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Precision agriculture for sugarcane management: a strategy applied for brazilian conditions

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ABSTRACT. The region of Areiópolis in São Paulo State is one of the major sugarcane producers in the world, and chemical management is the basis of the system making its production viable. Thus, the proposed methods for precision agriculture can be evaluated as an alternative for environment protection and can aid the search for greater productivity at the same time. The main objective of the present work was to compare the precision agriculture (PA) and traditional agriculture (TA) management systems and to highlight their distinctions, such as differences in grid sampling, production variation, plant failure and costs. Two experiments were set up, and the soil fertilizers were applied by corrective application methods to 16-ha lots using the average general fertility rate (GFR). The PA method had the highest productivity volume for conversion of green matter to sugar in the 4.0-ha plots. As the size of the PA plots decreased, the costs of soil analyses increased with potassium and lime analyses being the most expensive. The PA plots had more suitable grid sampling in terms of productivity, and the cost/benefit ratio was 4.0-ha. In general, the final cost was higher in the PA system compared to the TA system. The present results provide information to help select the better system between these techniques to manage tropical soils.

Keywords: tropical soil, soil sampling, fertility, management.

Agricultura de precisão para manejo da cana-de-açúcar: uma estratégia aplicada as condições brasileiras

RESUMO. A região de Areiópolis, Estado de São Paulo, é uma das principais produtoras de cana-de-açúcar do mundo e o manejo químico é a base para o sistema, tornando sua produção viável. Assim, métodos propostos pela agricultura de precisão podem ser avaliados como alternativa à proteção ambiental e a maior produtividade. O objetivo deste trabalho foi comparar os sistemas de produção, Agricultura de Precisão (AP) e a Agricultura Tradicional (AT) e destacar suas distinções, tais como as diferenças na grade de amostragem, a variação da produção; stand e custos. Dois experimentos foram instalados e o método de aplicação de fertilizantes e corretivos foi conduzido pela média da fertilidade geral (AT), com a aplicação localizada em lotes de 16-ha. O método de AP indicou maior produtividade, tanto para matéria verde quanto para açúcar no lote 4,0-ha; com a diminuição do tamanho dos lotes em AP, os custos das análises de solo aumentaram, principalmente para o potássio e o calcário; o grid mais adequado em termos de produtividade e relação custo benefício foi o de uma amostra a cada 4,0-ha; em termos gerais, o custo final foi maior na AP. Os resultados fundamentam a decisão sobre qual o melhor sistema para a gestão de solos tropicais.

Palavras-chave: solos tropicais, análise de solo, fertilidade, manejo.

Introduction

Precision agriculture (PA) has been widely employed in the world, particularly for grain crops. Farmers have adopted this technology motivated mainly due to the reduction of environmental impacts and better use of the production potential in a field (BRAMLEY, 2009; HABOUDANE et al., 2002).

The basic concepts of the site-specific management were developed in 1929 (LISLEY; BAUER, 1929), and their pioneer work reported studies on the site-specific application of fertilizers and soil correctives, specifically liming (GOERING, 1993). The emergence of new technologies, such as global position system (GPS) in the 1980s, has made it possible to automate site-specific fertilizers, soil corrective application and productivity measurements. These technologies have revitalized the earlier findings of Lisley and Bauer in 1929 leading to the beginning of precision agriculture (LISLEY; BAUER, 1929). Therefore, we describe PA as a new system of agriculture.

According to Auernhammer et al. (1994), the following two components are essential to evaluate the local variability, which is indispensable for the application of PA methods: 1) localized sampling of chemical and physical attributes (soil fertility); and 2) localized measurements of crop productivity (crop uptake) (AUERNHAMMER et al., 1994). In contrast, it was stated that PA is only feasible if its costs are lower than the traditional method (ODEH, McBRATNEY, 2000; SILVA et al., 2011; TWEETTEN, 1996). Concerning these references that discuss the "Potential of Precision Agriculture in sugarcane production" in Australia, the authors reported that, "[…] there is a real potential for the use of PA to decrease the environment impacts and to improve the sugar agroindustry results" (CANTARELLA et al., 2007; MOLIN, 2009; SILVA et al., 2011). Further, these authors suggested that

> […] at this stage, the concept of PA is still very recent and it is difficult to accurately predict the impact that it will have. Research work should be differentiated to better evaluate the two systems.

Thus, for sugarcane, there is not enough research to discuss this issue and its application to the country conditions, especially in Brazil (SILVA et al., 2011).

The discussion of commercial PA application to tropical soils has increased in the last decade. However, research support for this idea is lacking. Many producers do not have scientific support to decide which system to use, so they have to make a decision without any logical information (SILVA et al., 2011), which led us to evaluate the risk of impacts on the soil environment with regard to future economic problems for these farmers.

One important issue for the PA system, which has been studied in the past years, is the assessment of which adequate sampling scheme to adopt when estimating soil variability. Sampling schemes based on a regular grid have been the first to be suggested because they have been used in systems where no information about soil variability was available before the sampling (VAŠÁT et al., 2010). Different configurations of regular grids have been compared in the past and have proven that a regular grid with a triangular shape minimizes the maximal or the average kriging variance, which is more appropriate for the estimation of soil attributes in most cases (GARDNER et al., 2008; YFANTIS et al., 1987).

In addition to the sampling scheme shape, another aspect that directly affects the quality of soil variability mapping is the sampling density or number of samples taken per area (CORWIN et al., 2010; WOLLENHAUPT et al., 1994). Decreasing the space among samples causes the average or maximal kriging variance to also be decreased.

Many studies have indicated that a regular grid in a triangular shape and a sampling density of 1 to 2 samples per hectare is reliable depending on the special variability for the evaluation of soil variability (FRANZEN; PECK, 1995; VAŠÁT et al., 2010; WOLLENHAUPT et al., 1994). However, studies investigating soil sampling schemes for tropical and subtropical climates as well as edaphic conditions, such as Brazil, are lacking.

Another alternative to traditional fertility management (assessment of a central tendency in a field) is performing an evaluation of the soil variability in the area based on cells considering a central tendency for these cells and using these values to mapping soil attributes even if the performance of this approach is largely worse than mapping by grid sampling. In the study carried out by Wollenhaupt et al. (1994), the use of site-specific management in cells (5-9 composite samples taken in a zigzag pattern inside each cell with the cells measuring approximately 100 x 100 m) improved the accuracy of phosphorus and potassium mapping between 14 and 33% compared to the field average (WOLLENHAUPT et al., 1994). With the cell approach, however, approximately 38% of the studied area would receive incorrect fertilizer application. The grid soil sampling, which has also been evaluated by the authors of this work, showed an improvement of 20% compared to the cell method.

In an important study was noted the importance of studies investigating the number of samples necessary when adopting the PA methods in Brazilian conditions (DEMATTÊ, 2001). With regard to the frequent doubts concerning the tropical region, the author questioned the following: "How many soil samples should be taken for the system? One sample per hectare? Should the sampling method be the same for all regions?" The author also emphasized the fact that the costs involved in soil analyses are the major "bottleneck" of this system. These same questions have already been asked for soil sampling in the past for the TA system but have not been asked for the PA in sugarcane areas. Other questions also arise: Which system gives better productivity? Which system has higher cost? Which is the better plot size?

Therefore, the main objective of the present work was to compare soil and plants treated by two different soil management systems as follows: 1) uniform fertilizer application (traditional Agriculture, TA) and variable application (Precision Agriculture method, PA). The results indicated the advantages and disadvantages of both systems in the tropics for sugarcane culture. Thus, this work aimed to answer the following questions: Which is the better grid sampling for the PA system? Which system has the lower costs? Which has the lower fertilizer-corrective application? What differences can appear related to the plant industry parameters when soils are managed by these systems? These results will help to explain and guide PA application to tropical soils. The present experiment aimed to identify the comparative improvements and costs of uniform *vs.* variable application of soil fertility management within typical sugarcane blocks in Brazil.

Material and methods

Characterization of the area and experimental design

The studied area is located in the region of Areiópolis, São Paulo State, Brazil. The soil was a medium texture Typic Haplortox with low fertility, which is one of the most important soil classes in this region. The experiments were of medium time duration with one harvest from the original sugarcane plant and one from the second growth.

Two 16-ha areas for this study were selected, and each one was managed differently. One was managed by the traditional method (TA) where soils were collected in the 16 ha area, and we worked with the average of analysis. The second 16 ha area was divided into sub parcels with different dimensions as follows: 0.25, 0.5, 1.0, 2.0 and 4.0 ha. From each of these parcels, soil collections were made for the precision agriculture system.

The 16 ha area corresponding to the TA system was located contiguous to the PA system. To maintain strict control of the experiment, the 16 ha area was divided similarly to the PA system, i.e., with a setup of 64 small cells.

Grid sampling

Sampling systems that had previously been tested and considered satisfactory, as reported by Webster and Oliver in 1990 and Wollenhaupt in 1994, were adopted for the PA area (WEBSTER; OLIVER, 1990; WOLLENHAUPT et al., 1994). Geostatistical information has been previously reported by Isaaks and Srivastava in 1989 (ISAAKS; SRIVASTAVA, 1989).

All soil-sampling sites were georeferenced by the Global Positioning System (Trimble Pro-XRS). Soil samples composed of 6 individual samples taken at 0 to 20 and 20 to 40 cm depths were collected from each cell. In a model proposed by Odeh and McBratney (2003) was used to map the spatial distribution of the soils based on the field sampling (ODEH; McBRATNEY, 2000; McBRATNEY et al., 2003). Therefore, this system was adopted to chart the spatial distribution of the soil attributes and to draw the productivity maps.

Recommended criteria for fertilizers, soil corrective measures, experiment setup and harvesting

Soil fertility was analyzed using the following parameters: organic carbon, pH ($CaCl_2$), P, Ca, Mg, K, Al, H+Al, cation exchange capacity (CEC) and V% ([sum of cations/CEC] x 100). The recommendations for P, K, lime and gypsum followed several calibration curves reported in the literature for sugarcane (CANTARELLA, 2007). The application of the correctives and fertilizers to the cells was performed by PA machines. Granulometry (sand, silt and clay) was also determined (CAMARGO et al., 1986).

Both lime and gypsum were applied over the entire area and incorporated into the soil. A single rate of 40 kg ha^{-1} of nitrogen in the form of aqua-ammonia was applied during plowing. Different doses of phosphorus (in the form of super triple phosphate) and potassium (in the form of KCl) were applied to the small cells. The variety of sugarcane used was RB 84 5257, and it was planted in April. In July of the following year, the sugarcane from the experiments of the two areas was harvested (manually), weighed and analyzed. Afterwards, both areas were prepared for the second growth. Regarding potassium, the K_2O doses were calculated for each cell based on the pre-planting soil analyses and calibration curves. A single rate of 100 kg ha^{-1} of nitrogen was used. One year later, the second harvest followed the same criteria used for the first harvest.

Chemical correctives and fertilizers

Based on the soil analysis results and calibration curves, the amounts of lime, gypsum, phosphorus and potassium for the two areas were calculated. These quantities were then applied manually before planting. In the case of gypsum in the TA cells, the applied dose was 2.0 ton ha^{-1} for all cells. The dose for the PA method was 2.0 ton ha^{-1} for the 4.0-, 2.0- and 1.0-ha cells, and the doses were reduced to 1.5 ton ha^{-1} for the 0.5-ha cell and 1.25 ton ha^{-1} for the 0.25-ha cell. The final average dose of gypsum for the PA system was 1.7 ton ha^{-1} compared to 2.0 ton ha^{-1} for the TA system.

Other parameters evaluated for both management systems

Two months after the first harvest, an inspection was performed to determine empty spaces (more than 50 cm wide) where there were no new plants sprouting from the rhizomes. Measurements were performed as follows: a tape measure was placed on the experimental cell, and the number of empty spaces was counted in the three central rows. The percentage of empty spaces was calculated based on the total length of the three rows. Thus, the plant failure in both systems was determined.

The percentage of empty spaces was established and classified, based on the following ranges: less than 5%; 5-10%; 10-15%; 15-20%; and greater than 20%. During the procedure to verify the percentage of plant failure, a penetration resistance measurement was performed on the center of the furrow and in the central position between the rows using a penetrometer. The degree of compaction was also assessed in the three central rows of each plot with five replicates in the PA and TA areas. Graphs were produced based on the resistance to the penetration of the penetrometer tip, which generated the following degrees: 1, absence; 2, slight; 3, moderate; 4, severe; and 5, very severe. All of the measurements were determined with the same state of humidity.

The costs were calculated in relation to the corrective chemicals, fertilizers and soil analyses. For comparison, an estimate of the chemical correctives, fertilizers and soil analyses for the 16-ha area as a single treatment was calculated.

The costs were as follows (in US dollars): lime, US$21.00/ton; gypsum, US$16.00/ton; potassium chloride, US$0.34/kg of K_2O; phosphorus, US$0.57/kg of P_2O_5; and soil analyses, US$5.61/sample. The costs of the products were taken into consideration. Soil analyses evaluated levels of Ca, K, P, Al, H+Al and organic matter.

The main sugarcane attributes of the tests were evaluated statistically as were those that proved appropriate for this type of analysis, i.e., purity (PU), tons of cane per ha (TCh), sugar index (POL) and tons of POL per ha (TPh). The variation coefficients of these parameters (PU, TCh, POL, and TPh) for the PA and TA methods were first identified. Subsequently, based on these data, linear regression models were created to verify the possibility of estimating these attributes according to their variation. Thus, the dependent variable was the variation coefficient of each of these parameters. Logarithmic regression equations were obtained to estimate PU, TCh and TPh. The GLM procedure (blocks method) was performed to find the relation between the system (traditional and precision agriculture) and the size of the plots. In this case, significance was determined among the system, plot size, and abovementioned parameters. The statistical differences were identified among the averages of PU, TCh and TPh for the different systems and plot sizes using the GLM procedure and the Tukey-Kramer test for multiple comparison adjustments with a significance level of 0.05. Statistical Analysis System was used to develop these steps as described by SAS (1989a and b).

Results and discussion

Quantity and costs of applied nutrients

A vast number of factors must be considered for cost evaluation, and we considered some of these parameters. The costs of equipment and GPS systems were not included, but the costs of products were considered. Taking into account the costs of the chemical correctives, fertilizers and soil analyses (Table 1), the differences between the two methods varied according to the size of the sampled cell. Thus, the final cost of the PA method was 25% higher than that of the TA method for the 4.0-ha plot, 18% higher for the 2.0-ha plot, and 4% higher for the 1.0-ha plot. For the other cells, the costs were inverted. The cost of the TA was 8 and 6% higher for the 0.5-ha and 0.25-ha plots, respectively, and these higher costs were due to the greater amounts of gypsum and lime used.

Table 1. Simple Cost* variations of the corrective and fertilizer products applied in US dollars.

Area (ha)	Method	Lime	Gypsum	P_2O_5	K_2O	Soil Analysis	Total	Difference %
16	Conventional	52	32	83	44	0,70	212	-
	Precision Agriculture	56	32	83	44	0,70	215	2
4	Conventional	76	16	85	34	2,81	215	1
	Precision Agriculture	101	32	85	44	2,81	266	25
2	Conventional	59	32	85	44	5,62	226	7
	Precision Agriculture	68	32	105	55	5,62	265	25
1.0	Conventional	90	32	85	34	11,24	253	19
	Precision Agriculture	99	32	85	34	11,24	262	23
0.5	Conventional	99	32	85	34	22,48	273	29
	Precision Agriculture	72	24	105	34	22,48	257	21
0.25	Conventional	63	32	85	44	44,96	269	27
	Precision Agriculture	55	20	90	47	44,96	258	21

*Not taking in account costs of equipments neither application services, only products.

However, when the total area of the TA system was considered to be a 16-ha sampling grid (as companies routinely perform the cost evaluations) the costs of correctives, fertilizers and soil analyses using the TA system was 25% lower than that with the PA method for the 4.0-ha cell and 25, 23, 21 and 21% lower for the 2.0, 1.0, 0.5 and 0.25-ha cells, respectively (Table 1). Considered separately, the cost of soil analyses increased significantly from the 4.0-ha cell to the 0.25-ha cell with values ranging from US$ 2.81 to 44.96 regardless of the farming method employed. The latter value was higher than the cost of potassium used for the 0.25-ha cell, which could render this portion of the experiment economically impractical, depending on the final productivity.

Agricultural productivity

The 4.0-ha cell from the PA system had an average sugarcane production of 121 ton ha^{-1} compared to 107 ton ha^{-1} for the TA system (Table 2). There was variation of 24 and 21 ton ha^{-1} from the highest to the lowest productivity for the PA and TA methods, respectively. The difference in productivity for the other test cells between the two methods was not significant and was less than 6.0 ton ha^{-1}.

Table 2. Average productivity of two sugarcane harvests from both systems.

Plots (ha)	System[a] ton ha^{-1} of stalks			
	1[st] Harvest		2[nd] Harvest	
	PA	TA	PA	TA
4.0	121 (134-110)	107 (117-96)	100 (114-80)	85 (93-77)
2.0	106 (121-94)	112 (132-99)	93 (99-87)	95 (112-78)
1.0	115 (126-104)	109 (127-100)	95 (107-93)	86 (97-75)
0.5	115 (123-98)	114 (127-99)	95 (111-80)	97 (105-89)
0.25	105 (114-96)	107 (120-91)	97 (114-80)	91 (100-84)
Average	112,6	109.8	96.0	90.3
Plots (ha)	System[a] ton ha^{-1} of POL[2]			
	1[st] Harvest		2[nd] Harvest	
	PA	TA	PA	TA
4.0	18.2 (20.5-16.9)	16.7 (17.5-15.2)	15.1 (16.9-13.3)	13.1 (14.7-11.5)
2.0	16.4 (16.4-14.9)	16.8 (19.3-14.9)	14.0 (14.3-13.7)	13.8 (14.4-12.3)
1.0	17.4 (19.8-15.4)	16.8 (17.9-14.8)	14.4 (14.9-13.9)	13.2 (14.8-11.6)
0.5	17.0 (18.5-14.1)	16.9 (18.2-14.8)	13.8 (15.9-11.7)	14.0 (15.2-12.9)
0.25	16.3 (19.2-14.8)	16.7 (18.2-13.9)	13.6 (14.4-12.8)	14.8 (17.0-12.7)
Average	16.9	16.7	14.1	13.5

[a]PA, Precision Agriculture, TA, Traditional Agriculture; [2]POL (sugar index).

The final productivity averages for the two methods were 112.6 and 109.8 ton ha^{-1} for the PA and TA systems, and the difference between these averages was not significant. The lowest variation in the productivity for the PA site-specific system occurred in the 0.25-ha cell, indicating that this cell size was the best sampling size for this system. However, the 0.25-ha cells are not feasible due to the high cost of soil sampling (Table 1).

An analysis of the amount of POL ha^{-1} showed that the PA method resulted in higher productivity for the 4.0, 1.0 and 0.5-ha cells with an increase of 1.5, 0.6 and 0.1 ton ha^{-1}, respectively, as compared to the TA cells, which indicated differences between the methods. No significance differences were found for the other cells (Table 2).

The production results for the second harvest of sugarcane (Table 2) were significantly lower than those of the first harvest, which was consistent for sugarcane cultivation because progressively lower productivity occurs in each consecutive harvest. The data on the total productivity for both methods indicated only slight differences, except for the 4.0-ha cell, where the variation in productivity was 15 ton ha^{-1} higher in the PA cell compared to the TA cell. The average productivity for all the PA cells was 96 ton ha^{-1} compared to 90.3 ton ha^{-1} for the TA cells. Moreover, the average production variation for the PA cells was small ranging from 100 ton ha^{-1} for the 4.0-ha cell to 93 ton ha^{-1} for the 2.0-ha cell. In contrast, productivity showed higher variations for the TA system with a variation of 12 ton ha^{-1} and ranging from 85 ton ha^{-1} for the 4.0-ha cell to 97 ton ha^{-1} for the 0.5-ha cell. Moreover, the 4.0-ha cell produced more than the other cells regardless of the method employed although the PA method showed higher productivity. Nonetheless, the variation in productivity within each cell showed differences (Figure 1).

In addition, the POL ha^{-1} analyses indicated a difference in the larger cells of the PA system (Table 2). The average values of TPh in the 4.0, 2.0 and 1.0-ha cells were 15.1, 14.0 and 14.4 ton ha^{-1}, respectively, compared to 13.7 ton ha^{-1} in the smaller cells. These results indicated a higher sugar content of up to 1.5 ton ha^{-1}, which was a trend similar to that found in the first harvest. In contrast, the analysis of productivity under the TA system revealed that the sugar contents for the 4.0 and 1.0-ha cells were less those that observed in the PA system. The productivity data for both the first and second harvests showed that the larger cells from the PA system were more productive in terms of sugarcane and sugar, particularly in the 4.0-ha cell.

These results suggested that the different application of nutrients, especially for the larger cells, contributed to a higher total tonnage and also to a substantial increase in the amount of sugar per area. Using productivity as a criterion, the best sampling size was found to be the 4.0-ha cell.

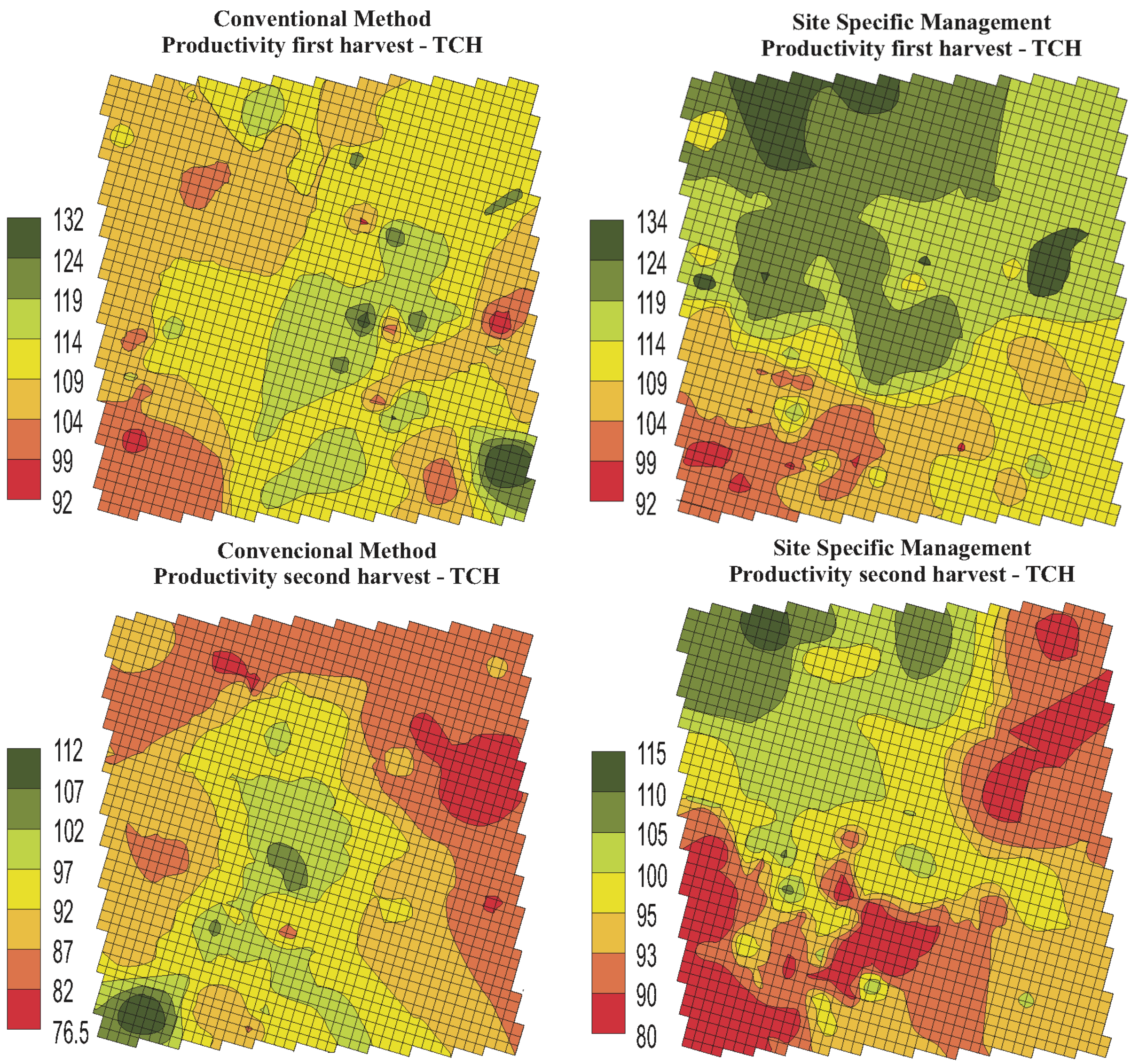

Figure 1. Spatial distribution of the productivity (ton ha^{-1}) in the first and second harvest (for the two-year tests).

Currently, the traditional soil sampling method uses one sample composed of 12 to 20 simple samples for a 20-ha area with fertilizer being applied in a uniform dose to the area. In contrast, the PA system uses a sampling grid of 1-2.5 points per ha in commercial areas. Some authors indicated that high-resolution grid soil sampling provides the most realistic description of nutrient distribution in soils (SCHEPERS et al., 2000). In contrast, a soil sampling strategy that is universally applicable is not realistic because of the intense variation between regions. The TA system treats large areas (approximately 20 ha) with the same soil management system.

Chemical fertilizer and correctives are distributed throughout of the Brazilian area due mostly to tradition. In contrast, the PA method is not widely used because research has not evolved in this area. Even if the PA system is widely used in some countries, many questions still persist. The understanding of the PA management in comparison with the traditional method can help communities decide which system is better.

Conclusion

The present results indicated that the grid size does not necessarily have to be 1.0-ha and may vary up to 4.0 ha, which may reduce the overall costs.

The final costs of correctives, fertilizers and soil analyses of the conventional method were found to be approximately 25% lower than that of the site-specific PA method. The cost of soil analyses for the 0.25-ha plot was higher than the costs of the potassium fertilizer applied to the plot rendering this plot size unfeasible as a sampling size.

The site-specific PA method in the 4.0, 2.0 and 1.0-ha plots produced more sugarcane and sugar than the conventional method. The highest sugarcane and sugar production from both harvests under the site-specific PA method, as well as the lowest coefficients of variation, were obtained for the 4.0-ha plot, which may be considered the most appropriate soil sampling plot for this soil.

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