physical and chemical attributes with sugar cane quality parameters.

According to Table 2 the Pearson correlation of the all soil physical attributes (clay and silt) presented a statistically significant ($p \leq 0.05$) positive moderate correlation with Brix only (r = 0.27 and 0.2) and as a consequence a moderate negative correlation between sand and Brix (r = - 0.28).

Table 2. Correlation between soil physical & chemical attributes with sugarcane quality parameters

	Brix	Pol	Purity	TRS
	(%)	(%)	(%)	(%)
Sand (g.kg^{-1})	**-0.28**	-0.12	0.01	-0.14
Clay (g.kg^{-1})	**0.27**	0.12	0.00	0.14
Silte (g.kg^{-1})	**0.20**	0.08	-0.02	0.10
SOM (g.dm^{-3})	**0.30**	**0.24**	0.00	**0.25**
pH	-0.11	-0.06	-0.13	-0.07
P (mg.dm^{-3})	-0.03	-0.01	-0.18	0.00
K (mmolc. dm^{-3})	0.02	-0.13	**-0.33**	-0.11
Ca (mmolc dm^{-3})	-0.04	0.00	-0.18	0.01
Mg (mmolc dm^{-3})	-0.01	0.01	-0.10	0.01
H+Al (mmolc dm^{-3})	**0.30**	**0.25**	**0.27**	**0.25**
C.E.C. (mmolc dm^{-3})	0.04	0.06	-0.13	0.07
B (mg dm^{-3})	**0.22**	0.11	0.13	0.12
Cu (mg dm^{-3})	0.15	0.12	0.01	0.13
Fe (mg dm^{-3})	**0.26**	**0.21**	0.10	**0.22**
Mn (mg dm^{-3})	0.04	0.03	-0.11	0.03
Zn (mg dm^{-3})	0.03	0.06	-0.13	0.07

In bold significant values ($p \leq 0.050$).

All analyzed sugar cane quality parameters (Brix, pol, purity and TRS) presented a statistically significant ($p \leq 0.05$) positive moderate correlation with H+Al (r = 0.30; 0.25; 0.27 and 0.25); Brix, pol and TRS presented a statistically significant ($p \leq 0.05$) positive moderate correlation with SOM (r = 0.30; 0.24 and

0.25) and Fe (r = 0.26; 0.21 and 0.22); Brix and B also presented a moderate correlation (r = 0.22) and purity presented a negative moderate correlation with K (r = -0.33). Those results differ from those obtained by Johnson and Richard Jr. (2005) which obtained a moderate negative correlations between TRS, and pol with P (r = 0.24, 0.31) and SOM (r = -0.31, -0.34).

Magalhães and Cerri (2008) evaluated the correlation among physical and chemical attributes of the soil with the sugarcane yield, obtaining correlations in general low to moderate.

Spatial analysis

Since the majority of the soil parameters present kurtosis $\leq$ 2.0 with sufficiently symmetry, with exception P, K, Ca, Mg, CEC, Cu e Zn, the geostatistics analyses was conducted.

The parameters of the variograms that obtained better adjustments and the statistics of prediction errors for each attribute are presented in the Tables 3 and 4 respectively.

Table 3. Variograms parameters

	Model	Ani	C	Co	(C+Co)	Major	Minor	SDI
		degree				m	m	%
Brix	Sph	93.59	0.227	0.124	0.351	355.6	129.8	35.4
Pol	Sph	83.66	0.12	0.17	0.29	355.6	139.4	59.7
Purity	Sph	273.91	0.41	0.55	0.96	355.6	133.9	57.5
TRS	Sph	84.31	0.12	0.17	0.30	355.6	140.5	58.1
Sand	Gaus	23.93	2032.42	239.92	2272.34	355.6	239.8	10.6
Clay	Gaus	-	1281.75	161.92	1443.68	297.7	-	11.2
Silt	Exp	32.93	154.99	63.12	218.12	355.6	197.6	28.9
SOM	Gaus	-	2.42	3.93	6.35	259.7	-	61.9
pH	Gaus	-	0.07	0.12	0.19	355.6	-	62.1
H+Al	Sph	285.15	4.81	15.16	19.97	243.7	74.4	75.9
B	Sph	-	0.00	0.00	0.00	355.6	-	58.8
Fe	Sph	-	34.68	95.57	130.25	57.6	-	73.4
Mn	Sph	-	0.18	0.87	1.05	81.1	-	82.3

where: Ani = anisotropy direction; C= Partial Sill; Co = Nugget; (Co+C) = Sill; SDI = [Co/(Co+C)]. Major and Minor range.

Taking into account the values presented in Table 3, it is possible to observe that the H+Al and Mn in study presented a SDI considered low according to Cambardella *et al.*, (1994), high for sand and clay and moderate for the others. Between the isotropic and anisotropic variograms, the anisotropic were the ones that better explained the events in study, with exception of clay, sand, SOM, pH, B, Fe e Mn. Isaaks and Srivastava~~,~~ (1989) apud Johnson and Richard Jr. (2005) define anisotropic variograms, or directional variograms, those capable to describe the structure in one direction and isotropic, or omnidirectional variogram, define the structure in any direction.

Table 4. Statistics of prediction errors of the cross validation

	ME	RMS	ASE	MSE	RMSS
Brix	0.001	0.424	0.426	0.006	0.996
pol	0.007	0.458	0.464	0.013	0.987
purity	0,001	0,845	0,833	0,003	1,009
TRS	0.002	0.462	0.469	0.003	0.986
sand	0.309	16.990	16.830	0.009	0.982
clay	-0.258	14.570	13.810	-0.006	1.001
silt	0.051	10.830	10.960	0.004	0.991
SOM	0.005	2.116	2.074	0.000	1.019
pH	0.001	0.375	0.358	0.000	1.046
H+Al	0.075	4.151	4.271	0.017	0.972
B	0.000	0.026	0.025	-0.002	1.014
Fe	0.087	11.340	11.820	0.006	0.964
Mn	0.016	1.042	1.044	0.014	1.000

where: ME: Mean Error; RMS: Root Mean Square; ASE: Average Standard Error; MSE: Mean Standardized Error; RMSS: Root Mean Square Standardized.

The anisotropy detected was geometric, where the nugget and sill were similar, while the range varied along the quadrants in the anisotropy ellipse formed. It can be checked that the anisotropy directions were the same, as 280º is almost the reciprocal of the 90 º direction for major range for the anisotropy ellipse, with exception of sand and silt which had the same direction of anisotropy.

In the data presented in Tables 3 and 4, it can be observed that there are MSE close to 0, RMS close of the ASE and RMSS close to 1, which attend the necessary conditions to make the surface maps, Figure 1.

The east area of the experimental plot presented low values for the sugar cane quality parameters, SOM, H+Al, B and Fe; where there is a high presence of sand and according to the correlation analysis presents an inverse correlation with Brix. Silt presented a large variability in the experimental area, although even with a significative correlation with Brix, which does not present variability of the same magnitude. It is suggested that future studies should investigate the variability and correlation of the soil attributes at different depths and the influence of the with sugarcane quality parameters in a multivariate analysis.

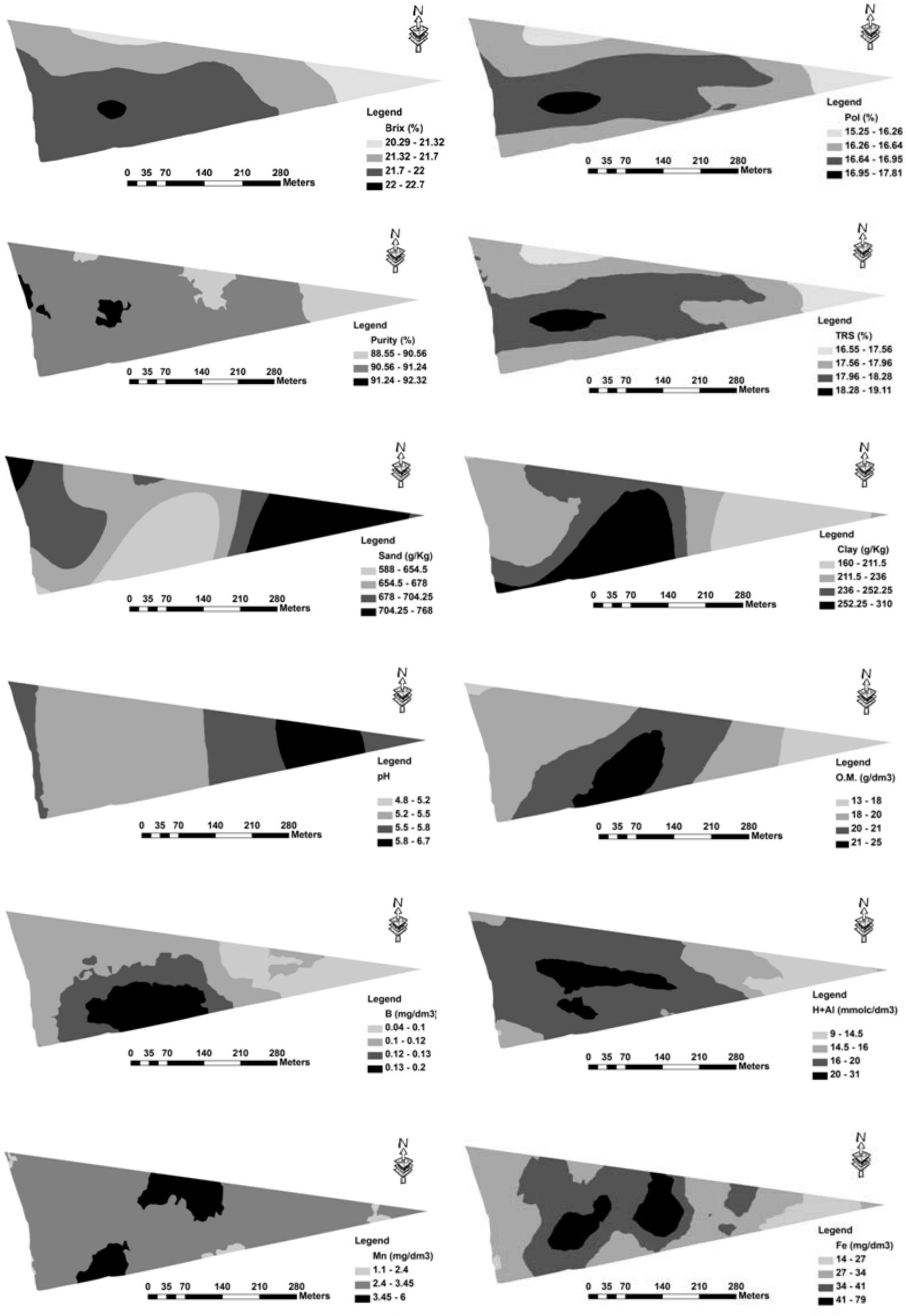

Fig. 1. Surface maps.

CONCLUSIONS

The spatial variability of some attributes in study was detected. The correlation obtained between sugarcane quality parameters and soil physical and chemical attributes were all considered moderate, and among than Brix with SOM, clay, H+Al, B and Fe presented the highest values. Considering that it is suggested that a simple correlation are not enough to explain such event, and a multivariate analysis could be used to explain it.

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