



SOIL AND WEED OCCURRENCE MAPPING AND ESTIMATES OF SUGARCANE PRODUCTION COST

A. A. Verruma^{1,2}, P. R. P. Martinelli², L. M. Rabello³, R. Y. Inamasu³, K. E. L. Santos⁴, G. M. Bettiol⁵, A. C. C. Bernardi^{6*}

¹ MSM Serviços Agrícola Ltda., Jauú, SP, Brasil

² Departamento de Agronomia, Instituto Taquaritinguense de Ensino Superior, Taquaritinga, SP, Brasil

³ Embrapa Instrumentação, São Carlos, SP, Brasil

⁴ PPG Ciências da Engenharia Ambiental, EESC/USP, São Carlos, SP, Brasil

⁵ Embrapa Cerrados, Planaltina, DF, Brasil

⁶ Embrapa Pecuária Sudeste, Rodovia Washington Luiz, km 234, 13560-970, São Carlos, SP, Brasil.

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ABSTRACT

The use of Precision Agriculture (PA) tools for variable rate herbicide application may contribute to the use of herbicides only in the areas with most weed occurrence, reducing environmental impacts and production costs. The aim of this research was to evaluate the soil apparent electrical conductivity and vegetation indexes, as well as to estimate the economic return of variable rate herbicide application for weed control in the sugarcane culture. The study was conducted in a field of 11 ha planted with sugarcane variety RB855453, which had a large infestation of bermudagrass. Measurements of soil electrical conductivity and NDVI were performed. Based on the maps generated, the area for application of pre- and post-planting herbicides was estimated. The results observed in the EC_a maps indicated that the study area could be divided into two sections with different soil textures. NDVI showed the bermudagrass occurrence areas, which represented 18% of the total. The simulation demonstrated that the use of PA could assist in reducing sugarcane production costs by 0.9 % in the stage of soil preparation and planting, 7.2% in the stage of cane-plant and 11.4% in the stage of sugarcane ratoon.

Keywords: *Saccharum officinarum*, Veris, Crop Circle, NDVI, *Cynodon dactylon*, bermudagrass.

MAPEAMENTO DO SOLO E OCORRÊNCIA DE PLANTAS DANINHAS E ESTIMATIVAS DO CUSTO DE PRODUÇÃO DE CANA-DE-AÇÚCAR

RESUMO

O uso de ferramentas da Agricultura de Precisão (AP) para a aplicação de herbicidas a taxa variável pode contribuir para o uso dos produtos apenas nas áreas mais afetadas, reduzindo os impactos ambientais e também reduzindo o custo de produção. Este trabalho teve como objetivo avaliar condutividade elétrica aparente do solo e índices de vegetação e estimar o retorno econômico da aplicação de herbicida a taxas variáveis para o controle de plantas

* alberto.bernardi@embrapa.br

daninhas na cultura de cana de açúcar. Este trabalho teve como objetivo avaliar condutividade elétrica aparente do solo e índices de vegetação e estimar o retorno econômico da aplicação de herbicida a taxas variáveis para o controle de plantas daninhas na cultura de cana de açúcar. O estudo foi realizado em um talhão de 11 ha plantado com a variedade RB855453 de cana-de-açúcar e apresentava grande infestação de grama-seda. Foram realizadas medidas da condutividade elétrica do solo e do NDVI. Com base nos mapas gerados estimou-se a área para aplicação de herbicidas de pré- e pós-plantio. Com base nos resultados obtidos na área em estudo pode-se concluir que a CE indicou que a área em estudo poderia ser dividida em 2 áreas com texturas do solo distintas. O NDVI indicou os locais no talhão que havia infestação de grama-seda e que esta área representava 18% da área total. A simulação indicou que o uso da AP pode auxiliar na redução dos custos de produção de cana-de-açúcar em 0,9% na fase de preparo de solo e plantio, 7,2% na fase de cana-planta e 11,4% na fase de cana-soca.

Palavras-chave: *Saccharum officinarum*, Veris, Crop Circle, NDVI, *Cynodon dactylon*, grama-seda.

INTRODUCTION

The competition between weeds and sugarcane culture results in yield losses (Mortensen et al., 1995; Nordmeyer et al., 1997; Arevalo & Bertoncini, 1999), since there is competition for water, light, and nutrients, and because they can also host pests (insects and nematodes) and phytopathogenic agents (bacteria, fungi or viruses). Among the main invasive plants of the sugarcane field is bermudagrass, which may cause up to 45% productivity loss (Cerrizuela et al., 1985).

The use of herbicides is the most widespread technology for weed control. Regarding bermudagrass, Arevalo (2002) recommended soil preparation in the dry period and use of a pre-emergent herbicide (Clomazone + Ametrine). Furthermore, other measures that can be taken to control bermudagrass are the cleaning of machines and implements, the use of fast-growing cultivars and the planting in February-March.

Nonetheless, the bermudagrass plants that were not controlled in the pre-emergent treatments can be controlled with post-emergent herbicides (Dimethylurea + Clomazone) according to Arevalo (2002). In the post-emergence application, the use of the Precision Agriculture (PA) tools can be interesting, as it allows the identification of the infected areas and the use of herbicides only in the places where

they are necessary and in the most appropriate dose (Balastreire & Baio, 2001). Thus, PA can be understood as a way of management of the production system, which will contribute to the reduction of environmental impacts and increase the economic return (Inamasu & Bernardi, 2014). Mortensen et al. (1995) and Balastreire & Baio (2001) had already demonstrated that the use of herbicides at a variable rate is a feasible and successful technology in many agricultural production systems.

Bernardi et al. (2015) described how PA involves the acquisition and processing of detailed and georeferenced information about the agricultural cultivation areas, to define more efficient management strategies, especially the rational use of inputs. PA tools were initially used in grain crops, but nowadays there are several experimental and practical results indicating the potential for use in sugarcane culture (Grego et al., 2014). According to Silva et al. (2011), the sugar-energy industry of the state of São Paulo indicated that PA technologies could increase product's yield and quality, reduce costs and minimize the environmental impacts of the sugarcane culture.

Nevertheless, PA requires tools to evaluate the soil spatial variability which

enables the reduction of intensive and expensive samplings (McBratney & Pringle, 1999). Soil apparent electrical conductivity (EC) integrates texture and water availability, two characteristics of the soil that affect productivity, and can help with the interpretation of culture yield variations (Kitchen et al., 1999; Machado et al., 2006; Bernardi et al., 2015). In Brazil, Machado et al. (2006) verified that EC values were related to soil clay content and its spatial variability and it was useful for the establishment of the limits of management zones in soybean plantation.

Vegetation indexes have been widely employed for crop and pasture biomass estimation, as remote sensing provides temporal and spatial patterns of the changes in the ecosystems and has been useful in the estimation of biophysical parameters (Numata et al., 2007, Bernardi et al., 2014). Remote sensing has a great potential to establish management zones, based on soil properties, as well as in weed occurrence. Mapping invasive plant infestation allows the orientation of pulverization decisions (Mortensen et al. 1995). According to Nordmeyer et al. (1997), the mapping is the first step of the control, as the information of spatial distribution will guide the application of pesticides. This mapping can be performed in several ways, such as systematic

samplings, history of the area, aerial photographs and remote sensing with sensors.

The Normalized Difference Vegetation Index (NDVI), considered a fast and efficient tool for the detection of plant variations (Rouse et al., 1973), is commonly used to evaluate the health, biomass and nutrient content of the plants. It can also be an indicator of the presence of weeds.

The agronomic, environmental and economic aspects must be considered in the sustainability analysis of a production system. Griffin & Lowenberg-Deboer (2005), in a review of various works on the use of PA, indicated that in 68% of the cases analyzed, the systems using PA were more profitable than the conventional cultivation systems. In the work of Sanchez et al. (2012), estimates of the costs for sugarcane fertilization were performed based on the use of geostatistics and mathematical modeling. Silva et al. (2011) pointed out that PA is only viable in case its costs are lower than the traditional method.

This research had the purpose of evaluating soil apparent electrical conductivity and vegetation indexes and estimating the economic return of herbicide application at variable rates for weed control in the sugarcane culture.

MATERIAL AND METHODS

The area of study utilized was a field of 11.15 ha located in the Cruzeiro Campo Farm (Code: 36004, Zone: 57 and Field: 11) in the geographical coordinates -48° 17' 20.961" W and -21° 23' 48.681"S in Guariba - SP, Brazil. The climate is classified as mesothermic (CWA - Köppen's System) with dry winter, with average temperatures higher than 22 °C in the warmest months and lower than 18°C in the coldest ones, the annual rainfall varies between 1.300 and 1.500 mm (Rolim et al., 2007). The soil is a clayey Dark Red Latosol (45% clay) according to São Paulo (1981).

The sugarcane (*Saccharum officinarum*) variety RB855453 was growing in the area and was in the regrowth of the 6th cut in the period of evaluation. Planting was performed with filter cake in the dose of 15-ton ha⁻¹ and vinasse in the dose of 55 m³ ha⁻¹. Annually in the rainy season (December), 450 kg ha⁻¹ of 20-00-30 (N-P₂O₅-K₂O) was applied in the cultivation. Annually, the harvest of the raw cane was performed mechanically. The area presented infestation with Bermudagrass (*Cynodon dactylon* (L.) Pers.).

The soil apparent electrical conductivity (EC_a) was measured with the equipment Veris model 3100 of Veris Technologies, Salina, KS, USA. To obtain the geographical coordinates of each measurement, a Garmin GPS (Garmin GPSmap 60CSx, Garmin Int. Corp., Olathe, KS, USA) was employed. This equipment collects measurements in two distinct depths: 0-30 cm and 0-90 cm. This analysis occurred in the period of sugarcane growth in the month of June. EC_a measurements were carried out according to Eq. 1:

$$EC_a = \frac{IL}{AV} \quad (1)$$

where,

EC_a = soil apparent electrical conductivity, $mS\ m^{-1}$;

I = electric current applied by the sensor to the ground, Ampere;

L = spacing between the pairs of electrodes, m;

A = area cross section of the electrodes (of the rotating discs) in contact with the ground, m^2 ; and,

V = potential difference in the electromagnetic field generated in the soil, measured by pairs of electrodes, volts.

The reflectance data were collected using the Crop Circle ACS-430 (Holland Scientific, Lincoln, NE) sensor in the same period as the EC_a measurements. The active ACS-430 sensor measures soil and cultures light reflectance emitted by a polychromatic modulated light emitting diode (LED) in 3 optical channels (670, 720 and 760 nm). The measurements were performed at approximately 0.5 m above and perpendicular to the soil. A global positioning system (GPS) Garmin (Garmin GPSmap 60CSx, Garmin Int. Corp., Olathe, KS) was used to obtain the altitude and geographical coordinates of each reflectance measurement. From the measurements, NDVI (Normalized difference vegetation index) and Chl (Chlorophyll Index) were calculated, respectively, according to Eq. 2

(Choudhury, 1987) and Eq. 3 (Gitelson et al., 2003):

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} \quad (2)$$

where,

ρ_{NIR} and ρ_R = percent near infrared and red reflectance, nm.

$$Chl = \frac{\rho_{NIR}}{\rho_{RE}} \quad (3)$$

where,

ρ_{NIR} and ρ_R = percent near infrared and red edge reflectance, nm.

Statistical parameters and geostatistical analyses were performed for EC_a , NDVI and Chl variables, focusing on the spatial continuity and dependence of soil and crop properties. Empirical directional semivariograms were calculated for the x- and y-directions. Semivariogram models were fitted to the empirical semivariograms $\hat{\gamma}(h)$ using Vesper (Oliveira, 2015) to estimate the structure of the spatial variation of a variable V and the semivariance (Grego, & Oliveira, 2015) using Eq. 4. Contour maps of all variables were estimated using ArcGIS 10.1 (ESRI, 2009).

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (4)$$

where,

$Z(x_i)$ and $Z(x_i + h)$ = observed values of Z at location x and $x + h$, respectively;

h = separation distance; and,

$N(h)$ = number of paired comparisons at distance h .

The items and coefficients for the estimates of sugarcane culture production cost were obtained based on the spreadsheets of Pecege (2012) and Faeg (2012). The culture cycle was divided into 3 steps composed of: 1) Planting: a) Inputs (cane-plant seedlings for planting and replanting), lime, gypsum, planting fertilizer, formicide, nematicide, desiccant herbicide, biological control; b) Machines

(pulverization, terracing, soil tillage, lime and gypsum applying, construction of roads and carriers, soil grooving and fertilization, seedlings, seedling transportation, mechanized planting, fertilizer top-dressing); c) Labor (labeling, topography and analysis, mechanized planting, seedling distribution, seedlings cutting, reapplication and fertilizer topdressing); 2) Ratoon: a) Inputs (lime, gypsum, fertilizer, formicide, nematicide, herbicides, biological control); b) Machines (lime and gypsum applying, herbicide application, ground leveling,

topdressing fertilization, insecticide and herbicide use); c) Labor (herbicide reapplication, release of the biological control, ant control) and 3) Harvest: mechanized cutting and transshipment, transportation of chopped cane, and support.

The prices were updated for the local values and converted to the dollar currency (US\$1.00 = R\$2.978). From the results obtained with EC and NDVI mapping, simulations of the production cost were performed considering a traditional cultivation system and a system using PA.

RESULTS AND DISCUSSION

The experimental semivariograms for the variables were calculated, and all the adjusted models were delimited for each sampling grid (Table 1). The spherical model was the one which best adjusted to the experimental variograms for altitude, EC (0-0.3m), NDVI and Chl. Conversely, for EC (0-0.9m) it was the exponential model. The spatial dependence presented in Table 1 was established based on the criteria of Cambardella et al. (1994) and can be considered strong for EC (0-0.3m), as the nugget effect was lower than

25% of the baseline. And moderate for altitude, EC (0-0.9m) and NDVI, as the nugget effect stayed between 26 and 75% of the baseline, and weak for Chl, as the values stayed above 76%.

The spatial dependence ranges indicated by the semivariogram models were higher for altitude, EC (0-0.3m) and NDVI, with values of 236 to 171m. On the other hand, for Chl and EC (0-0.9m), they were 70 and 61, respectively. These variables also presented the weakest spatial dependencies.

Table 1. Estimates of the parameters of the semivariogram models adjusted to the parameters altitude, EC (0-0.3m), EC (0-0.9m), NDVI and Chl for the field and sugarcane.

Variable	C_0	C_1	A	Model of Adjustment	Dependency $100[C_0 / (C_0 + C_1)^{-1}]$	Correspondence
Altimetry	3705963	7764876	236.3	Spherical	32.31	Moderate
EC (0-0.3m)	0.0000395	0.000208	214	Spherical	15.96	Strong
EC (0-0.9m)	18.13	6.411	60.8	Spherical	73.88	Moderate
NDVI	0.002391	0.001343	170.9	Exponential	64.03	Moderate
Chl	0.004252	0.001155	69.5	Spherical	78.64	Weak

C_0 = nugget effect; C_1 = structural variance; A = range.

Topography is one of the factors that can influence the production of culture, as well as the occurrence of weeds since it is

associated with the type of soil, texture, organic matter, and retention of water and nutrients. The GPS was used for the

altimetric survey of the area, instead of the topographical survey, as a way to reduce the costs and make an agiler data acquisition. The altitude data of Garmin GPS generated the altimetric map of the area (Figure 1A). It is observed that there are differences of a maximum of 17 meters in the area, as there are points located between 638 and 655 m above the sea level. These results are in accordance with Cremonini & Molin (2002), who had also demonstrated that the acquisition of altimetric maps by a GPS equipment is adequate for agricultural area management. The results of Sanchez et al. (2012) showed that the limits of the relief forms are reliable indicators of the specific zones for variable rate input application.

The soil electrical conductivity measurement (EC) is related to some soil properties such as texture, organic matter and CEC (Machado et al., 2006; Bernardi et al., 2014, 2015). As EC measurements (0-0.3m) presented a higher spatial dependency, the analysis will focus on

these results. The EC map of field 11 of the Cruzeiro Campo Farm (Figure 1B) shows a region of lower EC, represented by the lighter area, probably indicating soil zones tending to the medium texture. On the other hand, the darkest areas of the map probably show regions with clay texture). This information can be useful in the moment of establishing, for instance, herbicide management strategies, as the recommendation, can be different from clay texture soil to another with a sandy texture. The results of electrical conductivity of the soil in the surface layer (0-0.3m) indicate a distribution of values, basically into two distinct areas: up to 22 mS cm^{-2} and above 22 mS cm^{-2} , respectively with 50.4 and 49.6% of the total area (Figure 1B). The importance of using the EC map can be confirmed by the work of Nordmeyer et al. (1997), who reported significant correlations between the soil properties and weed occurrence.

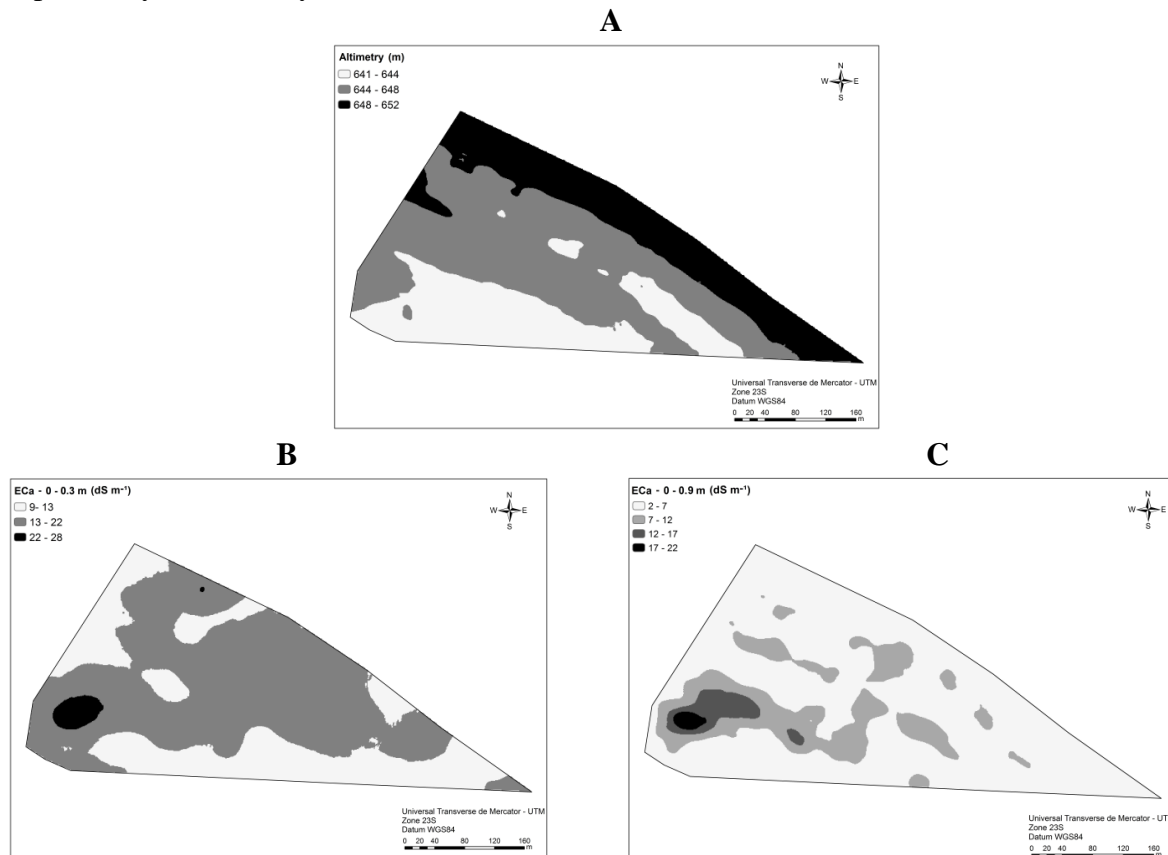


Figure 1. Altimetry kriged maps (A) and soil apparent electrical conductivity - EC_a in the depths of 0-0.3m (B) and 0-0.9 m (C). Guariba – SP

NDVI depends on the spectral contrast between the bands red and near infrared and is related to the amount of biomass, as well as the concentration and content of vegetable pigments (Numata et al., 2007). Thus, the areas with higher NDVI (darker areas) are indicative of the presence of weeds, especially the bermudagrass that was infecting the area, as demonstrated by Rouse et al. (1973).

The NDVI map (Figure 2A) enabled the calculation of the areas of each class. Thus, the highest values (between 0.01 and 0.2) has an extension of 9.1 ha and represents the area free from bermudagrass. Nevertheless, the other two categories (between 0.2 and 0.39 and 0.39 and 0.57) with a 2-ha extension, equivalent to 18.3% of the whole field has weed infestation. These results corroborate reports of Nordmeyer et al. (1997), in the sense that weed infestations occur in a

different way and aggregate spots.

The Canopy Chlorophyll content (Chl) of a culture is a biophysical variable which quantitatively expresses the photosynthetic capacity of the vegetation. It is related to biophysical parameters of the canopy, such as nitrogen content, biomass, green coloration, total leaf area index, CO₂ exchange balance, and absorbed photosynthetically active radiation - PAR (Gitelson et al., 2005). Despite the high similarity between NDVI and Chl maps, the second index (Figure 2B) presented a lower spatial dependency. Therefore, it was decided to use the information of the NDVI map for the weed occurrence estimates. Balastreire & Baio (2001) had already established that the mapping of spatial weed distribution would be the first step in the localized application of herbicides.

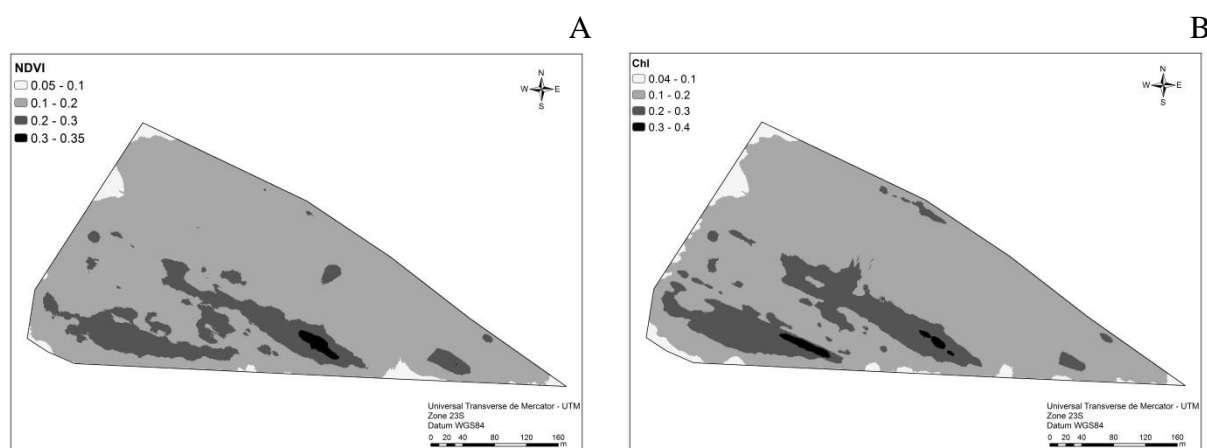


Figure 2. NDVI (A) and Chl (B) maps of the field cultivated with sugarcane. Guariba - SP.

From the information obtained with EC_a and NDVI, it was possible to perform a simulation of the culture production cost, comparing the conventional technology, treating the field in a uniform way, and the PA technology, applying herbicides only where there were weeds and varying the dose about the type of soil. For the simulation, EC_a information was considered, which indicated that the area under study could be divided into two regions with distinct soil textures. Additionally, the NDVI data that showed

the places in the field where there was bermudagrass infestation and that this area represented 18% of the total area. It was considered that, for the purpose of costs, EC_a and NDVI measurements would occur together with other operations, as previously demonstrated by Inamasu et al. (2007) and Rabello et al. (2008). With this information, and based on the spreadsheets of Pecege (2012) and Faeg (2012), the simulations of production cost that are in Table 2 were performed.

In the planting operations, it was

considered that there would be a reduction in the use of herbicide in pre-planting, and consequently, the use of machines and labor, as the area to be controlled would be reduced from 11.15 ha to only 2 ha. Thus, the cost of soil preparation and planting of this field would decrease from US\$ 30,093.46 to US\$ 29,813.20, representing 0.93% of the total. The significant reductions in production cost would be observed in the operations of cane-plant and sugarcane ratoon. Since by EC_a it was possible to divide the area into two distinct regions of the soil of heavier texture (50.4%) and another of lighter soil (49.6%), there would be a reduction in the post-planting herbicide doses, as the recommended doses are lower in lighter soils. In this case, the reduction would

occur only by the decrease in the amounts of herbicides applied, with the cost of machines and labor remaining unaltered. Mortensen et al. (1995) had already reported that, based on the spatial distribution of weeds, it was possible to reduce the application of post-emergent herbicides from 71 to 94% for dicotyledonous and monocotyledonous species, respectively.

Hence, the cane-plant cost would be reduced from US\$ 18,109.49 to US\$ 16,807.76 using PA, that is, 7.2%. The cost of sugarcane ratoon operations would be reduced by 11.4%, in other words, from US\$ 16,960.32 to US\$ 15,031.95.

Table 2. Estimates of sugarcane production cost in a field of 11.15 ha in the conventional and PA systems.

	Conventional			PA		
	Planting	Cane-plant	Sugarcane ratoon	Planting	Cane-plant	Sugarcane ratoon
	US\$					
1. Planting						
Inputs	14,553.49	-	-	14,421.39	-	-
Machines	9,794.62	-	-	9,748.82	-	-
Labor	5,745.36	-	-	5,642.99	-	-
Subtotal 1	30,093.46	-	-	29,813.20	-	-
2. Cane-plant and ratoon						
Inputs	-	1,781.96	2,569.38	-	834.58	971.08
Machines	-	439.99	1,770.69	-	439.99	1,770.69
Labor	-	862.27	1,247.53	-	507.93	917.47
Subtotal 2	-	3,084.23	5,587.61	-	1,782.50	3,659.24
3. Harvest						
Machines	-	14,610.20	10,957.65	-	14,610.20	10,957.65
Labor	-	415.06	415.06	-	415.06	415.06
Subtotal 3	-	15,025.26	11,372.71	-	15,025.26	11,372.71
Total (1+2+3)	30,093.46	18,109.49	16,960.32	29,813.20	16,807.76	15,031.95

The use of PA technology can help in the reduction of sugarcane production costs in 0.86% in the stage of soil preparation and planting, 7.2 in the step of cane-plant and 11.4% in the stage of sugarcane ratoon. The economic return of PA was also confirmed by Griffin &

Lowenberg-Deboer (2005) and Inamasu & Bernardi (2014), on. Also of Sanchez et al. (2012), who demonstrated that variable rate input application was the most efficient way, in the economic and environmental point of view, compared to the requests based on the average. These

results are reinforced by the observations of Silva et. al., (2011), who indicated that 96% of the sugar-energy sector of the State of São Paulo intends to expand the use of PA tools.

Considering that five ratoons are performed in the region under study, there would be a significant resource economy

during the culture cycle. However, it is important to highlight that these reductions occur about the characteristics of the area under study. It is not possible to generalize this information for all of the regions with sugarcane cultivation since there are many soil and climate differences for each region.

CONCLUSIONS

According to the results obtained in the area under study, it can be concluded that EC (0-0.3m) indicated that the studied area could be divided into two regions with distinct soil textures. NDVI showed the sites in the field where there was bermudagrass infestation and that this area

represented 18% of the total area. The simulation demonstrated that the use of PA could assist in the reduction of sugarcane production costs in 0.93% in the stage of soil preparation and planting, 7.2% in the stage of cane-plant and 11.4% in the stage of sugarcane ratoon.

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