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Supplementary Nitrogen Fertilization in Sugarcane

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Abstract

In Brazil, sugarcane (*Saccharum* spp.) is considered one of the most economically important crops. Nitrogen (N) is one of the most required elements in sugarcane cultivation. Nevertheless, the information about the soil and foliar applications of this nutrient in crops are discrepant. Therefore, the importance of this study is evident. Given the above, this study aimed to evaluate the soil-applied and foliar N fertilization of sugarcane. The experiment was conducted at the Araporã Bioenergia S.A. power plant, located at Fazenda Santa Rita, in the municipality of Itumbiara-GO. The 5 × 5 factorial design was adopted, with four repetitions, including five doses of soil-applied ammonium nitrate and five doses of foliar Amidic N polymer. The nutrient extraction, the experiment's initial and final total chlorophyll content, the biometric indexes and the industrial quality indexes were analyzed for sugarcane. The ammonium nitrate doses caused differences in fiber, sacarose content, total recoverable sugar, sugar cane Brix, magnesium, and zinc, which was statistically different for the foliar polymer doses. There was no increment of the production variables with the increase of the nitrogen supply in the soil. On the other hand, the levels of zinc and magnesium in the leaves increased 12% and 27%, respectively, reflecting the importance of this fertilization in sugarcane cultivation.

Keywords: amidic nitrogen, ammonium nitrate, *Saccharum* spp.

1. Introduction

Sugarcane (*Saccharum* spp.) is considered one of the greatest alternatives in the biofuel sector due to its great potential for producing ethanol and its respective by-products. Brazil is the largest sugarcane producer in the world, occupying an area of 8406.7 thousand hectares, which will be harvested in the 2020/21 crop, with an estimated production of 630.71 million tons of sugarcane, including 35.3 million tons of sugar and 35.6 billion litres of ethanol (CONAB, 2020).

In this context, the importance of Goiás' role has been increasing in the national sugarcane field. For the 2020/21 crop, there is an estimated 964.3 thousand ha, a production calculated in 75.7 million tons, and productivity of 78.5 kg ha^{-1}. Considering the national average of 72.7 kg ha^{-1}, Goiás can be listed as the second-largest Brazilian producer. Some factors favour its production increase, such as tropical climate, proper photoperiod, relief, and topography (CONAB, 2020).

The nitrogen (N) nutrient's main function is to promote the enlargement of the sugarcane's internodes or, in other words, development and productivity. It is the crop's fourth greatest element in concentration after carbon, hydrogen, and oxygen (Penatti, 2013). In addition, absorbed N increases the shoot's meristematic activity, resulting in greater tillering and leaf area index, increasing said index and solar radiation efficiency. It, therefore, increases dry matter accumulation (Chaves, 2008).

On the other hand, N has an important role in forming chlorophyll—the leaves' green pigments—whose purpose is to capture solar energy during the photosynthesis process. Thus, nitrogen deficiency in photosynthesis can be related to chlorophyll content decrease (Ciompi et al., 1996), activity decrease of enzymes related to the nitrogen (Delú-Filho, 1994) and carbon (Sugiharto et al., 1990) reduction cycle, and stomatal conductance decrease to water vapour (Guidi et al., 1998).

According to Penatti (2013), if proper doses of nitrogen fertilizers are applied in the plantation and cultivation of ratoon sugarcane, the fertilization's complementation will hardly present a positive response. Another unknown factor is the recommendation basis for the proper dose since there is no method to evaluate the N availability based on the soil or plant analysis.

Lately, foliar fertilization, especially nitrogen fertilization, is becoming increasingly popular in the sugar-energy sector. According to Castro (2009), in sugarcane, foliar-applied urea has a high capacity of penetration, foliar absorption, and increased mobility in the plant's tissues, with a foliar absorption 20 times in comparison with every other nutrient, exhibiting, as well, elevated synergistic power in the foliar absorption of several other nutrients. Trivelin et al. (1988) stressed that foliar nitrogen fertilization can increase in the effective utilization of the fertilizers by the crops, resulting in the nitrogen fertilizer economy, since N losses caused by soil leaching would be avoided.

Based on the hypothesis that Nitrogen doses and sources interfere with the sugarcane performance, this study's objective was to evaluate the efficiency of soil-applied and foliar nitrogen fertilization in nutrition and physiology biometry, and industrial quality of sugarcane grown in Dystrophic Red Latosol, Cerrado phase.

2. Material and Methods

The experiment was conducted in the municipality of Itumbiara, Goiás, in Fazenda Santa Rita. According to the Köppen classification, the region's climate is of the tropical type with dry season and droughts during the winter, which is dry and mild and rains from November to April. The municipality's average annual rainfall is 1597 mm. The air's relative humidity is 55%, with an average yearly temperature of 23.8 °C.

The crop previous to sugarcane was grass for grazing. During the soil preparation, 2 tons of dolomitic limestone and 1 ton of agricultural gypsum were applied by ha, while the previous crop was desiccated through subsoiling and harrowing. The plantation was performed on May 10, 2017, employing 500 kg ha^{-1} of the formulation 05-25-25 in a semi-mechanized plantation system, with a spacing between rows of 1.5 m, variety CTC-04, a variety of vigorous development, medium to large culms, resistant to most diseases, of a medium cycle, medium demand of fertility, high productivity, high sucrose level, and low fiber level (CTC, 2020). This area was ratooned for the first time in July 2018, moving to the second ratoon stage in 2019. The soil was characterized as Dystrophic Red Latosol, with the production environment B, and clayey texture with 53% of clay, according to the soil analysis performed in October 2018, reaching the depth of 50 cm, an average of 1.82, 0.86, 0.02, 4.36, and 0.28 $cmol_c/dm^3$ of Ca, Mg, Al, and H+Al, respectively. The average pH was 4.92. The area was delimited in September 2018. The randomized block design was adopted during the experimental design, in the 5 × 5 factorial design, with 4 four repetitions, including 5 five soil-applied ammonium nitrate and 5 foliar amidic N polymer doses totalizing 25 treatments and 100 patches.

Ammonium nitrate doses (32% N) were applied in the soil (0, 50, 100, 150, and 200 kg N ha^{-1}), once the application was performed over the sugarcane row. The recommended dose is 100 kg N ha^{-1} (Villalba et al., 2014). The foliar amidic N polymer doses (33% N), of the Agrichem company (0, 3.3, 6.6, 9.9, and 13.2 L ha^{-1}), were also applied manually, with a backpack's assistance sprayer. The 0 dose had only water. The recommended dose is 6.6 L ha^{-1}, as stated by the company, active in the region, and the volume employed is 333 L ha^{-1}. Rainfall data were measured each month (Figure 1).

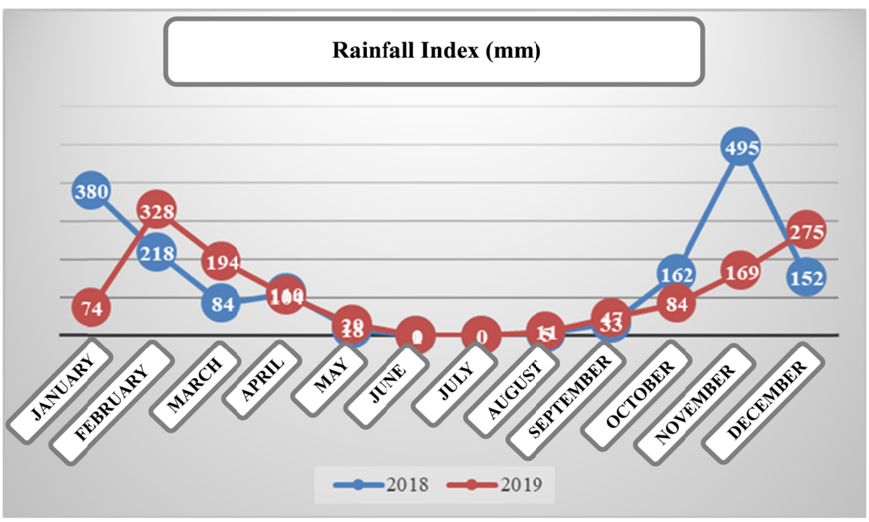

Figure 1. Rainfall behaviour in the years of 2018/2019 (January-December) during the experiment in the municipality of Itumbiara-GO

The soil fertilization was manually performed 130 days after the harvest. The foliar fertilization was performed 310 days after the harvest. It was adapted a Husqvama 325S25 backpack sprayer with a constant flow rate to avoid differences in the patch volume.

The first foliar analysis was performed 25 days before the foliar application and sent to the Safrar Laboratory. As for the harvest, it was performed in July 2019. The experimental patches were composed of four 10-meter-long rows, with a spacing between rows of 1.5 meter, composing an area of 60 m^2 by patch. The two centre rows were evaluated for the plants' analyses, ignoring two meters of each extremity. It is important to mention that, between the patches, the spacing of three meters was considered.

The biometric parameters evaluated were culm diameter, plant height, number of plants, and productivity. To measure the culms' mean diameter, ten culms were randomly selected from the patches. Then, every culm's lower, middle, and top part were measured with a calliper's assistance. As for the culm height, all available culms of the patches were measured after the harvest with a measuring tape's assistance. As for the number of plants, all those present on the patches were counted. And for productivity, all culms available on the patches were manually ratooned and weighed with a digital scale's assistance.

The industrial quality was assessed regarding total recoverable sugar (TRS) and sugarcane Pol, Brix, and fiber. Additionally, the plant's nutrient extraction and the total chlorophyll content at the beginning and end of the crop's conduction were evaluated. For the plant's nutrient extraction, 25 leaves of 15 centimetres were randomly collected, requiring the collection of the +1 leaf (recommendation of the Safrar Laboratory), the higher, unwound insertion leaf, exhibiting the first visible auricle. The leaves were collected during the experiment's harvest and were taken for foliar analysis, which was performed at the Safrar Laboratory in the municipality of Uberlândia-MG.

For the sugarcane's technical quality evaluations, ten culms were taken from each patch to the Araporã Bioenergia S.A. power plant's laboratory to assess the following parameters: TRS (represents the amount of total reducing sugars recovered from the sugarcane), sugarcane Pol (pol % juice—represents the apparent % of sucrose in a sugar solution), Brix (brix % juice—expresses the apparent % of soluble solids in a pure sucrose solution), and Fiber (the sugarcane's matter that is insoluble in water).

The Shapiro-Wilk W data normality test was performed. Then, the F test was applied ($p < 0.05$). When a significant difference was found between the doses, a simple linear regression analysis ($p < 0.05$) was performed. The representative model was selected according to the significance and the coefficient of determination. The statistical analyses were performed with the assistance of the computer program SISVAR® (Ferreira, 2014).

3. Results and Discussion

The soil and foliar fertilization factors evaluated did not present interaction for the variables Fiber, Pol, Total Recoverable Sugar (TRS), Initial Total Chlorophyll (Itc), and Final Total Chlorophyll (Ftc). Solely, the soil-applied ammonium nitrate (AN) doses caused differences in the results of Fiber, Brix, Pol, and TRS of sugarcane (Table 1), especially for dose zero, that is, no application. Solely, the foliar nitrogen (FN) fertilization caused no significant effect on the evaluated variables.

Table 1. Summary of the variables' analysis of variance: Fiber, Brix°, sacarose content (Pol), total recoverable sugar (TRS), Initial total chlorophyll (Itc), and Final total chlorophyll (Ftc) of sugarcane, submitted to different doses (0, 50, 100, 150, and 200 kg ha^{-1}) of soil-applied ammonium nitrate and foliar fertilization doses (0, 3.3, 6.6, 9.9, and 13.2 L ha^{-1}) of Amidic N polymer; Itumbiara-GO, 2019

Source of variation	DF	Mean square					
		Fiber	Brix	Pol	TRS	Itc	Ftc
Soil-Applied (AN)	4	0.27^{*}	0.78^{*}	1.28^{*}	103.24^{*}	12.22^{ns}	35.91^{ns}
Foliar (FN)	4	0.01^{ns}	0.20^{ns}	0.32^{ns}	24.38^{ns}	145.12^{ns}	40.19^{ns}
Soil-Applied × Foliar	16	0.08^{ns}	0.48*	0.57^{ns}	47.39^{ns}	67.26^{ns}	57.78^{ns}
Block	3	0.02^{ns}	0.42^{ns}	1.70^{ns}	128.02^{ns}	236.52^{ns}	52.34^{ns}
Error	72	0.10^{ns}	0.24^{ns}	0.41^{ns}	32.05^{ns}	80.95^{ns}	58.66^{ns}
CV (%)		2.90	2.64	4.21	3.70	19.12	17.92

Note. ^{ns}: non-significant. ** and *: significant at 5% of probability by the F test, respectively.

In Gomes' (2017) research—about the growth and production of culm dry matter, sugar and ethanol yielding of ratooned sugarcane, no difference was seen in the productivity of culms, gross yielding and ethanol yielding while employing 180 kg ha^{-1} of N. However, at the doses of 0, 60, and 120 kg ha^{-1}, differences were seen with greater gross yielding of sugar and ethanol, suggesting the use of 120 kg ha^{-1} of N in the source of ammonium nitrate.

In a work conducted in Linhares, ES, and employing doses of ammonium sulfate, Oliveira et al. (2017) verified that the sugarcane productivity varied from 73.8 to 105.1 t ha^{-1} in doses that varied from 0 to 100 kg N ha^{-1}, with a gain of decreasing productivity and increase of the N dose. This tendency was adjusted, resulting in the theoretical maximum at 130 kg ha^{-1} N. In this very work, Oliveira et al. (2017) concluded that the nitrogen use efficiency, when ammonium sulfate is employed as the N source, is between 40% and 50%.

Schultz et al. (2012), growing the varieties RB867515 and RB72454 in a commercial patch, showed, in an inoculation experiment with diazotrophic bacteria and fertilization with 120 kg ha^{-1} of N, that different behaviors were depending on the variety, as the RB867515 variety was proven to be responsive. The RB72454 variety was proven to be unresponsive. These results show the difference of results between experiments, including the results, in which no difference in the sugarcane productivity was seen with different soil-applied and foliar doses and nitrogen sources.

Mendonça et al. (2016) registered that the nitrogen doses (0, 16, 48, 64, 80, and 96 kg ha^{-1}) in sugarcane did not affect the growth of the cultivars, regardless of the sources (biofertilizer or urea) employed. No significant effect was seen by Oliveira et al. (2016) in the production of culms when the ratooned sugarcane was submitted to the treatments with and without soil-applied nitrogen in the urea source, employing doses between 0 and 180 kg ha^{-1}, which corroborates the present work.

The greatest sugarcane Fiber, Pol, and TRS levels were identified when the soil-applied ammonium nitrate fertilization was not performed (Figure 2). The omission of N in the growth and development of sugarcane is widely reported in the literature by several authors, such as Prado and Franco (2007), Prado et al. (2010), and Vale et al. (2011).

Prado et al. (2010), experimenting in greenhouses with sugarcane, corn, and soy, at FCAV/UNESP, campus Jaboticabal-SP, confirmed that the omission of N promoted the reduction of development, lower number of leaves, lower height, lower stem diameter, and less total dry matter in comparison with the treatment that received the full nutritional solution.

A work conducted by Boschiero (2017), at the São José da Estiva Power Plant, in the municipality of Novo Horizonte-SP, between 2010 and 2015 and in two places, made room for some considerations. A Place 1, using ammonium nitrate (AN) and urea (U) at the dose of 100 kg N ha^{-1}, the productivity did not respond to the N fertilizer application since N did not promote productivity increase in all 5 ratoons. At Place 2, however, AN 100 was superior, reaching the productivity of 114 t ha^{-1}.

The rainfall during the period in which the work was conducted may have interfered with the results, as stressed by Trivelin (2000), in 17 years of works presented as theses for the licensure title, and by Boschiero (2017), at the São José da Estiva Power Plant between 2010 and 2015. It happened due to the great amount of rain right after the soil fertilization, in October and November 2018, which may have caused N leaching, and due to a period of drought in the following months—December 2018 and January 2019—which delayed the foliar N application. Penatti (2013) underscores some points about foliar fertilization in sugarcane, including supplementary fertilisation in younger cane fields. The proper age for its application is between 7 and 8 months when the accumulation of dry matter is increasing.

Based on the mathematical model generated for each characteristic at each soil-applied AN dose, it was possible to state that there was a decrease of 0.06% in the sugarcane fiber level (Figure 2A). Nevertheless, even with said decrease, the levels remained adequate, according to Fernandes' (2000) classification. The authors said that the fibres' level should remain between 10.5% and 12.5% for the industries' energy maintenance. Fiber levels under 10.5% are undesirable depending on the power plants' energy balance since one needs to burn more bagasse to keep the boilers' heat power's heat power. The fibre level is very important for the energy maintenance of the sugarcane industries, as the ideal fibre level mean is 12%.

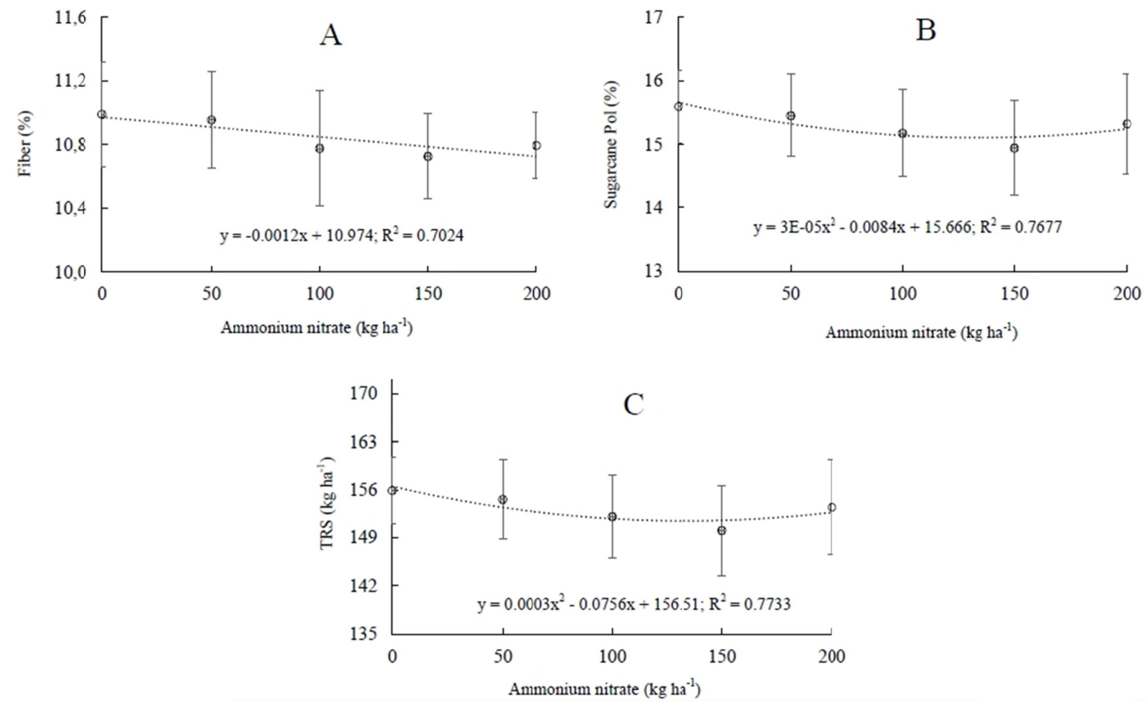

Figure 2. The concentration of sugarcane Fiber (A), sugarcane Pol (B), and TRS (C) at different doses of soil-applied ammonium nitrate applied in the cultivar CTC-04 in Itumbiara-GO, 2020

As for Pol and TRS, they presented quadratic behaviour. The greatest Pol (Figure 2B) and TRS (Figure 2C) concentrations were obtained at the doses of 140 and 126 kg ha^{-1} of soil-applied AN. Teshome et al. (2015) verified that the greatest results of sugarcane (variety B52-298) Pol (14.94%) were found with the lower doses of nitrogen. Additionally, Rhein et al. (2016) verified that the Pol of the sugarcane cultivar SP80-3280's juice caused decrease with the increase of the nitrogen dose via fertigation, including a significant decrease up to the dose of 200 kg ha^{-1} of N.

Table 2 presents the mean of the biometric variables submitted to different soil-applied ammonium nitrate (AM) doses and foliar amidic nitrogen (AN), where there was no statistical difference. Trivelin (2000) states that the proper dose for sugarcane, regarding its quality and biometric characteristics, is directly linked to the soil's concentration during the cultivation.

Table 2. Mean of the biometric parameters submitted to different doses of soil-applied ammonium nitrate (AM) and foliar Amidic N in Itumbiara-GO, 2019

	Doses	Productivity (T ha^{-1}) ^{ns}	No Plants (UN) ^{ns}	Plant Height (m) ^{ns}	Culm Diameter (cm) ^{ns}
Via Soil (kg ha^{-1})	0	142.76	103.9	4.88	2.45
	50	141.02	104.6	4.96	2.46
	100	141.02	104.5	4.98	2.45
	150	148.43	109.0	4.96	2.45
	200	146.86	110.2	4.91	2.38
Foliar (L ha^{-1})	0	145.40	106.8	4.88	2.44
	3.3	148.38	111.0	4.96	2.42
	6.6	141.92	104.5	4.96	2.41
	9.9	149.27	102.8	4.99	2.46
	13.2	143.01	107.2	4.89	2.45

Note. ^{ns}: Non significant.

There was no interaction or isolated effects of the sources and doses applied on the variables Initial and final total chlorophyll during cultivation, plant number, height, diameter, and productivity. The mean results were

47.06, 42.74, 106.43, and 4.94 m, 2.44 cm, and 145.59 t ha^{-1}, respectively, according to Table 3. It was verified that the doses of ammonium nitrate applied in the soil affected the variables Fiber, Pol, and TRS.

Table 3. Summary of the analysis of variance of the variables: Plant Number (PN), Plant Height (PH), Culm Diameter (CD), and Productivity (PROD) of sugarcane submitted to different doses (0, 50, 100, 150, and 200 kg ha^{-1}) of soil-applied ammonium nitrate and doses (0, 3.3, 6.6, 9.9, and 13.2 L ha^{-1}) of foliar fertilization with Amidic N polymer in Itumbiara-GO, 2019

Source of variation	DF	Mean square			
		PN	PH	CD	PROD
Soil-Applied (AN)	4	172.39^{ns}	0.03^{ns}	0.02^{ns}	247.39^{ns}
Foliar (FN)	4	193.11^{ns}	0.04^{ns}	0.01^{ns}	207.68^{ns}
Soil-Applied × Foliar	16	195.39^{ns}	0.07^{ns}	0.01^{ns}	264.92^{ns}
Blocks	3	274.84^{ns}	0.19^{ns}	0.03^{ns}	1639.25^{ns}
Error	72	210.36^{ns}	0.07^{ns}	0.01^{ns}	465.57^{ns}
CV (%)		13.63	5.32	4.33	14.82

Note. ^{ns}: non-significant. ** and *: significant at 5% of probability by the F test, respectively.

Schultz et al. (2017) confirmed that the varieties RB867515 and RB72454 of sugarcane fertilized with 120 kg ha^{-1} of nitrogen presented the Sugarcane Pol of 13.8%. Oliveira et al. (2017) found values of sugarcane Pol between 14.6% to 15% for RB92579, RB98710, RB99395, and RB961003. For Cunha (2017), the ascending doses of nitrogen reduced the sugarcane Pol up to the dose of 163.9 kg ha^{-1} of N, with 17.1%. The results above were similar to the present research's, with values between 15% and 16%. The sugarcane Pol reductions are explained by Malavolta & Moraes (2007). The nitrogen fertilization increased the vegetal growth, determining plants with greater humidity level but with loss of sucrose accumulation.

The content of total recoverable sugars (TRS) is employed in Brazil's sugarcane payment system since the crop of 1998/99 and said variable constitutes the features of reducing sugars and sucrose, fructose and glucose (Isejima et al. 2002). Based on it, the importance of studies that relate this variable with inputs employed in sugarcane, like nitrogen, becomes evident. There was no interaction between the application methods evaluated—soil-applied and foliar—and there was no isolated effect of the nitrogen doses for the biometric characteristics of plant number (Pn), plant height (Ph), culm diameter (Cd), and sugarcane productivity.

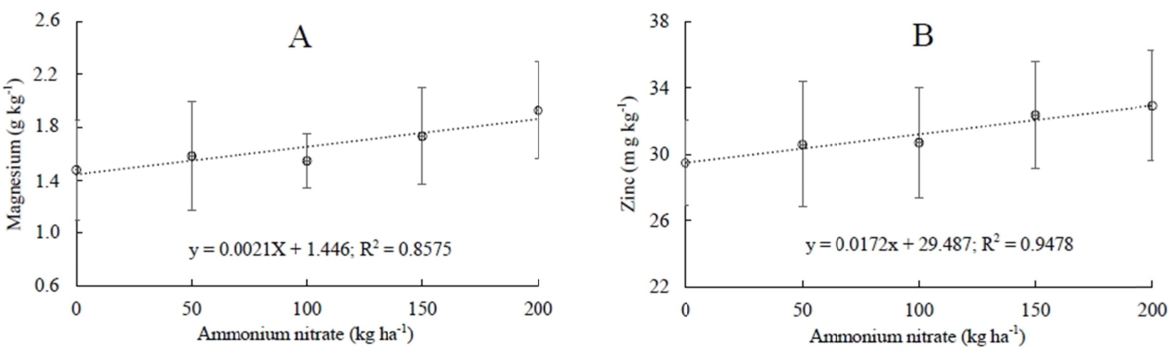

Figure 3. Behaviour representation of the Mg (A) and Zn (B) chemical characteristics in the sugarcane cultivar CTC-04, at different soil-applied doses of ammonium nitrate in Itumbiara-GO, 2020

An isolated effect of the soil-applied nitrogen doses was verified in Mg and Zn's foliar levels (Table 4). The dose of 200 kg ha^{-1} of soil-applied AN was verified as the one that resulted in the greatest levels of Mg and Zn, reaching levels of 1.87 g kg^{-1} and 32.93 mg kg^{-1}, respectively. Based on the models, it was confirmed that, when the soil-applied AN fertilization was increased in 50 kg ha^{-1}, Mg (Figure 3A) and Zn (Figure 3B) increased 0.10 g kg^{-1} and 0.86 mg kg^{-1}, respectively.

Table 4. Summary of the analysis of variance of the variables: Potassium (K), Magnesium (MG), Copper (Cu), Iron (Fe), Manganese (Mn), and Zinc (Zn) of the sugarcane leaves submitted to different doses (0, 50, 100, 150, and 200 kg ha^{-1}) of soil-applied ammonium nitrate and doses (0, 3.3, 6.6, 9.9, and 13.2 L ha^{-1}) of foliar fertilization with Amidic N polymer in Itumbiara-GO, 2019

Source of variation	DF	Mean square					
		K	Mg	Cu	Fe	Mn	Zn
Soil-Applied (AN)	4	1.68^{ns}	0.64^{**}	0.71^{ns}	4282.33^{ns}	445.27*	39.22^{**}
Foliar (FN)	4	1.10^{ns}	0.07^{ns}	1.56^{ns}	4320.78^{ns}	297.68^{ns}	1.61^{ns}
Soil-Applied x Foliar	16	0.70^{ns}	0.11^{ns}	1.05^{ns}	3589.63^{ns}	174.83^{ns}	2.86^{ns}
Repetition	3	4.17^{ns}	0.51^{ns}	6.14^{ns}	6161.48^{ns}	2409.41^{ns}	244.23^{ns}
Error	72	1.21^{ns}	0.12^{ns}	0.84^{ns}	2961.45^{ns}	172.74^{ns}	3.18^{ns}
CV (%)		8.37	20.61	27.57	27.67	11.98	5.71

Note. ^{ns}: non-significant. ** and *: significant at 1% and 5% of probability by the F test, respectively.

According to Kabata-Pendias (2011), and Taiz and Zeiger (2013), the Zn nutrient is related to the metabolism of carbohydrates and phosphate, as well as to the synthesis of enzymes, such as peptidases, proteinases, and dehydrogenases, since several enzymes require zinc ions (Zn^{2+}) to perform their activities. Additionally, Zn may be required for the synthesis of chlorophyll in some plants. Based on that statement, the importance of measuring said element in sugarcane nutrition becomes evident.

There is a strong relation between nitrogen fertilization and zinc in zinc absorption and the sugarcane's quality and growth features, as observed in Cunha's (2017) research. The researcher verified that applying different doses of nitrogen and zinc through fertigation affected the sugarcane's growth and development, promoting interferences in technological quality.

The relation between zinc absorption and nitrogen fertilization seen in present research results can be linked to the conditions of properly supplying nitrogen and water since it promotes the root system and zinc absorption, which also favours root development. It enables greater water and nutrient absorption and results in greater enlargement of internodes, which, in turn, results in greater sugarcane growth rate (Shigaki et al., 2004; Silva et al., 2014; Gobarah et al., 2014).

Results similar to the present research on the behaviour of the magnesium level determined in sugarcane leaves were verified in the research of Foletto et al. (2016). According to the study, the magnesium levels varied with applying the N doseN dose application; however, the best adjustment was provided by quadratic equation and the greatest level of this nutrient (3.04 g kg^{-1}) verified at the dose of 114.7 kg ha^{-1}.

According to Oliveira et al.'s (2011) and Foletto et al.'s (2016) results, the magnesium levels are within the proper range for the production of the studied sugarcane variety they vary between 1.0 and 3.0 g kg^{-1}.

4. Conclusion

The doses of soil-applied ammonium nitrate did not affect the biometric parameters.

The doses of foliar amidic nitrogen did not affect the biometric parameters either.

Since there was no significant difference between the nitrogen doses and application methods in this work, the producer will decide which is the best method and dose to be applied in his/her sugarcane crop.

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