

Sources and doses of nitrogen in plant cane production and residual effect on the first ratoon of sugarcane in a savannah Red Oxisol

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Abstract

The expansion of sugarcane cultivation, especially in areas with low natural soil fertility, such as savannah regions, requires greater efficiency in the application of nutrients, mainly nitrogen (N). The objectives of this study were to evaluate the effects of the application of different sources and doses of nitrogen on the dry matter yield and productivity of sugarcane in the plant cane cycle and the residual effect of such application on the first ratoon cycle of sugarcane (var. SP80-1816) cultivated in a dystrophic Red Oxisol. The experimental design was a randomized complete block design analyzed in a factorial scheme of 2 × 4 with three replications. The evaluated factors consisted of two sources of N (ammonium nitrate (AN) and urea (U)) and four doses of N (0, 60, 120 and 180 kg ha⁻¹). Samples of the aerial part of the sugarcane were collected. The structural components of the aerial part were separated, and the leaf dry matter (LDM), stalk dry matter (SDM) and dry matter of the aerial part (DMAP) were analyzed. The productivity of stalks (PS) was determined by weighing all stalks present in the useful area of each plot. In the plant cane cycle, AN resulted in greater gains in the SDM and PS of sugarcane than did U. In the first ratoon cycle, a residual effect was observed in response to N application, which showed an increase in SDM and PS. Under the conditions of this study, to achieve a higher PS in both cycles, the application of 180 kg N ha⁻¹ is recommended.

Keywords: *Saccharum* spp., first ratoon, urea, ammonium nitrate, nitrogen dose.

Introduction

The importance of sugarcane derives from its multiple uses, as it is used in nature, in the form of fodder for animal feed, or as a raw material for the manufacture of “rapadura”, molasses, “cachaça”, sugar and alcohol. Its residues also have high economic importance; vinasse is transformed into fertilizer, and bagasse is used as fuel (Caputo et al., 2008).

The area planted with sugarcane that was harvested for sugar and alcohol production in the 2017/18 season was 8.73 million hectares, producing 633.26 million tons (Conab, 2018). In 2018, Brazilian agribusiness promoted the export of 7.4 billion dollars in sugar and alcohol products, representing 7.3 % of total exports (Agrostat, 2019). To improve society, the economy and the environment, studies that promote the development of agricultural practices for sugarcane cultivation should be undertaken and expanded. According to Franco et al. (2008), the development of agricultural practices and the search for alternative sources to improve the utilization of nitrogen (N) by sugarcane crops are fundamental.

Nitrogen is the nutrient most demanded by plants; it is important for plant metabolism; it is a constituent of enzymes, proteins, DNA, RNA, chlorophylls and precursors of hormones (Malavolta and Moraes, 2007); it is required in large quantities for the production of sugarcane biomass, on average 1.4 kg of N per ton of stalk produced (Cantarella et al., 2007; Trivelin et al., 2002); it is one of the primary macronutrients of crops, being the most used, most absorbed and most exported; it is the most expensive nutrient; and it is the most leached nutrient in soils, requiring special precautions in its management to reduce the risk of contamination of the water table (Carvalho and Zobot, 2012). According to Zu et al. (2018), nitrogen is the main factor limiting the production of sugarcane in southern China.

Nitrogen is among the mineral nutrients most applied for the production of sugar cane in Brazil; it is also the most expensive nutrient, and the amount of N applied in the form of mineral fertilizers is generally the same as or lower than that exported by stalks or lost with the burning of

agricultural waste (Cantarella et al., 2007; Franco et al., 2011; Vitti et al., 2011).

In 2017, Brazil imported 23.9 million tons of fertilizer, with nitrogen accounting for 8.7 million tons (36 % of the total). Of the 8.7 million tons, urea (U) accounted for 5.4 million tons, ammonium sulfate accounted for 1.9 million tons and ammonium nitrate (AN) accounted for 1.3 million tons (Global Fert, 2018).

However, of all the N applied to sugarcane in the form of fertilizer, usually only 20 to 40 % is used by the crop, which negatively affects the cost of production and the environment (Mariano et al., 2012; Trivelin et al., 2002; Vieira-Megda et al., 2015).

Nitrogen utilization efficiency (NUE) has been studied in several crops to reduce N fertilization, which significantly increases production costs and can be an environmental problem when handled incorrectly. With regard to NUE, the source and dose of N applied are often studied because each fertilizer has a certain behavior in a given growing environment and the losses may be related to the source and amount of fertilizer that was applied (Bastos et al., 2017; Boschiero et al., 2018; Otto et al., 2017). Thus, increasing NUE through improving N sources and doses for each growing environment can significantly reduce fertilizer costs and the release of N into the environment without negatively affecting yields (Hajaria et al., 2013).

U is the nitrogen fertilizer most commonly applied to sugarcane because its cost per unit of N is lower than that of other fertilizers, despite the various forms of losses in the soil-plant system. The losses occur mainly by volatilization of ammonia (NH₃) and can vary from 10 to 94 %, depending on the climatic and handling conditions (Cantarella et al., 2007; Costa et al., 2003; Dattamudi et al., 2016; Silva et al., 1999) and nitrate leaching, which is aggravated by inadequate management of irrigation and sandy soils (Roberts, 2008). Losses can be mitigated by changing some management practices, including the N dose and source (Reay et al., 2012).

However, several questions arise regarding fertilizer use and inputs, and the use of nitrogen is one of the main topics under discussion. Differences in N response due to crop cycles, low N doses relative to those in other countries, high amounts of straw added to the system, biological N fixation (BNF) and cultivation of increasingly productive and N-responsive varieties indicate the need for more studies related to this topic.

To promote the best use of nitrogen fertilizers, this work aimed to evaluate the effects of the application of different sources and doses of nitrogen on the dry matter yield and productivity of sugarcane in the plant cane cycle and the residual effect of such application in the first ratoon cycle of sugarcane (var. SP80-1816) cultivated in a dystrophic Red Oxisol.

Results and discussion

Plant cane cycle

The nitrogen source (S) applied to sugarcane in the plant cane cycle had a significant effect on stalk dry matter (SDM), dry matter of the aerial part (DMAP) and productivity of stalks (PS). Regarding the dose (D) of N, there was a significant effect for all variables analyzed. However, the interaction between the N factors (SxD) had a significant effect only on the PS of sugarcane (Table 2). Schultz et al. (2015) reported that sugarcane with a 12-month cycle is

more responsive than sugarcane with an 18-month cycle to nitrogen fertilization. Franco et al. (2011) did not observe a significant effect of 40, 80 and 120 kg ha⁻¹ N applied in the plant cane cycle on DMAP, while Kolln et al. (2015) verified a significant effect on PS with doses of 70, 140 and 210 kg ha⁻¹ N applied through subsurface drip irrigation.

The effect of N dose on the LDM of sugarcane were determined; the data were fitted to a linear model, and an LDM of 0.102 kg plant⁻¹ was estimated at a dose of 180 kg ha⁻¹ N (Figure 2). This result corroborates that found by Zhao et al. (2014); the authors reported increasing mean values for the LDM of plant cane, ranging from 0.022 g plant⁻¹ in the absence of nitrogen to 0.094 g plant⁻¹ at a dose of 225 kg ha⁻¹ N. Oliveira et al. (2007), who worked with the cultivars RB72454, RB855113 and RB855536, observed a quadratic effect and an increase in LDM during the development cycle of the cultivars.

Figure 3a shows that AN increased SDM by 9.2 % compared to that obtained with U. The effects of N dose on SDM were determined according to the linear regression equation obtained, and an SDM of 0.362 kg plant⁻¹ was estimated at a dose of 180 kg ha⁻¹ N (Figure 3b). According to Franco et al. (2010), a higher SDM results in a greater accumulation of total N. Vitti et al. (2011) found that at harvest, approximately 75 % of the U that accumulated in the shoot was in the stalks. Bastos et al. (2015) found that with the application of 100 kg ha⁻¹ U, an average SDM of 59.73 t ha⁻¹ was obtained.

Figure 4a shows that AN increased DMAP by 6.5 % compared to that obtained with U. Figure 4b shows the effects of N dose on DMAP. According to the linear regression equation obtained, a maximum DMAP of 0.464 kg plant⁻¹ was estimated at a dose of 180 kg ha⁻¹ N.

Franco et al. (2008) concluded that the mean recovery of U nitrogen by sugarcane in the plant cane cycle was 30, 30 and 21 % for doses of 40, 80 and 120 kg ha⁻¹ N, respectively. Otto et al. (2009) studied sugarcane cultivated in two different places and found that nitrogen fertilization with U significantly increased DMAP 300 days after planting. Tavian et al. (2014) concluded that the best dose of nitrogen in the form of AN for the production of dry matter of forage sorghum was 116 kg ha⁻¹. Bastos et al. (2015) did not observe a significant effect of the application of N on the DMAP of sugarcane.

AN at doses of 60 and 120 kg ha⁻¹ N increased PS by 17.83 % and 15.21 %, respectively, relative to the PS values obtained with U (Figure 5a). With respect to the effects of N from different nutrient sources, NA and U had an effect on PS (Figure 5b). According to the linear regression equation obtained for NA, a PS of 158.69 t ha⁻¹ was estimated at a dose of 180 kg ha⁻¹ N, and according to the quadratic regression equation obtained for U, a PS of 149.28 t ha⁻¹ was estimated at a dose of 180 kg ha⁻¹ N.

In general, an increase in nitrogen dose resulted in greater increases in the PS of sugarcane (Figure 5b). Many studies have shown that the plant cane cycle responds less than the ratoon cycle to nitrogen fertilization (Otto et al., (2020); Vieira-Megda (2015); Otto et al., (2013)); however, several studies, such as those performed by Madhuri et al. (2011), Fortes et al. (2013) and Gava et al. (2018), also obtained the same result as that in this work and demonstrated a linear increase in PS in plant cane with increasing levels of nitrogen fertilization. These different responses between different cycles are related to factors such as the organic matter content in the soil, preceding crops, water availability and

Table 1. Chemical characterization of the soil in the experimental area before the beginning of the experiment, Raízen Factory, Jataí, GO, 2014.

Soil layer (m)	pH	OM (g kg ⁻¹)	P (mg dm ⁻³)	K	Ca	Mg	Al	H+Al	S	CEC	V (%)
0.00–0.20	5.8	76.00	20.00	1.10	28.00	14.00	0.00	20.00	43.10	63.10	68.00
0.20–0.40	5.9	80.00	14.00	1.00	29.00	15.00	0.00	20.00	45.00	65.00	69.00
0.40–0.60	6.5	64.00	7.00	0.60	7.00	7.00	0.00	25.00	14.60	39.60	37.00

¹Manual of chemical analysis for fertility evaluation of tropical soils (IAC, 2001). OM - organic matter; CEC - cation exchange capacity; V – base-saturated CEC.

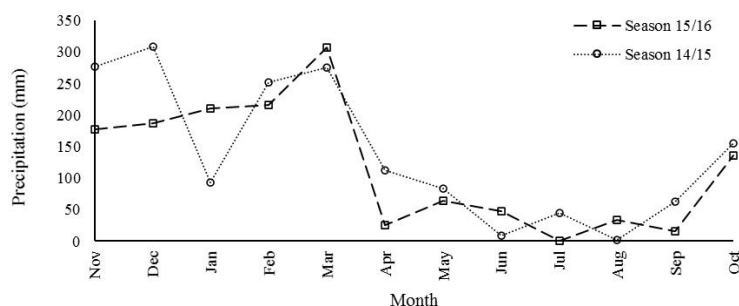


Figure 1. Rainfall during the experimental season of 2014/15 (plant cane) and the 2015/16 season (first ratoon), Jataí municipality, GO, Brazil. Normal Station INMET – Jataí - GO.

Table 2. Summary of analysis of variance results for leaf dry matter (LDM), stalk dry matter (SDM), dry matter aerial part (DMAP) and productivity of stalks (PS) of sugarcane crops (var. SP80-1816) subjected to different sources and doses of nitrogen in the municipality of Jataí, GO, in the 2014/2015 season.

SV	DF	Mean square value for the sources of variation ¹			
		LDM	SDM	DMAP	PS
Source of N (S)	1	0.00009ns	0.0056**	0.00434*	794.190**
Dose of N (D)	3	0.0025**	0.0092**	0.0213**	7545.429**
S x D	3	0.0001ns	0.0003ns	0.00035ns	134.444**
Block	2	0.0001ns	0.0077**	0.0058**	5.926*
Residue	14	0.0001	0.0005	0.0005	17.2990
CV		13.04	7.15	5.71	3.68

¹ Coefficient of variation (CV); source of variation (SV); degrees of freedom (DF); ns not significant based on the 5 % probability F test. ** and * indicate significance at 1 % and 5 % probability, respectively.

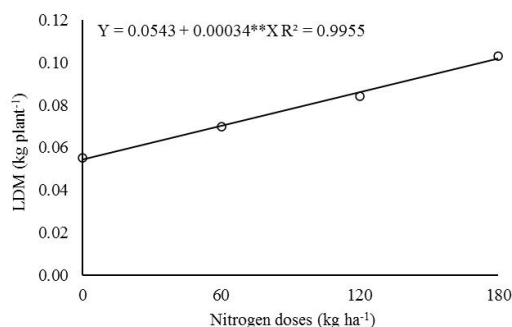


Figure 2. Leaf dry matter of sugarcane (var. SP 80-1816) in the plant cane cycle as a function of N dose in Jataí municipality, GO, in the 2014/2015 season. ** Significant at 1 % probability based on the F test.

Table 3. Summary of analysis of variance results for leaf dry matter (LDM), stalk dry matter (SDM), dry matter aerial part (DMAP) and productivity of stalks (PS) of sugarcane crops (var. SP80-1816) subjected to the residual effect of different sources and doses of nitrogen in the municipality of Jataí, GO, in the 2015/2016 season.

SV	DF	Mean square value for the sources of variation ¹			
		LDM	SDM	DMAP	PS
Source of N (S)	1	0.00008ns	0.0001ns	0.0004ns	21.508ns
Dose of N (D)	3	0.0001ns	0.0046*	0.0055ns	870.298*
S x D	3	0.0001ns	0.0009ns	0.0011ns	172.949ns
Block	2	0.000002ns	0.00005ns	0.00007ns	9.212ns
Residue	14	0.0002	0.0012	0.0023	228.621
CV		25.18	12.07	13.64	12.07

¹ Coefficient of variation (CV); source of variation (SV); degrees of freedom (DF); ns not significant based on the F test (5 % probability level). * Significant at the 5 % probability level.

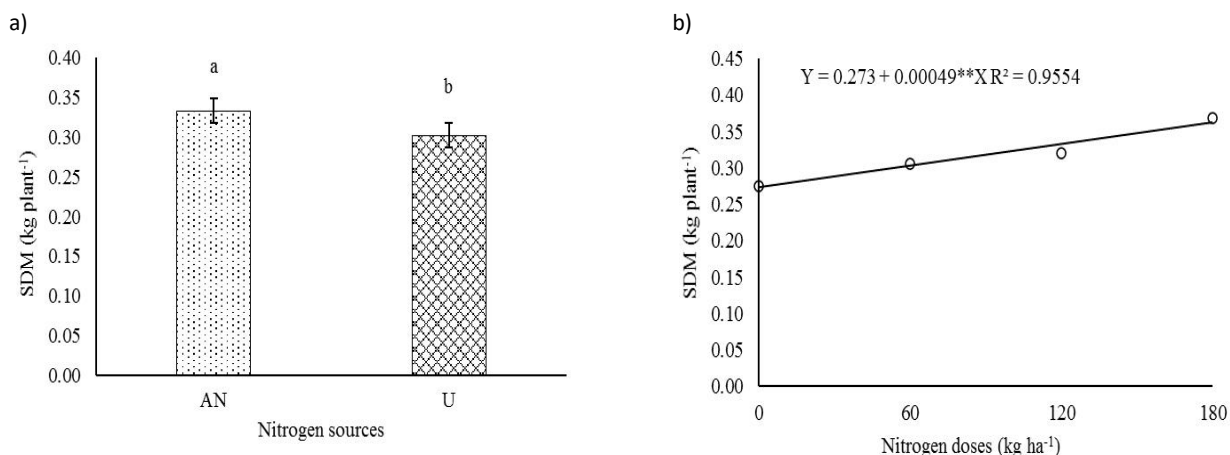


Figure 3. Stalk dry matter of sugarcane (var. SP 80-1816) in the plant cane cycle as a function of N source (a) and N dose (b) in Jataí municipality, GO, in the 2014/2015 season. Averages followed by the same letter do not differ significantly at the 5 % probability level based on the Tukey test. ** Significant at 1 % probability based on the *F* test. U: urea; AN: ammonium nitrate.

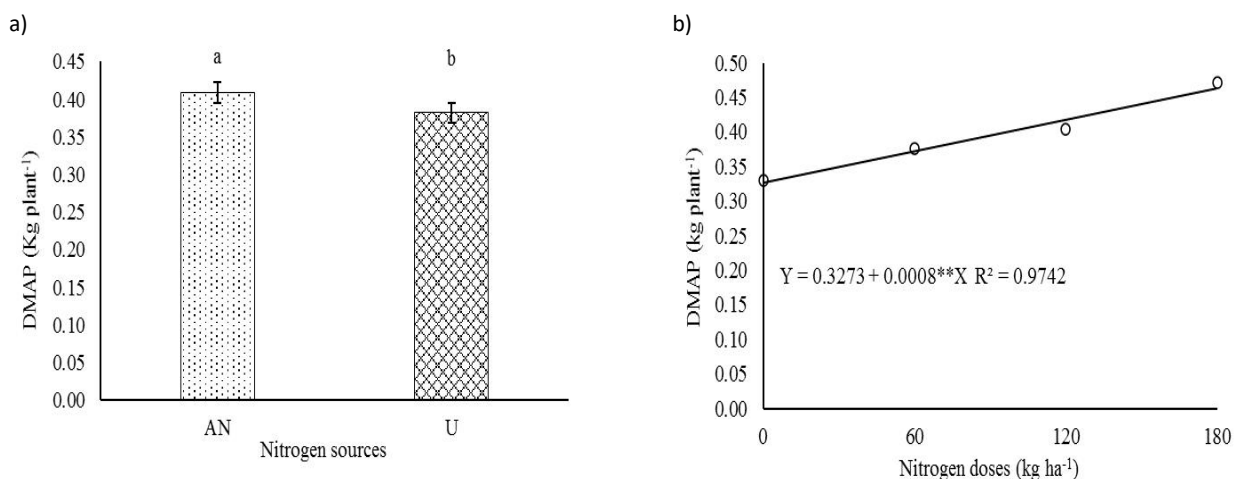


Figure 4. Dry matter of the aerial part of sugarcane (var. SP 80-1816) in the plant cane cycle as a function of N source (a) and N dose (b) in Jataí municipality, GO, in the 2014/2015 season. Averages followed by the same letter do not differ significantly at the 5 % probability level based on the Tukey test. ** Significant at 1 % probability based on the *F* test. U: urea; AN: ammonium nitrate.

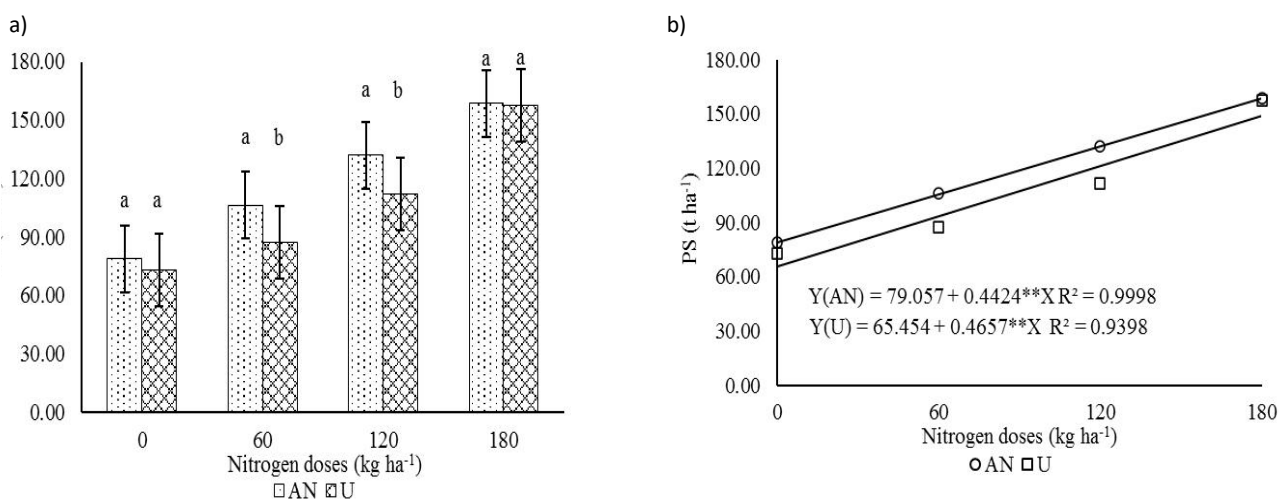


Figure 5. Productivity of stalks of sugarcane (SP 80-1816) in the plant cane cycle as a function of N source (a) and N dose (b) in Jataí municipality, GO, in the 2014/2015 season. Averages followed by the same letter do not differ significantly at the 5 % probability level based on the Tukey test. ** Significant at 1 % probability based on the *F* test. U: urea; AN: ammonium nitrate.

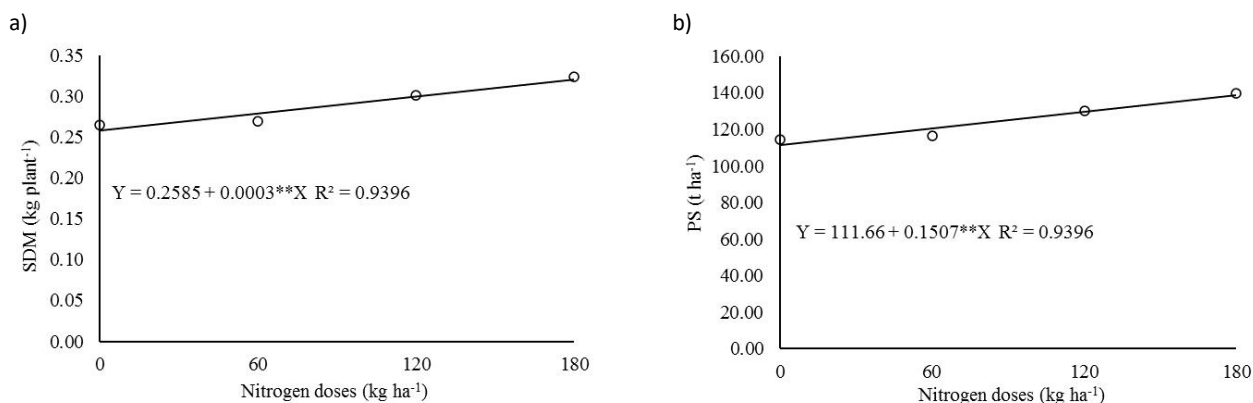


Figure 6. Stalk dry matter (a) and productivity of sugarcane (var. SP 80-1816) stalks (b) in the first ratoon cycle as a function of the residual effect of the dose of N (a) in Jataí municipality, GO, in the 2015/2016 season. ** Significant at the 1 % probability level based on the *F* test.

the production potential of the varieties. Franco et al. (2010) concluded that, on average, 70 % of the N in ratoon sugarcane is derived from fertilizer, while in plant cane, only 40 % is derived from fertilizer due to the greater stability of the ratoon cycle, which increases the utilization efficiency of N.

Kölln (2012) observed that fertilization at a 140 kg dose of N ha⁻¹ (first ratoon cycle) and 150 kg of N ha⁻¹ (second ratoon cycle) resulted in an SDM of 26.9 t ha⁻¹ and 18.5 t ha⁻¹ and a PS of 91.3 t ha⁻¹ and 56.7 t ha⁻¹, respectively. Kölln et al. (2015) reported that in two growth cycles of irrigated sugarcane, PS values of approximately 129 t ha⁻¹ and 108 t ha⁻¹ were obtained in response to 210 and 150 kg of N ha⁻¹, respectively. Rossetto et al. (2010), who studied fertilization with AN in different locations for two seasons, concluded that fertilization with N resulted in a significant increase in PS at 14 of the 15 studied locations and estimated a PS of approximately 91 t ha⁻¹ at a dose of 148 kg of N ha⁻¹.

Based on a review of several studies and considering different sugarcane crops in Brazil, Otto et al. (2016) concluded that of all fertilizer applied to sugarcane, only 26 % is used by the crop, while 32 % is immobilized, 19 % is lost via ammonia volatilization, 5.6 % is leached, 1.84 % is denitrified and 16 % is lost in other ways, resulting in a total loss of 42 % of the total N fertilizer applied. However, these data are a general average independent of source and dose, and these factors can increase or decrease these losses.

In general, when there was an influence of the source on the studied variables, AN had a more beneficial effect than U in all cases. The lower productivities found in environments where U was used were mainly due to the higher losses of N. Such losses have been a recurrent problem since the beginning of nitrogen fertilization. According to Otto et al. (2016), these losses have intensified with the advent of raw cane harvesting (without burning) because volatilization of ammonia is one of the main sources of N loss in sugarcane plantations, and these losses are mainly associated with the application of U to the soil surface without incorporation. Nitrogen losses are more pronounced when U is used as an N source than when AN is used, although there are some tools that decrease volatilization. However, even when using these tools in U fertilization, the losses are still higher than those observed with AN, and this difference is intensified in the current sugar cane management system with mechanized harvesting and the retention of large amounts of straw on the soil. Otto et al. (2017) concluded that the

volatilization of ammonia was on average 20 % of the total N-U applied under sugarcane straw, 14 % of the N-U treated with N-(n-butyl) thiophosphoric triamide (NBPT, a urease inhibitor) and 1 % of ammonium N-nitrate, which proves that even with tools to increase the efficiency of N-U use, AN has advantages in systems where it is not possible to recover fertilizer. Thus, the described results and the present study emphasize that AN results in higher yields of plant cane than does U, which corroborates the results of Costa et al. (2003), who mentioned that one way to reduce N losses is to change the U source to other types of fertilizer, such as sulfate and AN.

Residual effect – first ratoon cycle

The nitrogen dose (D) applied to plant cane had a significant effect on SDM and PS in the first ratoon cycle (Table 3). Vitti et al. (2007) and Franco et al. (2013) also observed a residual effect of dose of N on PS, while Bastos et al. (2018) concluded that residual N applied to plant cane did not influence the yield of the first ratoon but did influence the dry matter of the crop residues and stalks.

Boschiero (2017) concluded that an increase in N dose increases nutrient extraction by plants but does not necessarily result in an increase in the dry matter of the plants, which indicates luxury consumption of N by sugarcane. Schultz et al. (2010) did not observe a residual effect of fertilization applied during the previous cycle on the PS yield. Additionally, Megda et al. (2012) did not observe a residual effect of the nitrogen source on PS in the third ratoon cycle.

Thus, the present study corroborates these other studies and shows that the nitrogen dose applied to plant cane can have a great effect on sugarcane ratoon, mainly with respect to important yield variables such as dry matter, PS and crude sugar and alcohol yields.

The residual effect of N dose on SDM and PS was determined according to a linear regression equation, which showed an SDM of 0.321 kg plant⁻¹ and a PS of 138.79 kg ha⁻¹ at a dose of 180 kg ha⁻¹ N (Figure 6a and 6b). Fortes et al. (2013) observed a linear increase in PS and in the crude sugar and alcohol yield until the third ratoon, demonstrating the importance of nitrogen fertilization of plant cane in maintaining and even increasing future yields.

In some areas of sugarcane cultivation, a response of plant cane to nitrogen fertilization was not observed, as previously described. However, if there is no use of nitrogen by plant

cane or insufficient fertilization in environments where nitrogen fertilization is required, the ratoon yields will be impaired, as observed in Figure 6. Franco et al. (2015) mentioned that nitrogen fertilization in the plant cane cycle is often neglected, given that the response to this nutrient is more visible in sugarcane ratoon; however, subsequent ratoon yields and cane longevity may be greatly impaired when BNF and soil nutrient reserves are not sufficient to meet the crop need in the first cycle. Thus, with lower longevity, early interventions are needed in cane plantations, which will generate great losses for the producer.

According to Vitti et al. (2007), AN applied at a rate of 175 kg ha⁻¹ resulted in a residual effect, generating a PS of 86.3 t ha⁻¹. Wiedenfeld (2009) applied 112 kg of N ha⁻¹ in the first ratoon cycle and obtained a PS of 91.9 t ha⁻¹.

Materials and methods

Study Area

The experiment was conducted during two cultivation cycles (plant cane cycle and first ratoon cycle) under field conditions in an area of the Rio Paraiso II farm belonging to the Raízen corporation in the municipality of Jataí, GO. The geographical coordinates of the site are 17°43'15.23" S and 51°38'12.62" W, with an average elevation of 912 m. According to the Köppen classification (2016), the climate of the study area is Aw, i.e., tropical, with the rainy season in the months of October-April and drought in the months of May-September. The maximum temperature ranges from 35 °C to 37 °C, and the minimum temperature ranges from 12 °C to 15 °C. Rainfall occurred during the plant cane cycle and the first ratoon cycle, which received 1677 and 1422 mm, respectively, as shown in Figure 1.

Soil analysis

The soil of the experimental area was classified as a very clayey dystrophic Red Latosol (Santos et al., 2018) or a dystrophic Red Oxisol according to the U.S. Department of Agriculture. The chemical characteristics of the soil in the experimental area based on samples collected before the beginning of the experiment are presented in Table 1.

Experimental design

The experimental design was a randomized complete block design analyzed in a factorial scheme of 2 × 4 with three replications. The evaluated factors consisted of two sources of N (ammonium nitrate and urea) and four doses of N (0, 60, 120 and 180 kg ha⁻¹).

In the plant cane cycle, nitrogen fertilization was performed according to each treatment at 60 days after planting (DAP), and fertilizer was applied within 0.20 m of the planting line. In the first ratoon cycle, the nitrogen fertilization was 120 kg ha⁻¹, applied in all the experimental plots at 60 days after harvest. In the plant cane cycle and first ratoon cycle, all the treatments were fertilized in the planting groove with phosphorus (100 kg ha⁻¹) as triple superphosphate (P2O5), potassium (80 kg ha⁻¹) in the form of potassium chloride (K2O), and micronutrients, according to the results of the soil analysis and the recommendation of Sousa and Lobato (2004).

The experimental units consisted of five lines of sugarcane 5 m in length, spaced 1.50 m apart. The three central lines of each plot were considered the useful area, and 1 m at each end was disregarded.

Plant materials

The sugarcane variety used in this experiment was SP80-1816, developed by the Agronomic Institute of Campinas (IAC). Soil preparation was carried out by plowing and harvesting, followed by opening of the planting grooves. The planting was performed mechanically, and the number of buds planted per meter was based on the recommendation for the variety. Agricultural treatments related to the use of herbicides, insecticides, fungicides and other products for the control of weeds, pests and diseases were used according to the evaluation of infestation.

Yield components

Dry matter evaluations were performed on two demarcated plants located in the useful area of each plot. Samples were taken from the aerial part of the sugarcane, and the structural components of the aerial part were separated. The dry matter variables analyzed were LDM (leaf dry matter = green leaf dry matter + dry matter of the green leaf sheath + dry mass of the pointer sugarcane), SDM (stalk dry matter) and DMAP (dry matter aerial part = LDM + SDM).

PS (tons of stalks per hectare) was determined by weighing all stalks in the useful areas of the two central lines in the respective plots. For this measurement, the cut was made as close as possible to the soil. Then, the samples were weighed on a hook-type digital scale (accuracy = 0.02 kg) with a capacity of 50 kg.

Statistical analysis

The data were subjected to analysis of variance, applying the *F* test at the 5 % probability level. In the case of significance, regression analysis was performed for nitrogen dose, whereas for the nitrogen sources, the means were compared by the Tukey test at 5 % probability.

Conclusion

AN resulted in higher sugarcane yields in the plant cane cycle; however, there was no residual effect of any source of N in the first ratoon cycle.

Nitrogen dose had a strong effect in both evaluated cycles, and a dose of 180 kg ha⁻¹ nitrogen resulted in immediate increases in plant cane stalk and dry matter production, as well as a residual effect on these variables in the first ratoon cycle.

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