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EFEITO RESIDUAL DA ADUBAÇÃO NITROGENADA NA SEGUNDA SOQUEIRA DE CANA-DE-AÇÚCAR IRRIGADA EM LATOSSOLO VERMELHO DE CERRADO

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1 RESUMO

O Brasil é o maior produtor mundial de cana-de-açúcar e seus derivados e a adubação nitrogenada destaca-se como uma das práticas culturais de maior demanda de pesquisas e para a cultura da cana-de-açúcar. Buscando atingir a máxima eficiência adubação e, consequentemente, produtividade, é necessário aprimoramento das técnicas de manejo. Objetivou-se determinar o efeito residual de diferentes fontes e doses de nitrogênio, aplicados no ciclo de cana-planta, sob o crescimento, acúmulo de biomassa seca, atributos tecnológicos e produtividade de colmos da cana-de-açúcar (IACSP95-5000) irrigada, no ciclo de segunda soca, cultivada em um Latossolo Vermelho de Cerrado. O experimento foi conduzido em condições de campo, em área da Fazenda Rio Paraiso II pertencente à Usina Raízen, no município de Jataí, GO. O delineamento experimental utilizado foi em blocos ao acaso, analisado em esquema de parcela fatorial 2 × 4, com três repetições. Os tratamentos foram duas fontes de nitrogênio (ureia e nitrato de amônio), quatro doses de nitrogênio (0, 60, 120 e 180 kg ha^{-1}), aplicadas no ciclo de cana planta. Não foi verificado efeito residual das fontes e doses de N para as variáveis biométricas e massa seca. O efeito residual das doses de N promoveu um acréscimo na produtividade de colmos, rendimento bruto de álcool e rendimento bruto de açúcar.

Palavras-chave: *Saccharum officinarum* L, ureia, nitrato de amônio, rendimento bruto de açúcar.

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RESIDUAL EFFECT OF THE APPLICATION OF SOURCES AND DOSES OF NITROGEN ON SUGARCANE CULTIVATED IN CERRADO RED LATOSOL

2 ABSTRACT

Brazil is the world's largest producer of sugarcane and its byproducts, sugar and alcohol. The production of sugarcane is an activity of great social, economic and environmental importance

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for Brazil. Nitrogen fertilization stands out as one of the cultural practices of greater demand for research and for the cultivation of sugarcane. To achieve maximum efficiency, fertilization and, consequently, productivity, it is necessary to improve management techniques. The objective of this study was to determine the residual effects of different sources and nitrogen rates applied in the cane plant cycle on growth, accumulation of dry matter, technological analysis and productivity of irrigated sugarcane (IACSP95-5000) in the second rat cycle, cultivated in the Cerrado Red Latosol. The experiment was carried out under field conditions in the area of the Rio Paraiso II farm belonging to the Raízen cane plant factory in the city of Jataí, GO, Brazil. The collected soil was classified as Dystrophic Red Latosol. For the chemical and physical characterization, samples of the soil were collected from 0.00--0.10, 0.10--0.20 and 0.20--0.40 m layers. The experimental design used was randomized blocks, analyzed in a 2 × 4 factorial scheme, with three replications. The factors analyzed were two sources of nitrogen (urea and ammonium nitrate) and four doses of nitrogen (0, 60, 120 and 180 kg ha $^{-1}$). The parameters analyzed were the plant height, diameter of the stalks, length of the internodes, dry mass of the leaves, dry mass of the stalk, dry mass of the stem, total dry mass of the aerial part, juice brix, cane sucrose content, recoverable total sugar content, productivity of the stalks, yield of sugar and yield of alcohol. No residual effects of the sources or doses of N were observed for the biometric variables or dry mass. The residual N promoted an increase in the productivity of the stalks, yield of sugar and yield of alcohol.

Keywords: *Saccharum officinarum* L., urea, ammonium nitrate, yield of sugar.

3 INTRODUCTION

Brazil is the world's largest producer of sugarcane *(Saccharum officinarum*) and its derivatives, sugar and alcohol, favored by its extensive area and climate conducive to plant production throughout the year, whose production in the 2024/2025 harvest was approximately 689.83 million tons (CANA-DE-AÇÚCAR, 2024).

Sugarcane is of great social and economic importance to Brazil because of its multiple uses, being used in natura, in the form of fodder, for animal feed, or as a raw material for the production of brown sugar, molasses, sugar and alcohol. Its residues also have great economic importance: vinasse is transformed into fertilizer, and bagasse is transformed into fuel (CAPUTO *et al.*, 2008; OLIVEIRA *et al.*, 2023).

Studying a crop in its development environment can generate a large amount of information to adapt the best management and cultivar for specific environments (soil and climate), thus making it possible to explore the production site fully to promote the best crop yield and consequently greater profitability or competitiveness for sugarcane agroindustries (MARQUES; SILVA, 2008; HORSCHUTZ *et al.*, 2022).

Sugarcane production is an activity of great social, economic and environmental importance for Brazil and represents a source of various resources, jobs and foreign exchanges for the country. Due to the growing demand for ethanol, sugar, and energy and the production of second-generation alcohol, sugarcane has assumed an increasingly important role in Brazilian and global agriculture (PEREIRA, 2015).

Nitrogen is the nutrient required in the greatest quantity by cultivated plants; it is important for plant metabolism and is a constituent of enzymes, proteins, DNA, RNA, chlorophylls and a precursor of hormones (MALAVOLTA; MORAES, 2007; SILVA *et al.*, 2023). It is one of the primary macronutrients and is the most used, most absorbed and most exported by crops; it is the most expensive nutrient to obtain; it is the most leached in soils, requiring special care in its management owing to the risk of contamination of the water table (CARVALHO; ZABOT, 2012; CUNHA *et al.*, 2021).

Nitrogen fertilization stands out as one of the cultural practices with the greatest demand for research, and for sugarcane crops, studies on N present highly variable results (KORNDÖRFER *et al.*, 2002; CUNHA *et al.*, 2020). The development of agricultural practices and the search for alternative sources that aim at better use of N by sugarcane crops are essential (FRANCO *et al.*, 2008; GONÇALVES *et al.*, 2020). The accumulation of N in the soil occurs slowly, and nitrogen fertilization promotes an increase in total N stocks in the soil (WEBER; MIELNICZUK, 2009; SILVA *et al.*, 2023).

Several studies on the residual effect of nitrogen fertilization in sugarcane have been carried out (SCHULTZ *et al.*, 2010; MEGDA *et al.*, 2012; BASTOS *et al.*, 2018), but gaps remain, especially regarding the effects of different sources and doses associated with the use of irrigation.

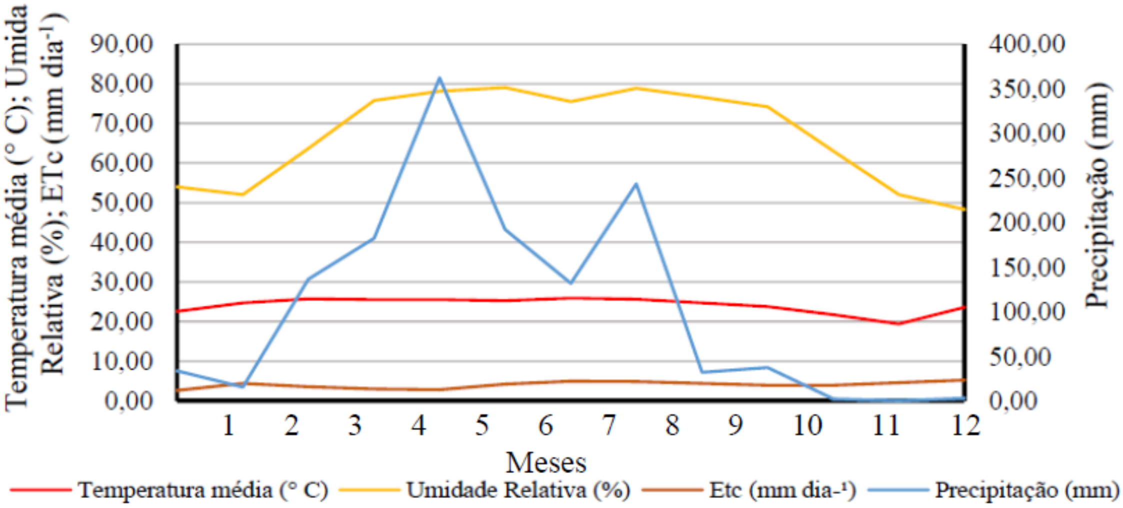
Water deficiency affects several aspects of sugarcane metabolism, especially photosynthesis (CHAVES; FLEXAS; PINHEIRO, 2009; MATA; MATA; OLIVEIRA, 2024). Maintaining adequate soil moisture throughout the growing period is important for obtaining potential crop yields since vegetative growth is proportional to the amount of water transpired by the crop (DALRI *et al.*, 2008; SILVA *et al.*, 2021). The use of irrigation during the dry season and dry spells is an alternative to mitigate the effects of poor rainfall distribution and increase the productivity and longevity of sugarcane fields (TEODORO *et al.*, 2013; SILVA *et al.).* , 2021). In this sense, production or response functions serve to guide farmers in decision-making regarding the quantity of inputs to be used in a given agricultural crop (TEODORO *et al.*, 2013).

To promote the optimization of the use of nitrogen fertilizers, this study aimed to determine the residual effects of different sources and doses of nitrogen, applied in the sugarcane–plant cycle, on the growth, accumulation of dry biomass, technological attributes and productivity of irrigated sugarcane (IACSP95--5000) in the second ratoon cycle in the Red Latosol of the Cerrado.

4 MATERIALS AND METHODS

The experiment was conducted under field conditions in an area of the Rio Paraiso II farm belonging to Raízen Mill in the municipality of Jataí, GO. The geographic coordinates of the site are 17°44'2.62"S and 51°39'6.06"W, with an average altitude of 907 meters. The climate of the site is Aw, tropical, with rain from October to April and dry months from May to September (KÖPPEN; GEIGER, 1928). The maximum temperature ranges from 35°C to 37°C, and the minimum temperature ranges from 12°C to 15°C (in winter, up to 5°C). The annual precipitation reaches approximately 1,800 mm, which is poorly distributed throughout the year, according to the climate data shown in Figure 1.

Figure 1. Meteorological data during the experimental period, Jataí – GO.



Source: INMET Normal Station – Jataí - GO. ETc via the Hargreaves–Saman method.

The soil in the experimental area is classified as a dystrophic red Latosol that is very clayey (SANTOS *et al.*, 2018). The chemical, physical-hydraulic, granulometric and textural classification characteristics of the samples collected before the experiment were performed are described in Table 1.

Table 1. Chemical, physical-hydraulic characteristics, granulometry and textural classification of the soil in the experimental area, in layers of 0.0–0.10, 0.10–0.20 and 0.20–0.40 m in depth, Jataí – GO.

Layer	**pH**	**MO**	**P Resin**	**S**	**K**	**Here**	**Mg**	**Al**
m	CaCl2	g dm $^{-3}$	--- mg dm $^{-3}$ ---		-------- mmol/l dm $^{-3}$ --------			
0.0-0.10	6.0	89.0	39.0	4.0	2.9	50.0	23.0	<1
0.10-0.20	5.7	76.0	16.0	4.0	3.7	28.0	14.0	<1
0.20-0.40	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/l dm $^{-3}$ --		%	-------------- mg dm $^{-3}$ --------------				
0.0-0.10	18.0	93.9	81.0	0.2	1,2	33.0	4.7	2.4
0.10-0.20	20.0	65.7	70.0	0.15	1,2	28.0	2.4	1.4
0.20-0.40	25.0	49.0	49.0	<0.2	1.0	23.0	0.9	0.4
Layer	Granulometry (g kg $^{-1}$)			Textural classification			θCC	θPMP
m	Sand	Silt	Clay				cm³	cm³
0.0-0.10	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

Manual chemical analysis for assessing the fertility of tropical soils (IAC, 2001). MO - Organic matter; CEC - Cation exchange capacity; V - CEC saturation by bases; θCC - Water content at field capacity; θPMP - Water content at permanent wilting point.

The experimental design used was randomized blocks, analyzed in a double factorial scheme, with three replications. The factors evaluated consisted of two N sources (ammonium nitrate and urea) and four N doses (0, 60, 120 and 180 kg ha $^{-1}$).

For sugarcane plants, nitrogen fertilization was carried out according to the treatments 60 days after planting; nitrogen was applied by broadcasting on the side of the row (0.20 m). In the first and second ratoon sugarcane plots, nitrogen fertilizer was applied at a rate of 120 kg ha^{-1} in all the experimental plots 60 days after harvest. All the sugarcane plants, first- and second-year sugarcane treatments, were fertilized in the planting furrow with phosphorus (100 kg ha^{-1}) in the form of triple superphosphate (P_2O_5), potassium (80 kg ha^{-1}) in the form of potassium chloride (K_2O), and micronutrients, according to the results of the soil analyses and the recommendations of Sousa and Lobato (2004).

The experimental units consisted of five 5 m long sugarcane rows spaced 1.50 m apart. The three central rows of each plot were considered useful areas, disregarding 1 m at each end.

The sugarcane variety IACSP95-5000, developed by the Agronomic Institute of Campinas (IAC), was used. Soil preparation was carried out via the conventional system by means of plowing and harrowing, followed by opening the planting furrows. Planting was carried out mechanically, according to the experience of the Raízen Plant, and the number of buds per meter was in accordance with the recommendations for the respective variety. The evaluations herein refer to the second ratoon cycle.

Cultural treatments related to the use of herbicides, insecticides, fungicides and other products related to the control of weeds, pests and diseases were used according to the need and infestation assessment and in accordance with the experience of Usina Raízen.

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.

Biometric evaluations were performed on four plants marked and located in the useful area of each plot. The variables analyzed were plant height (AP), measured from the ground to the ligule of the last completely open leaf, and stem diameter (DC), measured at the base of the stem with the aid of a digital caliper, and internode length (CE), measured from one internode.

Dry biomass assessments were performed on two plants demarcated and located in the useful area of each plot. Samples were collected from the aerial part of the sugarcane, separating the structural components of the aerial part, which included the green leaves (FV), the sheaths (B), the dead leaves and sheaths (FBM), the pseudostem (PC), the stem (C) and the emerging part (PE). The sum of the two components of the aerial part (PC and PE) is called the 'pointer'. The samples were subsequently dried in a forced air circulation oven at 65 °C until a constant mass was reached, after which the dry matter mass of each part of the plant was determined. The sum of the values corresponding to the biomass of each structural component of the plants (MSFV + MSB + MSFBM + MSPC + MSPE) allows the determination of the total dry mass of the aerial part (MSTPA), which is used in the calculations of the growth parameters (MARAFON, 2012).

The dry mass variables analyzed were MSF (leaf dry mass = green leaf dry mass + green leaf sheath dry mass + dead leaf dry mass + dead leaf sheath dry mass), MSC (stem dry mass), MSPT (tip dry mass) and MSTPA (total shoot dry mass).

The stalk productivity (tons of stalks per hectare – TCH) was determined by weighing the total stalks present in the useful area of the respective plots, and the weight of the stalks present in the two central lines of each plot was quantified. To this end, the cut was made as close to the ground as possible. The stalks were dehusked, and the pointer was detached. The samples were subsequently weighed on a hook-type digital scale (accuracy of 0.02 kg) with a capacity of 50 kg.

Samples were collected from 10 stalks per treatment, which were submitted for technological analysis at the agro-industrial laboratory of the Raízen Plant, Jatai - GO, to obtain the values of percentage of soluble solids (BRIX), percentage of raw sugar contained in the stalks (cane POL) and total recoverable sugar (ATR), according to the standards of the Consecana system (2006).

The gross sugar and alcohol yields were calculated via the quantity of raw sugar determined via technological analysis of the juice by sampling 10 stalks per treatment and were calculated via Equations (1) and (2), according to the methodology described by Caldas (1998):

$$RAç = \left(\frac{PCC * PC}{100}\right) \quad (1)$$

where:
RAç - sugar yield in kg ha $^{-1}$;
PCC - quantity of raw sugar in % contained in the stalks and determined in the laboratory;
PC - stalk productivity in t ha $^{-1}$.

$$RA = ((PCC * F) + ARL) * Fg * 10 * PC \quad (2)$$

where:
RA - yield of raw alcohol in liters per ton of sugarcane;
PCC - quantity of raw sugar in % contained in the stalks and determined in the laboratory;
F - stoichiometric transformation factor of sucrose into one glucose molecule plus one fructose molecule, equal to 1.052;
ARL are the free reducing sugars in %, whose values vary from 0.7--0.85%, with the distillery using 0.7 for high PCC;
Fg - Gay Lussac factor equal to 0.6475;
PC - stalk productivity in t ha $^{-1}$.

The data were subjected to analysis of variance, applying the F test at the 5% probability level, and, in the case of significance, regression analysis was performed for nitrogen doses, whereas for nitrogen sources, the means were compared with each other via the Tukey test at the 5% probability level via the SISVAR® statistical program (FERREIRA, 2011).

5 RESULTS AND DISCUSSION

The analysis of variance revealed a significant effect, in relation to the interaction between the factors F × D, for the variable stem diameter (DC). No significant effects were detected for the variables plant height (AP) and internode length (CE) (Table 2).

Table 2. Summary of the analysis of variance and means for the variables plant height (AP), stem diameter (DC) and internode length (CE) of the irrigated sugarcane crop (var. SP95--5000) in the second RR cycle, considering the residual effects of different sources and doses of nitrogen applied to the sugarcane plant, municipality of Jataí, GO, Brazil.

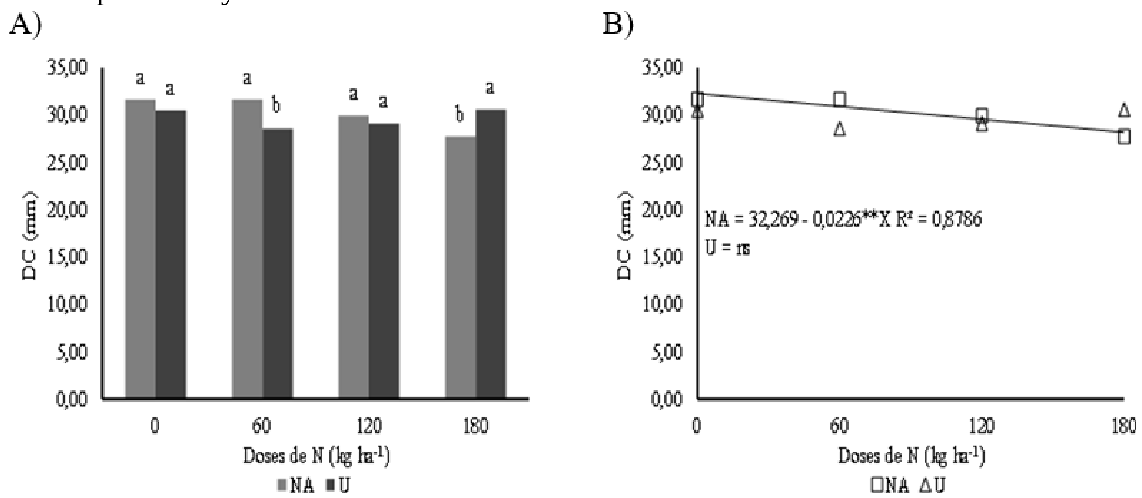
FV	GL	Mean Squares[1]		
		AP	A.D	EC
Sources of N (F)	1	0.007 ns	1.7821 ns	0.0975 ns
N (D) doses	3	0.0185 ns	4.3092 ns	0.4683 ns
F x D	3	0.0441 ns	9,1405 *	1.2611 ns
Block	2	0.0215 ns	0.3718 ns	0.0587 ns
Residue (a)	14	0.0143	1.7172	0.5411
CV (a)		5.38	4.37	6.61
		Averages		
N sources		(m)	(mm)	(cm)
IN		2.21	30.23	11.05
U		2.24	29.69	11.18
N rates (kg ha $^{-1}$)				
0		2.16	31.08	10.75
60		2.28	30.12	11.39
120		2.21	29.51	11.26
180		2.26	29.14	11.06
Interaction (F x D)				
NA 0		2.04	31.66	10.28
U 0		2.28	30.50	11.23
NA 60		2.27	31.65	11:00
U 60		2.29	28.58	11.79
NA 120		2.30	29.91	11.76
U 120		2.12	29.11	10.76
NA 180		2.23	27.72	11.18
U 180		2.30	30.57	10.94

[1] Coefficient of variation (CV). * significant at 5% probability. ns not significant according to the F test.

For AP, the U source did not significantly differ from the NA source. There was no significant difference between the N doses of 0, 60, 120 and 180 kg ha $^{-1}$ (Table 2).

Figure 2A shows that for the DC of sugarcane fertilized with the NA source, at a dose of 60 kg ha^{-1} N, there was an increase of 9.70% in relation to the U source. For the N dose of 180 kg ha $^{-1}$, the U source was 9.32% greater than the NA source. For the N doses of 0 and 120 kg ha $^{-1,}$ there was no significant difference between the nitrogen sources. Marcelo (2008), studying nitrogen sources and doses in sugarcane, did not observe a significant effect for the treatments in relation to the stem diameter.

Figure 2. Stalk diameter of sugarcane (var. SP95--5000) in the second ratoon cycle as a function of the residual effect of N source (A) and N dose (B) applied to sugarcane plants in the municipality of Jataí, GO, Brazil. 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. ns not significant according to the F test.

The DC of sugarcane as a function of nitrogen dose for the ammonium nitrate source conformed to a linear model, with an R^2 of 88% (Figure 2B). According to the linear regression equation obtained for NA, a maximum DC of 32.27 mm was estimated with a dose of 0 kg ha $^{-1}$ of N. According to the regression equation, a decrease of 4.20% in DC was obtained for each increase of 60 kg ha $^{-1}$ of nitrogen. Comparing the nitrogen doses of 0 and 180 kg ha $^{-1}$, a difference in DC in relation to these nitrogen doses of 12.60% was observed. Other authors did not observe an increase in the diameter of sugarcane stalks with increasing N dose under irrigation (URIBE, 2010; GONÇALVES *et al.*, 2020). Shekinah, Sudara and Rakkiyappan (2012), studying nitrogen fertilization in sugarcane during the cane-plant and cane-ratoon cycles, did not observe a significant effect on stem diameter, with average values of 28.70 mm and 27.80 mm, respectively, in the two cultivation cycles.

For CEs, the U source did not significantly differ from the NA source. There was also no significant difference between the N doses of 0, 60, 120 and 180 kg ha $^{-1}$ (Table 2). Cunha *et al.* (2016) reported that the CE increased by 6.4% every 80 days, totaling 19.3% between 90 and 330 DAP. Silva *et al.* (2016) reported isolated effects in their treatments, and at 330 DAP, they reported a CE of approximately 16 cm.

The analysis of variance revealed no significant effects on the variables leaf dry mass (MSF), stem dry mass (MSC), tip dry mass (MSP) and total shoot dry mass (MSTPA) of the sugarcane crop (Table 3). Schultz *et al.* (2010) reported variations in the accumulation of sugarcane straw among treatments. In contrast, Bastos *et al.* (2018) reported a residual effect of nitrogen application on the accumulation of sugarcane dry matter (ratoon cane).

Table 3. Summary of the analysis of variance and means for the variables leaf dry mass (MSF), stem dry mass (MSC), tip dry mass (MSPT) and total shoot dry mass (MSTPA) of the irrigated sugarcane crop (var. SP95--5000) in the second ratoon cycle subjected to the residual effect of different sources and doses of nitrogen applied to the plant cane, municipality of Jataí, GO, Brazil.

FV	GL	Mean Squares[1]			
		MSF	**MSC**	**MSPT**	**MSTPA**
Sources of N (F)	1	0.000004 ns	0.0468 ns	0.0002 ns	0.0495 ns
N (D) doses	3	0.0009 ns	0.0328 ns	0.0009 ns	0.0462 ns
F x D	3	0.0003 ns	0.0142 ns	0.0005 ns	0.0091 ns
Block	2	0.0015 ns	0.0007 ns	0.0008 ns	0.0016 ns
Residue (a)	14	0.0003	0.016	0.0005	0.0224
CV (a)		12.67	22.94	23.5	18.87
		Averages			
N sources		kg plant $^{-1}$			
IN		0.14	0.51	0.10	0.74
U		0.14	0.59	0.10	0.83
N rates (kg ha $^{-1}$)					
0		0.15	0.50	0.08	0.74
60		0.15	0.54	0.11	0.80
120		0.14	0.65	0.11	0.91
180		0.12	0.49	0.09	0.71
Interaction (F x D)					
NA 0		0.16	0.39	0.09	0.64
U 0		0.15	0.62	0.08	0.84
NA 60		0.16	0.51	0.10	0.77
U 60		0.14	0.58	0.11	0.83
NA 120		0.14	0.63	0.12	0.89
U 120		0.15	0.68	0.11	0.93
NA 180		0.12	0.49	0.08	0.69
U 180		0.13	0.50	0.11	0.74

[1] Coefficient of variation (CV). ns not significant according to the F test.

For MSF, MSC, MSPT and MSTPA, there is no significant difference between the NA and U sources. There was also no significant difference between the N doses of 0, 60, 120 and 180 kg ha $^{-1}$ (Table 3). Schultz *et al.* (2010) obtained a dry matter production of sugarcane straw of 15.7 t ha $^{-1}$ under the residual effect of fertilization of 150 m³ ha $^{-1}$ of vinasse + 40 kg ha $^{-1}$ of N as a top dressing. Fortes *et al.* (2011) reported that the recovery rates of nitrogen from urea in crop residues and sugarcane rhizomes after three harvests were 39%, 23% and 17%, respectively, indicating that N from crop residues is an important source of nitrogen for sugarcane. Boschiero (2017) concluded that increasing N doses increase nutrient extraction by plants, although this does not necessarily reflect an increase in plant dry matter, indicating a luxury consumption of N by sugarcane. According to Bastos *et al.* (2018), a residual dose of 120 kg ha $^{-1}$ of N promoted approximately 22.00 t ha $^{-1}$ of sugarcane dry matter.

The analysis of variance revealed a significant effect, in relation to the N dose (D), for the variables of stalk productivity (PC), gross sugar yield (RBAÇ) and gross alcohol yield (RBAL). The interaction effect of the factors F × D was significant for stalk productivity (PC). No significant effect was detected for the variables percentage of soluble solids (BRIX), total recoverable sugar (ATR) and percentage of raw sugar contained in the stalks (POL of sugarcane) (Table 4).

Table 4. Summary of the analysis of variance and means for the variables percentage of soluble solids (BRIX), percentage of raw sugar contained in the stalks (POL of the sugarcane), total recoverable sugar (ATR), stalk productivity (PC), gross sugar yield (RBAÇ) and gross alcohol yield (RBAL) of the irrigated sugarcane crop (var. SP95--5000), in the second ratoon cycle, subjected to the residual effect of different sources and doses of nitrogen, applied to the sugarcane plant, municipality of Jataí, GO, Brazil.

FV	GL	Mean Squares[1]					
		BRIX	**POL cane**	**ATR**	**PRAÇA**	**RBAÇ**	**RBAL**
Sources of N (F)	1	0.033 ns	1.575 ns	0.011 ns	4.806 ns	0.222 ns	0.106 ns
N (D) doses	3	0.047 ns	23.275 ns	0.225 ns	129,904 *	4,658 *	2,308 *
F x D	3	0.262 ns	15,593 ns	0.177 ns	108,224 *	3.364 ns	1.677 ns
Block	2	0.099 ns	24,029 ns	0.285 ns	80.264 ns	0.729 ns	0.385 ns
Residue (a)	14	0.098	20,625	0.225	27,178	1,338	0.65
CV (a)		1.51	2.82	2.88	4.26	5.74	5.65
		Averages					
N sources		%	%	$kg\ t^{-1}$	$t\ ha^{-1}$	$m^3\ ha^{-1}$	$t\ ha^{-1}$
IN		20.80	16.45	161.07	121.80	14.21	20.05
U		20.72	16.49	161.58	122.70	14.34	20.24
N rates ($kg\ ha^{-1}$)							
0		20.80	16.46	161.3	115.67	13.50	19.05
60		20.65	16.23	158.8	122.79	14,13	19.93
120		20.73	16.50	161.6	124.02	14.50	20.45
180		20.86	16.70	163.6	126.51	14.97	21.14
Interaction (F x D)							
NA 0		21.07	16.67	163.18	117.20	13.85	19.56
U 0		20.54	16.25	159.43	114.13	13,14	18.54
NA 60		20.70	16.21	158.76	116.78	13.43	18.93
U 60		20.61	16.24	158.84	128.81	14.83	20.92
NA 120		20.49	16.31	159.69	122.85	14.20	20.02
U 120		20.97	16.70	163.52	125.20	14.80	20.89
NA 180		20.94	16.62	162.67	130.38	15.35	21.67
U 180		20.78	16.78	164.54	122.65	14.59	20.60

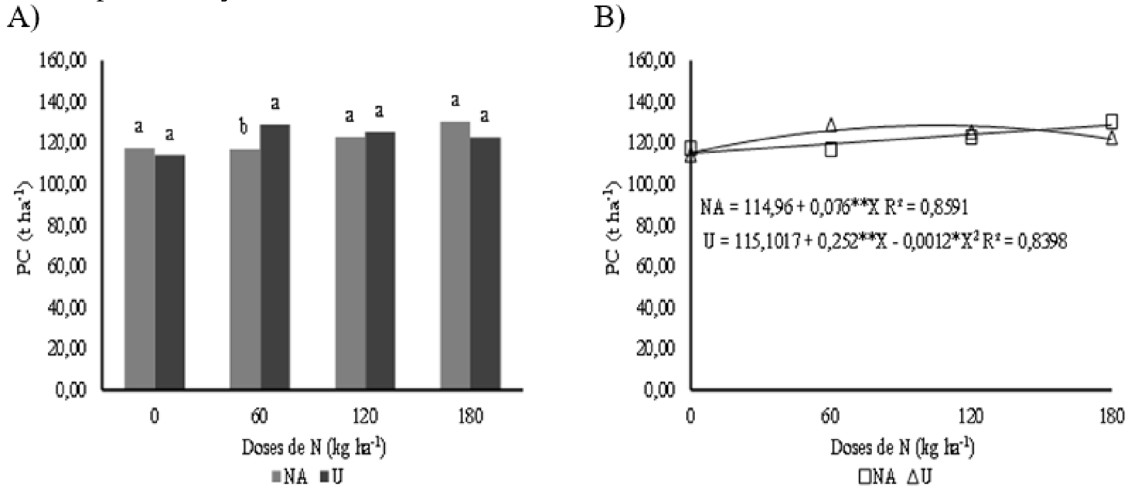
[1] Coefficient of variation (CV). * significant at 5% probability. ns not significant according to the F test.

Vitti *et al.* (2007) reported a significant effect of residual N doses in third-ratoon sugarcane on stalk productivity and cane POL. Megda *et al.* (2012) reported no residual effect of nitrogen sources on the stalk productivity of third-year sugarcane. Bastos *et al.* (2018) reported no effect of residual N dose on stalk productivity.

For BRIX, POL sugarcane and ATR, there is no significant difference between the NA and U sources. There was also no significant difference between the N doses of 0, 60, 120 and 180 kg ha $^{-1}$ (Table 4). The minimum POL content of sugarcane for maturation conditions is 13% (HORSCHUTZ *et al.*, 2022). Nitrogen fertilization can reduce the sucrose content and lead to increased energy consumption as a result of more intense vegetative development (WIEDENFELD, 1998; OLIVEIRA *et al.*, 2023). Silva *et al.* (2009), studying N and K fertilization levels, did not observe significant effects on the BRIX and POL of sugarcane; however, the values tended to decrease with increasing fertilization levels.

Figure 3A shows that the NA source at a dose of 60 kg ha^{-1} N provided a greater PC (9.34%) than did the U source; however, there was no significant difference between the sources of urea and ammonium nitrate at N doses of 0, 120 and 180 kg ha^{-1}.

Figure 3. Productivity of sugarcane stalks (var. SP95--5000) in the second ratoon cycle as a function of the residual effect of N source (A) and N dose (B) applied to sugarcane plants in the municipality of Jataí, GO, Brazil. Means followed by the same letters within the same N dose do not differ significantly according to Tukey's test at 5% probability.



** and * indicate significance at the 1% and 5% probabilities, respectively. ns not significant according to the F test.

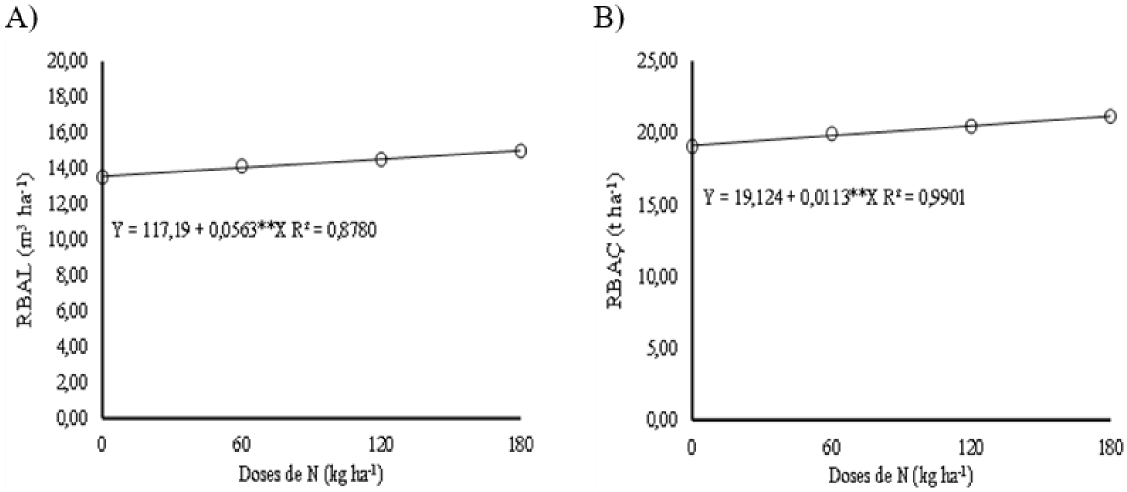
The productivity of sugarcane stalks as a function of nitrogen dose for the urea source conformed to the quadratic model, with an ^{R2} of 84% (Figure 3B). Increasing the dose of nitrogen for the urea source increased the productivity of sugarcane stalks to a dose of 105 kg ha $^{-1}$, and with the application of this dose of nitrogen, a maximum stalk productivity of approximately 128.33 tons ha $^{-1 \text{ was reached}}$. The maximum stalk productivity observed for the urea source at the nitrogen dose of 105 kg ha^{-1} was 10.31, 1.89, 0.21 and 5.25% greater than the stalk productivity observed at the nitrogen doses of 0, 60, 120 and 180 kg ha^{-1}, respectively (Figure 3B).

The productivity of sugarcane stalks as a function of nitrogen dose for the ammonium nitrate source conformed to a linear model, with an ^{R2} of 86% (Figure 3B). Increasing the dose of nitrogen for the ammonium nitrate source increased the productivity of sugarcane stalks to 180 kg ha $^{-1}$, and with the application of this nitrogen dose, a maximum stalk productivity of approximately 128.64 tons ha $^{-1 \text{ was reached}}$. According to the regression equation, an increase of 3.54% in stalk productivity was obtained for each increase of 60 kg ha $^{-1}$ of nitrogen for the ammonium nitrate source. Comparing the nitrogen doses of 0 and 180 kg ha $^{-1}$, a difference in stalk productivity in relation to these nitrogen doses of 10.63% was observed (Figure 3B).

For Vitti *et al.* (2007), the ammonium nitrate source, at a dose of 175 kg ha $^{-1}$, promoted a residual effect, generating a PC of 86.3 t ha $^{-1}$. In third-year sugarcane, higher doses of N applied in previous cycles maintained TCH, which was confirmed by the absence of recovery in the control treatment (FORTES *et al.*, 2013; CUNHA *et al.*, 2020).

The RBAL of sugarcane as a function of nitrogen dose conformed to a linear model, with an ^{R2} of 88%. In the RBAL as a function of N dose, the maximum linear increase was 14.99 m³ ha $^{-1}$ with a dose of 180 kg ha $^{-1}$ N (Figure 4A). According to the regression equation, an increase of 2.65% in the RBAL was obtained for each increase of 60 kg ha $^{-1}$ of nitrogen. Comparing the nitrogen doses of 0 and 180 kg ha $^{-1}$, a difference in the RBAL in relation to these nitrogen doses of 7.96% was observed.

Figure 4. Gross alcohol yield (A) and gross sugar yield (B) of sugarcane (var. SP95--5000) in the second ratoon cycle as a function of the residual effect of N dose applied to sugarcane plants in the municipality of Jataí, GO, Brazil.



** significant at 1% probability.

The RBAÇ of sugarcane as a function of nitrogen dose conformed to the linear model, with an ^{R2} of 99%. With respect to the RBAÇ as a function of N dose, a maximum linear increase of 21.16 t ha $^{-1}$ was observed with the 180 kg ha $^{-1}$ N dose (Figure 4B). According to the regression equation, an increase of 3.20% in the RBAÇ was obtained for each increase of 60 kg ha $^{-1}$ of nitrogen. Comparing the nitrogen doses of 0 and 180 kg ha $^{-1}$, a difference in the RBAÇ in relation to these nitrogen doses of 9.61% was observed.

For Fortes *et al.* (2013), regardless of the crop cycle and the N dose applied, there was no significant effect on sugar yield. Sugar and alcohol yields tend to increase with increasing levels of N and K topdressing fertilization (SILVA *et al.*, 2009; CUNHA *et al.*, 2020). In accordance with Shekinah, Sudara and Rakkiyappan (2012), who used the fertilization of 280 kg ha $^{-1}$ of N in sugarcane in the cane-plant and cane-ratoon cycles, they reported gross alcohol yields of 8.54 m ^{3} ha $^{-1}$ and 7.56 m ^{3} ha $^{-1}$, respectively.

6 CONCLUSIONS

The plant height, internode length, leaf dry mass, stem dry mass, tip dry mass, total aerial part dry mass, percentage of soluble solids (BRIX), percentage of raw sugar contained in the stems (LEL) and total recoverable sugar (ATR) of irrigated sugarcane did not differ with respect to the source (urea or ammonium nitrate) or nitrogen dose (0, 60, 120 or 180 kg ha^{-1}).

There was a residual effect of the N doses applied to irrigated sugarcane in the plant cane cycle, which promoted an increase in stalk productivity, gross alcohol yield and gross sugar yield in the second ratoon cycle.

The residual effects of urea and ammonium nitrate, at doses of 105 and 180 kg ha^{-1} N, respectively, provide the maximum productivity of irrigated sugarcane stalks (IACSP95-5000), with increases above 10% in relation to the dose of 0 kg ha^{-1} nitrogen.

Regardless of the N source, the N dose of 180 kg ha $^{-1}$ promoted a gross sugar yield of 21.16 t ha $^{-1}$ and a gross alcohol yield of 14.99 m³ ha $^{-1}$.

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