Productivity and technological quality of sugarcane under fertilization of nitrogen and molybdenum

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Abstract

The increase of N fertilization in sugarcane can negatively influence the technological quality of the crop for sugar and alcohol production. The use of Mo in fertilization combined with N can reduce this effect and increase agricultural and sugar yield. The objective of this study was to evaluate the levels of Mo in soil, roots and leaves of sugarcane fertilized with N and Mo, to measure agricultural and sugar productivity and to evaluate quality of the technological attributes for production of sugar and alcohol. Two varieties were cultivated (RB867515 and RB92579) under field conditions, submitted to two doses of N (0 and 60 kg ha⁻¹) and two doses of Mo (0 and 200 g ha⁻¹) both applied to the soil. The source of N used was urea and the source of Mo was sodium molybdate. RB867515 was influenced by Mo and agricultural and sugar productivity increased by 21%. N fertilization did not increase agricultural productivity but reduced the technological quality of sugarcane, and Mo did not change this reduction. It is suggested that N fertilization should be reduced in first crop cycle and Mo fertilization should be stimulated.

Keywords: Availability of molybdenum, molybdenum nutrition, nitrogen nutrition, technological attributes for sugar and alcohol production

1. Introduction

Sugarcane has been economically important for Brazil since the colonial period, the country is responsible for 33% of the world's production (CONAB, 2017), but it is a crop requiring high consumption of fertilizers, mainly N.

N is the second macronutrient most absorbed by sugarcane, extracting about 94 to 260 kg ha⁻¹, varying with genotype, soil and fertilization (Oliveira *et al.*, 2010). Despite the high uptake of N, the responses of the plant to N fertilization have been very varied. Azeredo *et al.* (1986) observed that in 80% of the cases, sugarcane in the first crop cycle (plant-cane) did not respond to N fertilization in evaluations carried out in 135 experiments in different regions of the country. However, Oliveira (2012) found an increase in agricultural productivity of sugarcane with increasing of N in three production environments in the Northeast of Brazil. Oliveira *et al.* (2013) also observed a positive variation of dry matter production of sugarcane in response to increase of N, when the variety SP813250 was cultivated with doses of up to 120 kg ha⁻¹ of N in three soils of different producing areas in Brazil.

Sugarcane absorbs N of the soil in the ammoniacal (N-NH₄⁺) and nitrate (N-NO₃⁻) forms, with predominance of the second form in aerated soils (Robinson *et al.*, 2011). For the assimilation of N-NO₃⁻, it is necessary that Mo be available in the soil in adequate quantities, by the action of Mo as nitrate reductase (ARN) activity regulator (Nie *et al.*, 2016), responsible for the first step of reducing NO₃⁻ to NH₄⁺ (Li-Ping *et al.*, 2007). Li-Ping *et al.* (2007) observed that ARN in sugarcane was elevated by increasing the concentration of Mo in the nutrient solution, when the varieties RB72454 and RB7575 were grown under four Mo doses (0; 0.01; 0.02; and 0.04 mg L⁻¹). Therefore, Mo can affect the

assimilation of N and influence the agricultural production and technological quality of sugarcane.

Mo also regulates the activity of nitrogenase (AN). This enzyme in diazotrophic bacteria associated with sugarcane is responsible for the reduction of atmospheric N₂ to NH₃ and its assimilation in plants. Li-Ping *et al.* (2007) evaluated the behavior of AN in sugarcane under the effect of increasing of Mo and found that despite the Mo application to raise AN, the increase in enzyme activity varied with the tissue and the genotype.

The low availability of Mo in the soil can reduce ARN, AN and N assimilation, reducing of agricultural productivity. The amount of Mo is low in most soils and the predominant anionic chemical form is molybdate, and its availability is influenced by chemical and mineralogical properties. For example, in high acid soils, nutrient availability is reduced (López *et al.*, 2007). Elevation of a pH unit in a soil of pH 3 can increase the availability of Mo by 100 times (Kaiser *et al.*, 2005). An alternative to increase the Mo content available in the soil is the Mo fertilization. In areas where limestone application was not feasible, Brennan and Boland (2007) observed that wheat yields were high when sowed on soils with pH higher than 4.3 in Australia. The availability of Mo can also be reduced by the presence of Fe and Al oxides (Vistoso *et al.*, 2009).

Mo fertilization may be a viable alternative to increase Mo availability in tropical soils cultivated with sugarcane because of the naturally low pH values of these soils or the high amounts of Fe and Al oxides. Thus, well-nourished plants with Mo can be more efficient in the use of N by effect of the Mo on ARN and AN, reducing the high N fertilization, without affecting agricultural and sugar productivity and the technological quality of sugarcane.

The objective of this work was to evaluate the levels of Mo in soil, roots and leaves of sugarcane fertilized with N and Mo, to measure the agricultural and sugar productivity and to evaluate the quality of the technological attributes for production of sugar and alcohol.

2. Materials and Methods

2.1. Location and description of place of study

The experiment was conducted in the Carpina Sugarcane Experiment Station (EECAC), in the Carpina

municipality of Pernambuco, located at the geographic coordinates 7°51'04"S and 35°14'27"W.

The municipality of Carpina has an altitude of 184 m, with predominant As' climate, rainy tropical weather with dry summer, according to the Köppen system and average annual temperature of 24.2 °C (Beltão *et al.*, 2005). Rainfall during the experiment was 1,359 mm (Figure 1). In addition, three slides of 25 mm of water were applied in the first two months after planting, due to the low rainfall rates at the beginning of the experiment.

Figure 1. Rainfall during the trial at the Carpina Sugarcane Experiment Station, Carpina, Pernambuco, Brazil.

The soil of the experimental area was classified as Dystrophic Yellow Red Argisol (Santos *et al.*, 2013). The chemical and physical characterization of the soil was performed in composite samples formed from the collection of 15 simple samples randomly collected and at two depths 0.0 to 0.2 and 0.2 to 0.4 m (Table 1). For the chemical characterization, the following were determined: the pH (H₂O), Ca²⁺, Mg²⁺, K⁺, Na⁺, Al³⁺,

(H + Al), P, P remaining (P-rem), Fe, Cu, Zn, Mn, Mo, NH₄⁺, NO₃⁻ and TOC (Total Organic Carbon). Extraction of Ca²⁺, Mg²⁺ and Al³⁺ was realized with 1.0 mol L⁻¹ KCl and dosed cations by titulometry. Also, P, K⁺, Na⁺, Fe, Cu, Zn, Mn and Mo were extracted with Mehlich-1, with P and Mo dosed by colorimetry, K⁺ and Na⁺ by flame photometry and Fe, Cu, Zn and Mn by spectrophotometry. Potential acidity (H + Al) was

determined with 0.5 mol L⁻¹ calcium acetate and titrated. TOC was determined by wet combustion with potassium dichromate and titration. All analyses

were performed according to the methodologies described by Donagema *et al.* (2011).

Table 1. Chemical and physical soil attributes at different depths

Attribute	Depth (m)	
	0.0 – 0.2	0.2 – 0.4
pH água (1:2,5)	5.20	4.80
Ca ²⁺ (cmol _c dm ⁻³)	2.10	1.80
Mg ²⁺ (cmol _c dm ⁻³)	0.50	0.60
K ⁺ (cmol _c dm ⁻³)	0.15	0.06
Na ⁺ (cmol _c dm ⁻³)	0.04	0.07
Al ³⁺ (cmol _c dm ⁻³)	0.50	0.70
(H + Al) (cmol _c dm ⁻³)	5.50	7.50
P (mg dm ⁻³)	19.00	4.00
Fe (mg dm ⁻³)	55.40	41.20
Cu (mg dm ⁻³)	0.10	0.30
Zn (mg dm ⁻³)	2.50	2.40
Mn (mg dm ⁻³)	6.60	5.00
Mo (mg dm ⁻³)	0.14	0.15
COT (g kg ⁻¹) ^(a)	1.19	1.25
NO ₃ ⁻ (mg dm ⁻³)	56.14	65.22
NH ₄ ⁺ (mg dm ⁻³)	20.02	20.64
CTC efetiva (cmol _c dm ⁻³) ^(b)	3.29	3.23
CTC potencial (cmol _c dm ⁻³) ^(c)	8.29	10.03
V (%) ^(d)	33.66	25.22
m (%) ^(e)	15.20	21.67
Areia Total (g kg ⁻¹)	723.00	681.00
Areia Grossa (g kg ⁻¹)	509.80	481.20
Areia Fina (g kg ⁻¹)	213.60	199.40
Silte (g kg ⁻¹)	117.00	80.00
Argila (g kg ⁻¹)	160.00	239.00
Ds (kg dm ⁻³) ^(f)	1.46	1.41
Dp (kg dm ⁻³) ^(g)	2.56	2.47
PT (%) ^(h)	43.21	42.79
θ _{CC} (Mg Mg ⁻¹) ⁽ⁱ⁾	0.12	0.13
θ _{PMP} (Mg Mg ⁻¹) ^(j)	0.06	0.08

^(a)Total organic carbon; ^(b)Effective cation exchange capacity; ^(c)Potential cation exchange capacity; ^(d)Saturation by bases; ^(e)Saturation by aluminum; ^(f)Bulk density; ^(g)Particules density; ^(h)Total Porosidy; ⁽ⁱ⁾Field capacity; ^(j)Permanent wilting point.

With the results of these chemical analyses, the saturation by bases (V), the saturation by Al (m), the effective cation exchange capacity ($\text{CEC}_{\text{effective}}$) and the potential cation exchange capacity ($\text{CEC}_{\text{potential}}$) were calculated.

The NH_4^+ and NO_3^- were extracted with 1.0 mol L^{-1} KCl and dosed by steam distillation by the Kjeldahl method, according to Tedesco *et al.* (1995).

Physically, the soil was characterized by granulometry, defining its textural class, soil density, density of particles, humidity in the field capacity (θ_{cc}) and the permanent wilting point (θ_{pmp}); hydraulic conductivity of saturated soil (K_0); and indirectly, the total porosity, using the determination of the densities. All the physical analyses were performed according to the methodology proposed by Donagema *et al.* (2011).

2.2. Experimental field

The sugarcane varieties RB92579 and RB867515 were used because they are widely cultivated in the Northeast of Brazil. The cultivation was submitted to two doses of N (0 and 60 kg ha^{-1}) and two doses of Mo (0 and 200 g ha^{-1}), based on the study of the interaction of N and Mo fertilization in sugarcane developed by Oliveira (2012), using urea as source of N and sodium molybdate as Mo source. Fertilizers were applied in the furrow during the planting of sugarcane. Sodium molybdate was diluted in water and applied with the aid of a costal sprayer to facilitate fertilizer application and improve distribution in the planting groove. The experimental design used was in randomized blocks, in a factorial arrangement of treatments ($2 \times 2 \times 2$), with four replications, totaling 32 experimental units. Each plot was comprised of seven grooves of 10 m in length, spaced by one meter, totaling 70 m^2 . The useful area was formed by the five central grooves, discarding a meter of the ends, totaling 40 m^2 .

The experiment started 40 days after the application of 2.45 Mg ha^{-1} of dolomitic limestone with total neutralization relative power (PRNT) of 89% in the total area and incorporated up to 0.2 m depth. The need for liming was calculated by the method of base saturation (Ribeiro *et al.*, 1999), estimating an increase in saturation to 60%. The fertilization was carried out in a foundation with the application of P and K. Phosphate fertilization was performed considering the available P content and soil texture according to Simões Neto *et al.* (2011), with 60 kg ha^{-1} of P_2O_5 being applied as triple superphosphate (40% P_2O_5). The recommendation of K was based on the production expectation, estimating yields above 100 Mg ha^{-1} and using an average K_2O efficiency of 1.4 kg Mg^{-1} of sugarcane (Oliveira *et al.*, 2010). Thus, 140 kg ha^{-1} of K_2O was applied as potassium chloride (60% K_2O). The planting of sugarcane varieties was carried out in grooves approximately 0.2 m deep and 14 Mg ha^{-1} of stems with seven months of age was distributed.

2.3. Sampling of soil, roots and leaves

Soil Mo contents were determined at 30, 70, 100, 130, 200 and 365 days after planting (DAP) at different stages of crop growth. Soil samples were collected in the useful area of the experimental plots at depths of 0.0 to 0.2 m and 0.2 to 0.4 m. Soil sampling was performed approximately 0.25 m away from the planting line, and three simple samples were collected diagonally per plot for the formation of a composite sample. Subsequently, the collected soil samples were air dried, stripped and sieved in a 2 mm mesh sieve. The Mo was extracted with Mehlich-1 and dosed by colorimetry, according to Donagema *et al.* (2011).

The Mo was evaluated in leaves e roots of sugarcane. At 70, 100, 130, 200 and 365 DAP three leaves +1 were randomly collected (diagnostic leaf or index leaf) and one root portion per plot. The collected plant

tissues were dried in a forced air circulation oven at 65 °C and ground. To evaluate the Mo content, the tissues were digested in nitroperchloric solution and spectrophotometer determination was conducted, according to the methodology proposed by Silva (2009).

2.4. Harvesting, agronomic evaluation and technological quality of sugarcane

Sugarcane harvest was carried out with straw burning at 365 DAP and the agricultural productivity (stems per hectare - TCH) was evaluated. The productivity was measured by the weighting of the stalks with a dynamometer in the useful plot and the agricultural productivity per hectare was calculated as a function of the productivity obtained in the useful plot. Ten (10) stems were selected randomly in the useful plot to evaluate the technological attributes. The samples were ground in forage and sub-samples, according to the methodology suggested by CONSECANA (2006). The subsamples were submitted to the hydraulic press for one minute, under pressure of 250 kg cm⁻², and the broth was collected and the following were determined: percentage of purity; total soluble solids (°Brix) with digital refractometer; percentage of apparent sucrose in the broth (Pol) using saccharimeter; and percentage of reducing sugars (AR).

The following were determined in the stem: percentage of fibers; percentage of sucrose in the stem (PC); and theoretical recoverable sugar (ATR). The variable fiber, Pol, purity and ATR were determined according to the methodology described by CONSECANA (2006). The yield of sugar or Pol per hectare (TPH) was calculated by the equation: $TPH = (TCH \times PC) / 100$, according to Lima Neto *et al.* (2013).

2.5. Data analysis

The levels of Mo in the soil, roots and leaves were evaluated as time-repeated measures. The statistical package SAS Learning 2.0 was used, following the procedure for mixed model, and the covariance test [AR(1), Ante (1), ARH (1), ARMA (1), CS, CSH, HF, TOEP, Lin (1), UN] which presented the lowest value of the Akaike criterion.

Regression analysis was performed as a function of time in the quantitative variables in which a significant effect ($P < 0.05$) was observed. The model that best represented the phenomenon was selected by the highest coefficient of determination (R^2) and the significance of the parameters was tested by the t test ($P < 0.05$). The data were submitted to analysis of variance (ANOVA), F test ($P < 0.05$) and Tukey test ($P < 0.05$) in the quantitative variables in which no significant effect was observed for regression.

The agricultural and sugar productivity and the technological attributes were evaluated according to the varieties of sugarcane as well as N and Mo fertilizations. Data were submitted to analysis of variance and the F test was performed ($P < 0.05$). The Tukey test ($P < 0.05$) was applied in variables in which the main effects and/or interaction were significant.

3. Results

3.1. Mo content in soil

The Mo content in the soil as a function of time was adjusted to the peak model (Figure 2A, B and C), except for the variety RB92579 fertilized with N, where the data adjusted to a linear model, when Mo (Figure 2D) was applied. When Mo was not applied, regardless of the application or not of N, the data of the Mo content in the soil adjusted to a quadratic model (Figure 2). Mo levels in soil from 30 DAP decreased with

N application in the variety RB867515 reduced the Mo content in the surface layer only in the absence of Mo fertilization (Figure 2B). The data of the Mo content in the soil were adjusted to a decreasing quadratic model and presented different minimum values in the absence of Mo fertilization (Figure 2A and B).

The Mo content in the soil was so low when the variety RB867515 was fertilized with N, that at 222 DAP no Mo was detected, whereas in treatment without N, the Mo content was 0.04 mg dm^{-3} . However, after reaching the minimum values, the Mo content increased until the end of the crop cycle (Figure 2A and B). Without Mo fertilization, the Mo content in the soil when the variety RB92579 was cultivated presented an inverse behavior to that of the variety RB867515. The low levels occurred in the absence of N (Figure 2C). However, Mo content was so low that it was not detected in both varieties when Mo was not applied.

The Mo contents were minimal at 190 and 260 DAP in the absence and presence of N, respectively (Figure 2C and D). When the variety received Mo fertilization,

the reduction of the Mo content was more accentuated with the N application (Figure 2D). Despite the decreasing linearity of Mo content with the application of the two nutrients, the lowest value was 0.06 mg dm^{-3} at 365 DAP and not detected at 260 DAP, when RB92579 received only Mo fertilization (Figure 2C and D).

The Mo contents in the topsoil increased with fertilization up to 30 DAP. Subsequently, they were reduced to a minimum and then tended to increase, except when RB92579 was fertilized with N and Mo (Figure 2). The increase in Mo content of the soil was of 21% when RB867515 was cultivated without N fertilizer. When not fertilized with Mo, the Mo contents were reduced from the beginning of the cycle in this variety.

When the sugarcane varieties were not fertilized with Mo, a quadratic reduction of the Mo contents in the soil was observed after planting (Figure 2). In the absence of Mo fertilization, there was no increase of Mo content in the soil along the crop cycle, since the naturally available stock was being absorbed from the soil.

Figure 2. Mo content in the 0 to 0.2 m depth layer in soil cultivated with sugarcane in the first crop cycle (cane-plant) at 0, 30, 70, 100, 130, 200 and 356 days after planting (DAP). (A) Variety RB867515 fertilized and not fertilized with Mo and fertilized with N; (B) Variety RB867515 fertilized and not fertilized with Mo and not fertilized with N; (C) Variety RB92579 fertilized and not fertilized with Mo and fertilized with N; (D) Variety RB92579 fertilized and not fertilized with Mo and not fertilized with N.

In the subsurface layer (0.2 to 0.4 m depth), the behavior of the Mo content was similar to that of the surface layer, with increments after the Mo fertilization, followed by reduction. In the absence of Mo fertilization, there was a reduction of Mo contents

throughout the crop cycle (Figure 3). However, Mo levels and their increments were higher with their supplementation, especially when the varieties were not fertilized with N (Figure 3).

Figure 3. Mo content in the 0 to 0.4 m depth layer in soil cultivated with sugarcane in the first crop cycle (cane-plant) at 0, 30, 70, 100, 130, 200 and 356 days after planting (DAP). (A) Variety RB867515 fertilized and not fertilized with Mo and fertilized with N; (B) Variety RB867515 fertilized and not fertilized with Mo and not fertilized with N; (C) Variety RB92579 fertilized and not fertilized with Mo and fertilized with N; (D) Variety RB92579 fertilized and not fertilized with Mo and not fertilized with N.

In the cultivation of RB867515 and in the absence of N fertilization, the increase in soil Mo content in the subsurface layer was 0.17 mg dm⁻³ and 0.05 mg dm⁻³ in the surface layer (Figure 2A and 3A). The highest Mo increments in the subsurface layer were due to the mode of application of sodium molybdate, which was at the bottom of the planting groove of the sugarcane at approximately 0.2 m depth. In addition, the reduction of the Mo content in this layer was higher, occurring faster and in a shorter time than in the superficial layer.

The reduction of the Mo content in the subsurface layer of the soil by N fertilization was more intense, mainly with Mo fertilization. N application reduced the Mo content of the soil by 40% when the varieties were fertilized with Mo (Figure 3).

When not fertilized with Mo, the N application differentiated Mo levels from soil only of RB92579. Thus, the N application promoted a faster reduction of the Mo content in the subsurface layer, which stabilized at 0.05 mg dm⁻³, at 160 and 52 DAP in the absence and presence of N fertilization, respectively (Figure 3).

The Mo content of the soil in the subsurface layer was higher as a function of the Mo fertilization, independently of the N application and of the variety.

Differently from the surface layer where it was observed that the Mo contents tended to zero. In the subsurface layer, the contents were higher, with minimum values of 0.03 mg dm⁻³ of Mo (Figure 3).

3.2. Mo content in leaf and root

In general, Mo content in the roots of the sugarcane varieties were higher than in leaves, on average, from 0.58 to 0.97 mg kg⁻¹ in the variety RB867515 and from 0.59 for 0.86 mg kg⁻¹ in the RB92579 (Table 2). There was a concentration of Mo in the roots and a dilution of the nutrient in the aerial part, influenced by the greater production of biomass of leaves than of roots.

Mo content in the leaf of the varieties was not different, but in the roots the Mo content of the variety RB867515 was higher than in the RB92579 (Table 2).

In the leaf, the Mo content was not influenced by the N addition, although independent of the Mo application and the variety. However, in the roots there was an increase in this content with the N application. This increase in the Mo content with N addition was significant in roots, independent of the variety and Mo application (Table 2).

Table 2. Mo content in the leaf and roots of the sugarcane varieties RB867515 and RB92579, with (w) and without (w/o) Mo application and with (w) and without (w/o) N application at 70, 100, 130, 200 and 356 days after planting (DAP)

Leaf								
Factor	RB867515				RB92579			
	w/o-Mo		w-Mo		w/o-Mo		w-Mo	
	w/o-	w-	w/o-	w-	w/o-	w-	w/o-	w-
DAP	mg kg ⁻¹							
70	0.66	0.60	0.82	0.91	0.74	0.73	0.96	1.06
100	0.37	0.37	0.43	0.40	0.36	0.38	0.44	0.45
130	0.28	0.55	0.64	0.56	0.29	0.29	0.37	0.44
200	0.68	0.82	0.96	0.93	0.77	0.78	0.83	1.06
365	0.40	0.29	0.45	0.43	0.40	0.36	0.56	0.53
Mean N	0.48	0.53	0.66	0.65	0.51	0.51	0.63	0.71
Mean Mo	0.50 b		0.65 a		0.51 b		0.67 a	
Mean	0.58 a				0.59 a			
Roots								
Factor	RB867515				RB92579			
	w/o-Mo		w-Mo		w/o-Mo		w-Mo	
	w/o-	w-	w/o-	w-	w/o-	w-	w/o-	w-
DAP	mg kg ⁻¹							
70	0.98	1.15	1.30	1.26	0.79	0.76	1.13	1.16
100	0.63	1.08	0.79	1.43	0.73	0.89	0.93	1.05
130	0.99	1.05	1.21	1.00	0.69	0.83	0.49	1.13
200	1.07	0.74	0.92	0.78	0.84	0.80	1.25	0.93
365	0.81	0.63	0.85	0.75	0.48	0.70	0.70	0.90
Mean N	0.90	0.93	1.01	1.04	0.71	0.80	0.90	1.03
Mean Mo	0.91 b		1.03 a		0.75 b		0.97 a	
Mean	0.97 a				0.86 b			

Equal lowercase letters in the line do not differ by Tukey test ($P < 0.05$).

3.3. Agricultural productivity

The effect of Mo fertilization on the yield of stalks and sugar depended of the variety. RB867515 res-

ponded positively to the Mo application, with increases of 21% in the values of TCH and TPH, but the Mo fertilization did not increase yield in RB92579 (Figure 4).

Figure 4. Agricultural productivity (A) and sugar (B) per hectare of the sugarcane varieties submitted the Mo application. Means in the same column followed by the same letter do not differ significantly by the Tukey test ($P \leq 0.05$). Uppercase letters compare the varieties and lowercase letters compare the effect of Mo.

The yields of TCH e TPH of the varieties depended of the absence or presence of Mo. There was no difference in yields of the varieties when Mo was not applied. However, the yields of TCH and TPH in RB867515 with the Mo application were 34% and 32% higher than in RB92579, respectively (Figure 4).

Therefore, it is recommended to use Mo fertilization in the fertility management of the variety RB867515, regardless of N fertilization. Additionally, N fertilization did not promote effect on the yields of the varieties, regardless of the Mo application (Figure 4).

3.4. Technological attributes of sugarcane for agribusiness

The purity of the sugarcane was not influenced by the Mo fertilization and the varieties, but it was reduced by the N application, regardless of the variety and Mo application (Figure 5).

The AR percentage varied by the Mo fertilization and there was the synergistic effect between the N application and the sugarcane varieties (Figure 5). The application of 200 g ha⁻¹ of Mo caused a deleterious effect on the AR percentage, but N fertilization on the variety RB867515 doubled the AR percentage. No differences were observed in the total soluble solids and Pol with the fertilizers application in the different varieties (Figure 5).

Figure 5. Purity (A and B), reducing sugars (C and D), total soluble solids (E and F) and apparent sucrose (G and H) of the sugarcane varieties submitted the combined application of N and Mo. Means in the same column followed by the same letter do not differ significantly by the Tukey test ($P \leq 0.05$). Uppercase letters compare the varieties and lowercase letters compare the effect of Mo or N.

No effects were observed for the N and Mo application on the fiber percentage in the different varieties (Figure 6).

The PC and ATR were influenced by the N application

(Figure 6). The application of 60 kg ha⁻¹ of N reduced the sugar percentage in both sugarcane varieties and the Mo fertilization not influenced to minimize this reduction.

Figure 6. Fiber (A), sucrose in the stem (B) and recoverable theoretical sugar (C) of sugarcane varieties submitted the application of N. Means in the same column followed by the same letter do not differ significantly by the Tukey test ($P \leq 0.05$). Uppercase letters compare the varieties and lowercase letters compare the effect of N.

4. Discussion

The soil Mo content in this study was linearly reduced with the cultivation time, when sugarcane was fertilized with N and Mo. Otto *et al.* (2009) observed that the N application in the planting of the variety SP81-3250 increased the root and shoot growth of sugarcane in Eutrophic Red-Yellow Latosol. Therefore, the increase of root biomass by N fertilization may have increased the Mo absorption in this study.

The reduction of Mo content in the soil surface layer cultivated with the variety RB867515 by N fertilization was due to higher Mo absorption. Oliveira *et al.* (2013) reported that N fertilization in RB867515 promoted an increase in shoot dry matter (MSPA) and Oliveira (2012) observed a higher Mo accumulation in sugarcane fertilized with N. However, Oliveira (2012) observed also that the application of doses up to 1,600 g ha⁻¹ of Mo promoted linear increases in the Mo content available from the soil.

The Mo content of the soil was increased up until 30 days after the application, because during that period there was no significant root growth and little or no Mo absorption (Jadoski *et al.*, 2010). The sugarcane only 30 DAP initiates bud and root primordia emission. During this period, the plants utilizes stem reserves to meet their nutritional requirements (Jadoski *et al.*, 2010). However, roots formed from this period absorbed Mo for assimilation of N-NO₃, due their action in regulation of the nitrate reductase enzyme (Li-Ping *et al.*, 2007; Nie *et al.*, 2016). In fact, Mo levels in the soil were reduced from this period (Figure 2).

The decrease Mo content in soil was higher when the plants approached the phase of higher dry matter accumulation (Jadoski *et al.*, 2010). The Mo absorption by the sugarcane varieties is mainly due to its role as an activator of the nitrate reductase enzyme.

The sugarcane tillering phase occurs from 40 to 120 DAP, when the aerial part begins to grow, with formation and elongation of the shoots up to 270 DAP (Jadoski *et al.*, 2010). The N uptake by sugarcane in these two phases is high, and the second phase is responsible for the greatest nutrient accumulation (Silveira and Crocomo, 1990).

Thus, considering that there is predominance of NO₃ to the detriment of NH₄⁺ in the aerated soils (Amoo and Babalola, 2017), the plants absorb Mo for use in the assimilation of N-NO₃, reducing the levels of this micronutrient in the soil (Robinson *et al.*, 2011). This reduction occurred up to 250 DAP in both N-fertilized varieties and in the absence of Mo (Figure 2). Subsequently, the Mo content increased in the soil surface layer because the absorption by the plants was reduced or ceased. Also, the increase Mo content in soil could be as a result of mineralization of the organic matter.

The highest levels of Mo with the Mo fertilization in the subsurface layer in relation to the superficial layer, occurred due to the application mode of the Mo. The Mo was sprayed in the stems that were planted at the bottom of the groove. In addition, the rapid reductions in Mo content in the subsurface layer can be explained by the higher density of positive charges to adsorb the molybdate anion, due to the 49% increase in the clay content in the subsurface layer in relation to the surface layer (Table 1).

The sugarcane stalks and N fertilizer were placed in grooves of 0.2 m depth in the plantation and soon after, there was heavy rainfall (Figure 1), and the Mo absorption was initially higher in the subsurface layer. Additionally, it is possible that N fertilization stimulated the root system of the sugarcane varieties to the subsurface layer, favoring a higher Mo absorption in this layer.

We found in this study that the Mo content differed only in the roots of the varieties, with RB867515 being more cumulative than RB92579 (Table 2). This higher Mo absorption by RB867515, was due to its higher growth and biomass production.

The greatest Mo accumulation in variety RB867515 may have been due to some factors: larger root system, which allowed for greater soil exploration and, consequently, greater access to available Mo; greater metabolic capacity of nutrient absorption of the variety; higher N uptake in the nitrate form; higher N-fixing capacity of the variety. There may have been a combination of more than one of these factors, making the RB867515 more Mo-accumulating than RB92579.

In addition, Mo levels in the roots of the varieties indicated a Mo concentration in RB867515 and a dilution in RB92579. One hypothesis for this is that RB867515 has a lower translocation capacity, and accumulates Mo in the roots.

Mo contents were higher both in the leaf and in the roots when Mo was applied, regardless of the sugarcane variety and N application (Table 2), demonstrating the effectiveness Mo application. Brennan and Bolland (2007) cultivated wheat in the absence and presence of Mo fertilization in acid soils. According to the authors, when the wheat received the dose of 160 g ha^{-1} of Mo, the grains produced presented an increase of 285% in the Mo content, corroborating the results of this work.

N fertilization promoted a greater growth of the root system (Otto *et al.*, 2009), positively influencing Mo absorption, independent of its application. In the aerial part, although the N addition also promoted an increase in Mo contents, the enzymatic activity probably required more Mo, not allowing a significant effect of the N application in the Mo contents.

Mo Fertilization influenced agricultural and sugar productivity of the RB867515 more than RB92579. Santos (2014) reported that Mo stimulated the activity

of the nitrate reductase enzyme in the RB867515 and had no effect on the enzyme activity in the RB92579. When the enzyme is more stimulated, there is an increase in N assimilation and increase of productivity. Few studies evaluated the yield of stems of different sugarcane varieties under the effect of Mo fertilization (Polidoro, 2001; Oliveira, 2012) and presented controversial results. Oliveira (2012) did not find a significant effect of Mo fertilization on sugarcane productivity. Polidoro (2001) reported an increase of 25% in shoot yield with the application of 400 g ha^{-1} of Mo, corroborating the results of this study.

The agricultural productivity found in this study was low. Oliveira *et al.* (2011) studying nutritional efficiency in sugarcane varieties reported that the yields of the varieties RB867515 and RB92579 in the cane-plant without irrigation were of approximately 90 Mg ha^{-1} . The low productivity in both varieties was attributed to the low quality of the buds used in the planting and the competition with spontaneous herbs in the first two months of cultivation. During the cultivation of sugarcane of this study no was herbicides application due to its negative effect on the population of N-fixing bacteria (Silva *et al.*, 2016). The competition with spontaneous herbs can decrease from three to four times the number of stems per linear meter and from six to seven times the productivity (Jadoski *et al.*, 2010).

Mo fertilization increased the levels of Mo available in the soil (Figures 2 and 3), promoting a higher Mo absorption by RB867515 (Table 2), stimulating the extraction of N (Oliveira, 2012). The Mo increased assimilation of N-NO_3^- , due to its acting as an activator of nitrate reductase (Li-Ping *et al.*, 2007) and/or enhancing the biological N fixation by the participation of Mo in the nitrogenase responsible for the reduction of N_2 to NH_3 (Li-Ping *et al.*, 2007), increasing the yield of stalks and sugar (Figure 4).

The increase in productivity promoted by N fertilization in the cane-plant cycle is controversial because

to the higher source of N absorbed in this cycle not is mineral origin (Franco *et al.*, 2011). However, there are studies that have shown antagonistic results. Franco *et al.* (2011), when evaluating aerial biomass in response to N fertilization in the cane-plant cycle, observed that the application of up to 120 kg ha⁻¹ of N did not promote increases in the variety SP81-3250 in Eutrophic Yellow Red Latosol. However, an increase of biomass was observed when the same variety was cultivated in dystrophic Red Latosol with application of up to 80 kg ha⁻¹ of N.

Azeredo *et al.* (1986), in evaluations carried out in 135 experiments in different regions of Brazil, observed that in 80% of cases the cane-plant did not respond to N fertilization. Oliveira (2012), in a study carried out in three environments in northeastern Brazil, found a positive variation of shoot yield in the variety RB92579, as a response to the increase of N. N fertilization reduced the purity of sugarcane (Figure 5). However, they were not lower than the critical percentages recommended by the Sugarcane Producers Council in Brazil (CONSECANA, 2006). In accordance with quality standards, industrial units may refuse loading of sugarcane when the purity percentage of the broth is <75% and in this study the values of purity were more high (Figure 5).

Tasso Júnior *et al.* (2007) evaluated the effect of different combinations of organic and mineral fertilization on the variety SP81-3250 and observed that the percentage of AR was 0.31% with the application of 120 kg ha⁻¹ of N, much smaller than the effect of the application of 60 kg ha⁻¹ of N found in this study. RB867515 concentrated more sugar with the application of less N than SP81-3250.

Andrade *et al.* (2000) also did not found differences on total soluble solids and the percentage of Pol in the variety SP79-2233 with application of up to 200 kg ha⁻¹ of N. Oliveira *et al.* (2011) found that the total soluble solids and the percentage of Pol in the varieties RB867515

and RB92579 were 21.3 and 18.5%, respectively. Therefore, the values are similar to those of this study.

Fiber percentage of the sugarcane varieties in this study were higher than the industry recommendation. Oliveira *et al.* (2009) reported that the recommended range of fiber percentage should be from 10.5 to 12.5% for energy maintenance of the agribusiness units processing sugarcane.

N fertilization reduced the sugar percentage. However, the sucrose percentage found in this study was 16% higher than the observed by Tasso Júnior *et al.* (2007). The ATR values found in this study were higher than the found by Oliveira *et al.* (2011). These authors reported ATR values in the varieties RB867515 and RB92579 of 151 and 147 kg Mg⁻¹, respectively. These values were approximately 92% of the value found in this study with the application of 60 kg ha⁻¹ of N (Figure 6).

5. Conclusions

Mo fertilization promoted increase of Mo content in both the superficial and subsurface layers of the soil. The sugarcane variety RB867515 was influenced by the Mo fertilization and the agricultural and sugar yield were increased with the Mo application. N fertilization did not increase agricultural productivity and reduced the sucrose percentage and recoverable theoretical sugar, and Mo did not change this reduction. It is suggested that N fertilization should be reduced in this cultivation cycle, but Mo fertilization should be stimulated.

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