




Best Practices of Nitrogen Fertilization Management for Sugarcane Under Green Cane Trash Blanket in Brazil

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Abstract The low efficiency of nitrogen (N) use from fertilizer applied to sugarcane is a major concern worldwide threatening the sustainability of sugarcane production. Further, the significance of N losses to the environment is becoming more important as global warming becomes a more significant issue. Improving nitrogen use efficiency is a major challenge for sugarcane cropping systems worldwide. Amongst other factors, N application method has a significant effect on the efficiency with which N is used by the crop. In Brazil, the sugar industry is rapidly moving towards green cane harvesting and the maintenance of a trash blanket (GCTB) between crops in a cycle. However, there is limited information regarding the most appropriate nitrogen fertilizer placement between ratoon crops in a GCTB system. The aim of this research was to evaluate the effect of different nitrogen application methods on the productivity of ratoon sugarcane being grown under a green cane trash blanket (GCTB) system. The application methods tested were: (1) control (no fertilizer applied), (2) fertilizer incorporated at 0.2 m in the centre of each interrow, (3) fertilizer applied to the

GCTB surface in both sides of the row, and (4) fertilizer incorporated at 0.08 m depth in both sides of the row. The incorporation of the fertilizer at 0.08 m depth on both sides of the row resulted in the best agronomic performance, producing approximately 13 and 12 % more cane tonnage and sugar yield, respectively, when compared to band surface application, which was the second best method.

Keywords Green cane · *Saccharum* spp. · Crop management · Fertilization

Introduction

Brazil is one of the largest consumers of fertilizers in the world, using approximately 13.4 million of tonnes NPK fertilizer in 2013, behind only China, India, and the USA. Of this total, only 28 % (3.75 million tonnes) was produced in the country (IPNI 2014). The consensus in the scientific community is that nitrogen is the most limiting nutrient worldwide (Malhi et al. 2001). In Brazil, N rates for sugarcane fertilization are typically applied based on average yield expectations, which are frequently not achieved, largely due to losses through run-off, leaching, and denitrification, all of which are influenced by soil and climatic characteristics. Variable rate technology which can be used to more accurately predict N requirements in accordance with soil variability has not been commonly adopted in Brazil (Amaral and Molin 2014). Thus, highly variable N losses are likely to occur and these can lead to large variations in nitrogen use efficiency (NUE). Further, N losses through leaching and run-off leading to lower N use efficiency are also influenced by soil characteristics (e.g. pH, CEC, organic matter, and texture), climatic factors (temperature and rainfall), agronomic practices (cultivation, soil

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preparation, and crop rotation), and handling of fertilizer applications (Malhi et al. 2001). Therefore, as Subbarao et al. (2006) highlighted “it is necessary to develop strategies for the efficient use of N in crop production that would meet high production requirements and also address the growing environmental concerns”.

To satisfy the N nutritional needs of the sugarcane crop cultivated in Brazil, relatively small amounts of nitrogen 30–60 kg ha⁻¹ is applied in the plant cycle, 60–120 kg ha⁻¹ to ratoon crops (Penatti et al. 1997; Spironello et al. 1997; Cantarella et al. 2007) for burnt cane, and up to 175–200 kg ha⁻¹ for ratoon crops in GCTB cane (Vitti et al. 2007; Prado and Pancelli 2008). Regardless of the dose of N fertilizer used in the sugarcane crop, the efficiency of uptake by the plant of the N provided is usually lower than 50 % in the tropics and <70 % in temperate regions (Malhi et al. 2001). In fact, studies indicate that NUE in sugarcane may vary, on average, from 20 to 40 % (Prasertsak et al. 2002; Trivelin et al. 2002a, b; Franco et al. 2008; Franco et al. 2011; Vitti et al. 2011). This relatively low uptake of N by sugarcane is most likely related to losses of N in the soil–plant system, resulting from the processes of denitrification, volatilization of ammonia (Trivelin et al. 2002b), leaching (Oliveira et al. 2002), and gaseous losses of N by the aboveground parts of the plant (Trivelin et al. 2002b).

One of the alternatives for increasing the efficiency of N uptake by the crop is the adoption of best management practices. Indeed, with the increasing interest of the scientific community in measuring emissions of greenhouse gases, researchers have observed that the method of N application may effect such emissions (Liu et al. 2005). According to van Kessel et al. (2013), the application of N fertilizer into the soil deeper than 0.05 m may reduce N₂O emissions, particularly in humid climates. In fact, it has been shown that emissions are lower when N fertilizer is deposited at 0.1 m compared to 0.05 m, since application

at 0.1 m increases the residence time of N₂O in the soil, improving chances of reduction in N₂O gas emission (Venterea and Stanenas 2008).

The use of mechanical sugarcane harvesting and trash blanketing leaves significant quantities of straw (10–20 Mg ha⁻¹) on the soil surface, which can affect the operation of N application by hindering the incorporation of the fertilizer into the soil. However, there are now soil-engaging tools available that allow cutting of the trash and placement of the fertilizer below the trash (Bianchini and Magalhães 2008). Thus, it is important to know whether the placement of fertilizer below or on the trash blanket has implications for sugarcane productivity. Therefore, the present work was initiated to assess the yield performance of a GCTB system during two ratoon crop seasons, under different methods of N fertilizer application.

Materials and Methods

The experimental site was at Sales Oliveira, SP, Brazil (20°52′31″S, 47°57′56″W), a soil mapped as Acrudox soil (Soil Survey Staf 2010), characterized as a D1 production environment on a scale from A to E, where an A environment has more favourable conditions for sugarcane cultivation and an E environment has more chemical and/or physical restrictions for sugarcane production (Vitti and Prado 2012). The variety selected was SP81-3250, which has medium maturation and good sprouting and is the second most cultivated variety in the central-south part of Brazil. The experiment began after the mechanical green cane harvest of the plant cane (first ratoon), and all trash was left over the soil in all treatments.

The experimental treatments were (1) control (no fertilizer applied), (2) fertilizer incorporated at 0.2 m in the centre of each interrow, (3) fertilizer applied on the GCTB surface banding in both sides of the row, and (4) fertilizer

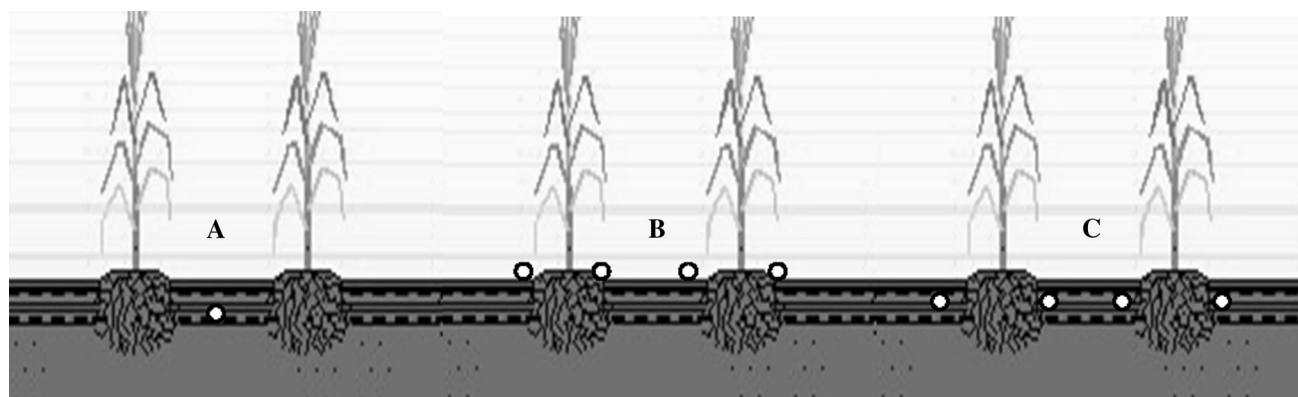


Fig. 1 N fertilizer applications: in the interrow at 0.2 m deep (a); surface application on the trash blanket GCTB (b); and incorporated application at 0.08 m deep (c)

Table 1 Chemical characteristics of soil in the experimental area

Depth (m)	SOM (g dm ⁻³)	pH (CaCl ₂)	P (mg dm ⁻³)	S (mg dm ⁻³)	K (mmolc dm ⁻³)	Ca (mmolc dm ⁻³)	Mg (mmolc dm ⁻³)	Al (mmolc dm ⁻³)	H + Al (mmolc dm ⁻³)	BS (mmolc dm ⁻³)	CEC (mmolc dm ⁻³)	V (%)
0–0.2	22	4.9	21	26	1.1	15	5	1	33	21.7	54.7	39.7
0.2–0.4	19	5.2	7	13	0.8	12	3	0	28	16.4	44.4	36.9

Values of 719 and 742 g kg⁻¹ of clay for 0–0.2 and 0.2–0.4 m

SOM soil organic matter, BS sum of bases, CEC cation exchange capacity, V base saturation

incorporated at 0.08 m deep in both sides of the row (Fig. 1). Experiment design was a randomized block with five replicates. The experiment was performed for two ratoon crop seasons, 2010 and 2011. Nitrogen rate used in each treatment was 120 kg ha⁻¹ N, as proposed by Penatti (2013) for nitrogen fertilization in GCTB cane. Each plot had six sugarcane rows, 20 m in length with the row spacing 1.5 m, with all measurements taken on the central four rows. The nitrogen source used was a solid fertilizer Nitrogran (35 % of N).

Prior to planting the crop in March 2008, soil samples were taken at depths of 0–0.2 m and 0.2–0.4 m (Table 1), for evaluation of plant available nutrients using the methodology described by Raij et al. (2001). The purpose of this sampling was to characterize the soil of the experimental area and also the application of soil correctives to increase the soil base saturation index to 70 % of CEC at pH 7.0.

During the experimental period, rainfall data (mm month⁻¹) were collected for calculation of the water balance (Fig. 2). In July 2009, the plant crop was harvested, and in October 2009 (90 days after the harvest—DAH) treatments with N fertilizer were installed. The N fertilizer was mechanically applied using a fertilizer applicator equipped with a rolling coulter, capable of opening a furrow spread over the fertilizer and closing it, without GCTB disturbance, or of applying the fertilizer on bands over the GCTB. In June 2010, a biometric evaluation was performed, counting the number of stalks in each plot and collecting 45 stalks at random which, once detashed and tops cut off, were weighed for yield calculation (cane tonnage per hectare). In the evaluation of technological quality, the methodology described by Fernandes (2003) was adopted, analysing the apparent sucrose content (pol% cane) and calculating sugar yield (Mg ha⁻¹ pol) and total recoverable sugar.

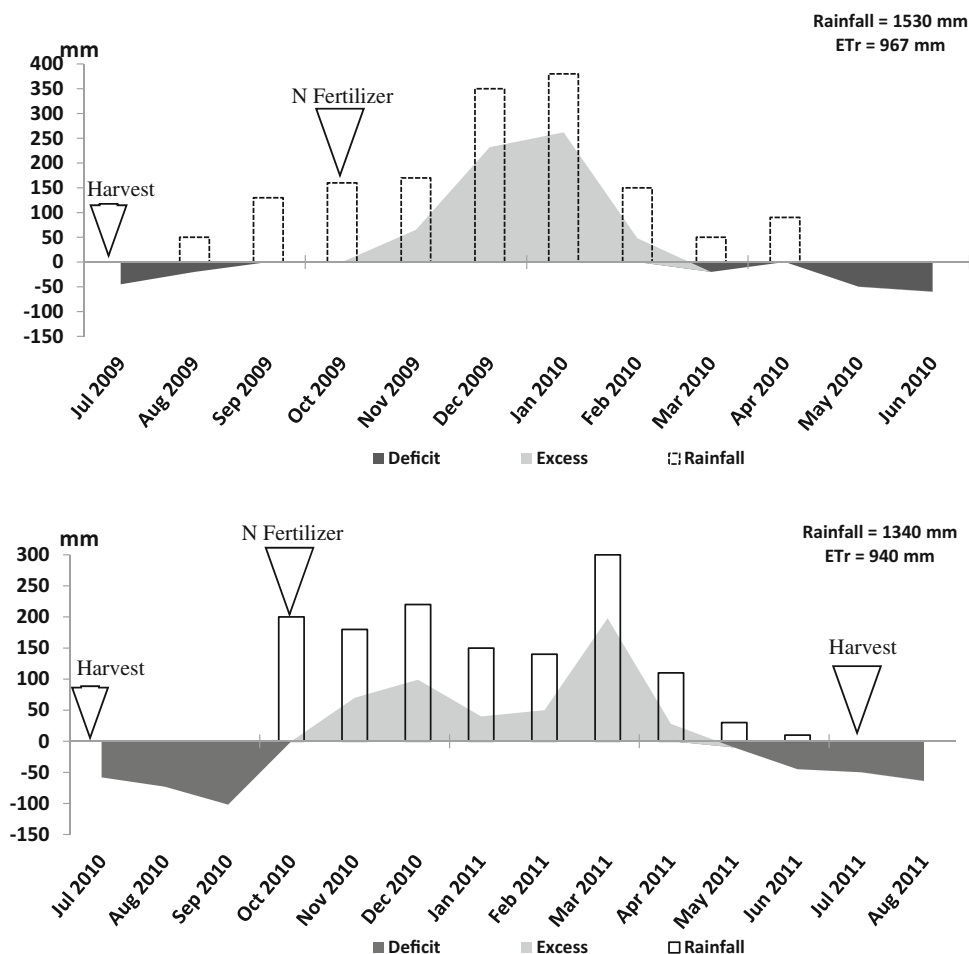
The first ratoon was mechanically green-harvested in July 2010. The methodology and sequence of experimental evaluations for the second year were the same as described for first year, occurring in the same chronological sequence, for the second ratoon harvested in July 2011.

The results were submitted to ANOVA via F test, and the averages compared by the t test with 95 % confidence.

Results and Discussion

The N fertilizer application method resulted in increased sugarcane yield during the years of the experiment (Table 2). The control treatment for the 2 years produced the lowest cumulative sugarcane tonnage of 145 Mg ha⁻¹. By contrast, when N was incorporated into the soil at 0.08 m deep on both sides of the row, the cumulative

Fig. 2 Annual water balance and rainfall for the experimental period (2009–2011)



sugarcane yield for the 2 years was 233 Mg ha^{-1} , an increase of 61 %. When the fertilizer was applied on the GCTB, or in the interrows, sugarcane yield was also higher than for control treatment. However, the N use efficiency was reduced by 13 % (GCTB) and 16 % (interrow), when compared to the incorporated application into the soil at 0.08 m deep. These differences compared to the placement at 0.08 m might, at least in part, be explained by the fact that fertilization was done early in the rainy season (Fig. 2) and that the interrow application was shallow (0.2 m), while the GCTB application was on the surface, contributing to the loss of N fertilizer through run-off.

Our results support the hypothesis that application of fertilizer N ($>0.08 \text{ m}$ depth) near the sugarcane row can be an effective strategy for improving NUE and yield in a GCTB systems. Several reports comparing conventional tillage with no tillage or reduced tillage have shown that N_2O emissions are directly related to the position where the N fertilizer is placed. Emissions have been less with deep placement compared to placement near the soil surface (Prasertsak et al. 2002; Venterea et al. 2005; Venterea and Stanenas 2008; Van Kessel et al. 2013).

Provided that nitrogen is made available in the solution, it is rapidly absorbed by roots and translocated to the leaves and stalks, raising N content in the plant and increasing the rate of crop development (Oliveira et al. 2013). Furthermore, sugarcane root density decreased exponentially with increasing distance from the crop rows regardless of N fertilization at planting, with higher root densities near the centre of the sugarcane stool, indicating concentrated growth of the root system (Otto et al. 2009). This probably explains why the application made in the crop interrow, although incorporated into the soil, is less efficient.

According to Robinson et al. (2009), the rapid growth of the aerial part, which will result in the final stalks, is affected by the architecture of the leaves, number of shoots, moisture, temperature, and quantity of nitrogen available in the soil. The application of N fertilizer at 0.08 m deep resulted in an average of 27 % more stalks per metre compared to the area where no nitrogen was applied (Table 2), resulting in a higher cane tonnage per hectare. Likewise, the sugarcane yield, there were no differences in stalk population (stalk m^{-1}) between the

Table 2 Average yield response to the method of nitrogen application, and stalk population (stalk m⁻¹) during 2010 and 2011

Method of application	2010	2011	Total
Cane tonnage (Mg ha⁻¹)			
Interrow	115 ^b	80 ^{ab}	195 ^b
Surface	129 ^a	76 ^b	205 ^b
Incorporated	139 ^a	94 ^a	233 ^a
Control	84 ^c	61 ^c	145 ^c
LSD (10 %)	5	14	18
CV (%)	9	15	8
Stalk population (stalk m⁻¹)			
Interrow	14.3 ^b	12 ^b	26.3 ^b
Surface	15 ^{ab}	12.4 ^b	27.4 ^b
Incorporated	15.9 ^a	13.1 ^a	29 ^a
Control	12.2 ^c	10.6 ^c	22.8 ^c
LSD (10 %)	1.03	0.62	1.1
CV (%)	6	4	4

Means within a column followed by the same letter do not differ significantly using the t test with 95 % confidence

LSD least significant difference, CV (%) coefficient of variation

surface and interrow application methods, but both were superior to the control by 20 % (surface application) and 15 % (interrow).

There was no difference in Pol and TRS between the N fertilizer application methods employed in these studies (Table 3). Although N fertilization increased vegetative growth, it does not affect the technological attributes as demonstrated by Vitti et al. (2007), Franco et al. (2010), and Rodrigues et al. (2013). Franco et al. (2010) only observed a deleterious effect of N fertilization, when the N rate applied was over 120 kg ha⁻¹, where Brix, Juice Pol, cane Pol, and TRS were lower in relation to the other treatments.

However, in these studies, because of an increase in sugarcane tonnage associated with the 0.08-m application depth, there were gains in sugar yield (TPH, $P < 0.01$) in both years (Table 3). There was a significant effect of N application method on sugar yield, and it was consistent across sampling times in 2010 and 2011 ($P < 0.01$), with the incorporation of N method being the most efficient with more than 60 % yield gain over the control. Again, there was no difference between the interrow and surface application method.

As final consideration, it is important to emphasize the need to apply N fertilizer incorporated in the soil and near to cane row. This kind of application can easily be adopted by sugarcane growers with increases in N use efficiency (kg of biomass per kg of N fertilizer applied), and it likely decreases the environmental risk by elevated nitrous oxide

Table 3 Average response of N application method on Pol (%), TPH (tonnes of Pol ha⁻¹), and TRS (total recovery sugar—kg Mg⁻¹ cane stalk) during 2010 and 2011

Method of application	2010	2011	Total
Pol (%)			
Interrow	18.6	13.8	32.4
Surface	18.6	13.9	32.5
Incorporated	18.6	13.7	32.3
Control	18.4	14.1	32.5
LSD	0.40	0.50	0.70
CV (%)	2	3	2
TPH (tonnes of Pol ha⁻¹)			
Interrow	21.6 ^b	11.2 ^{ab}	32.8 ^b
Surface	23.9 ^{ab}	10.6 ^b	34.5 ^b
Incorporated	25.9 ^a	12.9 ^a	38.8 ^a
Control	15.5 ^c	8.7 ^c	24.2 ^c
LSD	2.46	2.04	3.1
CV (%)	9	14	8
TRS (kg Mg⁻¹ cane stalk)			
Interrow	154.2	137.7	291.9
Surface	155.1	137.4	292.5
Incorporated	154.9	136.9	291.8
Control	151.4	139.6	291
LSD	3.54	4.50	5.9
CV (%)	2	3	2

Means within a column followed by the same letter do not differ significantly using the t test with 95 % confidence

LSD least significant difference, CV (%) coefficient of variation

and run-off, which is very important for biofuels production using sugarcane as a raw material.

Conclusion

The application of nitrogen to the ratoon of GCTB sugarcane promoted gains on stalk population stand (stalk m⁻¹), sugarcane tonnage (Mg ha⁻¹) and sugar yield (tonnes of Pol ha⁻¹). The method of N application incorporating the fertilizer at 0.08 m in the soil on both sides of the row resulted in the best agronomic performance. NUE was reduced, when the fertilizer was applied on GCTB surface or in the interrow, by approximately 12 and 16 %, respectively, compared with the incorporated fertilizer in the soil on both sides of the row.

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