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IMPLICATIONS OF SOIL SAMPLING PROCESSES ON RECOMMENDATIONS OF PHOSPHATE AND POTASSIUM FERTILIZERS ON SUGARCANE

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ABSTRACT - The aim of this work was to evaluate the implications of soil sampling methods, phosphate (P) and potassium (K) fertilizers cost for sugarcane cultivation. The sampling methods were evaluated over 35.09 ha in Igaraçu Tietê, SP, Brazil, being divided in: without soil sampling, one sample in 35,09 ha, one sample per plot, one sample by management zone, and 3.0 ha and 0.5 ha grid sampling. The Campeiro Software 6.0 was used to generate fertilizer maps showing the needs, deficit, and excess of P and K, based on these fertilizers recommendation at constant rate (without soil sampling, one sample in 35,09 ha, one sample per plot and one sample by management zone) and at variable rate (sampling grid of 3.0 ha) and all of them were compared to 0,5 grid sampling (that has higher detail). Furthermore, the fertilizer cost was evaluated for each sampling method and its recommendation. The join assessment results for deficits, excesses, percentage of area using the right fertilizer rate, and fertilizer cost by sampling method, indicate that higher detailed sample methods, as the sampling grid of 3.0 ha, followed by management zones and plots, respectively, improved the sugarcane fertilizer efficiency, despite the additional cost with soil sample, interpretation, and application of fertilizer.

Keywords: Sacharum spp, precision agriculture, variable rate, plots, management zones.

IMPLICAÇÕES DOS MODOS DE AMOSTRAGEM DO SOLO NAS RECOMENDAÇÕES DE FERTILIZANTES FOSFATADOS E POTÁSSICOS PARA A CANA-DE-AÇÚCAR

RESUMO - O objetivo deste trabalho foi avaliar as implicações dos modos de amostragem de solo na recomendação e custos com fertilizantes fosfatados e potássicos na cultura da cana-de-açúcar. Os modos de amostragem avaliados, em uma área de 35,09 ha em Igaraçu do Tietê, SP, Brasil, foram: sem amostragem de solo, uma amostra de solo média, 1 amostra média por talhão, 1 amostra média por zona de manejo, amostragem em grade de 3,0 ha e 0,5 ha. De posse dos teores de P e K no solo, e com auxilio do programa Campeiro 6.0, foram criados mapas de necessidades, déficits e excessos de P e K, considerando as recomendações de adubação fosfatada e potássica a taxa fixa para os modos de amostragem (sem amostragem de solo, uma amostra de solo, talhões e zonas de manejo) e a taxa variável (para amostragem em grade 3,0 ha) comparados com a grade de amostragem de 0,5 ha (maior nível de detalhamento). Além disso, foi avaliado o custo com fertilizante em cada modo de amostragem e recomendação de fertilizante. Os resultados da avaliação conjunta dos déficits, excessos, porcentagem de acerto e custo com fertilizante indicam que modos de amostragem com maior nível de detalhamento, como a amostragem em grade de 3,0 ha, seguido por zonas de manejo e talhões, respectivamente, foram superiores a aplicação de fertilizantes baseada em uma amostra média ou sem amostragem de solo. Apesar do custo adicional, as amostragens em grade, por zonas de manejo ou por talhões, apresentam grande potencial de maximizar a eficiência no uso de fertilizantes em cana-de-açúcar.

Palavras-chave: *Sacharum spp*, agricultura de precisão, taxa variável, zonas de manejo.

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1 INTRODUCTION

The evolution of sugarcane agro-industrial technology in recent years result in significant increase in Brazilian production. The 2012/2013 sugarcane productionreached 589 million tons, having grown at 8.48 million hectares, giving Brazilian sugarcane cultivation an average stalk productivity of about 69 Mg ha-1. From the total cultivated area, 52% is situated in São Paulo state, which presents an average productivity of 75 Mg ha-1 (CONAB, 2013). Despite those achievementes, the productivity is still below the genetic potential of the cultivars (ALBUQUERQUE; SILVA, 2008). Among the main factors limiting that productivity, the soil nutrient availability is the most relevant.

Up to the present, large agriculture areas are taken as homogenous, leading to the concept of average necessity for ferilizer inputs which results in, for example, the same formulation and/or amount of fertilizer being used for all the area, supplying no more than the average necessities, not taking into account, in this type, the specific necessities of every plot in the field (TSCHIEDEL; FERREIRA, 2002). On the other hand, in Brazil, a increasing growth is being observed in the last years in the use of geo-reference samplings for the fertility mapping of soil and, consequently, the distribution of correctives and fertilizers at a variable rate (RESENDE et al., 2010). The sampling that allow characterize a spacial variability of the soil attributes is the triggering point for the adoption of fertilizer applications at a variable rate. iWith that, geo-referred samples aligned in a sample grid, are . The ideal sampling density changes according to the area under study, as well as the consequent dependence on any attribute of the analized soil, making it difficult to extrapolate the recommendation. Split of the plot is performed by the sampling grid net mean of variable size, while the choice of the sampling net is done based on the costs.Low density sampling is frequently used for reducing costs. This procedure does not guarantee that, within each cell, the soil characteristics and properties will be always homogenous (RESENDE et al., 2010).

Productivity depends on land characteristics like topography, soil type, texture, humidity retention capacity, etc., which influence the soil fertility. Therefore, a preliminary diagnosis of the causes for productivity variation enables the correction advance on the simple soil sampling and reduces the number of collecting points. Although being a more laborious operation than the simple soil sampling and the creation of interpolated maps, the identification of homogenous management zones within the cultivation areas (MOLIN; CASTRO, 2008) is another form to obtain data for subsidising the application of fertilizers at a variable rate.

Application at variable rate appears as an alternative for enhancing the efficiency of fertilization in cultures, but a proper characterization of the variability, associated to the knowledge of the nutrient dynamics in the soil are factors that define that efficiency. In Brazil, application at variable rate of fertilizers has been carried out with application equipment at fixed rate within the management zones, or by means of equipment having electronic controllers apt to liberate different doses of products according to the necessities of each site. This kind of application has predominantly been made via broadcasting application (in total areas), causing doubts in relation to the availability of phosphorus in the soil, once this element has elevated capacity of fixaction onto the soil colloids, a fact which is worsened when this nutrient is applied by broadcasting.

In Brazil, there is a gap on specific researches related to fertlizing management. Because of this, aiming to contribute with more information about this subject, this work evaluates the amount of recommended fertilizers, as well as the costs of phosphate and potassium fertilizers in different proposed types of soil sampling.

2 MATERIAL AND METHODS

Of the research area is located in Igaraçu do Tiete, SP, and belong to the Barra Sugar Mill. The place has a history of many years of sugarcane cultivation, in a 35.09 ha of Oxisol area (EMBRAPA, 2006). The equipment GPSMAP GARMIM 60CSx was used for the definition of the area outline. Later, using the CAMPEIRO 6.0 program, data of this outline were downloaded. Via that program a sampling grid was defined (1 point at each 0.5 ha).. Using the GPS to locate the collection points, the soil was collected in a Dutch auger type, from layers of 0.0-0.20 and 0.20-0.40 m, in 5 sub-samplings located at 10 m from the site defined by the Campeiro 6.0 program. Data was collected through August 2009, during the season of sugarcane reformation, after revolving the soil. Those samples were duly identified and sent for laboratory analysis, where P and K contents were determined, according to the methodology proposed by RAIJ et al. (2001).

The Campeiro 6.0 program was used to confecctionate theme maps of P and K necessities, as well as of both deficit and excess of those nutrients, (GIOTTO, 2006). The geostatistics analysis was made to check both the existentence and the amount of the grid spacial dependency among the tests, based on the assumption of stationarity of the intrinsic hypothesis, which is estimated by means of Equation 1, according to Vieira (2000):

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad (1)$$

Where N(h) is the number of experimental pairs of observations $Z(x_1)$ and $Z(x_1+h)$, separated by an h distance. The variogram is represented by the graph γ*(h) versus h. From the adjustment of a mathematical model to the calculated values of γ*(h), the coefficients of nugget effects (C_0) are estimated, as well as the level (C_0+C_1) and the range (a) of the theoretical model for the variogram. For the choice of the variograma it was taken into consideration which one presented the lowest values in the average absolute deviation. The spacial distribution maps were obtained by means of data interpolation via ordinary kriging.

The typess of sampling and fertilizers recommendation on the 35.09 ha were as follows:

2.1 Without soil sampling and aplication at fixed rate – (WSS-FRA)

Many sugarcane producers do not use the soil sampling for fertilizer recommendation, and, in these cases, application is made of 500 kg ha^{-1} of a formulate having 25% of P_2O_5 and 25% of K_2O on the sugarcane field (Table 1).

2.2 One soil sample and fixed rate application (OSS - FRA)

For this kind of sampling, a composite sampling was withdrawn so as to represent the 35.09 ha. Average contents of P and K were taken into consideration for further recommendation of adubation, according to Spironello et al. (1997). , The standard formulate (00-25-25) may be or a formulate adequated to the necessities shown via soil analysis can be used (Tabel 1).

2.3 Sampling and application based on plot (PLOT)

Generally, sugarcane plots are sub-divided in relation to the soil topography and homogeneity having regarding mechanical operation optimization. The plots are usually smaller when in steeper areas and larger in plane areas, which, in general, reflects the existing variability in the soil, although large plots do not adequatly represent contents in the soil, necessity being therefore created for spliting those plots. Because of that, in this study, 5 plots were defined based on roads and terraces (Figure 1A). After that division, contents of P and K within each plot were considered for further adubation recommendations according to Spironello et al. (1997), taking into consideration the use of a formulate adequated to the needs appointed by the soil analysis (Table 1).

Table 1- *Results of soil analysis, recommendation of fertilizers in different sampling typess, in a sugarcane reforming area in Igaraçu do Tiete, SP, 2009.*

Types of Sampling and Fertilizer Application	Sampling	Results		Recomendation[4]		Fertilizer Formulate	
		P	K	P_2O_5	K_2O	Type	Quantity
		mg dm^{-3}	$mmol_c$ dm^{-3}	Kg ha^{-1}			Kg ha^{-1}
WSS-FRA	0	-	-	-	-	00-25-25	500
OSS-FRA	1[1]	29	4,7	80	60	00-25-25	320
						00-24-18	333
Plot	Plot 1[2]	27	1,2	80	120	00-20-30	400
	Plot 2[2]	31	2,9	80	80	00-25-25	320
	Plot 3[2]	20	5,7	80	60	00-24-18	333
	Plot 4[2]	37	7,4	80	0	TSP	195
	Plot 5[2]	18	6,8	80	0	TSP	195
Management Zone	Zone 1[3]	18	1,2	80	120	00-25-25	480
						00-20-30	400
	Zone 2[3]	25	3,6	80	60	00-25-25	320
						00-30-20	285
	Zone 3[3]	26	6,7	80	0	00-25-25	320
						TSP	195

WSS-FRA = Without soil sampling and aplication at fixed rate; OSS-FRA = One soil sample and fixed rate application; TSP = triple superphosphate; [(1)] 15 subsamples in 35.09 ha; [(2)] 4 subsamples per plot; [(3)] 10 subsamples in each management zone; [(4)] based on recommendations by Spironello et al. (1997).

2.4 Sampling and application based management zones (MANEGEMENT ZONE)

In this work three zones of management were created which were determined as a consequence of the clay contents as well as organic matters in the soil (SOM), based on a samplig grid of 0.5 ha. To define the management zones (Figure 1B), contents of clay and SOM were taken into consideration in 0.0 to 0.4 m layer, where 50% importance was attibuted to each factor, whereas the maximum value for both clay and SOM represented 100%. After spliting into three management zones, P and K average contents within each management zone were measured for further recommendation of adubation according to Spironello at al. (1997), considering that the producing unity has at its disposal only a standard formulate (00-25-25), or the use of a formulate adequated to necessities pointed by the soil analysis (Table 1).

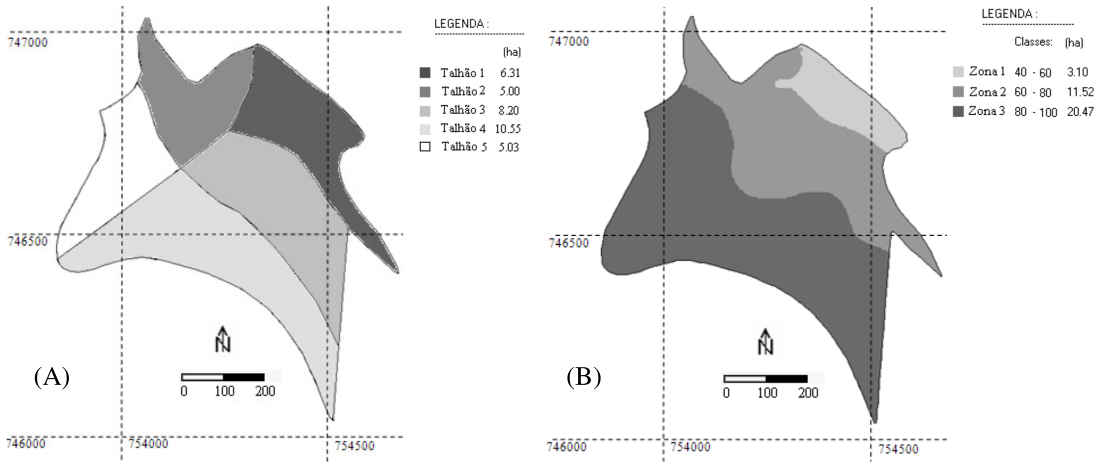

Figure 1- *Division of the area into plots (A) and management zones based on the índex clay + SOM (B) in a reforming area of sugarcane in Iguaraçu do Tietê- SP, 2009. Legenda = Legend; Talhão = Plot; Zona = Manegement zone.*

2.5 Grid sampling (GRID) and application at variable rate (VRA)

The rate application variable was determined by considering the grid sampling, from a sampling point at each 0.5 ha and fertilizer doses based on the regression equations adapted from the recommendations proposed by Spronello et al. (1997), by means of triple superphosphate (TSP) and potassium chloride (KCl) to meet the necessities of P_2O_5 (Figure 2A) and K_2O (Figure 2B)., The standard or ideal sampling and application type was considered for comparison among the other typess of sampling and fertilizer application.

An average content of each class was used in the regression equations adapted to the recommendations proposed by Spironello et al. (1997), having the specific recommended amount of P_2O_5 and K_2O, for an expected productivity of 100 a 150 Mg ha^{-1}. The regression equations used were as follows:

$$P_2O_5 = 225{,}57 - 43{,}04 \ln(x) \qquad R^2 = 0{,}99$$

(2)

$$K_2O = -2{,}1847x^3+21{,}512x^2-79{,}547x+181{,}31 \qquad R^2=0{,}99$$

(3)

Where X is the content of P and K in the soil, given in mg dm^{-3} and $mmol_c$ dm^{-3}, respectively.

By obtaining the regression equations, we aimed at subdividing the present classes of recommendation without missing the theoretic experimental references that already existing (Spironello et al.,1997) for sugarcane in SAoo Paulo state.

For the second application was of sampling by 0.5 ha grid, using fertilizer recommendation proposed by Spironello et al. (1997), with TSP and KCl application for meeting the P_2O_5 (Figure 2C) and K_2O (Figure 2D) necessities. For the same application type, the variable rate was also considered the 0.5 ha grid, with fertilizing recommendation based on the regression equations, but applying the formulate 00-25-25, aiming at first meeting the necessities of P_2O_5 (Figure 2A), and following, the K_2O necessities (Figure 2B). In this last application type, using the variable rate, contents pointed at 3.0 ha grid were taken into consideration, with further recommendation based on the regression equations, by means of application of TSP and KCl, as for meeting the necessities of P_2O_5 (Figure 2E) and K_2O (Figure 2F). For all these typess of fertilizer applications at variable rate, except for the third application type at variable rate, it was considered that application would be performed in the planting groove as needed amounts in isolated forms of KCl and TSP. Nevertheless, for this procedure, it would be necessary an adaptation of a sugarcane planter with isolated boxes of simple fertilizers and flow controllers, a technology already available.

Maps of P_2O_5 and K_2O excess and deficit were created by comparing the necessities of these elements among the type of application of the fertilizer at variable rate, based on the soil analysis in the 0.5 ha grid sampling, together with the adapted recommendations of classes already proposed by Spironello et al. (1997) (Figure 2A and 2B), and the other fertilizer aplication typess, within the comparative analysis of digital models – cells, Campeiro 6.0. From these maps, calculations were made of deficits and excesses P_2O_5 and K_2O (kg ha^{-1}). Besides, the adequate adubation percentage of thearea was calculated. As adequate adubation, we considered the area having a maximum deficit or excess of 10 kg ha^{-1} of P_2O_5 and K_2O.

The costs of fertilizers considered for TSP, KCl, formula 00-25-25, 00-24-18, 00-20-30, and 00-30-20 were, respectively, R$655.00 Mg^{-1}, R$1290.00 Mg^{-1}, R$1006.00 Mg^{-1}, R$831 Mg^{-1}, R$1031.00 Mg^{-1}, and R$980.00 Mg^{-1}, prices based on quotations for the month of August 2009, for Sao Paulo state (IEA, 2009). A value of R$56.00 was added to these quotations, reffered to the transportation from the port terminal to the city of Igaraçu of Tiete, SP (SIFRECA, 2009).

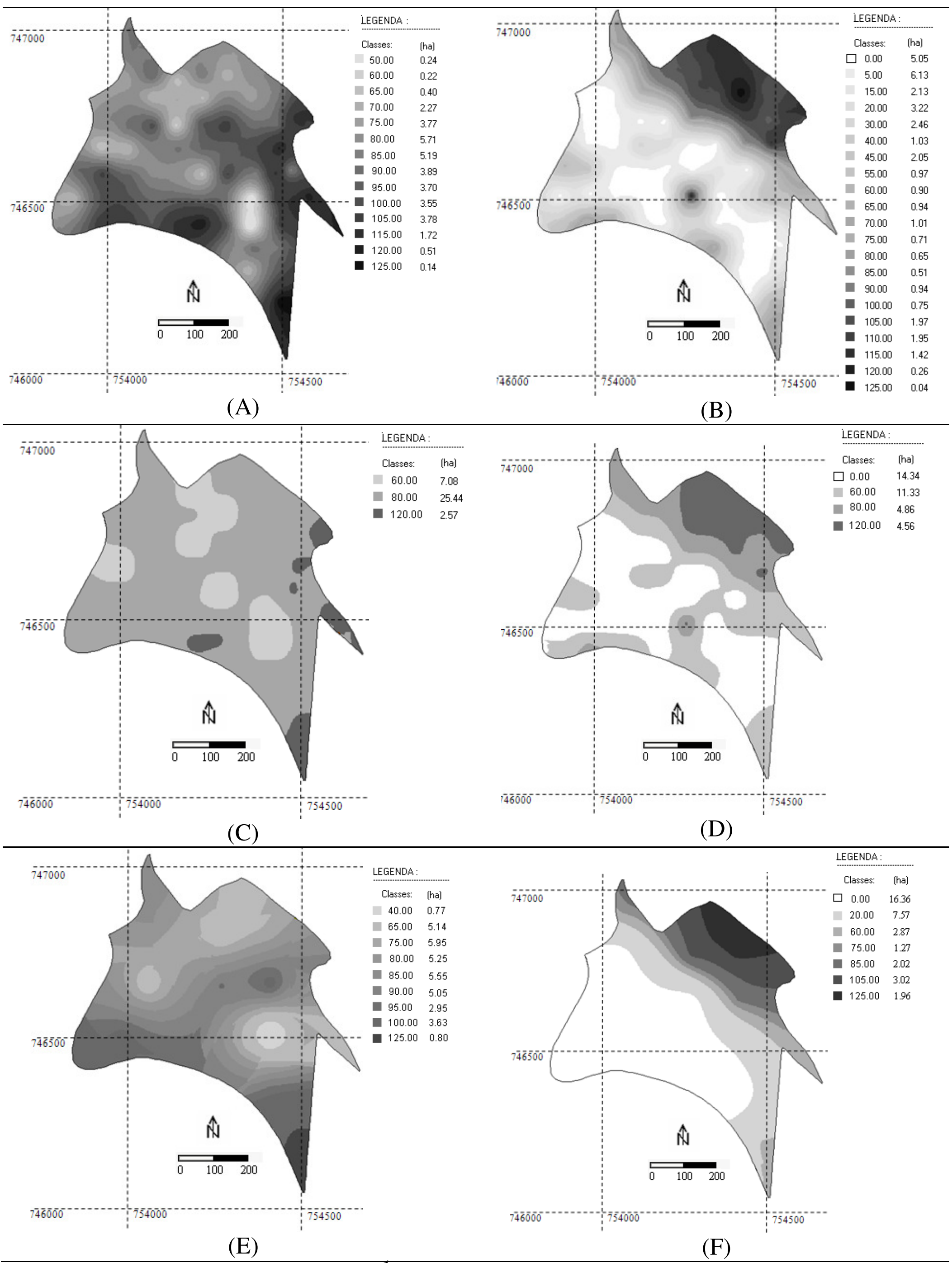

Figure 2 - *Necessity of P_2O_5 and K_2O kg ha^{-1}, considering a sampling grid of 0.5 ha with recommendations according to regression equations adapted from Spironello at al. (1997) (A and B), and according to classes proposed by Spironello et al. (1997) (C and D), and sampling grid of 3.0 ha under recommendations of regression equations adapted from Spironello et al. (1997) (E and F) in a reformation sugarcane area in Igaraçu do Tiete – SP, 2009. Legenda = Legend.*

3 RESULTS AND DISCUSSION

Values of chemical attributes P and K presented a wide range, once for P, the values varied from 10 to 63 mg dm^{-3}, and for K, from 0.9 to 10.3 $mmol_c$ dm^{-3} (Table 2). According to Coelho (2003), this wide range of values reveals the problems that can occur when the average of the attribute is used as the basis for the decision maker about the performance of chemical management of soil, and can happen both in areas with deficit or excess of nutrients.

K presented the highest VC (57.11%), above the 43.60% and 29.00% found by Marques Junior et. al. (2008) and Barbieri et al. (2008) in sugarcane cultivated soils. The VCs were classified according to criteria stablished by Warrick and Nielsen (1980). Thus, both the contents of P and K either in the densest sampling (0.5 ha) or in the widest one (3.0 ha) presented moderate variability, between 12% and 60%.

***Table 2 -** Descriptive analysis of P and K content and necessities of P_2O_5 and K_2O under different typess of soil sampling and adubation in a reforming sugarcane area in Igaraçu do Tiete-SP, 2009.*

Attributes	Average	Median	Minimum	Maximum	VC%	Cs	Ck	KS
P, grid 0,5 ha(1)	25,76	23,50	10,00	63,00	41,64	1,22	1,88	p<0,10*
K, grid 0,5 ha(1)	5,18	5,60	0,90	10,30	52,95	-0,06	-1,17	p>0,20ns
P, grid 3 ha(1)	28,42	24,00	10,00	59,00	46,36	1,11	1,50	p>0,20ns
K, grid 3 ha(1)	5,63	6,15	0,90	10,30	57,11	-0,03	-1,22	p>0,20ns
Necessity of P_2O_5, grid 0,5 ha(2)	89,24	90,00	47,00	126,00	19,10	-0,13	-0,15	p>0,20ns
Necessity of K_2O, grid 0,5 ha(2)	42,70	26,50	0,00	126,00	104,77	0,42	-1,44	p<0,01*
Necessity of P_2O_5, grid 0,5 ha(3)	82,57	80,00	60,00	120,00	17,94	1,55	2,62	p<0,01*
Necessity of K_2O, grid 0,5 ha(3)	46,86	60,00	0,00	120,00	96,92	0,31	-1,28	p<0,01*
Necessity of P_2O_5, grid 3 ha(2)	85,42	87,50	40,00	125,00	23,48	0,10	0,35	p>0,20ns
Necessity of K_2O, grid 3 ha(2)	39,17	10,00	0,00	125,00	121,94	0,70	-1,20	p>0,20ns
Management Zones – Clay+SOM(4)	79,47	83,00	44,00	98,00	15,56	-0,96	0,51	p<0,20*

VC: variation of coeficient (%); Cs – symetry coeficient; Ck coeficient of kurtosis; (1) contents of P in mg dm^{-3} and K in mmolc dm^{-3} used only as a basis for the criation of necessity maps of P_2O_5 and K_2O based in the adapted regression equations; (2) recommendation of P_2O_5 abd K_2O in Kg ha^{-1} based in the classes proposed by Spironello et al.(1997); (4) % Index for defining management zones; ns normal distribution according the Kolmogorov-Smirnov test (KS), at 5% of probability; * Non-normal distribution.

In both sampling grids, asymmetry of P content was positive, having a larger average than the data median, which indicates the existence of a high frequency of values under the average. For K contents, asymmetry was negative, lower averages than the data median, which indicates the existence of a high frequency of values above the average. Because of this, one can notice that the use of average contents for P and K would yield areas with deficit or excess of nutrients.

According to Isaaks and Srivastava (1989), the asymmetry coeficient is more sensitive to extreme values than the average and the standard deviation, once just one value can strongly influence the asymmetry coeficient, since the deviations between each value and the average are raised to the third power. For this work, values were near zero for most of the studied attributes. This shows that most of the attributes involved in the study are near to a normal distribution. Therefore, the data are adequate to the use of geostatitics. Another indication of normality is that average and median values, for most of the variables, are near to each other, showing symmetrical distributions.

The spherical model was the one that presented the lowest values in the absolut deviation average, within the deviation averages observed, in the normalized residual index and in the standard deviation in all the analised variables (Table 3). According to Grego and Vieira (2005), the spherical mathematical model is which predominates in works on soil science. Mcbratney and Webster (1986) studied variogram adjustment models for the soil attributes and reported that the spherical and exponential models are the most found.

The level (C_0 + C_1) corresponds to the point where all sample variance is of random influence, corresponding to the total variance obtained by the classical statiscs (Trangmar et al., 1985). The nugget effect (C_0) is an important standard of the variogram and indicates the non-explained variability taking into consideration the distance of the used sampling (Vieira, 2000). To evaluate the spacial dependency, Zimback (2001) proposed the spacial dependency índex (SDI) of the attibutes, which uses the relation $(C_1/(C_0+C_1))$ x 100, where the dependency is strong when greater than 75%, moderate, when between 25% to 75%, and low for the relationship smaller than 25%. For the evaluated attributes (Table 2), it was noted moderate spacial dependeny, which indicates a low contribution of the nugget effect (C_0) on the data variability, which improves the inferrence of values for places, not samples, using the ordinary krigging.

***Table 3 -** Geostatistical parameters of P and K contents and necessities of P_2O_5 and K_2O in different typess of soil sampling and adubation in a reforming sugarcane area in Igaraçu do Tiete-SP, 2009.*

Variáveis	Models	C_o(1)	C_0+C_1(2)	a(m)(3)	IDE%(4)
P, grid 0,5 ha(5)	ESF.	60,2	115,0	160	48
K, grid 0,5 ha(5)	ESF.	2,22	7,5	320	70
P, grid 3 ha(5)	ESF.	86,2	173,5	180	50
K, grid 3 ha(5)	ESF.	5,6	10,3	360	46
Necessity of P_2O_5, grid 0,5 ha (6)	ESF.	131,3	290,4	400	55
Necessity of K_2O, grid 0,5 ha (6)	ESF.	597,3	2001,4	320	70
Necessity of P_2O_5, grid 0,5 ha (7)	ESF.	80,7	219,4	560	63
Necessity of K_2O, grid 0,5 ha (7)	ESF.	652,2	2062,4	400	68
Necessity of P_2O_5, grid 3 ha (6)	ESF.	161,7	392,7	720	59
Necessity of K_2O, grid 3 ha (6)	ESF.	1249,9	2291,7	360	45
Manegement Zones – Clay+SOM	ESF.	25,8	153,0	400	83

(1)Nugget effect; (2) Level; (3)Range; (4) spacial dependency índex (ZIMBACK, 2001); (5)contents used only as basis for the creation of P_2O_5 and K_2O necessity, deficit and excess maps; (6) P_2O_5 and K_2O recommendations based on the adapted regression equations; (7) P_2O_5 and K_2O recommendations based on the classes proposed by Spironello et al. (1997).

The range is fundamentally important for the interpretation of variograms, indicating the distance up to where the sampling points are correlated among themselves (Vieira, 2000). P and K attributes showed values ranging from 160 to 180 m for P, and 320 to 360 for K in the sampling grids of 0.5 and 3.0 ha, respectively. This evident a shorter structural continuity for the variable P, that is, the sampling grid needs to be smaller for P than for K.

In evaluating the P_2O_5 and K_2O deficits and excesses, along with the percentage of the area with adequate adubation (Table 4), one can see that the aplication at a fixed rate (500 kg ha^{-1} of the formulate 00-25-25) led to excesses of 36 and 79 kg ha^{-1} for P_2O_5 and K_2O, respectively, as well as correct percentages of only 7% for P_2O_5, and 6% for K_2O, these being the lowest correct values found. The cost for the fertilizers was 112% higher, when compared to the application at a variable rate of KCl and TSP, based on the sampling in the 0.5 ha grid and recommendations according to the regression equations (standard adubation type in comparison to the others). Application at fixed rate also presented ferilizer costs 80% and 146% higher than the one at fixed rate, using average sampling and management zones, respectively, taking into consideration the application of an adequate formulate. Those results reinforce the importance of soil sampling aiming at fertilizing recommendation, and, in this case, further reduction in fertilizer costs.

***Table 4** - P_2O_5 and K_2O deficits and excesses percentage of area under adequate adubation, and fertilizers costs in a sugarcane reform area in Igaraçu do Tiete-SP, 2009.*

Type of Sampling and fertilizer application	Deficit[(1)]		Excess[(1)]		Adequate[(1)]		Cost
	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	
	kg ha^{-1}				%		R$ ha^{-1}
WSS-FRA, 00-25-25	0	0	36	79	7	6	531,00
OSS -FRA, 00-25-25[(2)]	-8	-6	0	40	63	11	340,00
OSS -FRA, 00-24-18[(2)]	-8	-13	0	27	63	13	295,00
Plot, formulate appropriate [(2)]	-8	-9	0	11	62	45	275,00
Manegement zone, 00-25-25[(2)]	-9	-2	3	41	52	23	355,00
Manegement zone, formulate appropriate [(2)]	-8	-10	1	5	61	51	216,00
Grid 0,5 ha + VRA, 00-25-25 suit K_2O[(3)]	-51	0	4	0	10	100	182,00
Grid 0,5 ha + VRA, 00-25-25 suit P_2O_5 [(3)]	0	-4	0	50	100	10	378,00
Grid 0,5 ha + VRA, KCl e TSP[(2)]	-4	0	0	3	78	84	240,00
Grid 3.0 ha + VRA, KCl e TSP[(3)]	-4	-2	1	8	75	62	217,00
Grid 0,5 ha + VRA, KCl e TSP[(4) (3)]	0	0	0	0	100	100	250,00

WSS-FRA = Without soil sampling and aplication at fixed rate; OSS-FRA = One soil sample and fixed rate application; VRA = variable rate application [(1)] strip of ± 10 kg ha^{-1} of P_2O_5 and K_2O as adequate adubation; [(2)] recommendation of P_2O_5 and K_2O based on classes proposed by Spironello et al. (1997); [(3)] recommendation of P_2O_5 and K_2O based on adapted regression equations; [(4)] adubation taken as standard for comparison to the other typess of sampling and fertilizer application.

For the fixed rate adubation, using an average sampling, either with milled formulate or with the adequate formulate, there was a low index accuracy, specially for K_2O. This enhances the importance of sampling that adequately characterizes the soil attributes. Sampling and application of fertilizers based on average produced either super- or subadubations, which had also been found by other authors, such as Chang et al. (2003), Wang et al. (2003) and Biscaro e Garzella (2006). The comparison between the costs of fertilizer when using a standard formulate (00-25-25) or an adequate formulate resulted respectively in 36% and 18% higher when compared to the variable rate application, in a comparison pattern. Nevertheless, by using only one soil sampling as a representative of the 35.09 ha, as well as the application of an adequate formulate for the necessities pointed by the soil analysis, there was a decrease of R$236.00 ha^{-1} in fertilizer costs in relation to the fixed rate application of 500 kg ha^{-1} of the formulate 00-25-25.

Fertilizer aplication, taking into consideration the average contents within the plots, considerably reduced both excesses and deficits, while increasing in 32% the area with adequate adubation with K_2O, in relation to the fixed rate adubation, by means of a median sampling and adequate formulates for the average necessicities. Those results point at a considerable improvement in the fertilzer application efficiency when sampling and fertilizer application are performed within the plots split by roads and/or terraces. The application of fertilizers at a fixed rate within each plot resulted in a reduction of R$256.00 and 25.00 ha^{-1} in fertilizer costs in relation to the application at a fixed rate of 500 kg ha^{-1} of formulate 00-25-25, and the application of an adequate formulate according to the necessities pointed at by an average sampling, respectively. Besides the capacity of detecting contents of nutrients present in the soil with more reliability, another advantadge of this adubation type is that the fertilizer application can be performed by means of conventional equipment, therefore eliminating the necessity of any special equipment for the application at a variable rate.

For the application on management zones, there was a considerable increase in correct adubation percentual, specially for K_2O, when compared to the application at a fixed rate, without soil sampling, and at a fixed rate using an average sampling for recommending the adubation. The application of fertilizers using the adequate formulates within each management zone displayed the second lower cost of fertilizers, that is, 146% lower than the one with fixed rate application of a standard formulate used for sugarcane. That cost reduction of fertilizers was also cited by Dellamea (2008) who found that the fertilizer application by management zones in soy cultures led to 17% economy in total amounts of inputs, as well a reduction of R$28.05 ha^{-1}, when compared to the fixed rate application of a standard formulate. By using that same fertilizer application type, a reduction of 37% in costs with fertilizers was observed in relation to the fixed rate application, based on soil sample values. Even more, the application by means of management zones of a formulate adequated to the necessities pointed at by the soil analysis yielded reductions of 16% and 8% in relation to the variable rate application, when taking into consideration a sampling grid of 0.5 ha and 0.3 ha, respectively. Those results, associated to the excess and deficit data of P_2O_5 and K_2O suggest that the management zones can considerably improve the efficiency of fertilizer use. For Focht et al. (2004), simple systems, such as the physical demarcation of the management zones via the “tracing method” and the application of the rates defined for each zone using the available equipment in the estate, can also be an efficient and economical system.

The application of formulate 00-25-25 at variable rate provided the lowest cost when the objective was fitting the K_2O necessities. Nevertheless, that adubation type resulted in 51 kg ha^{-1} for P_2O_5 and 50 kg ha^{-1} for K_2O excesses, while in only 10% of the area the adubation was adequate. Thus, the application at variable rate must be done by using simple formulates, since the variability of P and K attributes usually do not follow the same variation pattern, which makes it impossible to adequate the applied amounts to the plant necessities.

Adubation based on sampling in 0.5 ha grid, and in the classes suggested by Spironello et al. (1997) resulted in about 80% of accuracy (of P_2O_5 and K_2O) when compared to the fertilizer application based on sampling grade of 0.5 ha and recommendation based on the adapted regression equations by Spironello et al. (1997), but one can observe some excesses and deficits of P_2O_5 and K_2O, and a reduction of R$ 10 reais ha^{-1} on fertilizer costs. Although the advantages of using the regression equations are not so important in this work, one can cite that, from the introduction of mechanisms capable of electronically alter lower amounts of fertilizers there is the possibility of not using recommendation bands or classes for adubation, replacing that for regression equations, in which each content in the soil reflects a fertilizer dose and, consequently, a better adjustment between the recommended amounts and the very necessity of the plants.

For the application at a variable rate, based on the sampling in grid at each 3 ha, one can notice the reduction in accuracy percentages in relation to the sampling in grid at each 0.5 ha. This, once again, indicates that the sampling for adubation must be capable of detecting the existing variations in the soil, otherwise the fertilizer application will be misguided. This adubation type resulted in fertilizer costs,P_2O_5 and K_2O deficits and excesses, similar to the adequate fertilizer application within each management zone. Although, the accuracy percentages were superrior, indicating the preference for the application based on P and K contents of sampling in 3.0 ha grid.

The use of fertilizers adequated to the average necessities, either considering a sampling at the 35.09 ha, or the mean average sampling within the management zones, supplied reductions in excess of K_2O, increase in the area of adequate adubation, and reduction in costs with fertilizers when compared to the use of 00-25-25 formulate for meeting those necessities. This result indicates that only the availability or the capability of mixing formulates on the production facility would supply the improvement of adubation adequacy according to the plant necessities, as well as reduction in fertilizers costs.

For the grid sampling and further application at a variable rate, addicional investment in soil sampling and analysis, creation of maps, as well as proper equipment for the application at a variable rate are all necessary. Nevertheless, besides the reduction in fertilizer costs, there is the possibility of an increase in the sugarcane productivity as a result of denser samplings and fertilizer application more adequate to the actual necessities, which reduces the size of the area and the necessary time for paying for that investment.

4 CONCLUSIONS

Soil sampling and application of fertilizers adequated to the plots proved a simple method and great ability to increase efficiency in fertilizer use in sugarcane when compared to traditional sampling and fertilizer application.

Clay and SOM contents were effective in defining management zones, and this caused an increase in efficiency in the use of fertilizers compared to traditional sampling and fertilizer application.

The mere use of formulates adequated to the necessities showed by the different soil sampling typess yielded an increase in the percentage of the area under proper adubation, as well as in fertilizer costs.

The sampling grid has potential to maximize efficiency fertilizer use on sugarcane.

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