HARVEST MANAGEMENTS AND CULTURAL PRACTICES IN SUGARCANE[1]

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SUMMARY

The presence of trash from the mechanical harvest of green cane on sugarcane plantations promotes changes in the agricultural management, for example, in the mechanical cultural practices of ratoon cane in-between the rows and nitrogen (N) fertilization. The goal of this study was to evaluate the performance of sugarcane in different harvest systems, associated to the mechanical cultural practices in interrows and N rates. The study was carried out on a sugarcane plantation in Sales Oliveira, São Paulo, Brazil, with the sugarcane variety SP81-3250, on soil classified as Acrudox, in a randomized block design with split-split plots and four replications. The main treatments consisted of harvest systems (harvesting green cane or burnt cane), the secondary treatment consisted of the mechanical cultural practices in the interrows and the tertiary treatments were N rates (0, 30, 60, 90, 120 and 160 kg ha^{-1}), using ammonium nitrate (33 % N) as N source. The harvest systems did not differ in sugarcane yield (tons of cane per hectare - TCH), but in burnt cane, the pol percent and total sugar recovery (TSR) were higher. This could be explained by the higher quantity of plant impurities in the harvested raw material in the system without burning, which reduces the processing quality. Mechanical cultural practices in the interrows after harvest had no effect on cane yield and sugar quality, indicating that this operation can be omitted in areas with mechanical harvesting. The application of N fertilizer at rates of 88 and 144 kg ha^{-1} N, respectively, increased stalk height and TCH quadratically to the highest values for these variables. For the sugar yield per hectare (in pol %), N fertilization induced a linear increase.

Index terms: nitrogen fertilization, mechanical cultural practices, green cane, *Saccharum* spp.

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RESUMO: *SISTEMAS DE MANEJO DE COLHEITA E TRATOS CULTURAIS NA CULTURA DA CANA-DE-AÇÚCAR*

A presença da palha no campo, oriunda da colheita mecanizada sem despalha a fogo, implica em mudanças no manejo da cana-de-açúcar, como na realização do cultivo mecânico da soqueira e na fertilização nitrogenada. O objetivo deste trabalho foi avaliar o desenvolvimento da cana-de-açúcar submetida aos diferentes sistemas de colheita, associado à realização ou não do cultivo mecânico, e à aplicação de doses de nitrogênio (N). O trabalho foi desenvolvido na região de Sales Oliveira, SP, em área comercial de cana-de-açúcar, com a variedade SP81-3250 (2º corte), em um Latossolo Vermelho acriférrico. O delineamento foi em blocos casualizados com parcelas subsubdivididas, em quatro repetições, em que os tratamentos principais eram os sistemas de colheita (cana crua ou cana queimada); os tratamentos secundários à realização ou não do cultivo mecânico; e os tratamentos terciários às doses de N (0, 30, 60, 90, 120 e 160 kg ha^{-1}), usando como fonte o nitrato de amônio (33 % N). Os sistemas de colheita não diferiram para a produtividade da cana-de-açúcar (t ha^{-1} de cana - TCH), porém a cana queimada apresentou maior teor de sacarose (Pol) e açúcar total recuperável (ATR), sendo esse fato em razão, provavelmente, do aumento das impurezas vegetais que fazem com que a qualidade tecnológica diminua. O cultivo mecânico da soqueira após a colheita da cultura não apresentou nenhum impacto na produtividade de colmos e açúcar, indicando que essa operação pode ser desconsiderada em áreas com colheita mecânica. A aplicação de fertilizante nitrogenado aumentou a altura de colmos e TCH de forma quadrática com as doses de 88 e 144 kg ha^{-1} de N, proporcionando os maiores valores para essas variáveis. Para a produção de açúcar por hectare (TPH), houve aumento linear em razão da adubação nitrogenada.

Termos de indexação: adubação nitrogenada, cultivo mecânico, cana crua, Saccharum *spp.*

INTRODUCTION

Sugarcane is the raw material for sugar and ethanol production, and a biomass source for generating electric energy (CGEE, 2009). The common practice of pre-harvest detrashing by fire, despite facilitating harvesting, loading and transportation, generates greenhouse gas emissions into the atmosphere (GHG) and degrades most of the soil organic matter and nutrients in the crop residues (Mitchell et al., 2000).

On the other hand, the crop residues (trash) left behind after mechanical harvesting of green sugarcane are composed of leaves, sheaths, plant tips, and shredded stalk pieces (Vitti et al., 2008), which, in significant quantities from 10 to 30 Mg ha^{-1} (Trivelin et al., 1996), are relevant for nutrient cycles, improvement of soil fertility and microbial activity (Macedo et al., 2008). The relationship carbon/nitrogen (C:N) in trash is approximately 100:1 (Robertson & Thorburn, 2007), and adding this organic material to the soil may cause N immobilization by the microbial biomass (Vitti et al., 2008). Due to the slowness of N mineralization in the trash (Faroni et al., 2003; Vitti et al., 2011), the contribution of this process is not taken into account when managing N fertilizer of sugarcane ratoon (Vitti et al., 2007).

The effect of trash on sugarcane yield is complex. Several studies describe it as negative (Basanta et al., 2003), while others report a positive effect (Wood, 1991; Trivelin et al., 2002a). Relating the green cane harvesting system (without previous burning) with the soil properties and the yield potential of the sugarcane variety can help optimize the responses in sugarcane ratoon yield (Contin, 2007).

Nitrogen is an essential element for crop production and sugarcane absorption of this nutrient varies from 100 to 300 kg ha^{-1} for a stalk production of 100 Mg ha^{-1} (Cantarella et al., 2007; Franco et al., 2008b). The amount of existing N in plant residues from green cane harvesting that remain on the soil after harvest can be a source of N (40 to 80 kg ha^{-1} of N) during the following ratoon crop (Fortes et al., 2011; Vitti et al., 2011; Fortes et al., 2012) and can diminish the need for mineral fertilizer application. However, N-fertilization of the ratoon crops is imperative to satisfy the nutritional needs of N. The recommended N rates vary from 60 to 120 kg ha^{-1} N (Espironelo et al., 1996) for burnt sugarcane, and from 100 to 120 kg ha^{-1} of N for green cane (Vitti & Mazza, 2002). Research institutes have yet to establish an official recommendation for areas where sugarcane is harvested without previous burning.

Regardless of the N-fertilizer rate applied to sugarcane plants, their use efficiency of fertilizer-provided N is almost always less than 50 %. This value is lower than in other crops (between 50 and 70 %) (Cantarella et al., 2007). Studies indicate that the use efficiency of fertilizer N by sugarcane can vary from 20 to 40 % (Prasertsak et al., 2002; Trivelin et al., 2002b; Franco et al., 2008a; Franco et al., 2011; Vitti et al., 2011). This variation and low exploitation can be related to N loss in the soil-plant system, due to ammonia denitrification and volatilization (Trivelin et al., 2002a), leaching (Oliveira et al., 1999) and N gas loss by the aerial part of plants (Franco et al., 2008c).

In areas with mechanical cane harvesting, soil compression caused by agricultural machinery is inevitable, since all this equipment is extremely heavy and has a small contact surface with the soil. This small contact surface leads to a linear reduction of the soil total porosity and aeration, causing a decrease in yield and in ratoon sprouting, and tends to shorten the longevity of the sugarcane plantation (Segato et al., 2006). In this case, producers use the cultural practice of deep subsoiling in the interrow of the ratoon crop, to promote soil decompaction after mechanical harvesting operations. Studies on the effect of mechanical cultivation of ratoon crops on sugarcane yield showed a deleterious effect of this practice in areas harvested without burning (Blair, 2000; Campanhão, 2003; Castro et al., 2012), but with favorable effects in areas of burnt cane (Nunes Jr., 1998).

The objective of this study was to evaluate the response of sugarcane ratoon (2nd cut) on stalk and sugar yield, related to the application of N rates, treated or not with mechanical cultural practices, and harvested with previous burning ("burnt cane") or without previous burning ("green cane").

MATERIAL AND METHODS

The study was carried out in the region of Sales Oliveira, São Paulo, Brazil (20º 52' 31" S, 47º 57' 56" W), in soil classified as Acrudox, in a production environment characterized as D1 on a A to E scale, where A is an environment with the most favorable conditions for sugarcane development, and E an environment with low fertility (base saturation < 50 % and low cation exchange capacity) and/or physical restrictions (low water retention), as proposed by the AmbiCana program created by the Agronomic Institute of Campinas (Instituto Agronômico de Campinas, IAC-SP). The variety SP81-3250 was assessed in the 2nd cut (first ratoon). The maturation of this variety is medium and sprouting on trash is good (Coopersucar, 1995). In the State of São Paulo and the center-south of Brazil, SP81-3250 is grown on 13 % of the entire area used for sugarcane (Chapola et al., 2010).

The experimental delimitation was performed in randomized blocks, with split-split plots subdivided in four replications: main treatments (plots) constitute the harvest systems (green cane or burnt cane); secondary treatments (split-plots) are the application or absence of mechanical cultural practices in the interrows of the crop after harvest; and tertiary treatments (split-split plots) are the N rates (0, 30, 60, 90, 120, and 160 kg ha^{-1}) manually applied near the ratoon plants (source - ammonium nitrate: 33 % N).

Each plot consisted of fifteen 500 m-long rows of sugarcane and the split-plots of 250 m of the 10 central rows, and the other five were left as borders between the plots, which allowed burning of the plots and served as traffic area for the harvester. The split-split-plots were marked within the split-plots, and all consisted of five 10m-long central rows. These central rows were marked 20 m from the end of the split-plots, at a distance of 20 m between split-split-plots. An area of 5.7 ha was evaluated in the experiment.

Before planting, soil sampling was performed in the layers 0-0.2 and 0.2-0.4 m, to evaluate fertility by the method described by Raij et al. (1997). Theses samples were evaluated to characterize the soil of the experimental area. Liming was applied to raise the base saturation index (V%) to 70. In the 0-0.2 m layer, the pH ($CaCl_2$), SOM (soil organic matter) (g dm^{-3}), resin P (mg dm^{-3}), S (mg dm^{-3}), K, Ca, Mg, Al, H+Al (potential acidity), SB (sum of bases) and CEC (cation exchange capacity, in $mmol_c$ dm^{-3}) values and V% (base saturation) were, respectively: 4.9; 22; 21; 26; 1.1; 15; 5; 1; 33; 21.7; 54.7; and 39.7. In the 0.2-0.4 m layer, the pH ($CaCl_2$), SOM (g dm^{-3}), resin P (mg dm^{-3}), S (mg dm^{-3}) K, Ca, Mg, Al, H+Al, SB and CEC ($mmol_c$ dm^{-3}) values and V% were, respectively: 5.2; 19; 7; 13; 0.8; 12; 3; 0; 28; 16.4; 44.4, and 36.9. In particle-size analysis, 719 and 742 g kg^{-1} clay was detected in the layers 0-0.2 and 0.2-0.4 m, respectively.

During the experimental period (June-2008 to August-2009), rainfall was measured (mm $month^{-1}$) with a pluviometer located beside the experimental area, and a dry winter was confirmed (from June to September 2008, rainfall accumulation was only 25 mm). From October 2008 to June 2009, a distribution of rainfalls with over 100 mm per month occurred, allowing a good crop development. During the experimental period, 1,320 mm of accumulated rainfall were recorded.

In March 2007, cuttings of the variety SP81-3250 from the first cut were planted, after pre-heating the buds (30 min at 52.5 ºC) to prevent diseases. Semi-mechanical planting with a distribution of 15 to 20 buds per meter was used. The rows were spaced 1.50 m apart, with a plowing depth of 0.3 m and soil cover of 0.08 m.

The plantation was fertilized with 500 kg ha^{-1} with the 10-25-25 formula with 0.3 % B and 0.5 % Zn, resulting in the application of 50, 125, 125, 1.5, and 2.5 kg ha^{-1} of N, P_2O_5, K_2O, B, and Zn, respectively.

In July 2008, the 16-month-old sugarcane was harvested in a first cut and the primary treatments were applied. For this purpose, a mechanical sugarcane harvester was used. Ten days after harvest (10 DAH), the total area was fertirrigated with vinasse at 90 m^3 ha^{-1}, applying 150 kg ha^{-1} K.

As of the installation of the main treatments, tillering was monitored and mechanical weeding was performed. In June 2009, the number of stalks per split-plot was assessed in a biometric evaluation by randomly collecting 45 stalks. After cleaning and cutting off the tip of the sugar-cane plants, the stalks were electronically weighed and the height measured to calculate the yield (TCH: tons of cane per hectare). The method described by Fernandes (2003) was used to assess the technological quality, based on sugarcane Pol (Pol of cane, PC%), as well as TPH (tons of Pol per hectare) (Mg ha^{-1} Pol) and TSR (kg TSR TC^{-1}).were calculated.

The results were subjected to ANOVA by means of F testing, and the means compared by Tukey's test at 5 % probability, using the statistical program AgroEstat 2011. Polynomial regression analysis was used to compare N rates.

RESULTS AND DISCUSSION

The harvest systems (green or burnt cane) did differ in the biometric parameters (height and TCH) (Table 1). Similar results were reported by Ceddia et al. (1999), who found an average TCH of 66.7 Mg ha^{-1} in a system of green cane, and 67.8 Mg ha^{-1} in an area of burnt cane after five consecutive crops. Evaluating the effects of trash presence (green cane) and trash absence (burnt cane) on stalk growth in Lousiana - USA, Viator et al. (2009) found that trash promoted no increase or decrease in stalk height.

In harvest systems without previous burning, TCH increases are expected (Rossetto et al., 2010) due to nutrient recycling, in addition to a possible compensation effect on N supply throughout the ratoon cycle in function of the gradual mineralization of trash N (Vitti et al., 2011; Fortes et al., 2012). However, trash presence can affect sugarcane yield by hampering tillering. Sprouting can be affected in this way, because the varieties grown for commercial purposes in Brazil were genetically improved for the burnt cane harvest system, while at present, due to environmental issues, sugarcane is being harvested without previous burning, in a green cane harvest system (Tavares et al., 2010).

According to Basanta et al. (2003), leaving the trash on the ground after sugarcane harvest without previous burning protects the soil surface from direct sun radiation, diminishing water evaporation from the soil, when compared to soils with no plant cover (burnt cane). This may result in higher yields. However, these authors stated harmful effects of trash on yield (reduction), which was attributed to the fact

Table 1. Effect of the harvest system (Harv), adoption or non-adoption of mechanical cultural practices of sugarcane management (Cult) and nitrogen rates (N) on stalk height, stalk yield (TCH, tons of cane per hectare), cane Pol, TPH (tons of pol per hectare) and TSR (Total sugar recovery)

Harvest system	Height	TCH	Pol	TSR	TPH
	m	Mg ha^{-1}	%	kg TCH^{-1}	Mg ha^{-1}
Green cane	2.5	115	14.6^{b}	145.8^{b}	16.81
Burnt Cane	2.5	110	14.9^{a}	149.7^{a}	16.47
DMS	0.23	10.6	0.23	2.4	1.66
p>n	0.998^{ns}	0.229^{ns}	0.019*	0.014**	0.566^{ns}
Cultural practice					
With	2.5	112	14.8	148.1	16.59
Without	2.5	112	14.8	147.3	16.69
DMS	0.07	4.1	0.23	3.0	0.59
p>n	0.554^{ns}	0.978^{ns}	0.809^{ns}	0.537^{ns}	0.691^{ns}
N rate (kg ha^{-1})					
0	2.3	100	14.9	150.2	14.99
30	2.4	108	14.8	149.2	16.14
60	2.5	112	14.5	144.6	16.38
90	2.5	117	14.8	147.7	17.30
120	2.5	118	14.7	146.0	17.26
160	2.5	119	14.9	148.5	17.77
p>n	0.0001**	0.0001**	0.156^{ns}	0.099^{ns}	0.0001**
Harv × Cult	0.529^{ns}	0.637^{ns}	0.338^{ns}	0.537^{ns}	0.943^{ns}
Harv × N	0.254^{ns}	0.406^{ns}	0.581^{ns}	0.209^{ns}	0.495^{ns}
Harv × N	0.730^{ns}	0.812^{ns}	0.066^{ns}	0.076^{ns}	0.288^{ns}
Harv × Cult × N	0.607^{ns}	0.285^{ns}	0.042*	0.205^{ns}	0.089^{ns}
CV (%)	8	10	3	4	10

^{ns} non-significant, * and ** significant at 5 and 1 %, respectively.

that trash was shred after harvest, resulting in a trash cover with a thickness of 0.15 to 0.20 m, hampering ratoon sprouting.

When analyzing sucrose percentage (Pol) and total sugar recovery (TSR) in relation to the adopted harvest system, the values of Pol and TSR of burnt cane were higher than of green cane, in disagreement with Campanhão (2003) and Manechini (1997), who obtained higher Pol and TSR for green cane. This difference can be explained by the sugar loss through exudation after burning. However, loss in raw material quality in harvest systems without previous burning is expected, since there is a sugar loss due to cutting and transplantation of stalks in the mechanical harvest process (Ripoli, 2004). Besides, in the green cane system, the quantity of trash (plant impurities), present on the stalks after harvest is higher than in the burnt cane system, diminishing the final quality of the raw material (Pearce, 2006).

The value of TPH is calculated from the interaction between Pol and stalk yield. In this study, no difference in TPH between harvest systems was found, because there was no difference in cane yield (TCH), and the difference in Pol, although significant, was small (2 %) and did not affect TPH.

Our results showed no differences between the treatments with or without the application of cultural practices in interrows after harvest (Table 1). According to Blair (2000), these practices are used in interrows of ratoon crops for the decompaction of the subsurface soil layer, caused by machinery traffic during harvest. However, the literature results are controversial. In certain cases, these cultural practices increase yields (Souza et al., 2005) and in others, the contrary (Orlando Filho et al., 1998; Campanhão, 2003); while sometimes the yield is not affected at all, confirming the results of our study (Ide et al., 1994; Paulino et al., 2004; Camilotti et al., 2005).

In areas of sugarcane production on tropical soils, N fertilization is essential due to the low N availability for the crop. This was confirmed in this study, because the tested N rates improved crop development (Table 1), both in terms of biometric parameters and sugar yield per hectare (TPH). For the parameter plant height, a quadratic response was confirmed (Figure 1) at a rate of 88 kg ha^{-1} N, resulting in the tallest plants (2.50 m). This proves that within only one growing season, N in trash becomes insignificant for sugarcane nutrition compared to the fertilizer available after its application (Vitti et al., 2011).

In a wide bibliographic revision of 37 studies analyzing the response of sugarcane ratoon harvested without previous burning to the application of different N rates, Quassi de Castro & Otto (2013) confirmed that only six studies found no response to N fertilization, 21 described an average response (increase of yield up to 25 %) and 10 reported a high response to N fertilization in ratoons (increase of yield higher than 25 %). This great variation in sugarcane response to N-fertilizer indicates that there are various factors (climate, soil texture, handling techniques, cutting period, etc.) affecting the sugarcane response to N. This highlights the importance of studies that evaluate the sugarcane response curve to N, considering the great variability of fertility in the main soil types found in Brazil, the different sugarcane varieties grown for commercial purposes, the different harvest periods throughout the crop and, particularly, the lack of diagnostic methods for recommendation of N application to sugarcane.

According to Trivelin (2000), N is one of the most restrictive factors in sugarcane crop development. The crop response to N fertilization had already been demonstrated by other studies in Brazil (Trivelin et al., 2002a,b; Franco et al., 2008b; Fortes et al., 2011, 2012, 2013). However, the authors' opinions differ with regard to the relation between the maximum yield and required N rate. Korndörfer et al. (2002) obtained mean increases of 10 TCH with an application of 60 kg ha^{-1} N. Fortes et al. (2011) obtained the highest yield with 100 kg ha^{-1} N, while the average yield of three ratoon crops increased most with 120 kg ha^{-1} N (Fortes et al., 2013). In this study, the N rates with a quadratic effect on TCH with maximum yield (119 Mg ha^{-1}) were obtained with 144 kg ha^{-1} N (Figure 2). A similar behavior was found by Quassi de Castro & Otto (2013), after obtaining a response

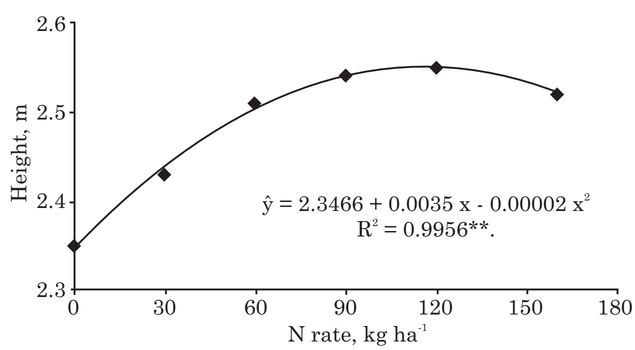

Figure 1. Effect of N-fertilizer rates on stalk height in sugarcane.

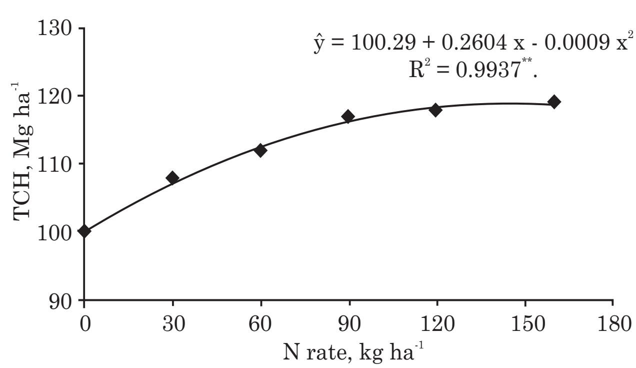

Figure 2. Effect of N-fertilizer rates on stalk yield (TCH) in sugarcane.

curve of the relationship between yield (TCH) and N rate applied in 37 experiments. In the study of these authors, there was a quadratic response to N fertilization, with maximum yields (95.36 Mg ha^{-1}) at 136 kg ha^{-1} N rates.

Cultural practices throughout the sugarcane cycle can alter the technological quality of raw material, mainly the sugar content in stalks. Studies show that N fertilization can diminish the percentage of sucrose (Pol), which is attributed to the effect of dilution due to the higher water content in the plant, and higher consumption due to plant development caused by N fertilization (Wiedenfeld, 1998). In general, for each percentage unit increase of TCH due to N, the sugar percentage in stalks decreases by 0.01 % (Korndörfer & Martins, 1992). Other authors (Espironelo et al., 1977; Silveira et al., 1981) also found harmful effects of N fertilization, especially at high N rates (above 120 kg ha^{-1} N), on sucrose (Pol) accumulation in sugarcane. However, in this study, there were no differences in Pol cane content in function of N fertilization. Nevertheless, the increasing N rates had a linear effect on TPH (Figure 3). These results confirmed the findings of Orlando Filho et al. (1994), Korndörfer et al. (1997, 2002), Trivelin et al. (2002b), Franco et al. (2010) and Fortes et al. (2013), that N fertilization also increased TPH, as a result of the yield increased by N fertilization.

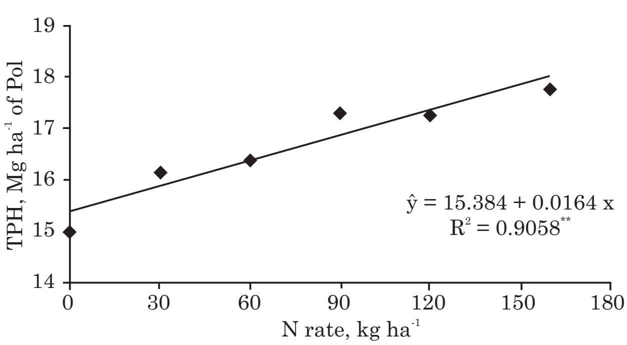

Figure 3. Effect of N-fertilizer rates on sugar yield (TPH) in sugarcane.

CONCLUSIONS

1. Adopting different harvesting systems in sugarcane does not lead to differences in stalk yield (TCH) and sugar yield (TPH). Pol percent and TSR values are higher in the burnt sugarcane systems.

2. The mechanical cultural practices of ratoon had no effects on stalk yield, sugar, or the technological quality of sugarcane, indicating the importance of discussing the need of this procedure after harvesting.

3. The application of N-fertilizer increased stalk height and TCH at doses of 88 and 144 kg ha^{-1} N, respectively, to the highest values for these variables.

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