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QUALIDADE TECNOLÓGICA DA CANA-SOCA SOB EFEITO RESIDUAL DE FONTES E DOSES DE NITROGÊNIO

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1 RESUMO

Devido à crescente demanda no aumento na produção de cana-de-açúcar tem ocorrido incremento no investimento em tecnologias para aumentar a produtividade e qualidade industrial. Objetivou-se avaliar o efeito residual de fontes e doses de nitrogênio, aplicados no ciclo de cana-planta, sobre a massa seca e atributos tecnológicos da primeira soqueira de cana-de-açúcar irrigada. O experimento foi conduzido em condições de campo, no município de Jataí-GO em um Latossolo Vermelho distrófico, muito argiloso. O material genético utilizado foi IACSP95-5000. O delineamento experimental utilizado foi em blocos ao acaso, analisado em esquema fatorial 2 × 4, com três repetições. Os tratamentos consistiram na aplicação de duas fontes de nitrogênio (ureia e nitrato de amônio) e quatro doses (0, 60, 120 e 180 kg ha^{-1}) aplicadas á cana-planta no ciclo precedente. Durante a primeira soqueira foi aplicado 120 kg ha^{-1} de nitrogênio nas respectivas parcelas. No final do ciclo da primeira soqueira da cana-de-açúcar, foram avaliados a massa seca do colmo, massa seca da parte aérea, açúcar total recuperável, rendimento bruto de açúcar e rendimento bruto de álcool. Os maiores valores de massa seca do colmo e massa seca da parte aérea foram encontrados nas doses 118 e 108 kg ha^{-1} de N.

Palavras-chave: *Sacharum oficinarum* L, nitrato de amônio, ureia, biomassa, irrigação.

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TECHNOLOGICAL QUALITY OF RATOON CANE UNDER THE EFFECT OF RESIDUAL NITROGEN SOURCES AND DOSES

2 ABSTRACT

Owing to the growing demand for increased sugarcane production, there has been an increase in investment in technologies to increase productivity and industrial quality. The objective of this study was to evaluate the residual effects of nitrogen sources and doses applied during the sugarcane–plant cycle on the dry mass and technological attributes of the first irrigated

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sugarcane raton. The experiment was conducted under field conditions in the municipality of Jataí, GO, which is a dystrophic Red Latosol that is very clayey. The genetic material used was IACSP95-5000. The experimental design was randomized blocks, analyzed in a 2 × 4 factorial scheme, with three replications. The treatments consisted of the application of two nitrogen sources (urea and ammonium nitrate) and four doses (0, 60, 120 and 180 kg ha $^{-1}$) applied to the sugarcane plants in the previous cycle. During the first raton, 120 kg ha-1 nitrogen was applied to each plot. At the end of the first rat cycle of sugarcane, the dry mass of the stalk, dry mass of the aerial part, total recoverable sugar, gross sugar yield and gross alcohol yield were evaluated. The highest values of dry mass of the stalk and dry mass of the aerial part were found at N doses of 118 and 108 kg ha $^{-1}$.

Keywords: *Sacharum oficinarum* L., ammonium nitrate, urea, biomass, irrigation.

3 INTRODUCTION

Brazil stands out in the global sugar-energy scenario, with sugarcane being the main crop responsible, which makes the country a reference in the agro-industrial scenario (Leite; Crusciol; Silva, 2011; Silva *et al.*, 2021). Sugarcane is a crop with high economic value and is used in the production of sugar, electricity and alcohol (Silva *et al.*, 2014; Marin *et al.*, 2019). Although the use of sugarcane in the production of sugar and ethanol is the best known, the plant can be used, even bagasse, which is used to feed boilers in biomass plants, generating energy mostly used by the plant itself (CEISEBR, 2023).

Owing to its socioeconomic importance and production demand to meet the country's internal needs and ability to export this fuel, large areas planted with sugarcane are needed (Sánchez-Román *et al.*, 2015; Silva; Mantese; Florian, 2023). Brazil also has land for the expansion of sugarcane cultivation, in addition to renewing the extraction of ethanol, a clean biofuel in relation to fossil fuels (Oliveira *et al.*, 2012; Silva *et al.*, 2021).

The area cultivated with sugarcane for sugar and alcohol activities should reach 8.33 million hectares, with a production of 713.2 million tons, resulting in the production of 29.69 billion liters of ethanol and 35 million tons of sugar (Sugarcane, 2024).

Because it is a crop grown in several regions with diverse climates, the quantity and technological quality of the crop can be significantly affected without the use of irrigation when associated with local climate conditions (Correia *et al.*, 2014; Carmo *et al.*, 2017). Therefore, the practice of irrigation can minimize the negative impacts resulting from prolonged droughts and increase the longevity of sugarcane plantations (ANA, 2017).

Another factor that presents a major limitation to productivity in sugarcane regions of Brazil is the supply of nutrients to sugarcane (Franco; Trivelin, 2010; Marin *et al.*, 2019). Owing to its multiple chemical and biological reactions in the soil, nitrogen is the most complex nutrient, which makes the management and recommendation of this nutrient difficult (Mota *et al.*, 2015).

As nitrogen is one of the nutrients that limits sugarcane growth the most, it becomes essential for growth, technological quality, productivity and sugar and alcohol yields (Costa *et al.*, 2016; Silva, 2017). It is estimated that to obtain good yields in stalk production, approximately 130 kg ha $^{-1}$ of nitrogen are needed (Oliveira *et al.*, 2017).

Thus, an alternative way to reduce the need for mineral fertilization is to use the nitrogen made available by the mineralization process through straw at the end of the cycle (Fortes *et al.*, 2013; Misra *et al.*, 2020). Studies have reported that during three consecutive cycles, 12.7 g kg of nitrogen may be available through the mineralization of straw, increasing soil fertility, which contributes to crop development (Fortes, 2010; Adetoro *et al.*, 2020).

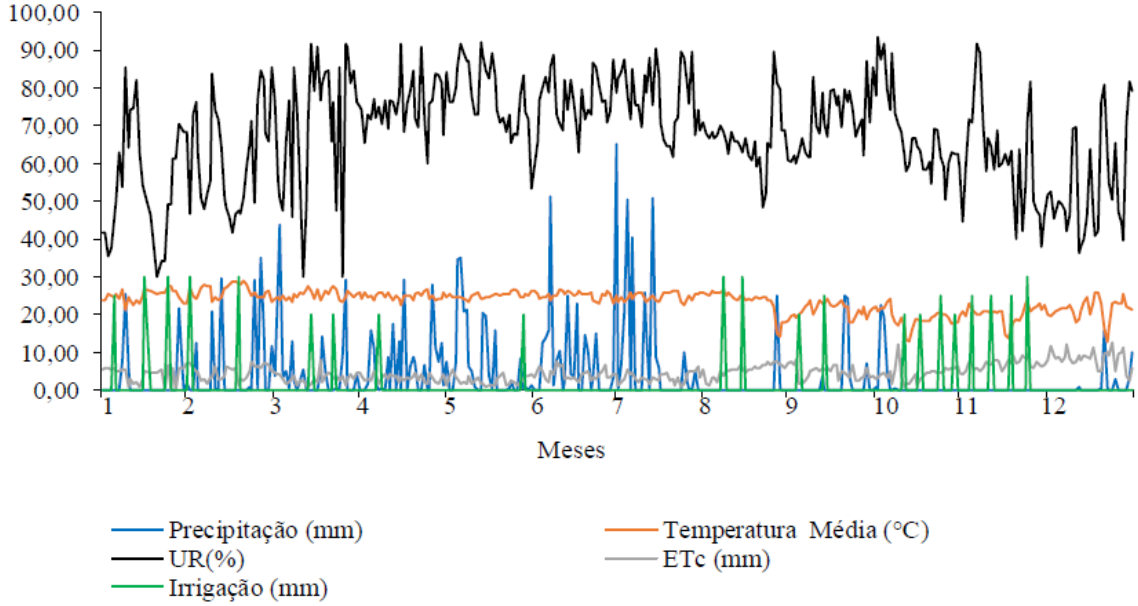
In this context, the objective of this study was to evaluate the residual effects of nitrogen sources and doses applied in the sugarcane–plant cycle on the dry mass and technological attributes of the first irrigated sugarcane ratoon.

4 MATERIALS AND METHODS

The experiment was implemented at the Raízen Plant under field conditions in the municipality of Jataí, GO. According to Köppen and Geiger (1928), the climate of the area is of the Aw type, tropical, characterized by a rainy period in the months of October to April and a dry period in the months of May to September.

During the experiment, daily meteorological data on temperature (°C), relative humidity (%) and daily precipitation (mm) were collected by means of a meteorological station. During this period, average values of temperature (23.44°C), relative humidity (67.94%) and precipitation (4.11 mm) were found. Water replacement was performed on the basis of the daily ETc of the crop as described in Figure 1.

Figure 1. Daily meteorological data were collected during the experimental period at Jataí, GO.



The soil of the experimental area is classified as a dystrophic red Latosol that is very clayey (Santos *et al.*, 2018). After the sugarcane harvest, soil samples were taken from the 0–10, 10–20, and 20–40 cm layers for the chemical characterization of the soil, according to the methodology proposed by Embrapa (2013). For the physical determinations of the soil, disturbed and undisturbed soil samples were collected with the aid of Uhland rings at depths of 0–10, 10–20, and 20–40 cm. The results of the soil characteristics are shown in Table 1.

Table 1. Chemical, physical-hydraulic, granulometric and textural characteristics of the soil in the experimental area.

[1] Layer	pH	MO	P_{resin}	S	K	Here	Mg	Al
cm	CaCl2	kg dm $^{-3}$	----mg dm $^{-3}$----		-------------- mmol $_c$ dm $^{-3}$ --------------			
0-10	6.0	89.0	39.0	4.0	2.0	50.0	23.0	<1
10-20	5.7	76.0	16.0	4.0	3.7	28.0	14.0	<1
20-40	5.5	53.0	9.0	16.0	4.0	13.0	7.0	<1
Layer	H+Al	CTC	V	B	Ass	Faith	Mn	Zn
m	mmol $_c$ dm $^{-3}$		%	--------------------mg dm $^{-3}$--------------------				
0-10	18.0	93.9	81.0	0.2	1,2	33.0	4.7	2.4
10-20	20.0	65.7	70.0	0.15	1,2	28.0	2.4	1.4
20-40	25.0	49.0	49.0	0.20	1.0	23.0	0.9	0.4
Layer	Granulometry (g kg $^{-1}$)				Textural classification		θ_{CC}	θ_{PMP}
m	Sand	Silt	Clay				cm ^{3} cm $^{-3}$	
0-0.10	96.0	82.0	822.0		Very clayey		46.3	22.6
0.10-0.20	97.0	82.0	822.0		Very clayey			
0.20-0.40	85.0	71.0	845.0		Very clayey		45.8	22.6

[1] θ_{CC} – Field capacity; θ_{PMP} – permanent wilting point; P, K, Ca and Mg: Resin; S: Calcium phosphate 0.01 mol L-1; Al: KCl 1 mol L $^{-1}$; H+Al: SMP; B: hot water; Cu, Fe, Mn and Zn: DTPA; MO - Organic matter; pH - $_{CaCl2}$; CEC - Cation exchange capacity; V - Saturation of the CEC by bases.

The experimental design used was a randomized block design with a 2 × 4 factorial scheme and three replications. The factors consisted of two N sources (urea and ammonium nitrate) and four doses (0, 60, 120 and 180 kg ha $^{-1}$) applied 60 days after planting in sugarcane plants.

The other cultural treatments related to soil correction fertilization were carried out considering the expected crop yield of 120 t ha $^{-1}$ in flat sugarcane. One hundred kg ha $^{-1}$ of phosphorus (P_2O_5), 80 kg ha $^{-1}$ of potassium (K_2O) and micronutrients, if necessary, were applied in the planting furrow, according to the results of the soil analyses (Sousa; Lobato 2004). At 60 days after the regrowth of the ratoon, fertigation with nitrogen at a dose of 120 kg ha $^{-1}$ was carried out in all the experimental plots.

The experimental area consisted of 1200 m2, and each plot consisted of five lines measuring 5 m in length, with a spacing of 1.50 m between them, totaling an area of 37.50 m2 per experimental plot. The two central lines of each plot were considered the useful area of the plot, disregarding 2 m at each end.

Planting was carried out mechanically with the IACSP 95--5000 variety developed by the IAC, which is characterized by excellent performance in mechanized planting and harvesting, good sprouting of ratoon crops under straw, and excellent performance in winter planting. Cultural treatments related to the control of invasive plants, pests and diseases were carried out according to the experience of the plant.

Irrigation was performed by a ZIMMATIC central pivot, model PC 08-64/03-647/01-646/L4 + AC, in galvanized steel, low pressure, with 12 support towers, a total irrigated area of 139.31 ha $^{-1}$, and a speed of 268 mh $^{-1}$ in the last tower, applying a minimum gross depth for a 100% turn of 1.35 mm. The irrigation depth was determined as performed commercially through the IRRIGER® software. The software uses the Penman–Monteith method, adapted by Allen *et al. (1989), to estimate evapotranspiration on a daily scale*, *with* micrometeorological data of solar radiation, air temperature, wind speed and relative humidity.

At the end of the sugarcane cycle, 10 plants were collected from their respective plots to determine the technological attributes of the juice. On the basis of these attributes, the gross sugar and alcohol yields were calculated according to the methodology described by Caldas (1998).

$$RBAÇ = \left(\frac{PCC \times PC}{100}\right) \quad (1)$$

where:
RBAÇ - Sugar yield, kg ha $^{-1}$;
PCC - Quantity of raw sugar, %;
PC - Stalk production, kg ha $^{-1}$;

$$RBAL = ((PCC \times F) + ARL) \times Fg \times 10 \times PC \quad (2)$$

where:
RBAL - Yield of raw alcohol in liters per ton of sugarcane;
PCC - Quantity of raw sugar, %;
F - Stoichiometric transformation factor of 1.052, dimensionless;
ARL - These are free reducing sugars (0.7 to 0.85%);
Fg - Gay Lussac factor (0.6475), dimensionless;
PC - Stalk production, kg ha $^{-1}$.

The dry mass of this material was subsequently determined, where subsamples were subjected to drying in a forced air circulation oven at 65 °C until constant mass was reached to determine the dry matter mass of each part of the plant. The sum of the values corresponding to the biomass of each structural component of the plants ($MS_{FV} + MS_{B} + MS_{FBM} + MS_{PC} + MS_{PE}$) allows the determination of the total dry biomass of the aerial part (MST_{PA}), which is used in the calculations of the growth parameters (Marafon, 2012).

The data were subjected to analysis of variance, applying the F test at a 5% probability level. For significance, the quantitative variables were adjusted and submitted to regression equations. The qualitative variables were compared via the Tukey test at the 5% probability level via the statistical program SISVAR ® (Ferreira, 2011).

5 RESULTS AND DISCUSSION

Table 2 shows that the analysis of variance revealed a significant effect of the N source on the variables stem dry mass (MSC), aerial part dry mass (MSPA), gross sugar yield (RBAÇ) and gross alcohol yield (RBAL). The dose factor had a significant effect on all the variables analyzed. The interaction effect was significant for both the gross sugar yield (RBAÇ) and gross alcohol yield (RBAL) variables.

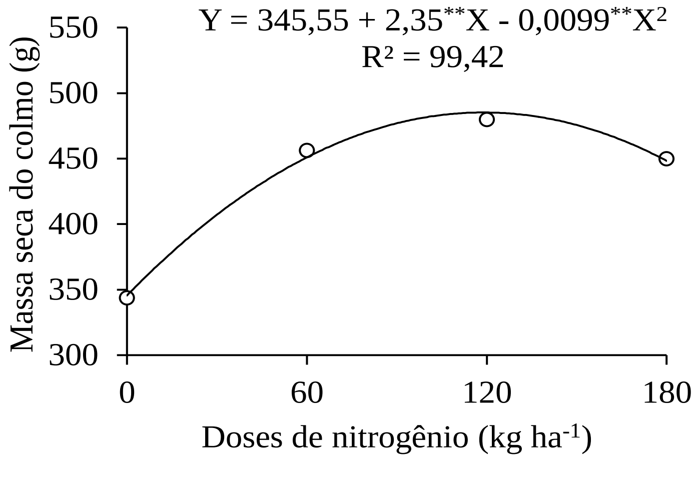
Table 2. Summary of the analysis of variance for the variables stem dry mass (MSC), aerial part dry mass (MSPA), total recoverable sugar (ATR), gross sugar yield (RBAÇ) and gross alcohol yield (RBAL) of irrigated sugarcane (first ratoon cycle).

FV	GL	QM [1]				
		MSC	MSPA	ATR	RBAÇ	RBAL
Source	1	21989.39 **	20024.34 *	33.39 ns	15.32 **	7.48 **
Dose	3	1313.94 ns	1429.12 ns	120.61 **	78.20 **	39.12 **
Source x Dose	3	6746.71 ns	12363.37 ns	8.36 ns	3.69 *	1.88 *
Block	2	15281.89 *	19109.91 *	27.58 ns	28.10 ns	13.62 **
Residue 1	14	2821.82	4095.73	7.42	0.78	0.39
CV(%)		12.28	9.96	2.1	3.98	4.04

[1] Dry mass of the stalk (MSC), dry mass of the aerial part (MSPA), total recoverable sugar (ATR), gross sugar yield (RBAÇ) and gross alcohol yield (RBAL) of sugarcane; coefficient of variation (CV). ** and * indicate significance at the 1% probability and 5% probability, respectively; ns not significant according to the F test.

Figure 2 shows that the MSC as a function of the nitrogen dose applied to sugarcane in the previous cycle conformed to a quadratic model, with an R^2 of 99.40%. Increasing the nitrogen dose increased the MSC of sugarcane to a dose of 118 kg ha^{-1}, reaching a maximum MSC of 485.23 g. The maximum MSC observed at the nitrogen dose of 118 kg ha^{-1} was 28.78, 7.06, and 7.60% higher than the MSC observed at nitrogen doses of 0, 60, and 180 kg ha^{-1}, respectively. Residual nitrogen fertilization significantly affects the dry matter of the stalks in the subsequent cultivation of sugarcane, corroborating the results of the present study (Bastos *et al.*, 2015; Silva; Mantese; Florian, 2023).

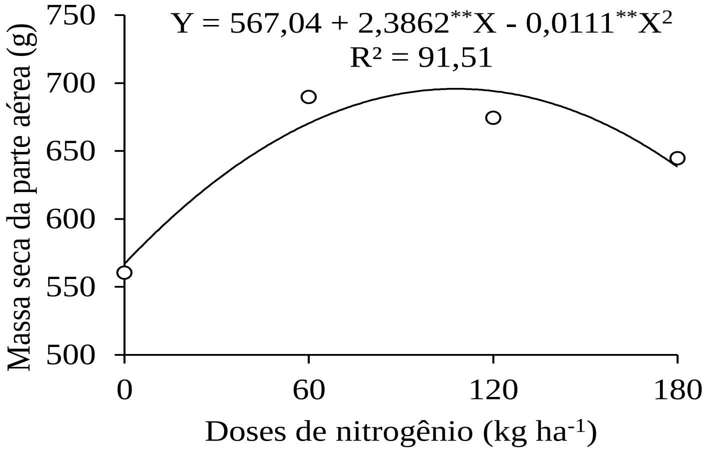
Figure 2. Dry mass of irrigated sugarcane stalk in the first ratoon cycle as a function of residual N dose. ** significant at 1% probability according to the F test.



Gomes (2017), evaluating the sources and doses of nitrogen in sugarcane in a Red Latosol of the Cerrado, reported an increase of 22.74% when a dose of 118 kg ha $^{-1}$ of N, in the form of urea, was applied in relation to the 0 kg treatment (without N application), a value lower than those reported in this study.

Figure 3 shows that the MSPA as a function of nitrogen dose in sugarcane fit a quadratic model, with an R^2 of 91.51%.

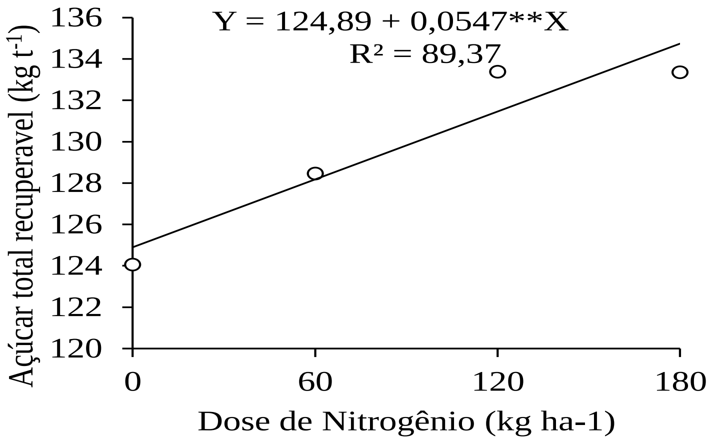
Figure 3. Dry mass of the aerial part of irrigated sugarcane in the first ratoon cycle as a function of the residual N dose. ** significant at 1% probability according to the F test.



With increasing nitrogen dose, the MSPA of sugarcane increased to a dose of 107 kg ha^{-1}, reaching 695.79 g. The maximum MSPA observed at a nitrogen dose of 107 kg ha^{-1} was 18.50, 3.64 and 8.25% greater than the MSPA observed at nitrogen doses of 0, 60, and 180 kg ha^{-1}, respectively. Travian *et al.* (2014) reported that the application of 116 kg ha $^{-1}$ N, in the form of ammonium nitrate as a top dressing, resulted in the highest dry mass production. Generally, an increase in shoot mass and a decrease in root mass can be observed with nitrogen application (Otto *et al.*, 2009; Misra *et al.*, 2020).

Figure 4 shows that the total recoverable sugar (ATR) content as a function of the nitrogen dose for sugarcane conformed to a linear model, with an ^{R2} of 89.37%.

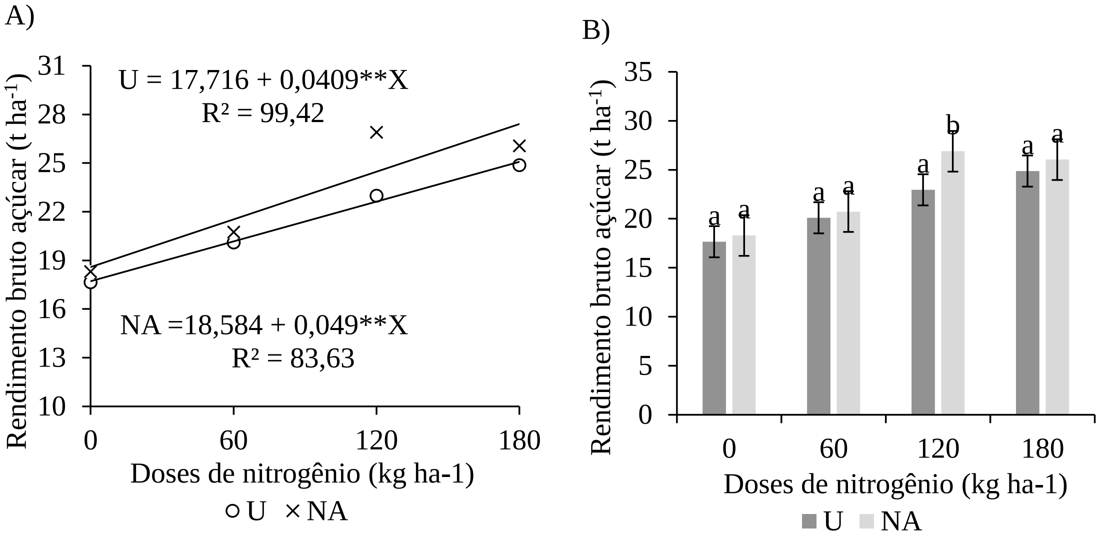
Figure 4. Total recoverable sugar content of irrigated sugarcane in the first ratoon cycle, depending on the residual N dose. ** significant at 1% probability according to the F test.



The highest ATR was found at the dose of 180 kg ha^{-1}, with values that were 7.30, 4.87 and 2.43% higher than those observed at doses of 0, 60 and 120 kg ha^{-1}, respectively. According to the regression equation, an increase of 2.43% was obtained for each increase of 60 kg ha $^{-1}$. Some authors have reported a linear increase in the ATR with increasing N dose (Silva, 2014; Feder, 2021). Boschiero (2017) reported that the application of 100 kg ha $^{-1}$ N, in the form of ammonium nitrate and calcium, increased the ATR, corroborating the results obtained in this study. At harvest, Joris (2015) reported an ATR of 130 kg t $^{-1}$, values close to those reported in the present study, at a dose of 180 kg ha $^{-1}$.

In the breakdown of the dose factor for each source level, linear increases of 9.78% and 10.72% in gross sugar yield were observed for each increase of 60 kg ha $^{-1}$ in urea and ammonium nitrate, respectively (Figure 5A). At the dose of 180 kg ha $^{-1}$, an increase in gross sugar yield of 29.34 and 32.17% was observed compared with the lowest dose of N, in the form of urea and ammonium nitrate, respectively.

Figure 5. Gross sugar yield of irrigated sugarcane in the first ratoon cycle as a function of the residual N dose (A) and N source (B). Means followed by the same letters within the same N dose do not differ significantly according to the Tukey test at 5% probability. ** significant at 1% probability according to the F test.

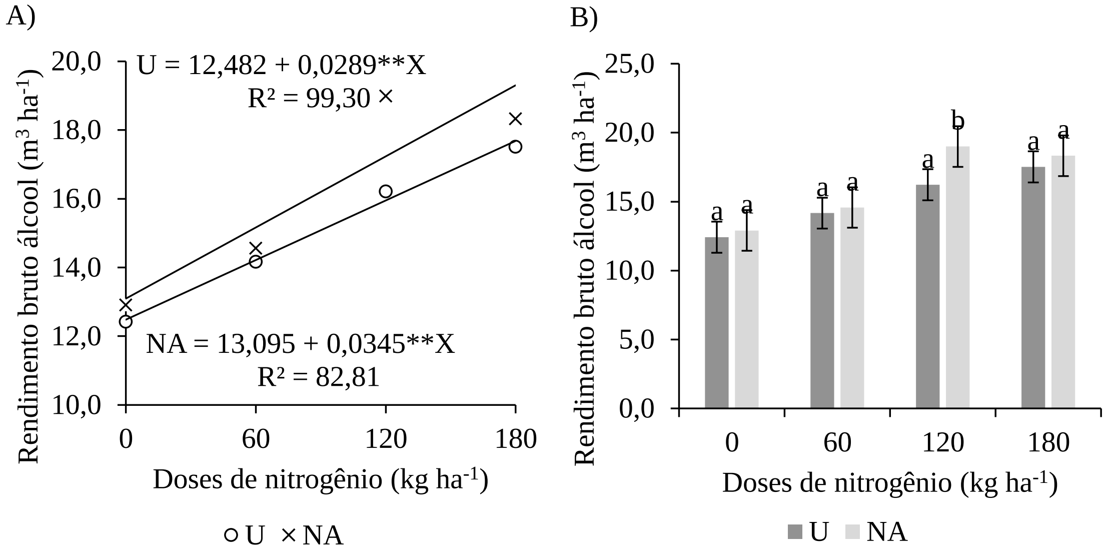


The effects of N rates on gross sugar yield generally promote significant effects at rates above 140 kg ha $^{-1}$ and yield values greater than 22 t ha $^{-1}$ (Vale, 2009; Feder, 2021). Some authors reported a significant effect of residual N on total sugar productivity when a single rate of 100 kg ha $^{-1}$ was applied to all the treatments after the previous crop was harvested (Vitti *et al.*, 2007; Misra *et al.*, 2020).

In the breakdown of sources for each dose level, a higher gross sugar yield was observed at the dose of 120 kg ha $^{-1}$ ammonium nitrate. At this dose, ammonium nitrate resulted in a 14.58% greater gross sugar yield than did the urea source. At doses of 0, 60, and 180 kg ha $^{-1}$, no significant difference was detected between the N sources (Figure 5B). Boschiero (2017) reported that the application of U and NA generally results in higher stalk and sugar yields for the NA source.

Figure 6A shows linear increases of 9.80 and 10.72% in the gross alcohol yield for each increase of 60 kg ha^{-1} in N-urea and N- ammonium nitrate, respectively. At the dose of 180 kg ha $^{-1}$, an increase in the gross alcohol yield of 29.41% and 32.16% was observed compared with the lowest doses of N-urea and N- ammonium nitrate, respectively.

Figure 6. Gross alcohol yield of irrigated sugarcane in the first ratoon cycle as a function of residual N dose (A) and N source (B). Means followed by the same letters within the same N dose do not differ significantly according to Tukey's test at 5% probability. ** significant at 1% probability according to the F test.



Silva (2017) reported a significant effect on gross alcohol yield with respect to the N dose factor, with a dose of 123.75 kg ha $^{-1}$ resulting in a yield of 19.80 m ^{3} ha $^{-1}$. Vale (2009) reported an RBAL of 15 m ^{3} ha $^{-1}$ at a dose of 133 kg ha $^{-1}$. Water replacement can interact with residual N in sugarcane plants, influencing the gross alcohol yield (Bastos *et al.*, 2016; Adetoro *et al.*, 2020).

In the breakdown of sources for each dose level, a higher gross sugar yield was observed at the dose of 120 kg ha $^{-1}$ ammonium nitrate. At this dose, the gross alcohol yield of ammonium nitrate was 14.61% greater than that of the urea source. At doses of 0, 60 and 180 kg ha $^{-1}$, no significant difference was detected between the sources (Figure 6B). Gomes (2017) reported a significant difference between ammonium nitrate and urea at N doses of 60 and 120 kg ha $^{-1}$; at the respective doses, ammonium nitrate resulted in increases of 20.75 and 18.67%, respectively, compared with urea.

Nitrogen fertilization of sugarcane results in increased productivity and greater vegetative vigor of the first ratoon, which highlights the importance of evaluating residual N in sugarcane regrowth.

6 CONCLUSIONS

The best values of dry mass of the stalk and dry mass of the aerial part of sugarcane are found at a dose of approximately 120 kg ha $^{-1}$ of nitrogen.

The maximum total recoverable sugar (ATR) of irrigated sugarcane in the first ratoon cycle was verified at a dose of 180 kg ha $^{-1}$ nitrogen.

The ammonium nitrate source at a dose of 120 kg ha^{-1} of N resulted in higher gross sugar and alcohol yields than did the urea source, indicating increases above 14.50%, whereas for the N doses of 0, 60 and 180 kg ha$^{-1,}$ there was no significant difference between the nitrogen sources.

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