

Dry matter accumulation and sugar and alcohol yield of sugarcane submitted to nitrogen sources and doses

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ABSTRACT

The study aimed to evaluate the nitrogen sources and doses application effects on the dry matter production and the sugar and alcohol gross yield of sugarcane (SP80-1816) in the cane-plant cycle in a dystrophic Red Oxisol. The experiment was conducted in the Fazenda Rio Paraiso II field, belonging to Usina Raízen, in Jataí - GO. The experimental design used was randomized blocks, arranged in a factorial scheme (2 x 4), with three replications. The treatments consisted of two nitrogen sources (urea and ammonium nitrate) and four nitrogen doses (0, 60, 120, and 180 kg ha⁻¹). Dry matter variables were analyzed in sub-subdivided plots, as four evaluation periods were added (210, 250, 290, and 330 days after planting). The evaluation periods influenced sugarcane dry matter, and urea favored these variables to the ammonium nitrate's detriment. In contrast, the opposite occurred for stalk yield and sugar and alcohol yields, in which ammonium nitrate provided greater increments. The increase in nitrogen doses provided linear gains in practically all studied variables.

Keywords: *Saccharum* spp., Ammonium nitrate, Urea, Stalk yield, Industrial quality.

Acúmulo de matéria seca e rendimento de açúcar e álcool por cana-de-açúcar submetida a fontes e doses de nitrogênio

RESUMO

O estudo teve por objetivo avaliar os efeitos da aplicação de fontes e doses de nitrogênio na produção de matéria seca e no rendimento bruto de açúcar e álcool em cana-de-açúcar (SP80-1816), no ciclo de cana-planta, em um Latossolo Vermelho distrófico. O experimento foi conduzido em campo, em área da Fazenda Rio Paraiso II, pertencente à Usina Raízen, em Jataí - GO. O delineamento experimental utilizado foi em blocos ao acaso, em esquema fatorial (2 x 4), com três repetições. Os tratamentos foram constituídos por duas fontes de nitrogênio (ureia e nitrato de amônio) e quatro doses de nitrogênio (0, 60, 120 e 180 kg ha⁻¹). As variáveis de matéria seca foram analisadas em parcelas sub-subdivididas, pois foram adicionadas quatro épocas de avaliação (210, 250, 290 e 330 dias após o plantio). As épocas de avaliações influenciaram na matéria seca da cana-de-açúcar e a ureia favoreceu essas variáveis em detrimento do nitrato de amônio, enquanto o inverso ocorreu para a produtividade de colmo e rendimentos de açúcar e de álcool, em que o nitrato de amônio proporcionou maiores incrementos. O aumento nas doses de nitrogênio proporcionou ganhos lineares em praticamente todas as variáveis estudadas.

Palavras-chave: *Saccharum* spp., Nitrato de amônio, Ureia, Produtividade de colmo, Qualidade industrial.

1. Introduction

Brazil retains the world's first and second place of sugarcane (*Saccharum* spp.) and bioethanol largest producer, respectively. This crop plays an important role in the Brazilian economic and social scenario, standing out as one of the main commodities produced in the country. This raw material provides the basis for the alcohol production (anhydrous and hydrated); sugar; paper; liquor; food products for animals; vinasse used as fertilizer; in addition to straw and bagasse that can be used to generate energy (Marin et al., 2016).

Sugarcane, when compared to the cultivation of other raw materials, such as corn for bioenergy production, produces three times more alcohol per area. Among sugarcane's main positive aspects, we can highlight low production cost, high yield, low nitrogen use (N), excellent renewable energy/fossil energy balance, and good greenhouse gas mitigating potential (Cortez, 2012).

One of the main factors determining an agricultural enterprise's income is the crop's adequate nutritional status. Therefore, it is necessary to know if the plants are well-nourished since it is directly related to productivity and the raw material quality (Prado, 2008). Nutritional deficiency causes visible metabolic breakdowns in the plant, directly influencing the crops' agronomic yield (Epstein & Bloom, 2006).

The plants submitted to N omission showed less development, fewer leaves, less height, smaller stalk diameter, and less dry matter accumulation than plants cultivated in excellent nutritional conditions. Thus, nutritional deficiency can promote a 90% reduction in total dry matter production compared to the treatment receiving the complete nutrient solution (Prado et al., 2010). N omission's harmful effect on plant growth is widely reported by several authors (Prado & Franco, 2007; Prado et al., 2010; Vale et al., 2011).

One of the most accurate characteristics for predicting the optimal N doses to be applied in coverage is the dry matter and the N accumulated in the plant (Cantarella et al., 2007; Rambo et al., 2008). The plant's dry matter is affected by the available N content since it is a protein, enzyme, coenzyme, nucleic acid, phytochrome, and chlorophyll constituent (Schroder et al., 2000). In studies by Vale et al. (2011), it was found that N and P were the nutrients that most limited the sugarcane plant's growth, with reductions of 91 and 57%, respectively. In that same study, regarding the roots' growth, the authors observed that N's and Ca's omission promoted the greatest limitations, which were in the order of 83 and 48%, respectively.

The nitrogen fertilization response in sugarcane can be associated with greater development of the root

system and greater nutrient accumulation, both in the roots and aerial parts (Otto et al., 2009). Studies in the literature show N's importance in sugarcane culture along the cane-plant cycle (Gava et al., 2010; Franco et al., 2011; Sánchez-Roman et al., 2015; Vitti et al., 2011).

However, nitrogen fertilization can reduce sucrose content and increase energy consumption due to more intense vegetative development (Wiedenfeld, 1998, 2000). Silva et al. (2009), studying N's and K's fertilization levels, did not observe significant positive effects for sugarcane's BRIX and POL; however, the values tend to decrease with increasing fertilization levels. Although sometimes it does not affect industrial quality, nitrogen fertilization can increase stalk productivity (Fortes et al., 2013; Sánchez-Román et al., 2015).

Despite studies showing N's importance for sugarcane, there is still a need to know the best sources and doses of this element providing the best sugarcane's culture agronomic performance in the Goiás State.

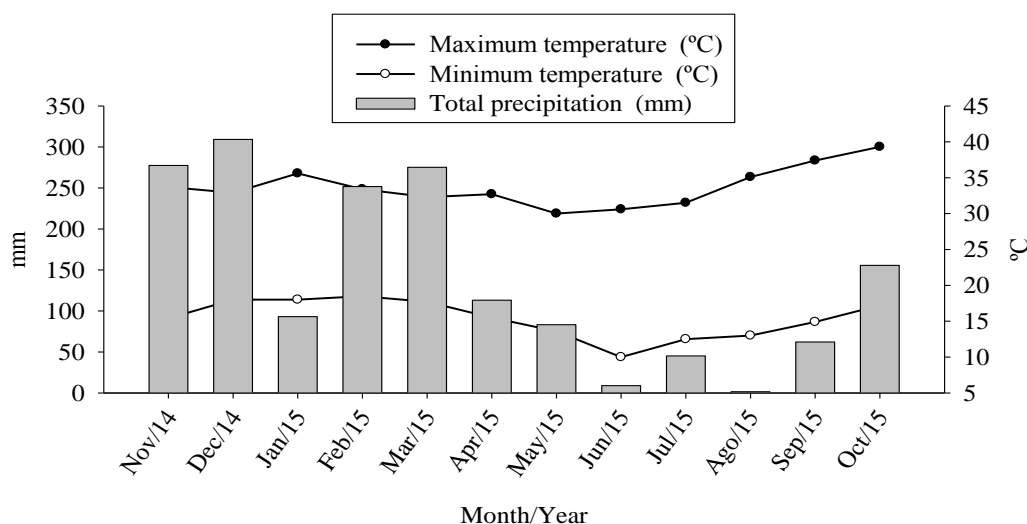
Thus, the present study aimed to evaluate the nitrogen sources and doses effects on the dry matter production and sugar and alcohol productivity of sugarcane, along the cane-plant cycle, grown in a dystrophic Red Oxisol of Cerrado.

2. Material and Methods

The study was conducted in the experimental area of Fazenda Rio Paraiso II, belonging to factory Raízen, in Jataí – GO, at 17° 43' 15.23 "S and 51° 38' 12.62" W, with an average altitude of 912 m. According to Köppen (2016) classification, the local climate is Aw-type, tropical, rain season from October to April, and dry from May to September. The maximum temperature ranges from 35 to 37 °C, and the minimum from 12 to 15 °C. The rainfall that occurred during the period of the experiment was 1676.5 mm (Figure 1).

The soil of experimental area was classified as a dystrophic Red Oxisol, very clayey texture, Cerrado phase (Santos et al., 2018). The soil chemical characteristics in the experimental area before implementing the experiment are described in Table 1.

The experimental design used was randomized blocks, analyzed in a sub-subdivided plot scheme (2 x 4 x 4), with three replications, for the dry matter variables. The factors analyzed were two sources of nitrogen (urea and ammonium nitrate), four nitrogen doses (0, 60, 120, and 180 kg ha⁻¹), and four evaluation periods (210, 250, 290, and 330 days after planting (DAP)). The production and yield variables were analyzed in a factorial scheme (2 x 4), with two sources, four nitrogen doses, and three replicates.



Source: INMET Normal Station - Jataí - GO.

Figure 1. Total rainfall (mm), maximum and minimum temperatures (°C) in Jataí, GO, Brazil, during the experiment conduction with cane-plant in 2014/2015 harvest.

Table 1. Initial chemical characterization of the soil in the experimental area, in Jataí - GO, Brazil, 2014/2015 harvest.

Soil layer (m)	pH H ₂ O	OM (g kg ⁻¹)	P (mg dm ⁻³)	K	Ca	Mg	Al		S	CEC	V (%)
							mmol _c	dm ⁻³			
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

OM - Organic Matter; CEC - Cation exchange capacity; V - CEC saturation by bases.

The nitrogen fertilization was carried out according to the treatments, applied 60 DAP (Sousa & Lobato, 2004). All treatments were fertilized in the planting furrow with phosphorus in the form of triple superphosphate (155.55 kg ha⁻¹), potassium in the form of potassium chloride (100 kg ha⁻¹), and micronutrients, according to the soil chemical analysis results, for an expectation of yield above 120 t ha⁻¹ of stalks (Sousa & Lobato, 2004).

The experimental units consisted of six rows of sugarcane 5 m long, spaced 1.50 m apart. The useful area was the three central rows of each plot, with 1 m at each end.

The sugarcane variety cultivated was SP80-1816, developed by the Sugarcane Technology Center (CTC). This variety has high fiber content, has no tipping and medium demand in soil fertility, stands out for a good adaptation to the Brazilian Cerrado's edaphic and climatic conditions, and its maturation is semi-precocious in the cane-plant cycle.

The conventional system carried out the soil preparation, employing plowing and two harrows, followed by the planting furrows' opening with a simple furrow. Then, sowing was carried out using mechanized tools. Fifteen yolks were distributed per linear meter,

according to the technical recommendations for the variety used.

The crop 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 infestation assessment and technical recommendations for each product, with no maturation agent being employed.

The biomass evaluations were carried out in two plants located in the useful area of each plot. For that, stalks and pointers (plus green leaves) were collected at 210, 250, 290, and 330 DAP, and then the samples were subjected to drying in a forced air circulation oven at 65°C until constant mass for stalk dry matter (SDM) and pointer dry matter (PDM) determination. The harvest was carried out at 330 DAP, the stalks were unpacked, and the pointer was detached, then weighed on a digital scale, hook type (precision = 0.02 kg), and capacity of 50 kg.

The gross yields of sugar and alcohol were calculated using the raw sugar quantity determined by the raw material's quality attributes, using ten stalks per plot. With the data obtained in the laboratory according to Consecana methodology (2006), Equations 1 and 2 were used, according to Caldas (1998):

$$SY = \left(\frac{YSS * SY}{100} \right) \quad (1)$$

where:

SY - Sugar yield in kg ha⁻¹;

YSS - Amount of raw sugar in % contained in the stalks and determined in the laboratory (Consecana, 2006);

SY - Stalk yield in t ha⁻¹

$$AY = \left((YSS * F) + FRS \right) * Fg * SY * 10 \quad (2)$$

where:

AY- Raw alcohol yield in liters per ton of sugarcane;

YSS - Amount of raw sugar in % contained in the stalks and determined in the laboratory (Consecana, 2006);

F - Stoichiometric transformation factor of sucrose in a glucose molecule plus a fructose molecule, equal to 1.052;

FRS - These are free reducing sugars in %, whose values range from 0.7 to 0.85%, and the distillery uses 0.7 for high YSS;

Fg - Gay Lussac factor equal to 0.6475;

SY – Stalk yield in t ha⁻¹.

The data obtained in the field and laboratory were subjected to analysis of variance, applying the F test at the 5% probability level. In case of significance, regression analysis was performed for nitrogen doses and evaluation times. For nitrogen sources, the averages were compared using the Tukey test at 5% probability.

The statistical program used was SISVAR[®] (Ferreira, 2019).

3. Results and Discussion

When analyzing the dry matter variables, it is observed that the PDM was influenced by the interaction of nitrogen doses and evaluation times. In contrast, the SDM was influenced by the interaction between nitrogen sources and doses and the interaction of nitrogen sources and evaluated periods. (Table 2). It shows a significant interaction between nitrogen sources and doses for the yield of sugarcane stalk (SY), gross sugar yield (GSY), and gross alcohol yield (GAY). In response to N application, significant results for these same variables were also obtained by Resende et al. (2006) and Franco et al. (2010).

It can be seen in Figure 2A that, depending on the evaluation times, the behavior of the pointer dry matter was always quadratic, regardless of the nitrogen (N) dose applied. This finding demonstrates a peak in matter gain, and after that date, the pointer matter started to decrease. The highest pointer dry matter was estimated between 240 and 270 DAP, except at the 180 kg ha⁻¹ N dose, above 330 DAP. Oliveira et al. (2010), studying the growth and accumulation of dry matter in sugarcane varieties, verified the quadratic adjustment behavior for the accumulation of dry matter in leaves + pointer, in the cane-plant cycle, for the ripening varieties early (SP79-1011, RB813804, RB863129, RB872552, and RB943365) and of medium-late maturation (RB72454, RB763710, SP78-4764, SP81-3250, RB867515, and RB92579).

Table 2. Analysis of variance for pointer dry matter (PDM), stalk dry matter (SDM), stalk yield (SY), gross sugar yield (GSY), and gross alcohol yield (GAY) of sugarcane (SP80-1816) in the cane-plant cycle, submitted to nitrogen sources and doses, at different evaluation times, Jataí - GO, Brazil, 2014/2015 harvest.

Source of variation	DF	Mean square				
		PDM	SDM	SY	GSY	GAY
Sources (S)	1	0.000021 ^{ns}	0.0021 ^{ns}	794.1901 ^{**}	12.6585 ^{**}	6.5000 ^{**}
Block	2	0.000235	0.0112	5.9269	3.6986	1.7271
Error (a)	2	0.000841	0.0007	17.2993	0.753	0.3673
Doses (D)	3	0.003327 ^{**}	0.0128 ^{**}	7545.4296 ^{**}	152.6089 ^{**}	77.6049 ^{**}
Sources x Doses	3	0.000172 ^{ns}	0.0020 [*]	134.4442 ^{**}	8.6617 ^{**}	4.2223 ^{**}
Erro (b)	6	0.000131	0.0003	-	-	-
Evaluation times (DAP)	3	0.001988 ^{**}	0.1439 ^{**}	-	-	-
Int. S x DAP	3	0.000061 ^{ns}	0.0037 ^{**}	-	-	-
Int. D x DAP	9	0.000375 ^{**}	0.0012 ^{ns}	-	-	-
Int. S x D x DAP	9	0.000109 ^{ns}	0.0011 ^{ns}	-	-	-
Erro (c)	54	0.000056	0.0006	-	-	-
CV (a)	-	38.09	11.29	3.68	5.31	5.2
CV (b)	-	15.03	7.67	-	-	-
CV (c)	-	9.84	10.99	-	-	-

CV (coefficient of variation); DF (degree of freedom); ** and * - significant at 1 and 5% probability, respectively. ^{ns} (not significant by the F test).

The 180 kg ha⁻¹ dose was responsible for the highest dry pointer matter, except for 210 DAP (Figure 2B). Nitrogen is highly important for sugarcane, constituting about 1% of the plant's total dry matter. Its deficiency causes chlorophyll and amino acid synthesis reduction and a decrease in the available energy for carbohydrate and carbon skeleton production, negatively affecting growth and yield (Malavolta et al., 1997). This nutrient also acts in cell division and expansion, so the nutrient is linked to the plant leaves' development.

Regardless of the N source applied, the stalk dry matter increased linearly as the sugarcane cycle progressed (Figure 3A), so that urea provided lower values up to 250 DAP, compared to AN, and higher from this stage. There was a linear increase in stalk dry matter due to an increase of N doses using the AN source. A quadratic behavior was found for the urea source so that at 120 kg ha⁻¹ N dose, the dry matter was 12.97% higher than the values found for AN (Figure 3B).

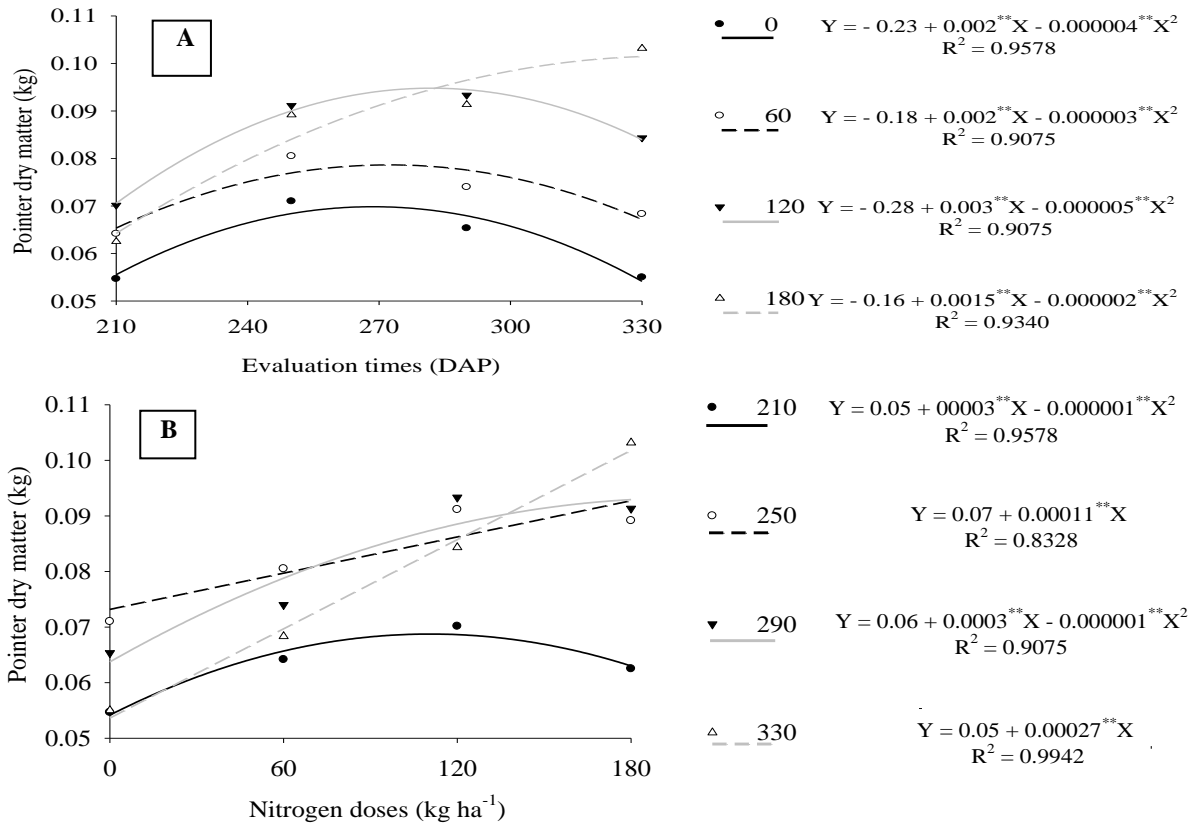
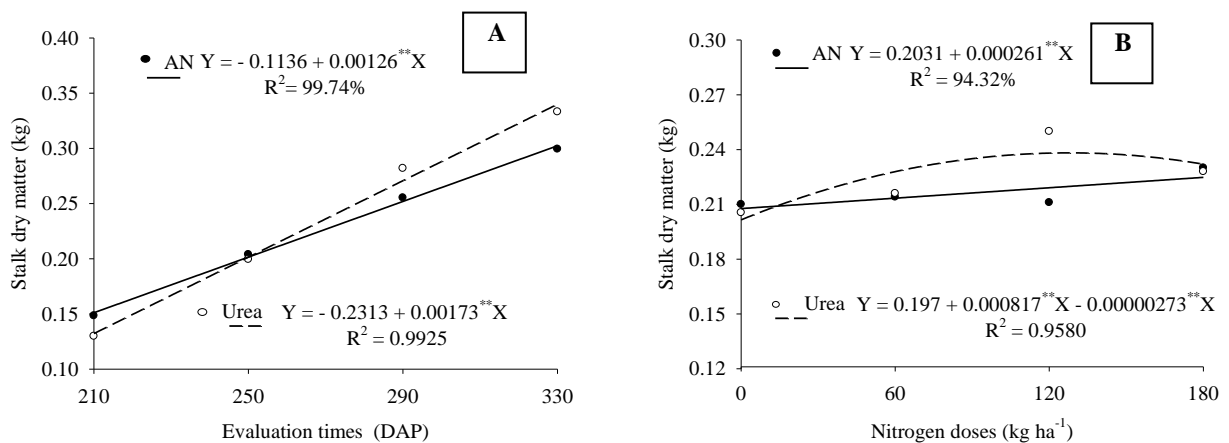


Figure 2. Pointer dry matter of sugarcane (SP 80-1816) in the cane-plant cycle according to the evaluation times (A) and N doses (B), Jataí - GO, Brazil, 2014/2015 harvest.



** and * significant at 1 and 5% probability by the F test.

Figure 3. Stalk dry matter of sugarcane (SP 80-1816) in the cane-plant cycle according to the evaluation times (A) and N doses (B), Jataí - GO, Brazil, 2014/2015 harvest.

Vieira-Megda et al. (2015) found that the application of 100 kg N ha⁻¹ as urea promoted dry matter production from leaves and sugarcane pointer, at 340 days after harvest, of 7.6 Mg ha⁻¹, corresponding to a Nitrogen accumulation of 73.9 kg ha⁻¹. The urea source provided SDM values 9.56 and 10.16% higher than the AN source at 290 and 330 DAP, respectively (Table 3). This same source was also responsible for the largest dry stalk matter at a dose of 120 kg ha⁻¹ (Table 3).

Table 3. Stalk dry matter (kg) of sugarcane (SP 80-1816) in the cane-plant cycle submitted to nitrogen sources and doses, Jataí - GO, Brazil, 2014/2015 harvest.

Evaluation times (DAP)	Ammonium nitrate	Urea
210	0.15 a	0.13 a
250	0.20 a	0.20 a
290	0.25 b	0.28 a
330	0.30 b	0.33 a
Nitrogen doses (kg ha ⁻¹)	Ammonium nitrate	Urea
0	0.21 a	0.20 a
60	0.21 a	0.22 a
120	0.21 b	0.25 a
180	0.23 a	0.23 a

Means followed by the same letters within the different N sources do not differ significantly by the Tukey test at 5% probability.

In Table 4, it is observed that in the N doses of 60 and 120 kg ha⁻¹, the stalk yield was, respectively, 17.83 and 15.21% higher when fertilized with AN than using the urea source. Therefore, this result is different from what was observed for dry matter. The lower stalk yield resulting from urea application in these medium doses was probably due to the lower nitrogen supply than AN since urea has a greater N loss potential due to its susceptibility to ammonia volatilization. This phenomenon is mainly due to the urease enzyme present in the soil (Trivelin et al., 2002; Fortes et al., 2013; Cantarella et al., 2007).

On the other hand, ammonium nitrate, especially under high precipitation conditions and sandy soils, is more susceptible to N losses by leaching. This process can cause environmental damage due to the groundwater and springs contamination and has a higher cost per N unit than urea (Cantarella et al., 2007). It is noteworthy that the soil used in the current study has a very clayey texture. Mariano et al. (2012) and Vieira-Megda et al. (2015) reported that of all N applied via urea to sugarcane, only 20 to 40% are used by the crop, negatively affecting production costs and the environment.

Studies show that irrigation is one way to reduce N losses due to NH₃ volatilization (Gava et al., 2010; Cantarella et al., 2007). Kissel et al. (2004) mention that from 10 to 20 mm of rain is considered enough to

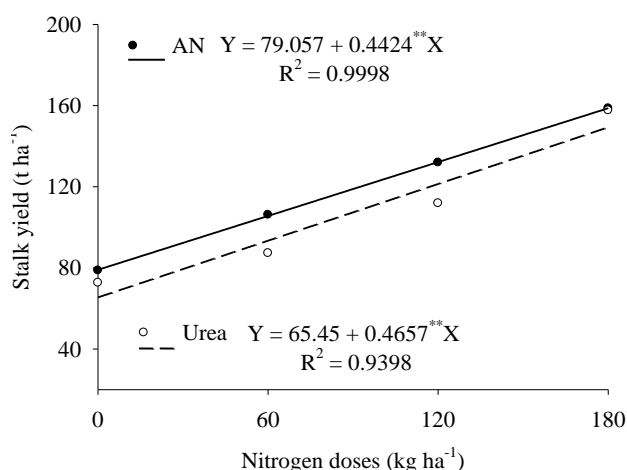
incorporate urea and reduce or even eliminate NH₃ losses in bare soil areas. Also, this precipitation must occur within 1 to 3 days to be effective.

The linear regression equations obtained for N (AN and U) sources promoted the maximum stalk yield of 158.69 and 149.28 t ha⁻¹, respectively, estimated at a Nitrogen dose of 180 kg ha⁻¹ (Figure 4). These results corroborate those found by Rhein and Silva (2017), who observed linear increments of stalk yield up to a Nitrogen dose of 200 kg ha⁻¹ in the form of urea. Santana et al. (2020) concluded that the cane plant responded positively to nitrogen fertilization and increased the ton of stalks per hectare (TSH) by 18.66%, adding up to 129.45 kg ha⁻¹ of N in the form of urea.

Table 4. Stalk yield (t ha⁻¹) of sugarcane (SP 80-1816) in the cane-plant cycle submitted to nitrogen sources and doses, Jataí - GO, Brazil, 2014/2015 harvest.

Nitrogen doses (kg ha ⁻¹)	Ammonium	Urea
0	78.7 a	72.7 a
60	106.2 a	87.3 b
120	131.9 a	111.9 b
180	158.6 a	157.7 a

Means followed by the same letters within the different N sources do not differ significantly by the Tukey test at 5% probability.



** and * significant at 1 and 5% probability by the 5% F test.

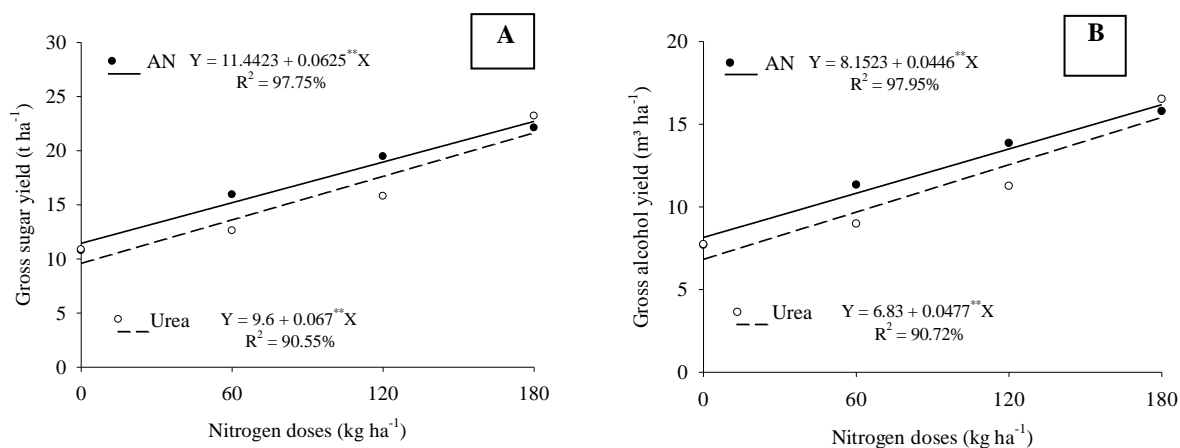
Figure 4. Stalk yield of sugarcane (SP 80-1816) in the cane-plant cycle according to the nitrogen doses, Jataí - GO, Brazil, 2014/2015 harvest.

In Figures 5A and 5B, it can be seen that the behavior of the gross sugar and alcohol yields were similar to that presented by the stalk yield, which shows that at higher N doses (180 kg ha⁻¹), no difference between the use of ammonium nitrate or urea was found. However, when using smaller doses (60 and 120 kg ha⁻¹), ammonium nitrate is responsible for higher yields (Table 5).

Table 5. Gross sugar and alcohol yield of sugarcane (SP 80-1816) in the cane-plant cycle, submitted to nitrogen sources and doses, Jataí - GO, Brazil, 2014/2015 harvest.

Nitrogen doses (kg ha ⁻¹)	Gross sugar yield (t ha ⁻¹)		Gross sugar alcohol (m ³ ha ⁻¹)	
	Ammonium nitrate	Urea	Ammonium nitrate	Urea
0	10.8 a	10.9 a	7.7 a	7.7 a
60	15.9 a	12.6 b	11.3 a	9.0 b
120	19.5 a	15.8 b	13.8 a	11.3 b
180	22.1 a	23.2 a	15.8 a	16.5 a

Means followed by the same letters within the different N sources do not differ significantly by the Tukey test at 5% probability.

**Figure 5.** Gross sugar (A) and alcohol (B) yield of sugarcane in the cane-plant cycle according to the nitrogen doses, Jataí - GO, Brazil, 2014/2015 harvest.

In general, concerning the N sources, urea stood out in some situations for accumulating dry matter, while ammonium nitrate promoted higher stalk yield and agro-industrial yields. It is known that currently, urea becomes cheaper in production due to the lower cost per N unit; however, its losses mainly due to the volatilization of ammonia are greater. Thus, these sources' efficiency will depend on several factors, where the application form and the fertilization management are the most influencing the final efficiency.

4. Conclusions

In this study, the evaluation times influenced the accumulation of dry matter of pointer and stalk. Urea favored the variables dry matter accumulation, while ammonium nitrate, stalk yield, and sugar and alcohol yields. The nitrogen doses increase provided linear increments for stalk yield, gross alcohol yield, and gross sugar yield. The pointer dry matter and the stalk dry matter responded in a quadratic way.

Authors' Contribution

Flávio Henrique Ferreira Gomes contributed to the installation of the experiment, data collection, statistical

analysis and writing of the paper. Frederico Antonio Loureiro Soares was the supervisor of the first author, contributing to the approval of the project with the company Raízen, statistical analysis and assistance in writing the paper. Antonio Evami Cavalcante Sousa was co-supervisor of the first author, contributed to the implementation of the experiment, data collection and correction of the paper. Edson Cabral da Silva contributed to the implementation of the experiment, data collection and correction of the paper. Marconi Batista Teixeira contributed to the approval of the project with the company Raízen and assistance in data collection. Alefe Viana Souza Bastos contributed to the implementation of the experiment, data collection and correction of the paper. Cicero Teixeira Silva Costa contributed to the implementation of the experiment, data collection and correction of the paper. Vitor Marques Vidal contributed to the implementation of the experiment, data collection and correction of the paper. Leonardo Rodrigues Dantas contributed with data collection, scientific writing and paper submission.

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