USING SOIL ATTRIBUTES TO MODEL SUGAR CANE QUALITY PARAMETERS

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ABSTRACT

The crop area of sugar cane production in Brazil has increased substantially in the last few years, especially to meet the global bioethanol demand. Such increasing production should take place not only in new sugar cane crop areas but mainly with the goal of improving the quality of raw material like sugar content (Pol). Hence, models that can describe the behaviour of the quality parameters of sugar cane may be important to understand the effects of the soil attributes on those parameters. The objective of this work was to fit mathematical models to the sugar cane Brix, pol and fiber using the physical chemical soil attributes as predictors. This work was carried out in an area of 10 ha located in Araras/SP, Brazil, during three crop cycles starting from 2008. The chemical soil attributes analyzed were the macro and micronutrients, and the soil physical attribute was the soil texture. The variables used in the models were chosen using stepwise procedure, and the fit of the models was made by means of multiple regressions. We compared the results using kriging to map the Brix and pol with the true and estimated values. The models presented a R2 varying from 0.36 to 0.46 during all two crop cycles for Brix, from 0.15 to 0.47 for pol and from 0.12 to 0.80 for fiber. Those results allowed obtaining a residue between 0.3 e 0.4 as result for the Brix, pol and fibre estimations, representing the third quartile of the estimated data by means of the models throughout the experiment.

Keywords: precision agriculture, stepwise, multiple regressions, spatial variability.

INTRODUCTION

Brazil is the largest sugar cane producer worldwide. According to the Brazilian National Food Supply Company – CONAB (2011), in the 2010/2011 season, 8 million ha of land was used to produce sugar cane; the Brazilian sugar cane production in the 2010/11 season was 624 million tons. Of this total, 288.7 million tons was used for the production of sugar, and 336.2 million tons was used for the production of ethanol. These numbers represent a 8.4% increase in sugar cane production compared with the previous season (CONAB, 2011).

Currently, sugar cane production is increasing to meet the global bioethanol demand. By this purpose, it is a tendency that the crop area of sugar cane keep expanding, estimating for the 2024/25 season 17 M ha (Landell et al. 2010) will be used for sugarcane cultivation. Although there are nearly 90 M ha available for agricultural expansion in Brazil (Leite et al. 2009), sugar cane production must take place not only in new sugar cane fields but mainly with the goal of improving the sugar cane yield (approximately 81 Mg ha^{-1}), which, in Brazilian sugar cane fields, has the genetic potential of 381 Mg ha^{-1} (Waclawovsky et al. 2010).

Among the factors related to the crop yield are the chemical attributes of the soil, which, in addition to having spatial variability, can vary over time for a given location (BERNOUX, 1998a, b). Due to the environment and human actions, these variations can exhibit a greater intensity in some properties than in others (BRAGATO & PRIMAVERA, 1998; BURKE et al., 1999; SLOT et al., 2001). The variability of soil properties has been investigated by several authors and has been attributed to several factors, such as the characteristics of the parental material (soil genesis) and those soil-formation factors that do not act over time but according a specific pattern.

Studies as Ribeiro et al. (1984), Prado et al. (1998), Landell et al. (1999), Landell et al. (2003) and Braga (2011) reported that soil attributes from the surface and subsurface influence differently on sugar cane yield, as well as the crop cycles. Johnson & Richard Jr. (2005) analysed the correlation of the soil chemical attributes with the yield and sugar cane quality parameters over a span of three years. A high degree of variability and spatial correlation was observed in both the soil properties and sugar yield and quality, suggesting that the PA approach is justified. The authors found that correlations between the soil properties and sugar cane yield did occur but that they were marginal and, thus, further studies should include assessments of the micronutrients.

Kumar & Verma (1997) applied multiple regression analyses among the leaf nutrients, sugar cane yield and juice quality parameters. They observed that the quantities of N, P, K, Zn and Cu explained 93% of the variation and that the leaf quantities of N, P, K and Cu explained 95% of the variation in the % sucrose and % commercial sugar content, respectively. Furthermore, these authors claimed that, under the conditions of the experiment, the leaf nutrient analysis could be used as a prediction factor of the sugar and cane yield. Landell et al. (2003) evaluated the effects of the subsurface chemical soil attributes in the south central region of Brazil on the sugar cane yield of clones and variety RB72454. Correlation and multiple regression analyses were performed with the selected variables based on the R^2 via a stepwise procedure. The clone yield model for the 3rd harvest, as a function of the base saturation and phosphorus content, presented 31% of the variation in the sugar cane yield (t ha^{-1} day^{-1}) explained by these two attributes. For variety RB72454, 47% of that variation was explained by the sum of the bases and the contents of calcium and organic matter.

Under Brazilian conditions, the use of correlation models between the quality parameters of sugar cane and soil attributes may help in the rationalization of the inputs and increase the quality of the raw material. Based on this context, the main goal of this study was to analyze the correlation among the soil physical and chemical attributes with the sugar cane quality parameters, Brix, pol and fibre, through a multivariate analysis (stepwise procedure) by selecting the main variables and to present a mathematical model to explain the variation of those quality parameters.

MATERIAL AND METHODS

The experiment was conducted in a commercial sugar cane field (10 ha) belonging to São João Mill, located in Araras, São Paulo State, Brazil, during three consecutive cycles: November 2008 (plant cane), December 2009-March 2010 (first ratoon – standover cane) and July 2011 (second ratoon). The area is located 166 km north of São Paulo city in the southeast region of Brazil at 22º 23' 38" S and 47º 18' 04" W. The field is 657 m above sea level and has a slope of 1.2%. The sugar cane variety planted in 2007 was SP80-3280 and was mechanically green-harvested during all of the cropping seasons. Currently, this variety represents approximately 4% of the sugar cane grown in Brazilian fields.

The area was divided into a regular 30-m grid (n=117) by means of the Pathfinder Office software (Trimble© Navigation Limited Sunnyvale, CA). The location points were made using a GPS GeoExplorer™ 3 (Trimble© Navigation Limited, Sunnyvale, CA) device. The plant samples were collected at each point to determine the sugar cane quality parameters just prior to the harvest. For this purpose, 10 plants were collected randomly in 2 m lengths of the same row. The Brix was determined using a refractometer, pol was determined using a polarimeter and fiber was determined based on the bagasse (Consecana, 2006).

Immediately after harvesting, soil samples were collected (0 – 0.2 m and 0.2 – 0.5 m) at each grid point to determine the soil's physical and chemical attributes. The chemical attributes analyzed were the soil organic matter (SOM), soil pH, P, K, Ca, Mg, H+Al, sum of bases (SB), cation exchange capacity (CEC), base saturation (V), B, Cu, Fe, Mn, Zn (Raij et al., 1987) and the physical attributes of the clay and sand content (Embrapa, 1979). With exception of soil's physical attributes that were done just on the first year, all of the operations performed at the end of the cane crop were undertaken in the second and third crop cycle (first and second ratoon). It was created a refined grid points for the 2011 sampling data, adding more 13 points randomly on the original grid, spaced 10 m from the closest point, totaling 130 grid points for the last year of the experiment.

The end of the year is a rainy season around the region of the experiment, because of that the first ratoon was not able to be harvested on December 2009, becoming a standover cane that was harvested on March 2010. So on this case, the plant samples of the first ratoon were collected on December 2009, following the grow cycle of the variety which represents the top of its maturity. In the middle of August 2010, because of the rigorous dry season the area suffered a partial accidental burn; the sub-area reached by the fire was around 1/3 of the total area (Fig. 1), affecting 44 points of the sampling grid – which were exclude from the variable selection and modeling process, avoiding external influence.

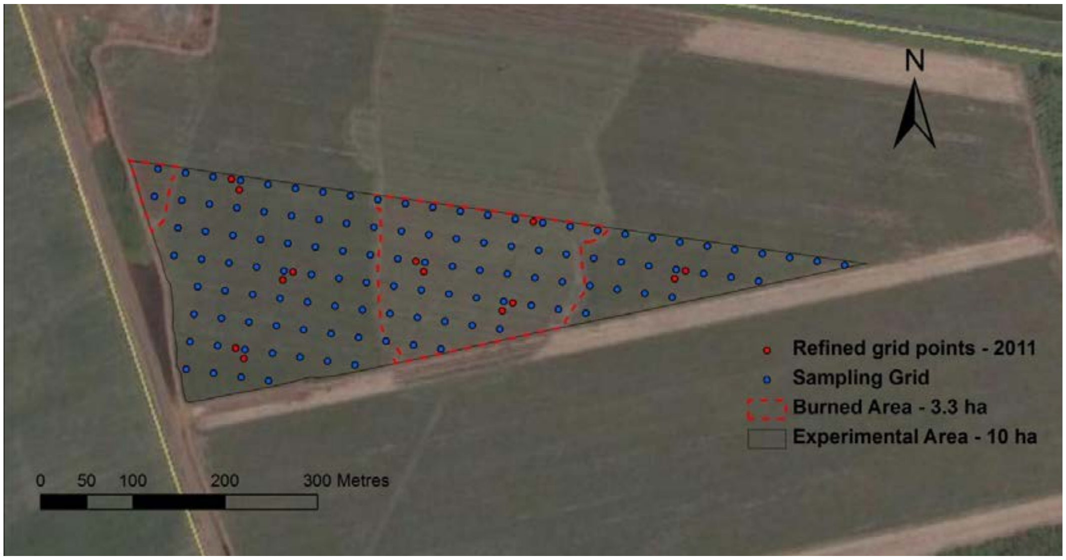

Fig. 1. Experimental Layout - Grid sampling, refined grid points and burned area.

Conventional descriptive statistical analyses of the samples were performed as a first approach for the evaluation of the parameters throughout the experiment. Skewness and kurtosis indices, together with Kolmogorov-Smirnov statistics, were calculated to test the normality of the data distribution. Additionally, box-plots were generated for each variable, and an analysis of spatial distribution was performed using three-dimensional surface plots to identify the outliers and artefacts. The outliers detected were treated using the mean of the four nearest neighbours from the outlier, adapted from Jolliffe (1986). This methodology was used as an alternative to reject the detected outliers from each variable.

Prior the modeling process, it was selected 70 points from the total grid aiming to run the variables selection process and create the models, afterwards, these created models were applied on the whole dataset. The variables selection was done by means of Stepwise procedure, forward direction with probability coefficient of 0.25 to include variables into the model. The independent variables on the selection and modeling process were the soil's physical and chemical attributes of both layers, except SB, CEC and V aiming to avoid multicollinearity. The independent variables from the previous crop cycle were used to model the quality parameters (dependent variables: Brix, pol and fiber) for the next crop cycle, i.e., the soil attributes sampled after the 2008 harvest (plant cane) were used to model the quality parameters for the second cycle (first ratoon) and the soil attributes sampled after the 2010 harvest (first ratoon – standover cane) were used to model the quality parameters for the third cycle (second ratoon) – excluding the sample points affected by the fire. After the selection process, the models were fitted by means of multiple regressions using the standard least squares method for Brix, pol and fiber of the second and third crop cycles.

The digital quality mapping (DQMa) and the digital quality modeling (DQMo) for Brix, pol and fiber were interpolated into a 2 m grid by global point kriging using Vesper 1.6 (The University of Sydney, Sydney, Au). For each variogram Space Dependence Index (SDI), being the ratio of nugget variance and sill, expressed as percentage, was calculated (Cambardella et al., 1994). The outputs from Vesper were carried out in ArcGIS 9.3 using the Spatial Analyst extension (Environmental Systems Research Institute, ESRI; Redlands, CA, USA).

RESULTS AND DISCUSSION

Exploratory statistical analysis

Based on descriptive analyses of the soil physical attributes, soil chemical attributes, leaf nitrogen and sugar cane quality parameters (Table 1) during the first year, all parameters (except for P, Ca, SB and CEC in the first layer and sand, P, SB and Mn in the second layer) of the 117 sampled points presented a distribution where the means and medians were similar, thereby revealing distributions that were only slightly asymmetrical. A similar case was repeated for the following year (except for Fe and SB in the first layer and P in both layers of the second year). Phosphorus variability is difficult to study because it has low mobility, especially in clay soils, and it is common for samples to be defiled by residual fertilizer particles.

Skewness and/or kurtosis coefficients presented values negative and near zero (except for P, K, Ca, Mg, SB, CEC, Cu and Zn in the first layer and P, K, Ca, Cu, Fe Mn and Zn in the second layer, which presented high values of skewness and/or kurtosis in the 2008 data). The majority of the variables from the 2010 dataset showed values higher than 2 for skewness and/or kurtosis. Johnson & Richard Jr. (2005) detected a significant and positive skew with a mean greater than the median for the majority of these properties, with the exception of K, Mg, CEC, and S, which were not significantly skewed.

All distributions were considered non-normal for the Kolmogorov-Smirnov statistic at a 5% level of significance with the following exceptions: Brix in 2011; pol in 2010 and 2011; fibre in 2010; sand and clay in both layers in 2008; V in both layers in 2008 and 2010; Fe0-0.2 in 2008. The coefficients of variation showed that only Brix, pol, fibre, pH (both layers) and sand (both layers just for the first year) during the three years had low variation ($CV \leq 12\%$), which was in agreement with the criteria reported by Warrick & Nielsen (1980).

The box plot and the analysis of spatial distribution showed that the detected outliers were the main cause of the high skewness, kurtosis and CV values as well as the non-normality of these distributions. The outlier values were replaced by the mean of the neighbours, thereby cleaning the data for the remaining of the analysis.

Table 1. Descriptive analysis for physical and chemical soil attributes and sugar cane quality parameters

	2008 (n = 117)						2009-2010 (n = 117)						2011 (n = 130)					
	med	mean	CV	sk	k	p-value	med	mean	CV	sk	k	p-value	med	mean	CV	sk	k	p-value
Brix	-	-	-	-	-	-	20.8	20.7	2.6	-0.36	0.31	0.02	19.2	19.1	4.1	-0.28	0.76	>0.15
pol	-	-	-	-	-	-	15.9	15.9	3.3	-0.59	0.41	>0.15	14.5	14.4	5.8	-0.59	1.17	>0.15
fiber	-	-	-	-	-	-	12.4	12.4	3.6	2.07	12.68	>0.15	11.5	11.7	7.2	0.93	1.14	<0.01
$Sand_{0-0.2}$	678.0	677.7	6.1	0.03	-0.30	>0.12	-	-	-	-	-	-	-	-	-	-	-	-
$Clay_{0-0.2}$	235.5	232.5	14.0	-0.06	-0.10	>0.15	-	-	-	-	-	-	-	-	-	-	-	-
$SOM_{0-0.2}$	20.0	19.6	12.1	-0.20	-0.10	<0.01	18.0	18.7	11.6	0.51	2.51	<0.01	-	-	-	-	-	-
$pH_{0-0.2}$	5.5	5.5	7.3	0.60	-0.04	<0.01	5.3	5.3	6.5	0.41	-0.29	<0.01	-	-	-	-	-	-
$P_{0-0.2}$	51.0	65.2	103.6	5.40	34.60	<0.01	45.0	60.4	92.2	5.22	37.88	<0.01	-	-	-	-	-	-
$K_{0-0.2}$	1.0	1.1	31.8	1.50	3.30	<0.01	0.9	0.9	34.7	2.23	8.10	<0.01	-	-	-	-	-	-
$Ca_{0-0.2}$	37.0	39.4	40.4	2.40	9.40	<0.01	32.0	34.6	35.3	2.60	13.21	<0.01	-	-	-	-	-	-
$Mg_{0-0.2}$	12.0	13.4	45.7	2.30	8.70	<0.01	10.0	10.6	38.6	2.22	8.25	<0.01	-	-	-	-	-	-
$H+Al_{0-0.2}$	16.0	17.3	26.0	0.40	0.10	<0.01	22.0	21.4	23.6	0.27	-0.52	<0.01	-	-	-	-	-	-
$SB_{0-0.2}$	50.9	54.1	39.8	2.13	6.55	<0.01	43.6	46.2	33.8	2.66	13.39	<0.01	-	-	-	-	-	-
$CEC_{0-0.2}$	68.1	71.4	26.1	2.40	8.60	<0.01	66.0	67.8	19.7	3.13	19.27	<0.01	-	-	-	-	-	-
$V_{0-0.2}$	74.0	73.5	13.6	-0.13	-0.59	>0.15	67.0	66.9	14.5	0.17	-0.50	>0.15	-	-	-	-	-	-
$B_{0-0.2}$	0.1	0.1	24.2	0.06	0.50	<0.01	0.1	0.1	14.3	0.35	-0.26	<0.01	-	-	-	-	-	-
$Cu_{0-0.2}$	0.9	0.9	29.0	2.50	11.70	<0.01	1.1	1.2	103.1	9.59	98.61	<0.01	-	-	-	-	-	-

$Fe_{0-0.2}$	34.0	34.4	33.4	0.80	1.60	>0.05	55.0	61.5	95.0	9.41	96.69	<0.01	-	-	-	-	-	-
$Mn_{0-0.2}$	2.9	2.9	34.0	0.60	0.03	<0.03	4.8	5.5	85.7	8.61	85.41	<0.01	-	-	-	-	-	-
$Zn_{0-0.2}$	0.4	0.4	43.4	3.70	21.20	<0.01	0.4	0.5	75.8	4.67	27.90	<0.01	-	-	-	-	-	-
$Sand_{0.2-0.5}$	652.0	649.8	6.2	-0.03	-0.18	>0.15	-	-	-	-	-	-	-	-	-	-	-	-
$Clay_{0.2-0.5}$	253.5	253.9	12.2	0.16	-0.18	>0.15	-	-	-	-	-	-	-	-	-	-	-	-
$SOM_{0.2-0.5}$	14.0	13.8	11.3	0.95	2.88	<0.01	12.0	12.6	11.9	0.68	-0.12	<0.01	-	-	-	-	-	-
$pH_{0.2-0.5}$	5.30	5.3	6.8	0.01	-0.35	<0.01	5.2	5.2	7.0	0.09	-0.36	0.02	-	-	-	-	-	-
$P_{0.2-0.5}$	20.0	29.1	96.0	3.12	12.92	<0.01	20.0	25.7	77.8	3.34	18.19	<0.01	-	-	-	-	-	-
$K_{0.2-0.5}$	0.60	0.6	40.7	1.71	3.38	<0.01	0.4	0.4	46.9	0.68	0.78	<0.01	-	-	-	-	-	-
$Ca_{0.2-0.5}$	23.0	24.5	32.9	1.41	3.67	<0.01	20.0	21.2	34.6	1.65	7.04	<0.01	-	-	-	-	-	-
$Mg_{0.2-0.5}$	9.00	9.9	34.9	0.81	0.54	<0.01	8.0	8.4	35.9	1.59	6.48	<0.01	-	-	-	-	-	-
$H+Al_{0.2-0.5}$	18.0	17.5	24.4	0.60	0.72	<0.01	20.0	19.9	20.9	0.33	-0.16	<0.01	-	-	-	-	-	-
$SB_{0.2-0.5}$	33.2	35.1	31.7	1.04	1.63	<0.01	29.1	30.0	33.4	1.69	7.77	<0.05	-	-	-	-	-	-
$CEC_{0.2-0.5}$	51.4	52.7	16.7	1.11	2.21	<0.01	49.0	50.1	15.8	2.13	10.36	<0.01	-	-	-	-	-	-
$V_{0.2-0.5}$	65.0	65.3	16.6	-0.08	-0.53	>0.15	60.0	58.7	19.0	-0.16	-0.19	>0.15	-	-	-	-	-	-
$B_{0.2-0.5}$	0.1	0.1	24.1	-0.19	-0.45	<0.01	0.1	0.1	17.7	-0.66	3.08	<0.01	-	-	-	-	-	-
$Cu_{0.2-0.5}$	0.6	0.6	34.0	2.78	14.19	<0.01	0.6	0.6	29.6	1.15	2.79	<0.01	-	-	-	-	-	-
$Fe_{0.2-0.5}$	22.0	22.2	38.4	2.51	13.45	<0.01	30.0	31.6	31.7	1.83	7.08	<0.01	-	-	-	-	-	-
$Mn_{0.2-0.5}$	1.0	1.5	243.1	9.31	92.59	<0.01	1.6	1.8	53.7	2.05	7.29	<0.01	-	-	-	-	-	-
$Zn_{0.2-0.5}$	0.2	0.2	47.4	2.46	8.41	<0.01	0.2	0.2	68.5	1.18	1.77	<0.01	-	-	-	-	-	-

where: med - median; CV – coefficient of variation; sk – skewness; k – kurtosis; p-value for normality test. Brix, pol, fiber, V in (%); sand, clay in (g kg-1); SOM in (g dm-3); P, B, Cu, Fe, Mn, Zn in (mg dm-3); K, Ca, Mg, H+Al, SB and CTC in (mmolc dm-3).

Variables selection and modeling process

By using Stepwise procedure, via forward direction with 0.25 significance level to input the variables into the model, It were selected from two to 11 variables among the 28 initial variables (Table 2) throughout the analyzed years using Brix, pol and fiber as dependent variables. All the selected variables were statistically significant at 5 and/or 10% of probability.

All the models were statistically significant at 5% level, explaining 36 and 46% of Brix variation, 15 and 47% of pol variation, 12 and 80% of fiber variation for the first and second ratoon respectively. All the RMSE ranged between 0.33 to 0.50%, being no more than 1% of the respective variables. Based on the selected variables for both crop cycles, it was possible to verify that they did not follow any pattern. Except pH0-0,2 and Fe0,2-0,5 for Brix both crop cycles, the rest of the variables did not reply from the first to the second cycle. This event may have been caused due to several factors and different scenarios, such as the plant sampling time for analysis of quality parameters, which for the first ratoon was done in December 2009 – following the peak of the maturity; however, for the second ratoon the plant sampling was done in June 2011 due the previous crop cycle become standover cane, being harvested in March 2010. It is also possible to claim the different climate conditions that each crop cycle was submitted.

These results were different from results reported by Braga (2011), which analyzed the correlation among physical and chemical soil attributes and quality parameters of sugar cane SP79-1011 variety, on its third cycle (second ratoon). The author reported 0.20 of correlation coefficient between Brix and aluminum saturation and 0.18 among fiber and Al and aluminum saturation, based on soil and plant data sampled simultaneously. The crop variety, combined with the crop cycle studied and the sampling methodology may be the reasons for the divergence between the study's results.

Regarding the selected variables, all them have their particularity on the plant growth development and sugar concentration along the crop cycle. The pH and H+Al, which were relevant variables on the models, when at suitable levels are suitable for root development and nutrients absorption, contributing for yield increase (Faroni and Trivelin, 2006; Bologna-Campbell, 2007; Vitti et al. 2007) and sugar concentration. Thus, it is possible to report that each scenario will have different relevant variables that may explain events such as the quality parameters of sugar cane, furthermore, although the models showed significant statistic coefficients, taking in account the group of selected variables in each quality model and their coefficient signals, it was impossible to have an agronomical explanation for such relationships, then some variables and coefficients may be purely mathematical adjustments.

Table 2. Brix, pol and fiber models

1º ratoon (2009)						2º ratoon (2011)					
Coef.	Brix	Coef.	Pol	Coef.	Fiber	Coef.	Brix	Coef.	Pol	Coef.	Fiber
Soil data - 2008						Soil data - 2010					
12.8	Interc.	12.6	Interc.	11.9	Interc.	28.8	Interc.	16.1	Interc.	29.7	Interc.
0.006	$Areia_{0-0.2}$*	0.004	$Areia_{0-0.2}$*	0.039	$MO_{0-0.2}$*	-1.311	$pH_{0-0.2}$*	0.091	$H+Al_{0-0.2}$*	-0.024	$Areia_{0-0.2}$*
0.627	$pH_{0-0.2}$*	0.111	$SOM_{0-0.2}$*	-0.122	$Mn_{0-0.2}$*	-0.046	$H+Al_{0.2-0.5}$*	-0.199	$Mn_{0-0.2}$*	-0.018	$Argila_{0-0.2}$*
-0.034	$Ca_{0-0.2}$*	-0.065	$Mg_{0.2-0.5}$*			-1.999	$Cu_{0.2-0.5}$*	-0.038	$H+Al_{0.2-0.5}$**	-0.011	$Argila_{0.2-0.5}$**
0.216	$SOM_{0.2-0.5}$*	-0.029	$Fe_{0.2-0.5}$*			-0.334	$Mn_{0.2-0.5}$**	-2.646	$Cu_{0.2-0.5}$*	0.806	$pH_{0-0.2}$*
-0.022	$Ca_{0.2-0.5}$*					1.962	$Fe_{0.2-0.5}$*	1.659	$Zn_{0.2-0.5}$**	-0.821	$K_{0-0.2}$*
-0.034	$Fe_{0.2-0.5}$*									1.305	$Cu_{0-0.2}$**
										1.860	$Zn_{0-0.2}$*
										1.391	$K_{0.2-0.5}$*
										-0.040	$Ca_{0.2-0.5}$*
										13.73	$B_{0.2-0.5}$*
										-2.077	$Cu_{0.2-0.5}$*
R^2	0.364		0.158		0.124	R^2	0.465		0.478		0.804
Fcalc	0.0001*		0.0305*		0.015*	Fcalc	0.0002*		0.0001*		0.0001*
RMSE	0.395		0.430		0.335	RMSE	0.502		0.502		0.448

Where: Brix, pol and fiber in (%); coef. – Model coefficient; Interc. – Model intercept; R2 – coefficient of determination; Fcalc – F test; RMSE – root mean square error; * - statistically significant at 5%; ** - statistically significant at 10%.

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The parameters of the variograms for each attribute measured and estimated for both years (Table 3) that provided better adjustments were chosen based on the root mean square error and Akaike criteria.

Table 1. Variograms obtained for Brix, pol and fibre using measured and estimated values

		Model	C	Co	(C+Co)	A (m)	IDE (%)
1ª soca	$Brix_{measured}$	Gaussian	0.0429	0.2234	0.2663	113.8	83.8
	$Brix_{estimated}$	Exponential	0.1043	0.0600	0.1643	123.7	36.5
	$Pol_{measured}$	Gaussian	0.0418	0.2043	0.2461	300.0	83.1
	$Pol_{estimated}$	Exponential	0.0221	0.0171	0.0392	39.6	43.6
	$Fiber_{measured}$	Gaussian	0.0439	0.0954	0.1393	47.7	68.4
	$Fiber_{estimated}$	Exponential	0.0048	0.0114	0.0162	65.3	70.3
2ª soca	$Brix_{measured}$	Exponential	0.2240	0.2317	0.4557	55.3	50.8
	$Brix_{estimated}$	Gaussian	0.1604	0.1000	0.2604	37.4	38.4
	$Pol_{measured}$	Exponential	0.2867	0.2778	0.5645	72.1	49.2
	$Pol_{estimated}$	Gaussian	0.1793	0.1594	0.3387	30.0	47.0
	$Fiber_{measured}$	Exponential	0.7787	0.0221	0.8008	111.3	2.7
	$Fiber_{estimated}$	Gaussian	0.3722	0.2618	0.6340	112.5	41.3

where: C= Partial Sill; Co = Nugget; (Co+C) = Sill; A = Range; SDI = [Co/(Co+C)].100

The estimated and measured Brix for the first ratoon presented SDI values that were considered moderate (26 to 75%) and low (76 to 100%) (Table 3), respectively. For the second ratoon, they had moderate spatial dependence, according to Cambardella et al. (1994). The estimated and measured pol showed a low/moderate degree of spatial dependence for the first ratoon and a moderate spatial dependence for the second ratoon. The estimated and measured fiber showed a moderate degree of spatial dependence for the first ratoon and a high degree of spatial dependence for the second ratoon, except fiber estimated. In general, the refined grid created for the second ratoon sampling was responsible for the variograms being more robust with the spatial structure described as having better SDI values as compared to the year before, and maps not so smoothed (Fig. 2). Thus, it is possible to recommend the creation of a refined grid using a percentage of the grid points, locating them closer than the distance between points of the regular grid, in order to satisfy the requirement of minimizing the ratio of the smallest to largest separation distance (Bramley & White, 1991; Bramley, 2005).

Brix and pol models from the second ratoon obtained lower R2 than fiber model (second ratoon), but it was possible to observe that they represented the burned area with overestimates values, whereas it was expected higher values of sugar concentration if in case of no fire accident on the experiment.

The soil attributes represent only a portion of the factors that affect sugar cane quality, and it is known that climate changes, management choices and genotypes may contribute to the variability of the quality. However, generating models describing the quality parameters with a small range of residue may provide explanation of how these quality parameters of this specific variety and scenario reacted to such soil attributes concentrations, making possible to confront those information with the literature, providing answers of which controlled attributes should be focused to improve quality.

Taking in account the results of this analysis, SOM showed to be an important attribute, because it was selected both first and second layer to describe the three quality parameters studied, being justified its absence on the second ratoon models because of high correlation among SOM and micronutrients verified in pre-analysis, resulting on the selection of attributes such as Cu, Mn, B, Fe and Zn. Beyond of SOM, pH and H+Al showed their importance as well, whereas in satisfactory levels they promote the nutrients absorption by the plants and root development, as discussed previously.

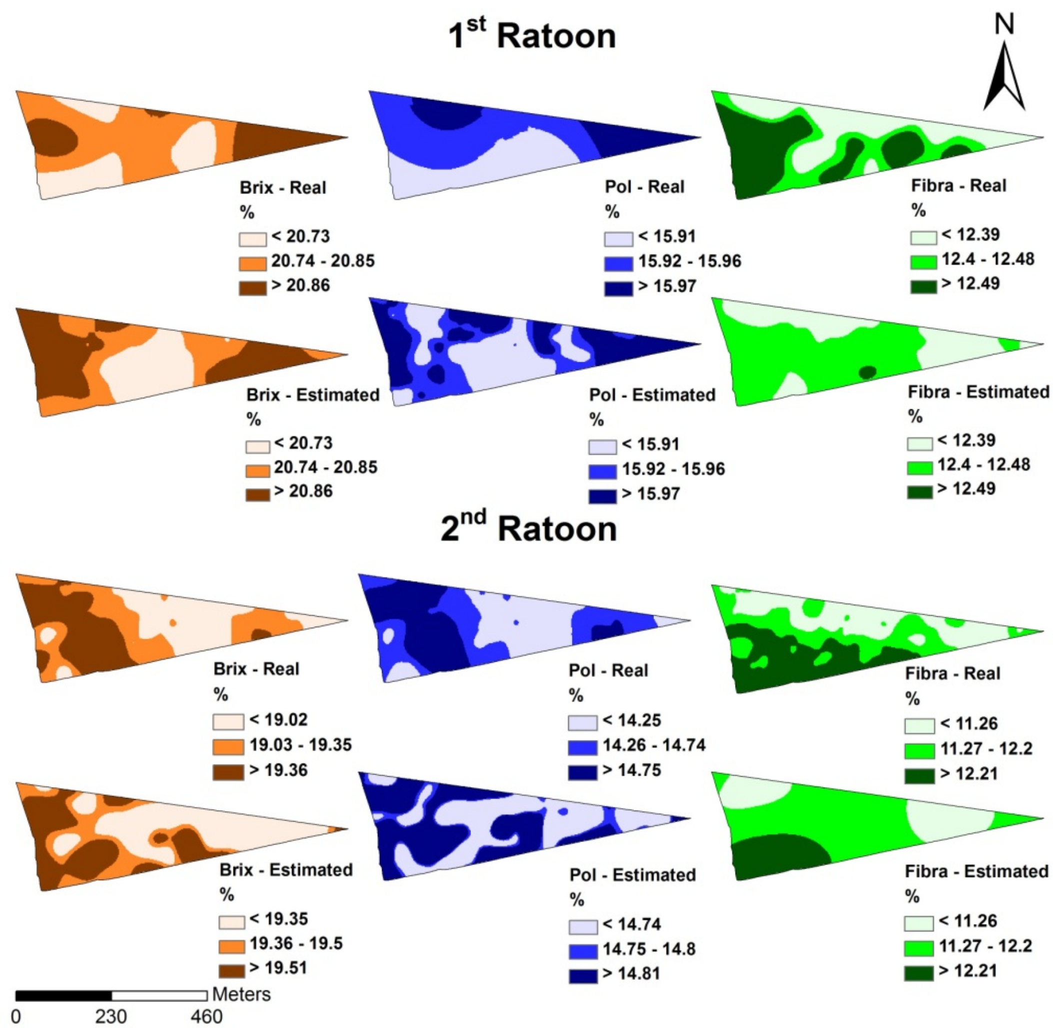

Fig. 2. Spatial variation of Brix, pol and fiber in the study area.

CONCLUSION

The selection of the main variables to explain the quality parameters of sugar cane along two crop cycles by means of Stepwise procedure allowed the determine the following variables MO, pH and H+Al as relevant to describe Brix, pol and fiber concentration. The regression models showed determination coefficients from low to high, with low values of RMSE, being able to the spatial structure of the estimated and measured values within the experiment area.

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