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DESENVOLVIMENTO E PRODUTIVIDADE DE CANA-DE-AÇUCAR IRRIGADA E ADUBADA COM DIFERENTES FONTES DE NITROGÊNIO

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1 RESUMO

Grande parte do nitrogênio aplicado na forma de fertilizantes não é aproveitado pela cultura de cana-de-açúcar no ciclo que recebeu a aplicação, cuja parte do remanescente no solo pode ser disponibilizada para as soqueiras subsequentes. Portanto, o objetivo deste estudo foi avaliar o efeito residual de fontes e doses de nitrogênio, aplicados à cana-planta (IACSP 95-5000), nas variáveis biométricas e produtividade de colmos em primeira soqueira irrigada. O experimento foi conduzido em condições de campo, no município de Jataí - GO, em um Latossolo Vermelho distrófico, muito argiloso. 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 de forma única em 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, foram avaliados diâmetro do colmo, altura de planta, número de entrenós, comprimento de entrenós e produtividade de colmos. As maiores doses de N aplicadas em cana-planta proporcionam melhores respostas na primeira soqueira.

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

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DEVELOPMENT AND YIELD OF SUGARCANE IRRIGATED AND FERTILIZED WITH DIFFERENT SOURCES OF NITROGEN

2 ABSTRACT

Much of the nitrogen applied in the form of fertilizers is not used by the sugarcane crop in the cycle in which it was applied, and part of the remaining nitrogen in the soil can be made available for subsequent raton crops. Therefore, the objective of this study was to evaluate the residual effects of nitrogen sources and doses applied to sugarcane plants (IACSP 95--5000) on biometric variables and stalk productivity in the first irrigated rat onion crop. The experiment

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was conducted under field conditions in the municipality of Jataí, GO, in a very clayey dystrophic Red Latosol (Oxisol). The experimental design used 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 in a single manner to plant sugarcane in the previous cycle. During the first raton, 120 kg ha $^{-1}$ of nitrogen was applied to the respective plots. At the end of the first rat cycle, stem diameter, plant height, number of internodes, internode length and stem productivity were evaluated. Higher doses of N applied to sugarcane plants provide better responses in the first mouse.

Keywords: *Sacharum oficinarum* L., ammonium nitrate, urea, fertilizer.

3 INTRODUCTION

As it is a crop that adapts to different Brazilian regions, including semiarid regions, sugarcane stands out in the country's economy (CARMO *et al.*, 2017). The areas destined for sugar and alcohol activities are expected to reach 8,627.9 thousand hectares, with the state of São Paulo covering 49.9% (4,305.4 thousand hectares) of the entire national area cultivated with sugarcane, followed by Goiás 11.3% (975.3 thousand hectares) and Minas Gerais 11% (950.7 thousand hectares). Therefore, these states with the highest production reached 517.38 million tons, with São Paulo being responsible for 356.19 million, Minas Gerais being responsible for 81.88 million and Goiás being responsible for 79.31 million (CANA-DE-AÇÚCAR, 2024).

A necessary factor for achieving high productivity, according to Thorburn *et al.* (2011), is nitrogen (N) fertilization. However, owing to its complex dynamics in the soil, nitrogen presents a variable response in crops, which motivates more refined studies by the scientific community (AMARAL; MOLIN, 2011).

The response to nitrogen fertilization in ratoon cane is more evident than that in plant cane, which reflects the greater vigor of the ratoons; that is, it increases the production potential of the crop (VITTI; TRIVELIN, 2011; PENATTI, 2013). The adequate management of nitrogen fertilization in ratoons without burning is still a matter of doubt since nitrogen levels can be directly affected by the remaining straw (ALVES, 2016). According to Fortes *et al.* (2013), the use of nitrogen made available by the straw mineralization process at the end of the sugarcane crop cycle can reduce the need for mineral fertilization.

OM is an important source of N, and approximately 79% of the nitrogen found in plants in tropical environments comes from organic matter present in the soil (DOURADO NETO *et al.*, 2010). The use of N from fertilizers in soils with a history of fertilization in previous cycles exceeds 30% of the total applied N (JORIS, 2015).

Another factor that affects the agro-industrial productivity of sugarcane is the water deficit caused by irregular rainfall (SILVA *et al.*, 2014). Therefore, irrigation and management techniques to increase water use efficiency must be adopted to obtain good yields (ORRILLO *et al.*, 2016). Therefore, the objective of this study was to evaluate the residual effects of nitrogen sources and doses on the first ratoon of irrigated sugarcane in a Red Latosol of the Cerrado.

Brazil stands out in the global scenario of energy agriculture, of which sugarcane is the main producer (LEITE; CRUSCIOL; SILVA, 2011). According to the FAO (2017), Brazil is responsible for 40% of global production.

Owing to its importance and demand in production to meet the country's internal needs and to be able to export fuel, there is a need for large areas planted with sugarcane (SÁNCHEZ-ROMÁN *et al.*, 2015). The growing demand for increased sugarcane production has resulted in increased investment in technologies to increase the productivity and industrial quality of raw materials (DANTAS NETO *et al.*, 2006).

Owing to its complex dynamics in the soil, nitrogen is the nutrient that has attracted the most attention from researchers, as it presents a variable response in crops (AMARAL; MOLIN, 2011). Insufficient application of nitrogen results in lower yields, lower quality and increased vulnerability to certain pests (ABDEL-RAHMAN; AHMED; VAN DEN BERG, 2010).

In Brazil, the response to nitrogen fertilization is more expressive in sugarcane ratoons than in plant cane, especially in regions where ratoons are cultivated in dry and cold or dry and hot climate periods, which are not very favorable for the mineralization of organic N (MAEDA, 2009). According to Joris (2015), the response to high doses of N in ratoons may suggest that the application of less than 120 kg ha $^{-1\ N}$ in a management system with greater productive potential may compromise the longevity and productivity of the crop. With increasing nitrogen applied, the proportion between tips and stalks increases and reaches three times greater than normal in the growth phase, which results in a vegetative increase in the plant (FRANZÉ, 2010).

Urea is the most widely used nitrogen source in Brazil because of its lower cost per unit of nitrogen than other nitrogen sources (TASCA *et al.*, 2011). However, the problem with using urea is loss due to ammonia volatilization, which can reach up to 60% of the total value when applied to the surface (MEGDA, 2013). Thus, the search for greater efficiency in the use of nitrogen has resulted in interest in the use of alternative sources (SORATTO *et al.*, 2011).

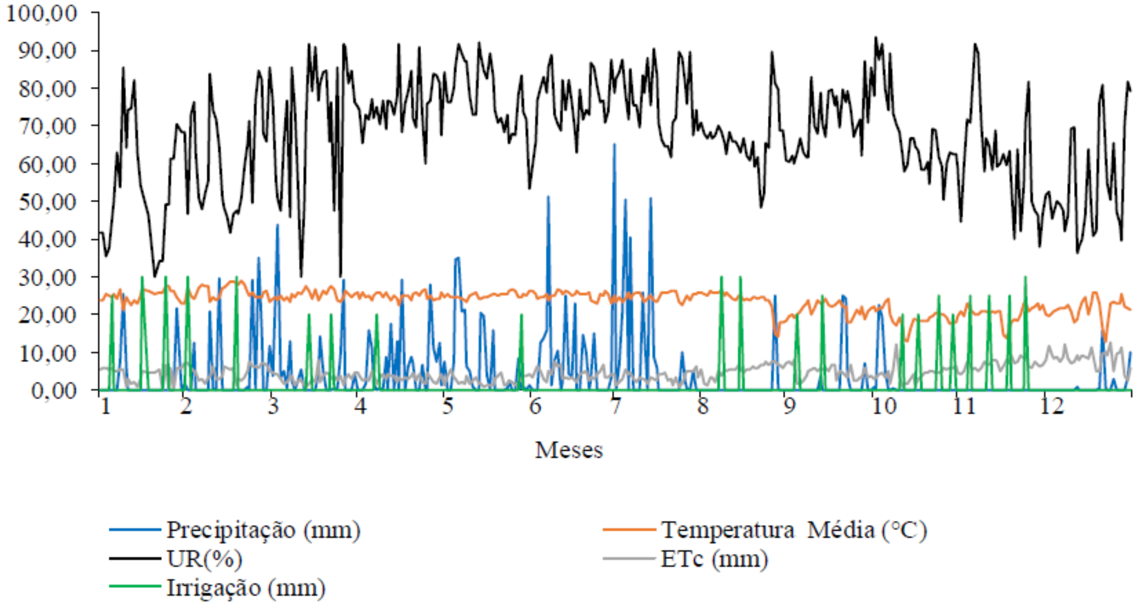
In this context, the objective of this study was to evaluate the residual effects of nitrogen sources and doses applied to sugarcane plants on biometric variables and stalk productivity in the first irrigated ratoon crop in the Red Latosol of the Cerrado.

4 MATERIALS AND METHODS

The experiment was implemented under field conditions at the Raízen Plant in the municipality of Jataí, GO. According to Köppen (1928), the local climate is of the Aw type, tropical, characterized by a rainy period from October to April and a dry period from 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 located at the same site as the study site. 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 (ALLEN *et al.*, 1989), 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 Teixeira *et al.* (2017). 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 randomized blocks, arranged in a 2 × 4 factorial scheme, with 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 to sugarcane plants.

The other cultural treatments related to soil correction fertilization were carried out considering an 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, a dose of 120 kg ha $^{-1}$ nitrogen was applied to all the experimental plots.

The experimental area consisted of 1200.0 m2, and each plot consisted of five lines 5.0 m in length, with a spacing of 1.5 m, totaling an area of 37.5 m2 per experimental plot. The two central lines of each plot were considered the useful area of the plot, disregarding 2.0 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 central pivot with a speed of 268 mh $^{-1}$ in the last tower, which allows the application of a minimum gross depth for a 100% turn of 1.35 mm. The irrigation depth was the same as that used commercially via 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 on solar radiation, air temperature, wind speed and relative humidity.

At the time of harvest, two samples were collected from each experimental plot of two plants to evaluate the following variables: plant height (ALT), stem diameter (DC), number of internodes (NE) and internode length (CE). Plant height was measured via a tape measure from the soil to the leaf +1. Stem diameter was determined via a digital caliper in the basal region of the collected plant. The number of internodes was obtained by counting the stems. Internode length was measured from one internode to another via a graduated ruler.

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 value obtained was extrapolated to (t ha $^{-1}$).

The data were subjected to analysis of variance, applying the F test at the 1% and 5% probability levels. When the quantitative variables were significant, they were adjusted and submitted to regression equations. The qualitative variables were compared via the Tukey test at the 5% probability level. The statistical program used was SISVAR® (FERREIRA, 2011).

5 RESULTS AND DISCUSSION

Table 2 presents the analysis of variance for the variables plant height (ALT), stem diameter (DC), number of internodes (NE), internode length (CE) and productivity (PROD). For the dose factor, a significant effect was observed at the 1% probability level for all the variables evaluated. For the source factor, a significant effect was observed at the 1% level for ALT, DC and NE, whereas PROD was significant at the 5% level for the same factor.

Table 2. Summary of the analysis of variance for the variables stalk productivity (PC), plant height (ALT), stalk diameter (DC), number of internodes (NE), internode length (CE) and productivity (PROD) as a function of nitrogen source and dose

FV	GL	QM [1]				
		ALT	**A.D**	**NE**	**EC**	**PROD**
Sources	1	667.7 **	3.38 **	6.77 **	0.20 ns	225.03*
Doses	3	714.53 **	1.37 **	1.83 **	0.63 **	2425.72**
Sources x Doses	3	54.61 ns	0.62 ns	0.08 ns	0.09 ns	73.99 ns
Block	2	134.72 ns	0.28 ns	0.38 ns	0.08 ns	1021.74**
Residue	14	51,52	0.18	0.26	0.1	36.59
CV (%)		4.3	1.42	3.77	2.6	4.42

[1] Plant height (ALT), stem diameter (DC), number of internodes (NE), internode length (CE) and stalk productivity (PC) of sugarcane; coefficient of variation (CV), source of variation (FV). ** and * indicate significance at the 1% probability and 5% probability, respectively; ns indicates not significant according to the F test at the 5% probability.

The ALT as a function of nitrogen dose for sugarcane fit a linear model with an R^2 of 92.95%. The highest ALT was found at the dose of 180 kg ha $^{-1}$, whose values were 13.65, 9.10, and 4.55% higher than those observed at the doses of 0, 60, and 120 kg ha $^{-1}$ applied in the previous cycle, respectively. According to the regression equation, an increase of 4.55% was obtained for each increase of 60 kg ha $^{-1}$ of N (Figure 2A). Cunha *et al.* (2016) reported that the application of N in soil with a very clayey texture results in a daily growth of 1.42 cm d $^{-1}$, which is 6.3% greater than that in the absence of N. Bastos *et al.* (2017) reported increases in ALT only when N was applied in isolation. Dinh *et al.* (2017), under irrigated conditions, reported more expressive responses with increasing amounts of N applied; however, at doses of 180 and 270 kg ha $^{-1}$, there were no significant differences.

The application of higher doses of N from fertilizer results in a positive linear increase in the residual effect of fertilization (BOLOGNA-CAMPBELL, 2007). This may explain the increasing response of plant height as a function of the dose of nitrogen applied in the previous cycle, as shown in Figure 2A.

Figure 2. Plant height during the first ratoon cycle as a function of the residual dose (0, 60, 120, 180 kg/ha) of nitrogen (A) and the source (urea–U, ammonium nitrate–NA) of nitrogen (B). Means followed by the same letters within the same N dose do not differ significantly according to the Tukey test at 5% probability. ** and * indicate significance at the 1% and 5% probability levels, respectively, according to the F test.

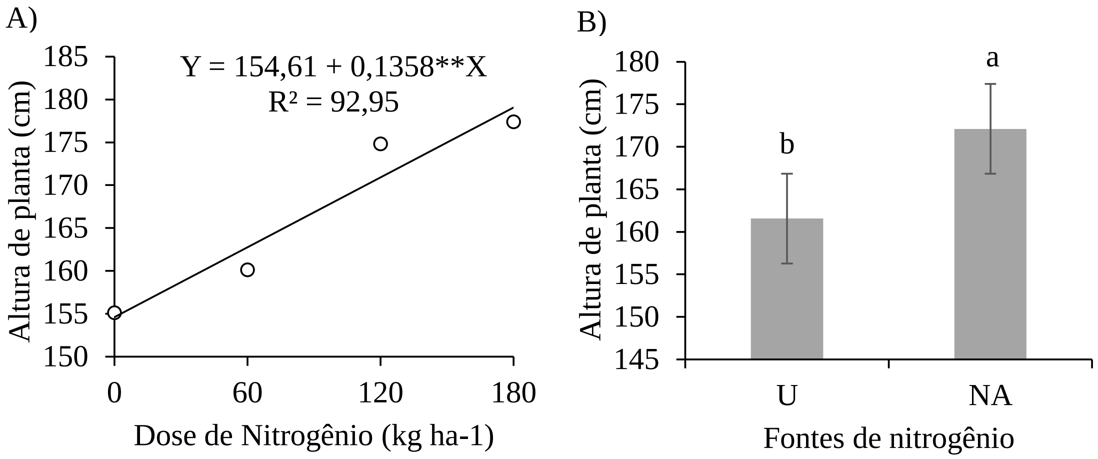
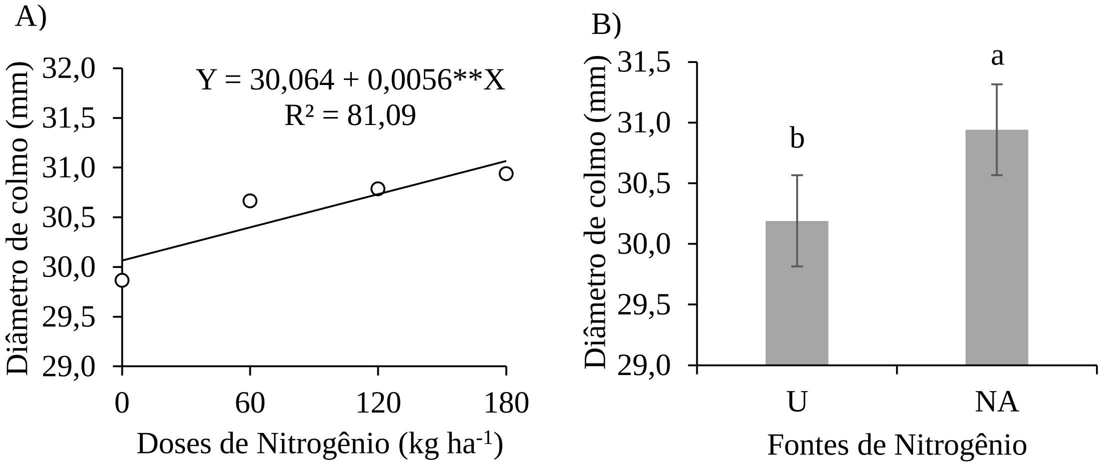


Figure 2B shows a significant effect on ALT depending on the N source applied. When ammonium nitrate (NA) was applied, the highest ALT of 172.11 cm was obtained, which corresponds to an increase of 6.12% compared with the application of urea (U). Gomes *et al.* (2018), under conditions similar to those of the previous study, reported a 5.33% greater increase in the ammonium nitrate source when urea was purchased at a dose of 180 kg ha^{-1}.

The DC as a function of the nitrogen dose applied in the previous cycle for sugarcane fit a linear model, with an ^{R2} of 81.09% (Figure 3A). The highest DC was observed at the dose of 180 kg ha^{-1}, which was 3.22, 2.15 and 1.07% higher than those observed at the doses of 0, 60 and 120 kg $ha^{-1, \text{ respectively}}$, applied in the previous cycle. According to the regression equation, an increase of 1.07% was obtained for each increase of 60 kg ha^{-1}. These results corroborate those of Bastos *et al.* (2017), who reported increases in the stem diameter of sugarcane with the application of N to ratoon cane.

The dose of 100 kg ha^{-1} nitrogen fertilizer in all the treatment plots likely did not meet the crop requirements at the lowest N doses, compromising the vigor of the ratoon (VITI; TRIVELIN, 2011). This may explain the increase with increasing doses applied in the previous cycle, as shown in Figure 3A.

Figure 3. Stalk diameter during the first ratoon cycle as a function of the residual dose (0, 60, 120, 180 kg/ha) of nitrogen (A) and the source (urea–U, ammonium nitrate–NA) of nitrogen (B). Means followed by the same letters within the same N dose do not differ significantly according to the Tukey test at 5% probability. ** and * indicate significance at the 1% and 5% probability levels, respectively, according to the F test.



N sources had a significant effect on DC, with diameters of 30.19 and 30.94 mm for urea and ammonium nitrate, respectively (Figure 3B). Therefore, the stalk diameter of sugarcane fertilized with ammonium nitrate was 2.42% greater than that of sugarcane fertilized with urea. This increase may be associated with the greater availability of N when ammonium nitrate was used, since urea results in greater losses through volatilization. Silva (2017), under similar conditions, studied the optimization of nitrogen sources and doses in irrigated sugarcane in the cerrado and reported a maximum stalk diameter of 33.72 mm, which is close to that reported in this study.

The use of ammonium nitrate reduces N losses by volatilization and increases N availability (Marcelo, 2008), which may explain the greater response of the ammonium nitrate source in the present study. N losses from urea vary depending on the application method; when applied in strips, losses reach 46% within 20 days after application, whereas application over the entire area results in losses of 37% (VITTI *et al.*, 2007b).

Figure 4A shows that the NE as a function of nitrogen dose for sugarcane conformed to a linear model, with an ^{R2} of 81.79%. The highest NE was found at the dose of 180 kg ha $^{-1}$, which was 8.27, 5.51 and 2.75% higher than those observed at the doses of 0, 60 and 120 kg ha $^{-1}$ applied in the previous cycle, respectively. According to the regression equation, an increase of 2.75% was obtained for each increase of 60 kg ha $^{-1}$. Cunha (2014) reported that at 300 DAP, under an irrigated regime with 100% water replacement, the maximum NE was 15.40, which is close to the values reported in this study. Silva (2017), evaluating the optimization of nitrogen sources and doses in irrigated sugarcane, reported that the maximum NE of the IACSP 95--5000 variety was 20.76 at 330 DAP. According to Oliveira *et al.* (2016), the number of internodes of sugarcane cultivars may be related to the characteristics inherent to the cultivar, which may explain the lower NE values found in this study.

Figure 4. Number of internodes in the first ratoon cycle as a function of the residual doses (0, 60, 120, 180 kg/ha) of nitrogen (A) and sources (urea–U, ammonium nitrate–NA) of nitrogen (B). Means followed by the same letters within the same N dose do not differ significantly according to the Tukey test at 5% probability. ** and * indicate significance at the 1% and 5% probability levels, respectively, according to the F test.

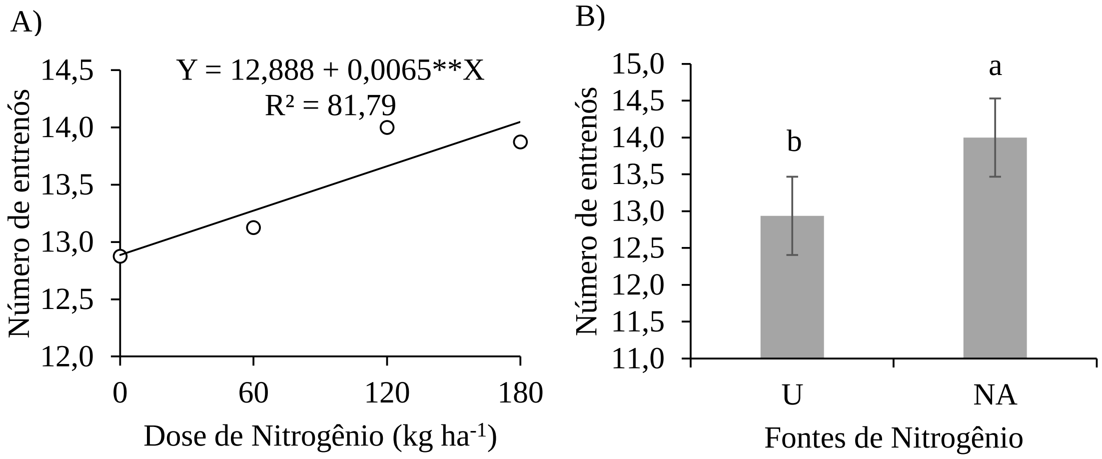


Figure 4B shows a significant effect on the number of internodes depending on the nitrogen source. Compared with the crop fertilized with urea, the sugarcane fertilized with ammonium nitrate presented a greater number of internodes (7.58%) (Figure 4B). This occurs because nitrogen applied in the ammoniacal form has longer-lasting effects, which results in a greater residual effect (VIEIRA, 2009). Regardless of the dose applied, approximately 40% of the ammonium present in the ammonium nitrate source remains in the soil–plant system as a residual effect for the next harvest (VITTI *et al.*, 2007a).

Figure 5 shows that the CE as a function of nitrogen dose for sugarcane conformed to a linear model, with an R^2 of 98.56%. The greatest internode length was found at the dose of 180 kg ha $^{-1}$, which was 5.88, 3.92 and 1.96% greater than those observed at the doses of 0, 60 and 120 kg ha $^{-1}$ applied in the previous cycle, respectively. According to the regression equation, an increase of 1.96% was obtained for each increase of 60 kg ha $^{-1}$. Gomes *et al.* (2018) reported that the application of ammonium nitrate resulted in a linear increase of up to 180 kg ha $^{-1}$, with the highest dose resulting in an internode length of 7.85 cm.

The linear increase as a function of the dose may indicate greater residual nitrogen with increasing dose applied to the sugarcane plant. Sartori (2010) concluded that an increase in the N dose results in a greater length of sugarcane internodes.

Figure 5. Internode length during the first ratoon cycle as a function of the residual N dose. ** and * indicate significance at the 1% and 5% probability levels, respectively, according to the F test.

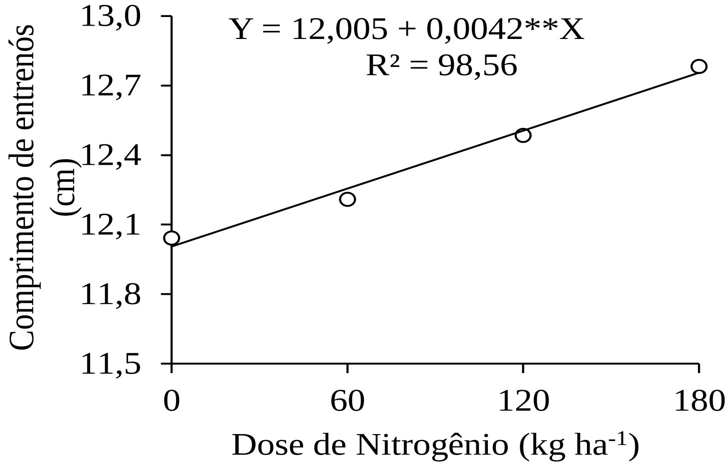


Figure 6A shows that the stalk productivity as a function of nitrogen dose for sugarcane fit a linear model with an R^2 of 92.87%. The highest productivity was found at the dose of 180 kg ha^{-1}, which was 28.23, 18.82, and 9.41% higher than the productivity observed at the doses of 0, 60 and 120 kg ha^{-1}, respectively, applied in the previous cycle. According to the regression equation, an increase of 9.41% was obtained for each increase of 60 kg ha^{-1}.

Esperancini *et al.* (2015), evaluating the optimal economic dose of nitrogen in sugarcane applied via drip fertigation under the conditions of the second ratoon of the cultivar SP80-3280, reported a productivity of 140 t ha^{-1} at a dose of 175 kg ha^{-1}.

Evaluating sugarcane productivity related to residual nitrogen from fertilization, Vitti *et al.* (2007a) reported a linear response for stalk production as a function of nitrogen dose in the second ratoon, whereas in the following year, with the application of 100 kg ha^{-1} nitrogen in the third ratoon, the same response was observed in all the treatments, corroborating the results of this study.

Figure 6. Stalk productivity in the first ratoon cycle as a function of the residual doses (0, 60, 120, 180 kg/ha) of nitrogen (A) and sources (urea–U, ammonium nitrate–NA) of nitrogen (B). Means followed by the same letters within the same N dose do not differ significantly according to the Tukey test at 5% probability. ** and * indicate significance at the 1% and 5% probability levels, respectively, according to the F test.

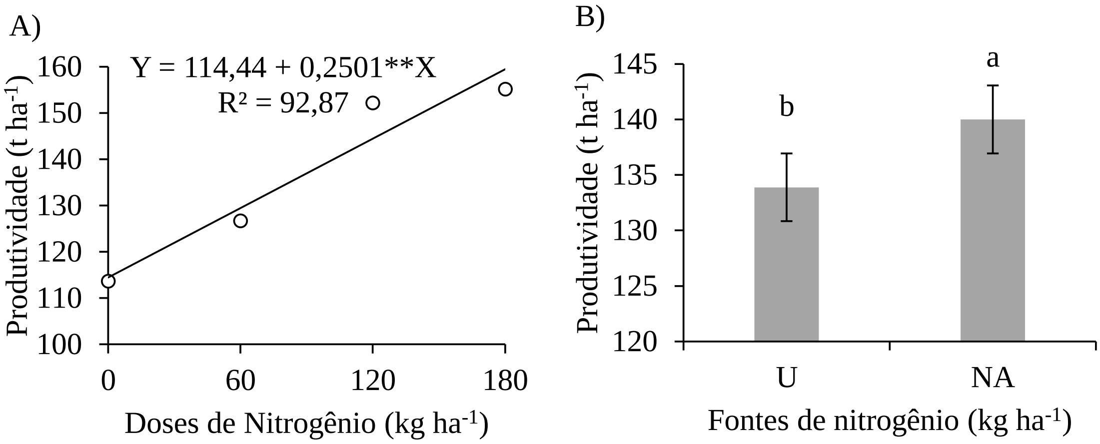


Figure 6B shows the significant effect of the source factor on stalk productivity. Compared with that under urea fertilization, the stalk productivity of sugarcane fertilized with ammonium nitrate was increased by 4.37%. Sousa Junior, Duarte and Dias (2017) reported that a dose of 120 kg ha^{-1} ammonium nitrate resulted in greater increases in tons of stalk per hectare (TCH) than did the application of urea at the same dose. Gomes (2017), evaluating the stalk productivity of sugarcane (var. SP 80+1816) as a function of N dose, reported a greater response to ammonium nitrate at doses of 60 and 120 kg ha $^{-1}$. The lower response of stalk productivity to the urea source may be associated with volatilization losses. According to Vitti *et al.* (2007b), the ammonium nitrate source results in lower volatilization losses than does urea.

6 CONCLUSIONS

Compared with urea, ammonium nitrate applied to sugarcane plants provides greater responses to biometric growth variables in the first ratoon.

Compared with the application of urea, sugarcane fertilized with ammonium nitrate in cane plants presented an increase in stalk productivity in the first ratoon of approximately 4.40%.

The dose of 180 kg of N applied to sugarcane plants, regardless of the source applied, increased the plant height (13.65%), stalk diameter (3.22%), number of internodes (8.27%), internode length (5.88%) and stalk productivity (28.23%) of sugarcane (first ratoon).

Higher doses of N applied to sugarcane plants result in better responses in the first ratoon.

7 ACKNOWLEDGMENTS

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