OXISOL SUBSURFACE CHEMICAL ATTRIBUTES RELATED TO SUGARCANE PRODUCTIVITY

Marcos Guimarães de Andrade Landell[1]*; Hélio do Prado[1]; Antônio Carlos Machado de Vasconcelos[1]; Dilermando Perecin[2]; Raffaella Rossetto[1]; Márcio Aurélio Pitta Bidoia[1]; Marcelo de Almeida Silva[1]; Mauro Alexandre Xavier[1]

[1]*IAC/APTA - Centro de Cana-de-Açúcar, C.P. 206 - 14001-970 - Ribeirão Preto, SP - Brasil.*
[2]*UNESP/FCAV - Depto. de Ciências Exatas, Via de Acesso Prof. Paulo Donato Castellane, s/n. - 14884-900 - Jaboticabal, SP - Brasil.*
**Corresponding author <mlandell@iac.sp.gov.br>*

ABSTRACT: In spite of the great homogeneity found in the morphological characteristics of Oxisols, there is great chemical diversity in subsurface layers of these soils. Studies indicate that crop yield presents significant correlation with the chemical attributes of the subsurface, which, are more stable than attributes found in the plough layer, subject to greater alterations as a consequence of agricultural exploration. This work evaluated the effects of subsurface chemical attributes of Oxisols of the South Central region of Brazil, on the yield of sugarcane clones and of variety RB72454, during the first, second and third cropping cycles. Productivity data were obtained between 1993 and 1998. Soils were characterized in terms of their mechanical analysis and chemical traits at 0.8 to 1.0 m; correlation studies between these attributes and mean daily productivity as well as multiple regression analysis were also carried out; variables were selected based on their R^2 values by means of the stepwise procedure. The subsurface chemical traits of the Oxisols influenced sugarcane productivity, especially the 3rd harvest; the clone productivity model for the 3rd harvest as a function of base saturation and phosphorus content presented R^2 = 0.31, i.e., 31% of the variation in sugarcane yield (t ha^{-1} day^{-1}) can be explained by these two attributes. For variety RB72454, 47% of that variation is explained by the sum of bases and contents of calcium and organic matter. Variations on productivity at 1st and 2nd harvests can be better explained by pH_{water}.
Key words: yield, soils, linear models, chemical analysis

ATRIBUTOS QUÍMICOS DE SUBSUPERFÍCIE DE LATOSSOLOS E PRODUTIVIDADES DA CANA-DE-AÇÚCAR

RESUMO: Embora haja homogeneidade nas características morfológicas na classe dos Latossolos, existe grande diversidade química na subsuperfície. Trabalhos indicam que a produção agrícola apresenta correlação significativa com atributos químicos de subsuperfície, que são mais estáveis que na camada arável, sujeita a alterações decorrentes da exploração agrícola. Pelo exposto, o presente estudo avaliou os efeitos dos atributos químicos de subsuperfície de Latossolos da região Centro-Sul do Brasil na produtividade agrícola dos três primeiros cortes de clones de cana-de-açúcar e da variedade RB72454. Utilizaram-se os dados de produtividade agrícola correspondentes ao período de 1993 a 1998. Os solos foram caracterizados sob o ponto de vista granulométrico e químico na profundidade entre 0,8 e 1,0 m e foram feitos estudos de correlação entre tais atributos e as médias de produtividade agrícola diária durante o ciclo dos clones de cada ensaio e da variedade RB72454 e análise de regressão múltipla, com as variáveis selecionadas pelo procedimento "stepwise" em função do R^2. As características químicas de subsuperfície dos Latossolos influenciaram na produtividade agrícola da cana-de-açúcar, principalmente no 3^o corte. Para as médias dos clones, o modelo de produtividade do 3^o corte em função de saturação por bases e fósforo, mostra R^2 = 0,31, ou seja, que 31% da variação de TCH dia^{-1} pode ser explicada por esses dois atributos. No caso da variedade RB72454, essa mesma variação no 3^o corte é explicada em 47% pelos atributos soma de bases e teores de cálcio e matéria orgânica. As variações de produtividade de 1^o e 2^o cortes foram melhor explicadas pelo $pH_{água}$.
Palavras-chave: produção agrícola, solos, modelos lineares, análise química

INTRODUCTION

Sugarcane cropping in the South Central region of Brazil has experienced significant productivity increases in recent years. This evolution is the result of genetic breeding research and of application of management techniques better suitable for the crop, increasing the expression of its genetic potential. Great diversity can be observed in the chemical and physical characteristics of soils cultivated with sugarcane in the South Central region of Brazil. Therefore, the phenotypic expression in the edaphic-climatic context should be deemed as a priority during the process through which new varieties are obtained (Landell et al., 1997).

Some papers demonstrated the influence of soil attributes on sugarcane productivity with distinctive responses for the plough layer and for the subsurface layer. Climate and a more adequate management have greater influence on final sugarcane productivity than soil fertility in the plough layer (Bittencourt et al., 1990). On the other hand, crop productivity shows significant correlations with subsurface chemical attributes (Ribeiro et al., 1984; Prado et al., 1998) and these correlations are different for plant cane and ratoon (Landell et al., 1999). In pedology, the subsurface horizon is adopted as a diagnostic horizon because it is under little or no influence of management. Knowing the chemical, physical and morphological attributes of the subsurface is critical for studying sugarcane cropping environments, because it is part of the soil volume that will be explored by the sugarcane's root system, especially in ratoon growing cycles.

The use of yield models and the identification of the degree of importance of the several soil attributes at each crop cycle can provide assistance for nutrient-supply and variety-management practices in the various cropping environments, and provide orientation to estimate bare land value. This identification can also contribute toward pedotransfer function studies, which are becoming increasingly important in soil science in order to identify edaphic traits that would dependably indicate the yield potential of a given environment. The use of yield modeling can be justified by the synthesis of the knowledge generated by research, decisions about management systems, and action program analyses (Boote et al., 1996).

This work was developed over the hypothesis that the chemical and granulometric attributes of soil subsurface layers have great influence on sugarcane productivity, aiming to evaluate the effects of such attributes of Oxisols on sugarcane productivity of the first three harvests.

MATERIAL AND METHODS

The study was carried over mean sugarcane productivity data from the 1st, 2nd and 3rd harvests of 43 varietal competition assays performed in South Central Brazil, between latitudes 15°12' and 22°50'S, and installed during the 1993-1998 period, involving the following oxisols: Rhodic Eutrudox, Rhodic Hapludox, Rhodic Acrudox, Typic Eutrudox and Typic Hapludox.

Soils were sampled at depth between 0.8 and 1.0 m. Evaluations included pH in water, organic matter (OM), phosphorus (P), potassium (K), hydrogen (H), aluminum (Al), calcium (Ca), magnesium (Mg), and granulometry (clay and sand), and the calculation of the sum of bases (SB), cation exchange capacity (CEC) and base saturation (V). The chemical characteristics were evaluated according to Raij et al. (1987) and the granulometric analysis was made according to Camargo et al. (1986). Liming and fertilization were performed according to usual recommendations for sugarcane crop (Raij et al., 1996). Values of soil attributes of the sampled layer, separated by fertility classes, were utilized for correlation and regression studies (Table 1). Because of the great range of variation of base saturation values of the subsurface, traditionally classified as dystrophic (V < 50%), the present work made a distinction between Dystr.$_{(30-50)}$ and Dystr.$_{(<30)}$, corresponding to V ranges between 30 and 50%, and V lower than 30%, respectively. The Dyst.$_{(30-50)}$ soils correspond to the mesotrophic soils described by Prado (1998).

Because of differences on the number of days of the cropping cycle of the assays, especially between plant cane and ratoon cane cycles, the values for tons of sugarcane per hectare (TSH) were divided by the number of days of each cycle, indicating the mean daily accumulation of green matter during the cycle, (t ha^{-1} day^{-1}), reducing interferences of cycles of heterogeneous duration. Some assays were harvested in the middle of the harvesting season, thus reducing interactions between cycle and harvest. Data came from mean productivities of the different clones utilized in the assays, as well as from the mean productivities for variety RB72454, because it was present in all assays as a standard variety.

Correlation studies were performed between productivity and soil attributes of the soil layer between 0.8 and 1.0 m, as well as multiple regressions analyses by the stepwise procedure, using the SAS software (SAS Institute, 1990). Analyses of variance were performed and means of each harvest were compared by the Duncan test at 5%.

Table 1 - Mean values for subsurface attributes of the Oxisols separated by fertility classes.

Soil	Occur.	pH_{water}	OM	P	K	H	Al	Ca	Mg	SB	CEC	V	Clay	Sand
	%		g kg^{-1}	mg kg^{-1}	---------------------			mmol$_c$ kg^{-1}			---------------------	%	-- g kg^{-1} --	
Eutr.	14	6.10	10.7	5.67	0.8	12.8	0.0	11.8	4.2	18.4	31.3	60	491	412
Dystr.$_{(30-50)}$	23	5.56	14.4	6.70	0.4	18.8	0.5	9.3	3.7	13.4	32.7	41	579	307
Dystr.$_{(<30)}$	30	5.02	10.4	4.92	0.5	18.5	3.3	5.8	2.3	8.7	30.5	29	508	445
Acric	12	5.34	11.5	5.80	0.4	14.8	0.8	4.5	1.9	6.8	22.2	31	577	339
Alic	21	4.83	8.6	6.22	0.3	13.6	12.9	4.4	1.6	6.3	35.8	17	410	519

Note: Eutr: eutrophic; Dystr.$_{(30-50)}$ = dystrophic with V between 30 and 50%; Dystr.$_{(<30)}$ = dystrophic with V lower than 30%.

RESULTS AND DISCUSSION

No correlation was obtained for productivity of the 1st and 2nd harvests with the major part of the evaluated subsurface chemical and granulometric attributes (Table 2). Studying the relationship between soil attributes in the plough layer and productivity, Beauclair (1994) pointed out that fertilizations and corrections performed along several cropping seasons tend to have an equalizing effect on soil characteristics. While liming and fertilization practices applied to sugarcane plantation have stronger effects on productivity until the 2nd harvest, in the present work subsurface chemical attributes had greater importance at the beginning of the 3rd harvest. The superior response of the ratoon cane (3rd harvest) in relation to subsurface attributes is strongly related to the root development dynamics.

Studying six sugarcane varieties, Vasconcelos (2002) verified an increase in root dry mass along crop cycles until the fourth harvest. The author pointed out that the amount of roots is not as important as the root system distribution architecture and efficiency. Formation of a great mass of surface roots can compete for photoassimilates with the aerial part, while deeper roots, in spite of also competing for photoassimilates, play an essential role in the absorption of water and nutrients necessary to maintain vital processes during water stress periods.

This observation justifies the greater influence of subsurface attributes on ratoon crops and could perhaps explain why some varieties, in certain edaphic "niches", present great longevity, maintaining good productivities even after the fifth harvest. Such "niches" have satisfactory chemical attributes in the subsurface, improving the balance between absorption of nutrients and metabolic energy expenditure.

Table 2 - Coefficients of correlation between chemical attributes of Oxisols from the South Central region of Brazil and productivities (TSH) of three sugarcane harvests.

	Mean for Clones			RB72454		
	TSH1	TSH2	TSH3	TSH1	TSH2	TSH3
pH_{water}	0.45**	0.36*	0.40**	0.42**	0.29*	0.42**
OM	--	--	0.33*	--	--	0.39*
P	--	--	0.30*	--	--	0.34*
K	--	--	0.32*	--	--	0.37*
Al	--	--	-0.27*	--	--	--
Ca	--	--	--	--	--	0.32*
Mg	--	--	0.38**	--	--	0.49**
SB	--	--	0.44**	--	--	0.50**
V	0.35*	0.31*	0.47**	--	--	0.47**
Clay	--	--	--	--	--	0.31*
Sand	--	--	--	--	--	-0.36*

*Significant at 5%; **significant at 1%.; TSH1, TSH2, TSH3 = tons of sugarcane per hectare in the 1st, 2nd and 3rd harvests, respectively.

Differently from other chemical attributes, the pH in water was well correlated to productivities during the three harvests. This is probably related to the smaller range of pH variation in the profile, which would allow a significant correlation with crop productivities since the first harvest, when the root system is theoretically still exploring less profound layers. Silveira et al. (2000) reported the smallest variabilities in soil profiles to be associated to pH. Such results confirm the findings by Beauclair (1991), who demonstrated that pH at depths between 0 and 0.25 m had good correlation with crop productivity until the 3rd harvest.

The greater effect of subsurface phosphorus in the 3rd harvest might explain part of the limited response normally observed with the application of this nutrient in ratoon canes, made at the most superficial layers with little mobility to deeper layers. This confirms results of Korndörfer et al. (1998) and of several research reports of the Instituto Agronômico de Campinas (IAC) during the last five decades (Raij et al., 1996).

On the other hand, sugarcane plants respond well to phosphorus application. Beauclair (1991) observed great influence of the phosphorus applied to the planting furrow on the productivity of the first two harvests, confirming the importance of this nutrient for sugarcane, especially on the yield of the 1st harvest.

Calcium contents had an effect only on the productivity of variety RB72454 in the 3rd harvest, which was not observed for the mean productivity of the clones in any of the harvests, indicating a high response of that variety to subsurface calcium. Calcium contributes the most toward root growth in deeper layers (Ritchey et al., 1981). The influence of subsurface calcium content on the productivity of the same variety was also verified by Dias et al. (1999). Base saturation (V) was correlated to productivity for clone means during the three harvests, but only in the 3rd harvest for RB72454. Landell et al. (1999) found differences with respect to the influence of soil subsurface chemical attributes of different sugarcane varieties, such as a greater correlation of base saturation with the productivities of varieties RB72454 and SP70-1143, while variety SP79-1011 did not present a direct influence of any of the chemical attributes of the soil. This denotes differences in behaviour when the varieties are faced to the edaphic conditions under which they develop, indicating a genotype-environment interaction, the causes of which being attributed to physiological and biochemical factors inherent to each genotype (Cruz & Regazzi, 1994).

The mean productivity of the clones in the 3rd harvest was negatively correlated to aluminum content, which corroborates information provided by Landell (1989). This was not observed, however, for variety RB72454, which might indicate a greater tolerance of this genotype to aluminum, and partially explain its broad adaptability in the several regions where it is grown. Maule et al. (2001) show that the variety RB72454 is one of the less sensitives to differences in chemical attributes between a Typic Albaqult and an Arenic Hapludult.

For the multiple regressions analyses by the stepwise procedure (Tables 3 and 4), the greater influence of subsurface attributes was verified in the 3rd harvest. For clone means, the productivity model as a function of V and P had a R^2 = 0.31, i.e., 31% of the variation in TSH day^{-1} can be explained by these two attributes. For variety RB72454, 47% of the same variation in the 3rd harvest is explained by attributes SB, and Ca and OM contents. These influences of subsurface attributes on productivity variations can be considered to be high, because there are many other factors which could interfere with such variations. Yield models can be utilized to evaluate possible causes of yield changes with time, for a given region (Boote et al., 1996). However, this is a difficult task to tackle because variations in yield can be confounded with variations in climate, cultural practices and the use of improved genotypes. Coefficients of determination around 0.2 (20%) in models that do not particularize climate effects can be considered excellent (Beauclair, 1994).

The coefficients of the final equation represent effects related to each factor, when all other listed factors are in the model (additional effects). Therefore, the additional coefficients should not be interpreted as isolated effects for the factor, since there are dependence among them (e.g., calcium and SB).

Differences between mean productivities of the clones were observed only when alic soils were compared to eutrophic soils (Figures 1 and 2). These differences were not observed for RB72454 or in the 2nd harvest,

Table 3 - Stepwise analysis for the first three harvests, among subsurface chemical attributes of Oxisols in South Central Brazil and clone productivity (t ha^{-1} day^{-1}).

Harvest	Variable	R^2		Regression equation
		Additional	Accumulated	
1st	pH_{water}	0.21	0.21	$Y = 0.0121+0.0499pH_{water}$
2nd	pH_{water}	0.13	0.13	$Y = 0.0932+0.0363pH_{water}$
3rd	V	0.22	0.22	$Y = 0.1161+0.0066P+0.0025V$
	P	0.09	0.31	

Table 4 - Stepwise analysis for the first three harvests, among subsurface chemical attributes of Oxisols in South Central Brazil and productivity for variety RB72454 (t ha^{-1} day^{-1}).

Harvest	Variable	R^2		Regression equation
		Additional	Accumulated	
1st	pH_{water}	0.17	0.17	$Y = 0.0226+0.0468pH_{water}+0.0053P$
	P	0.06	0.23	
2nd	pH_{water}	0.09	0.09	$Y = 0.1486+0.03430pH_{water}$
	SB	0.25	0.25	
3rd	Ca	0.13	0.38	$Y = 0.1409+0.0615OM-0.2839Ca+ 0.22592SB$
	OM	0.09	0.47	

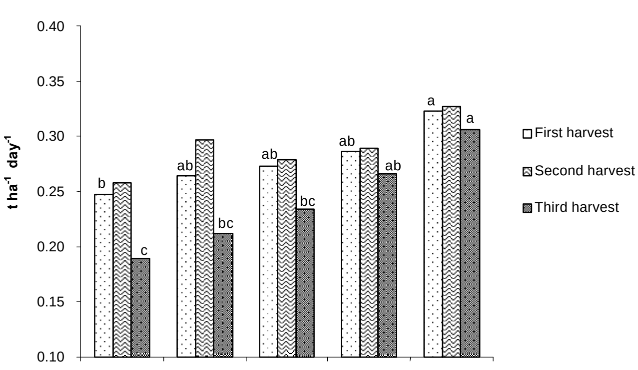

Figure 1 - Daily crop productivity for the mean of competition clones for different soil fertility classes. For each harvest, means with common letters do not differ among themselves by the Duncan test at 5%.

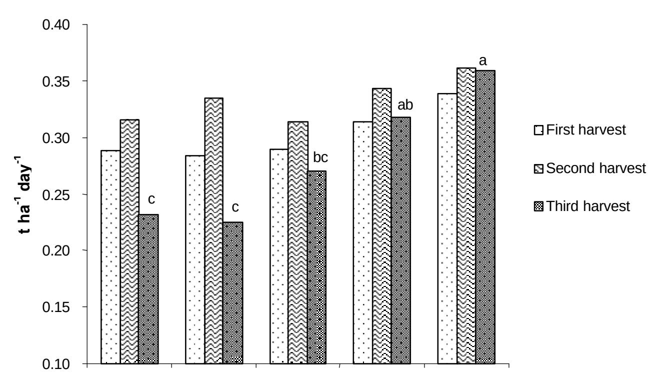

Figure 2 - Daily crop productivity for variety RB72454 for different soil fertility classes. For each harvest, means with common letters do not differ among themselves by the Duncan test at 5%.

confirming that liming and fertilization practices performed at planting reduce differences between soils with regard to the influence of their chemical attributes on productivity. With respect to the 3rd harvest, differences were observed between soils in relation productivity for RB72454 and for the clone mean. For the eutrophic soils, productivities were superior to those found in $Dystr._{(<30)}$, acric and alic soils. The better productivities obtained for eutrophic soils can be justified by their subsurface chemical attributes, as exemplified by their Ca, Mg, and K levels. The values for these nutrients progressively decrease from eutrophic soils to $Dystr._{(30-50)}$, $Dystr._{(<30)}$, acric and alic soils (Table 1). Data confirm those presented in Table 2, i.e., from the 3rd harvest forth, the crop is more intensely influenced by subsurface attributes.

REFERENCES

BEAUCLAIR, E.G.F. Relações entre algumas propriedades químicas do solo e a produtividade da cana-de-açúcar (*Saccharum* spp.), através de regressão linear múltipla. Piracicaba: USP/ESALQ, 1991. 90p. Dissertação – Mestrado

BEAUCLAIR, E.G.F. Produtividade da cana-de-açúcar em função de alguns macronutrientes presentes no caldo e no solo. Piracicaba: USP/ESALQ, 1994. 98p. (Tese – Doutorado)

BITTENCOURT, V.C.; CARMELLO, Q.A.C.; BEAUCLAIR, E.G.F.; JOÇO, J.; CLEMENTE, J.L. Produtividade da cana-de-açúcar e suas relações com a fertilidade dos solos e o manejo da cultura. **STAB – Açúcar, Álcool & Subprodutos**, v.8, p.10-14, 1990.

BOOTE, K.J.; JONES, J.W.; PICKERING, N.B. Potencial uses and limitations of crop model. **Agronomy Journal**, v.88, p.704-716, 1996.

CAMARGO, O.A.; MONIZ, A.C.; JORGE, J.A.; VALADARES, J.M.A.S.V. **Métodos de análise química, mineralógica e física dos solos**. Campinas: Instituto Agronômico, 1986. 94p. (Boletim Técnico, 106).

CRUZ, C.D.; REGAZZI, A.J. **Modelos biométricos aplicados ao melhoramento genético**. Viçosa: UFV, 1994. 390p.

DIAS, F.L.F.; MAZZA, J.A.; MATSUOKA, S.; PERECIN, D.; MAULE, R.F. Produtividade da cana-de-açúcar em relação a clima e solos da região noroeste do Estado de São Paulo. **Revista Brasileira de Ciência do Solo**, v.23, p.627-634, 1999.

KORNDÖRFER, G.H.; FARIA, R.J.; MARTINS, M. Efeito do fósforo na produção da cana-de-ano e cana soca em solo de cerrado. **Pesquisa Agropecuária Brasileira**, v.33, p.389-395, 1998.

LANDELL, M.G.A. Comportamento da cana-de-açúcar (*Saccharum* spp.) frente a níveis de alumínio, em solução nutritiva. Jaboticabal: UNESP/FCAV, 1989. 117p. (Tese - Doutorado)

LANDELL, M.G.A.; CAMPANA, M.P.; FIGUEIREDO, P.; ZIMBACK, L.; SILVA, M.A.; PRADO, H. **Novas variedades de cana-de-açúcar**. Campinas: Instituto Agronômico, 1997. 28p. (Boletim Técnico, 169).

LANDELL, M.G.A.; PERECIN, D.; VASCONCELOS, A.C.M.; ROSSETTO, R.; BIDÓIA, M.A.P.; SILVA, M.A. Correlação da produtividade de variedades de cana-de-açúcar com atributos químicos do horizonte B de Latossolos roxos em Conquista, MG, Brasil. **STAB – Açúcar, Álcool & Subprodutos**, v.18, p.23, 1999.

MAULE, R.F.; MAZZA, J.A.; MARTHA JR., G.B. Produtividade agrícola de cultivares de cana-de-açúcar em diferentes solos e épocas de colheita. **Scientia Agricola**, v.58, p.295-301, 2001.

PRADO H. **Solos tropicais:** potencialidades, limitações, manejo e capacidade de uso. Jaboticabal: FUNEP, 1998. 231p.

PRADO H.; LANDELL, M.G.A.; ROSSETTO, R.; CAMPANA, M.P.; ZIMBACK, L.; SILVA, M.A. Relation between chemical sub surface conditions of subsoils and sugarcane yield. In: WORLD SOIL SCIENCE CONGRESS, 16., Montpellier, 1998. **Proceedings**. Montpellier: ISSS, 1998. v.1, p.232.

RAIJ, B. van; QUAGGIO, J.A.; CANTARELLA, H.; ABREU, C.A. **Análise química de solos para fins de fertilidade.** Campinas: Fundação Cargil, 1987. 170p.

RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J.A.; FURLANI, A.M.C. **Recomendações de adubação e calagem para o Estado de São Paulo**. 2.ed. Campinas: Instituto Agronômico; Fundação IAC, 1996. 285p. (Boletim Técnico, 100).

RIBEIRO, M.R.; HALSTEAD, E.H.; JONG, E. Rendimento da cana-de-açúcar e características das terras da microrregião da Mata de Pernambuco. **Revista Brasileira de Ciência do Solo**, v.8, p.209-213, 1984.

RITCHEY, K.D.; SILVA, J.E.; ESPINOSA, W.; LOBATO, E. Downward movement of calcium and the improvement of subsoil rooting in oxissols of Brazil. In: SYMPOSIUM ON THE SOIL/ROOT SYSTEM, 1., Londrina, 1980. **Proceedings.** Londrina: Fundação Instituto Agronômico do Paraná, 1981. p.137-151.

SAS INSTITUTE. **Statitistical analysis system:** procedures guide for personal computers. Version 6. Cary: Statistical Analysis System Institute, 1990. 705p.

SILVEIRA, P.M.; ZIMMERMANN, J.P.; SILVA, S.C.; CUNHA, A.A. Amostragem e variabilidade espacial de características químicas de um Latossolo submetido a diferentes sistemas de preparo. **Pesquisa Agropecuária Brasileira,** v.35, p.2057-2064, 2000.

VASCONCELOS, A.C.M. Desenvolvimento do sistema radicular e da parte Aérea de socas de cana-de-açúcar sob dois sistemas de colheita: crua mecanizada e queimada manual. Jaboticabal: UNESP/FCAV, 2002. 140p. (Tese - Doutorado)

Received November 08, 2002
Accepted July 12, 2003