Fertilization/ Original Article

Ammonium chloride as an alternative source of nitrogen for sugarcane during two consecutive cycles

Michele Xavier Vieira Megda[(1 ✉)] ,
Eduardo Mariano[(2)] ,
José Marcos Leite[(3)],
Marcio Mahmoud Megda[(1)] and
Paulo Cesar Ocheuze Trivelin[(4)]

[(1)] Universidade Estadual de Montes Claros, Departamento de Ciências Agrárias, Avenida Reinaldo Viana, nº 2.630, Bico da Pedra, Caixa Postal 91, CEP 39440-000 Janaúba, MG, Brazil. E-mail: michelemegda@unimontes.br, marcio_agr@yahoo.com.br

[(2)] Universidade Estadual Paulista Júlio de Mesquita Filho, Faculdade de Ciências Agronômicas, Departamento de Produção e Melhoramento Vegetal, Avenida Universitária, nº 3.780, Altos do Paraíso, CEP 18610-034 Botucatu, SP, Brazil. E-mail: dumariano@gmail.com

[(3)] Compass Minerals, Rodovia Piracicaba-Limeira (SP 147), Km 125, Marrafon, CEP 13495-000 Iracemápolis, SP, Brazil. E-mail: jose.leite@produquimica.com.br

[(4)] Universidade de São Paulo, Centro de Energia Nuclear na Agricultura, Avenida Centenário, nº 303, São Dimas, CEP 13416-900 Piracicaba, SP, Brazil. E-mail: pcotrive@cena.usp.br

✉ Corresponding author

Abstract – The objective of this work was to evaluate the effect of the application of ammonium chloride as a nitrogen source for sugarcane (*Saccharum* sp.) on the development of the crop's shoot and roots during two consecutive cycles. The experiment was conducted on a Typic Hapludox in the first and second sugarcane ratoons. The treatments consisted of four N doses (50, 100, 150, and 200 kg ha^{-1}) applied as ammonium chloride (NH$_4$Cl), besides a control, without the application of N. The increase in the NH$_4$Cl dose increased in up to three times soil electrical conductivity in the layer of 0.0–0.2 m, with a consequent increase in the concentration of chlorine in leaves. In the second cycle, the contents of chlorine increased in 1,900 mg kg^{-1} in the leaf with the application of 200 mg kg^{-1} NH$_4$Cl, when compared with the control. In the first cycle, the application of NH$_4$Cl doses above 200 kg ha^{-1} N promoted a decrease in shoot productivity. In both cycles, there was no effect of the NH$_4$Cl doses on root dry matter. High doses of NH$_4$Cl, in consecutive sugarcane cycles, result in a decrease in the productivity of stalks for processing.

Index terms: *Saccharum*, electrical conductivity, nitrogen fertilization, root system, stalk productivity.

Cloreto de amônio como fonte alternativa de nitrogênio para cana-de-açúcar durante dois ciclos consecutivos

Resumo – O objetivo deste trabalho foi avaliar o efeito da aplicação de cloreto de amônio como fonte de nitrogênio para cana-de-açúcar (*Saccharum* sp.) no desenvolvimento da parte aérea e radicular da cultura durante dois ciclos consecutivos. O experimento foi conduzido em Latossolo Vermelho distrófico típico nos ciclos de primeira e segunda soqueira. Os tratamentos consistiram de quatro doses de N (50, 100, 150 e 200 kg ha^{-1}) aplicadas na forma de cloreto de amônio (NH$_4$Cl), além do controle, sem aplicação de N. O aumento da dose de NH$_4$Cl elevou em até três vezes a condutividade elétrica do solo na camada de 0,0–0,2 m, com consequente aumento na concentração de cloro nas folhas. No segundo ciclo, os teores de cloro aumentaram em 1.900 mg kg^{-1} na folha com a aplicação de 200 mg kg^{-1} de NH$_4$Cl, em comparação ao controle. No primeiro ciclo, a aplicação de doses de NH$_4$Cl acima de 200 kg ha^{-1} de N promoveu queda na produtividade de colmos. Em ambos os ciclos, não houve efeito das doses de NH$_4$Cl na fitomassa seca de raízes. Elevadas doses de NH$_4$Cl, em ciclos consecutivos da cana-de-açúcar, resultam em decréscimos na produtividade de colmos industrializáveis.

Termos para indexação: *Saccharum*, condutividade elétrica, adubação nitrogenada, sistema radicular, produtividade de colmos.

Introduction

Brazil is the world's largest sugarcane (*Saccharum* spp.) producer, accounting for 35% of the crop's output, and also the leading sugar producer and exporter. According to Companhia Nacional de Abastecimento (Acompanhamento…, 2017), sugarcane production in the 2016/2017 harvest totaled 657 million tons in a 9 million hectare area, with an average yield of 73 Mg ha^{-1}. However, studies indicate that sugarcane yield is still far below the genetic potential of the currently used cultivars, which can produce above 300 Mg ha^{-1} stalks for processing (Waclawovsky et al., 2010).

In general, for their development, crops require high nitrogen doses, which are one of the main factors responsible for increasing agricultural production. Although N composes, on average, 1% of total plant dry matter, its deficiency compromises plant growth and crop yield. In Brazil, the N doses applied to sugarcane crops are relatively low, representing one third of the ones applied in other producing countries (Robinson et al., 2011). According to these authors, the average N application in Australia has increased from 100 to 200 kg ha^{-1} in the last 30 years, whereas in India, China, and Pakistan extreme doses range from 400 to 750 kg ha^{-1} N.

It should be noted that Brazil has become increasingly dependent on imported fertilizers, which currently account for 75% of total N demand, ranking the country as the fourth major importer of feedstock for the production of N fertilizers. Besides its costs, N use in agriculture causes environmental concerns, since the uptake by crops of the applied N fertilizer is less than 40% (Fortes et al., 2011; Franco et al., 2011). Most applied N is lost into the atmosphere as ammonia gas and nitrous oxide or even leached as a nitrate anion (Börjesson et al., 2009).

Losses are even more worrisome in sugarcane crops, whose residues on soil surface reach 15 Mg ha^{-1} after the mechanical harvest of raw cane; this hinders the incorporation of N to the soil and increases the risks of N losses by the volatilization of ammonia gas, especially urea, due to the high susceptibility of the nutrient to enzymatic hydrolysis by the action of urease when it is applied superficially and in direct contact with plant residues (Mariano et al., 2012, 2016). Therefore, studies on new N sources are crucial, which may increase N use efficiency by sugarcane.

Ammonium chloride, a byproduct of sodium bicarbonate production, contains 25 and 65% N and chlorine, respectively, and can be used as a nitrogen fertilization source in crops (Ashraf et al., 2005; Megda et al., 2012). Vieira et al. (2010) evaluated the response of sugarcane to ammonium chloride doses and found an increase in yield in the first year of application, followed by a decrease in stalk and sugar production per area in the next cycle, when the residual effect of that source was assessed. Studies have shown that high doses of ammonium chloride may decrease crop growth (Megda et al., 2014; Vieira-Megda et al., 2015; Leite et al., 2016), requiring further investigation on its viability as a N source. Negative effects of the chloride ion on crop development are mainly related to the increase in the osmotic potential of the soil solution, which induces plants to hydric stress and also causes a direct toxic effect, mainly on the enzymatic and membrane systems (Alves et al., 2011). Therefore, since sugarcane is a semi-perennial crop, new studies should investigate its responses to N fertilization with ammonium chloride, not only within one, but also within consecutive cycles.

The objective of this work was to evaluate the effect of the application of ammonium chloride as a nitrogen source for sugarcane on the development of the crop's shoot and roots during two consecutive cycles.

Materials and Methods

The experiment was conducted in a commercial area of first and second sugarcane ratoons during the 2009/2010 and 2010/2011 crop seasons, in the region of Piracicaba, in the state of São Paulo, Brazil (22º35"S, 47º37"W, at an altitude of 619 m).

The soil was classified as a Latossolo Vermelho distrófico típico (Santos et al., 2013), i.e., a Typic Hapludox, according to Soil Survey Staff (2014). Two correctives – 2 Mg ha^{-1} dolomitic limestone and 2 Mg ha^{-1} agricultural gypsum – were incorporated into the soil by heavy harrowing. The cultivar SP89-1115 of sugarcane was planted on March 8, 2008, using two seedlings per meter, providing a distribution of 17–20 buds per meter of furrow, at a depth of 0.15 m. Mineral fertilization was carried out with the application of potassium chloride and simple superphosphate into the planting groove, in order to supply 120 kg ha^{-1} K$_2$O and 120 kg ha^{-1} P$_2$O$_5$, respectively. The cane plant

was harvested mechanically without burning events in June 2009, and crop residues (pointers, leaves, and pieces of stalk) were deposited on soil surface.

Soil chemical attributes were analyzed at the depths of 0.0–0.2 and 0.2–0.4 m, according to Raij et al. (2001). For both layers, the obtained values were: 4.6 pH in $CaCl_2$ 0.01 mol L^{-1}, 29 mg dm^{-3} phosphorus resin, 5.0 $mmol_c$ dm^{-3} Al extracted with potassium chloride, and 0.5 mg dm^{-3} Zn. For the first and second layers: 39 and 33 g dm^{-3} organic matter by the colorimetric method, respectively; 4.3 and 4.6 $mmol_c$ dm^{-3} potassium extracted by ion-exchange resin; 13 and 29 $mmol_c$ dm^{-3} Ca; 6.0 and 12 $mmol_c$ dm^{-3} Mg extracted by ion-exchange resin; 72 and 80 $mmol_c$ dm^{-3} H+Al by the SMP method; 0.24 and 0.17 mg dm^{-3} B; 2.0 and 3.8 mg dm^{-3} Cu; 76 and 67 mg dm^{-3} Fe; 6.9 and 5.3 mg dm^{-3} Mn; 72 and 80 $mmol_c$ dm^{-3} H+Al; 95.3 and 125.6 $mmol_c$ dm^{-3} cation exchange capacity at pH 7.0; sum of bases of 23.3 and 45.6 $mmol_c$ dm^{-3}; and base saturation of 24 and 36%.

The experimental design was a randomized complete block design with four replicates and 202.5 m^2-experimental plots, each containing 10 rows of 15 m with a row spacing of 1.5 m.

The treatments consisted of four N doses (50, 100, 150, and 200 kg ha^{-1}) applied in the form of ammonium chloride, besides a control, without N application. The N source was applied manually on the residual sugarcane straw, which totaled 17.2 Mg ha^{-1}, in a band, 0.2 m away from the crop row.

In addition, 90 kg ha^{-1} K_2O in the form of KCl were applied in all treatments. Due to the high P content of 29 mg dm^{-3} in the soil, phosphate fertilization was not carried out. Fertilization treatments were applied on September 28, 2009, 90 days after harvesting (DAH), on the first ratoon; and on October 6, 2010, 150 DAH, on the second ratoon.

Soil electrical conductivity (EC) was determined at 60 days after fertilization (DAF) in the first ratoon and at 30 DAF in the second, at the layers of 0.0–0.2 and 0.2–0.4 m, as proposed by Raij et al. (2001), in order to express the total concentration of salts (μS cm^{-1}) in the soil solution. It should be pointed out that EC was determined at 30 DAF in the second ratoon to reduce the time between its evaluation and fertilization, in order to estimate the concentration of salts in the rhizosphere before total absorption by plants.

In both harvests, in February 2010 and 2011, at 60 DAF, diagnostic leaves were collected to determine leaf chlorine concentration. Five leaves at position +1 (F+1), identified according to the Kuijper system, were randomly collected in each plot, comprising a composite sample. The samples were dried in a forced-air circulation oven at 65ºC and ground in a Wiley-type mill (30-mm mesh), and chlorine concentrations were obtained according to Malavolta et al. (1997), using the silver nitrate titration method.

The dry matter production of the sugarcane shoot and root system was determined at the end of the vegetative cycle of the second ratoon, at 210 DAF. To evaluate shoot dry matter, all vegetal material was collected in 2 m of each row, one sample per plot. The number of tillers in the samples was counted, the dry matter of the material was quantified, and the average dry matter per tiller was obtained. The tillers were also counted in 15 m of each row (three 5-m segments) per plot, and the average number of tillers per hectare (considering that 1 ha with a row spacing of 1.5 m has 6,667 linear meters) was determined. Stalk yield (Mg ha^{-1}) was calculated by multiplying the number of tillers per hectare by the average dry matter of tillers estimated in 2 m.

After weighing the shoot material, the samples with natural moisture were crushed in a mechanical grinder. Subsamples of this material were packed in hermetically sealed plastic bags, weighed on an analytical scale, and dried in a ventilated oven at 65ºC to obtain plant moisture and dry matter.

Root dry matter was evaluated in the second cycle in May 2011, at 230 DAF, as described by Otto et al. (2009). Belowground rhizomes were also sampled in 1 m of each row planted with sugarcane. Roots and rhizomes were separated from the soil using 2-mm mesh sieves, and, in the laboratory, root samples were washed in 1-mm mesh sieves and dried at 65ºC for moisture determination.

Stalk yield per hectare, i.e., tons of sugarcane stalks per hectare (TSH), was evaluated in May 2010 and August 2011, at 240 and 300 DAF, in the first and second cycles, respectively, by mechanical cutting and weighing of the chopped cane in an instrumented truck. Four rows per plot (second, third, fourth, and fifth rows) were collected, totaling 60 linear meters per plot. The results of each plot were extrapolated to 1 ha considering 6,667 m of cane row per hectare.

The results were subjected to the analysis of variance using the F-test, at 95% probability, with the SAS software (SAS Institute Inc., Cary, NC, USA). Subsequently, for significant causes of variation, the regression analysis was applied to verify the effect of N doses.

Results and Discussion

The increase in the N dose applied in the form of ammonium chloride reduced TSH in the two cycles evaluated, represented by a decreasing linear equation (Figure 1). In the first cycle, an average yield of 105 Mg ha^{-1} was reached with the control, and one of 75 Mg ha^{-1} with the dose of 200 kg ha^{-1} N.

There was a reduction in stalk yield from the first to the second ratoon, from 89 to 74 Mg ha^{-1} when applying the control and 200 kg ha^{-1} N, respectively. These results may be attributed to the high concentration of salts in the rhizosphere in the initial phase of crop development, in the first and second cycles, when the plants had 30 cm of height on average, mainly due to chlorine excess in the soil, since the Cl^{-} anion accounts for 65% of ammonium chloride composition. In the control, EC values were rather high, averaging 70 μS cm^{-1} at 60 DAF in the first cycle and above 100 μS cm^{-1} at 30 DAF in the second one, increasing considerably with the increase of ammonium chloride doses (Figure 2).

The dose of 200 kg ha^{-1} ammonium chloride corresponded to 520 kg ha^{-1} Cl^{-} plus 60 kg ha^{-1} Cl^{-} added as KCl (90 kg ha^{-1} K$_2$O). In general, plants take up a high amount of chlorine, an important anti-cation along with K^{+} (Taiz et al., 2017). However, in excess, chloride can dissipate the cytosolic pH, damaging several enzymatic reactions. Vieira et al. (2010) and Megda et al. (2012) evaluated the residual effect of ammonium chloride doses on the yield of sugarcane cultivated on a Typic Hapludox and, despite the increase in shoot yield observed in the first experimental year, there was a decrease in crop shoot with the increase of the applied doses. In the following harvest, when the residual effect of ammonium chloride doses was assessed, there was a significant reduction in crop yield. As sugarcane is considered moderately sensitive to soil salinity (Santana et al., 2007), the decrease in shoot yield at 60 DAF due to ammonium chloride

doses may have been aggravated by the excess of salts in the rhizosphere.

In addition, climatic factors must be taken into account, since they have great influence on stalk yield. Although rainfall (1,862 mm) was intense in the 2009/2010 crop season, fertilization was carried out in the second ten-day period of September, when rainfall was low, averaging 9 mm (Figure 3); there was also water deficit in November. The reports found in the literature show that, when water availability is reduced in the soil, the response to fertilization decreases due to hydric stress (Otto et al., 2011). However, according
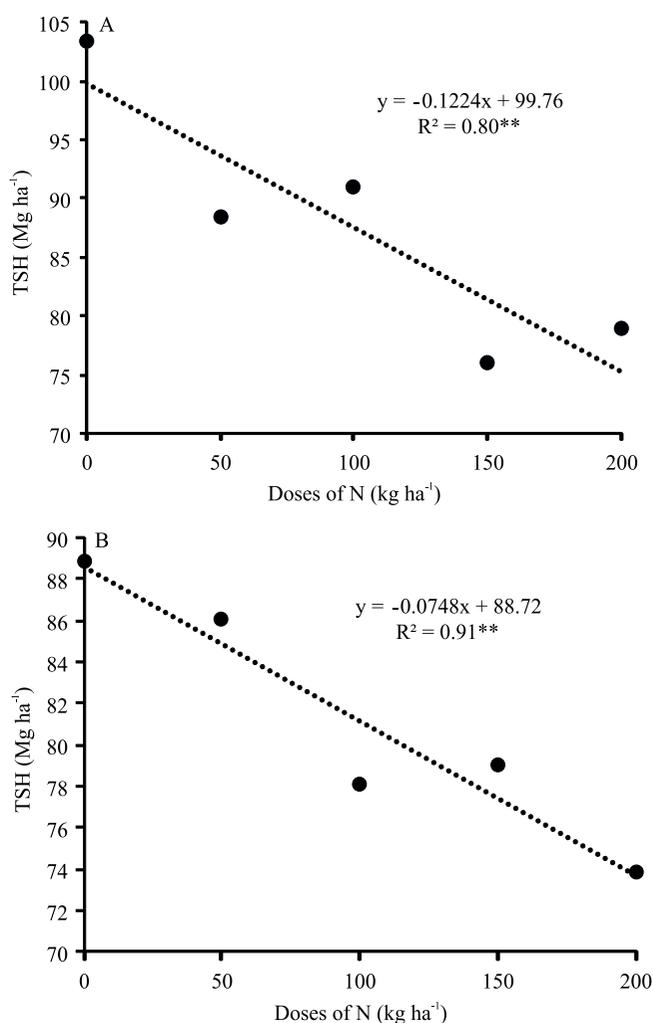

Figure 1. Tons of sugarcane stalks per hectare (TSH) in the first sugarcane (*Saccharum* spp.) ratoon, in the 2009/2010 harvest (A), and in the second ratoon, in 2010/2011 (B), as a function of the application of N doses as ammonium chloride (NH$_4$Cl). **Significant at 5% probability.

to Inman-Bamber & Smith (2005), a well-distributed annual rainfall of 1,000 mm is enough to obtain high sugarcane yields. It should be pointed out that chlorine is highly mobile in the soil and, depending on rain volume, it can be partially leached, mainly at higher doses of ammonium chloride; however, due to the low rainfall observed at fertilization, plants probably absorbed large amounts of that nutrient.

Studies have shown a reduction in plant growth and crop yield under saline stress (Jacobs & Timmer, 2005). These authors attributed the decrease in yield to the increase in osmotic pressure and the reduction in the hydric potential of the soil solution generated by the excess of ions in the rhizosphere, hindering water uptake by plant roots. Water is an essential factor for cell expansion, and its limitation implies in a lower cell and tissue growth and leaf area, affecting yield.

In the second ratoon cycle, rainfall totaled 1,550 mm and, although temperature and solar radiation allowed a high potential evapotranspiration of the crop, water storage in the soil was low during initial crop development and part of the vegetative phase (Cardozo & Sentelhas, 2013), limiting the real evapotranspiration (Figure 3).
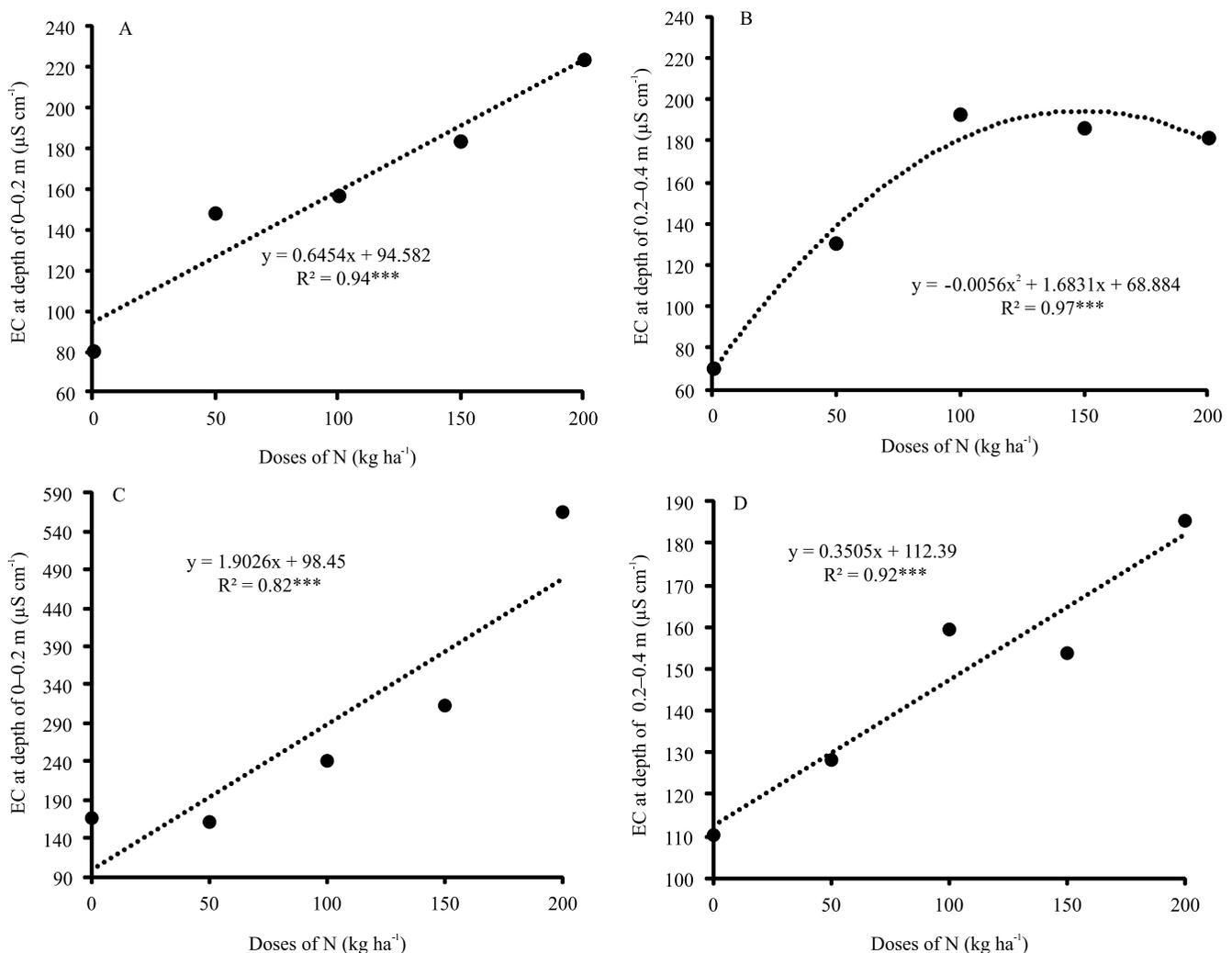

Figure 2. Electrical conductivity (EC) of the soil solution as a function of the application of N doses as ammonium chloride (NH_4Cl) at the depths of 0.0–0.2 m (A) and 0.2–0.4 m (B) at 60 days after fertilization (DAF) in the first sugarcane (*Saccharum* spp.) ratoon, in the 2009/2010 harvest, and at 0.0–0.2 m (C) and 0.2–0.4 m (D) at 30 DAF in the second sugarcane ratoon, in 2010/2011. ***Significant at 1% probability.

The increase in ammonium chloride doses was accompanied by a linear increase in soil EC in both cycles and depths evaluated (Figure 2). In the first cycle, at the depth of 0.0–0.2 m, at 60 DAF, the values of EC ranged from 80 to 220 $\mu S\ cm^{-1}$ for the control and the highest applied dose, respectively. In the soil layer of 0.2–0.4 m, there was a quadratic effect of ammonium chloride doses on EC, which ranged from 70 to 190 $\mu S\ cm^{-1}$ for the control and the highest dose

of 200 kg ha^{-1}, indicating the translocation of part of the fertilizer to the soil subsurface layer.

In the second cycle, EC at the 0.0–0.2-m layer was on average three times higher than that in the first cycle, evidencing that a large amount of salts accumulated in the soil arable layer from one cycle to the next. The EC values obtained in the subsurface layer of 0.2–0.4 m in the second cycle were similar to those of the first one, probably due to the lower rainfall volume in the 2010/2011 crop season, reducing the leaching of ions to deeper layers. According to Santana et al. (2007), yield decrease in sugarcane stalks can reach 50% in soils with high EC. The authors reported a linear evapotranspiration reduction of up to 20% under greenhouse conditions, as well as a dry matter decrease in sugarcane roots and shoots, regardless of soil texture.

There was a linear increase in chlorine contents in the diagnostic leaves with the increase of the ammonium chloride doses in the two cycles evaluated (Figure 4). In the first ratoon, at 60 DAF, the control plot had a high chlorine content in F+1, suggesting a high content of this nutrient in the soil used in the experiment due to previous fertilization, mainly with KCl. At the highest ammonium chloride dose, chlorine increased by 600 mg kg^{-1} in the diagnostic leaf, when compared with the control plants.

At 30 DAF in the second ratoon, Cl^- content at F+1 was approximately 9,000 mg kg^{-1}. These results also suggest a high chlorine content in the soil from the previous cycle. Symptoms of Cl^- toxicity are more common than deficiency, and tolerance depends on the species. For example, the most sensitive crops may show symptoms at 3,000 mg kg^{-1} dry matter, and the most tolerant ones at 20,000 mg kg^{-1} (Furlani, 2004). As previously mentioned, the sugarcane crop is considered moderately sensitive to high contents of salinity ions in the soil, such as Cl^- (Santana et al., 2007). According to Bethke & Drew (1992), the passive uptake process of chlorine can lead to its accumulation in large amounts in the shoots, causing enzymatic disturbances or unbalance of the electrochemical potential of cells, leading to a higher energy expenditure and causing toxicity, which decrease yield.

In the second ratoon cycle, the increase in ammonium chloride doses promoted a quadratic effect on stalk dry matter at 210 DAF. For both cycles, the doses of 100 and 150 kg ha^{-1} N resulted in the highest
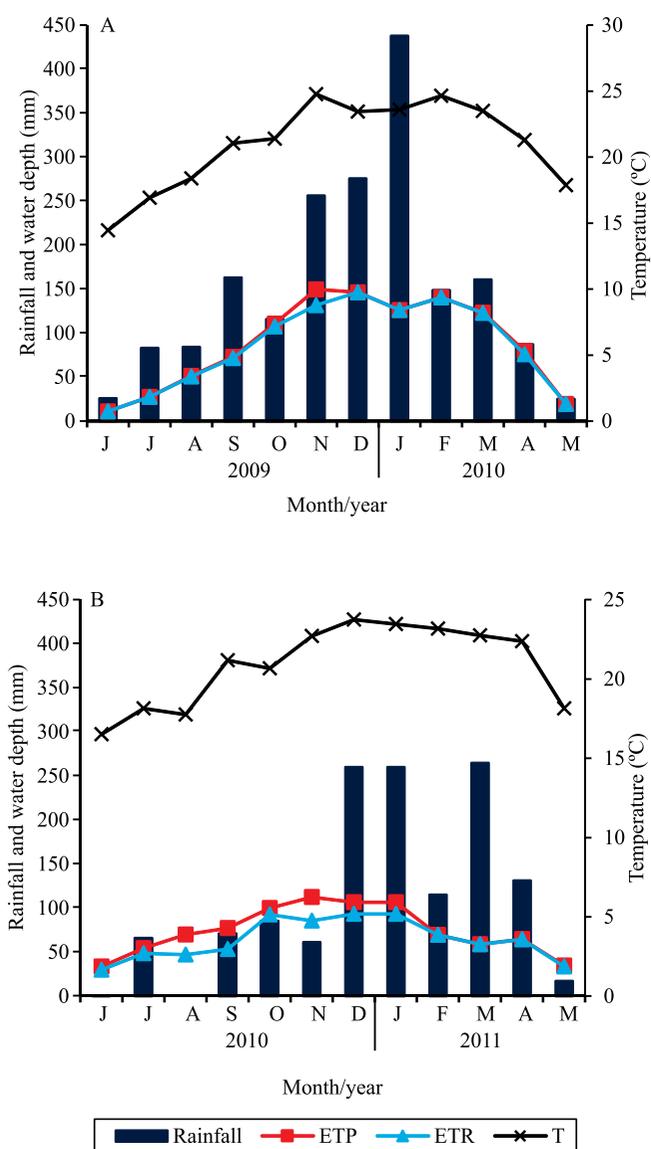

Figure 3. Climatic water balance in the first sugarcane (*Saccharum* spp.) ratoon, in the 2009/2010 harvest (A), and in the second ratoon, in 2010/2011 (B). ETp, potential evapotranspiration; ETr, real evapotranspiration; and T, temperature.

yield of 16 Mg ha^{-1}, while 200 kg ha^{-1} N decreased yield (Figure 5). Total dry matter accumulation of shoots, however, showed a linear increase of 2.2 Mg ha^{-1}, when comparing the yield of 21.3 Mg ha^{-1}, obtained with the control, with that of 23.5 Mg ha^{-1}, with the dose of 200 kg ha^{-1} N.

Presented as a powder, ammonium chloride has a very fine particle size, which confers it a high solubility; under low humidity conditions, this salt accumulates in the most arable layer of the soil, causing hydric stress to fertilized plants and consequent soil water loss (Munns & Tester, 2008). This explains why, despite the significant increase in stalk dry matter at 210 DAF,

the yield of stalks with natural moisture, for future processing, decreased with the increase of ammonium chloride doses at 300 DAF. Other studies have also shown a negative effect of ammonium chloride on crop yield, but the N dose studied was 100 kg ha^{-1} (Leite et al., 2016; Mariano et al., 2016). Furthermore, K$^+$ is essential to transport carbohydrates to stalks, which is directly related to water accumulation in this compartment. Since the Cl$^-$ ion is an important anti-cation, excess of Cl$^-$ may have affected negatively sugar transport and stalk moisture.

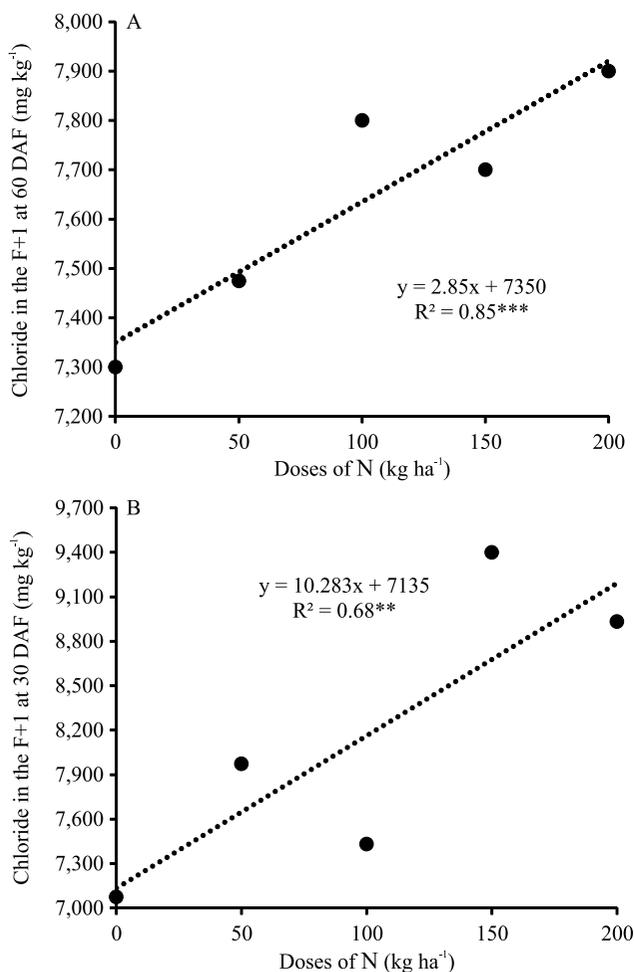The increase in the ammonium chloride dose increased N accumulation in sugarcane shoots

Figure 4. Chloride concentration in the diagnostic leaf (F+1) of sugarcane (*Saccharum* spp.) as a function of the application of N doses as ammonium chloride (NH$_4$Cl) at 60 days after fertilization (DAF) in the first sugarcane ratoon, in 2009/2010 (A), and at 30 DAF in the second sugarcane ratoon, in 2010/2011 (B). *** and **Significant at 1 and 5% probability, respectively.
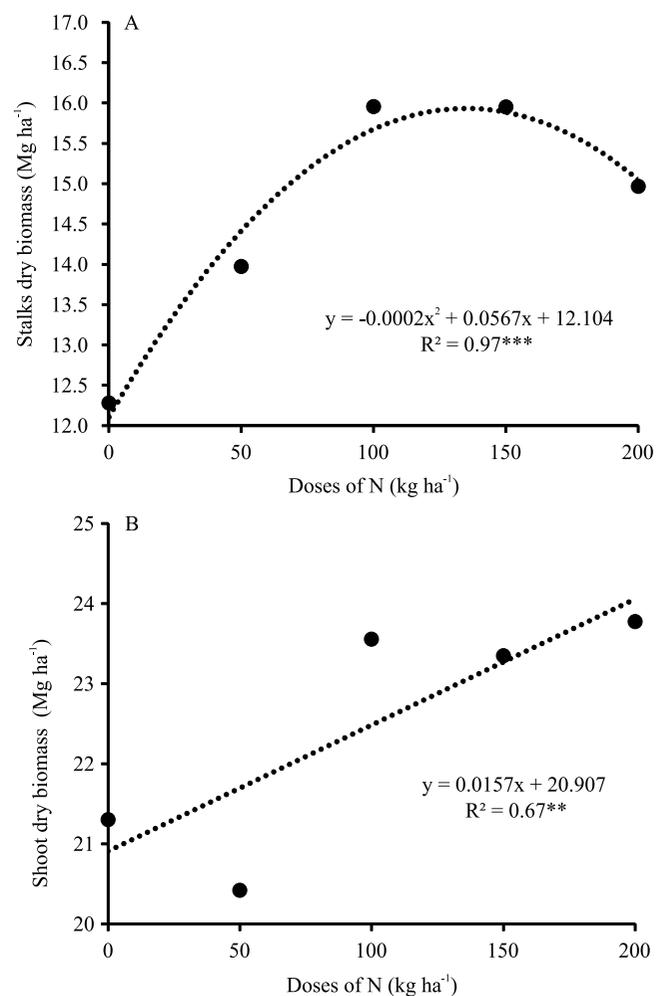
Figure 5. Dry matter of stalks (A) and total shoot (tillers, dry leaves, and pointers) (B) of sugarcane (*Saccharum* spp.) as a function of the application of N doses as ammonium chloride (NH$_4$Cl) in the in the second sugarcane ratoon, in 2010/2011 harvest. *** and **Significant at 1 and 5% probability, respectively.

and stalks (Figure 6), and, in spite of an increase in N accumulation in the shoots, it was inversely proportional to stalk yield. Franco et al. (2010), Mariano et al. (2015), Vieira-Megda et al. (2015), and Leite et al. (2016) found similar results studying N sources at the dose of 100 kg ha^{-1}. These authors were unanimous regarding the need for new studies including other doses of ammonium chloride and with the reapplication of this source in consecutive cycles.

The increase in ammonium chloride doses increased linearly the dry matter of rhizomes, accompanied by an increase in N accumulation in this compartment,
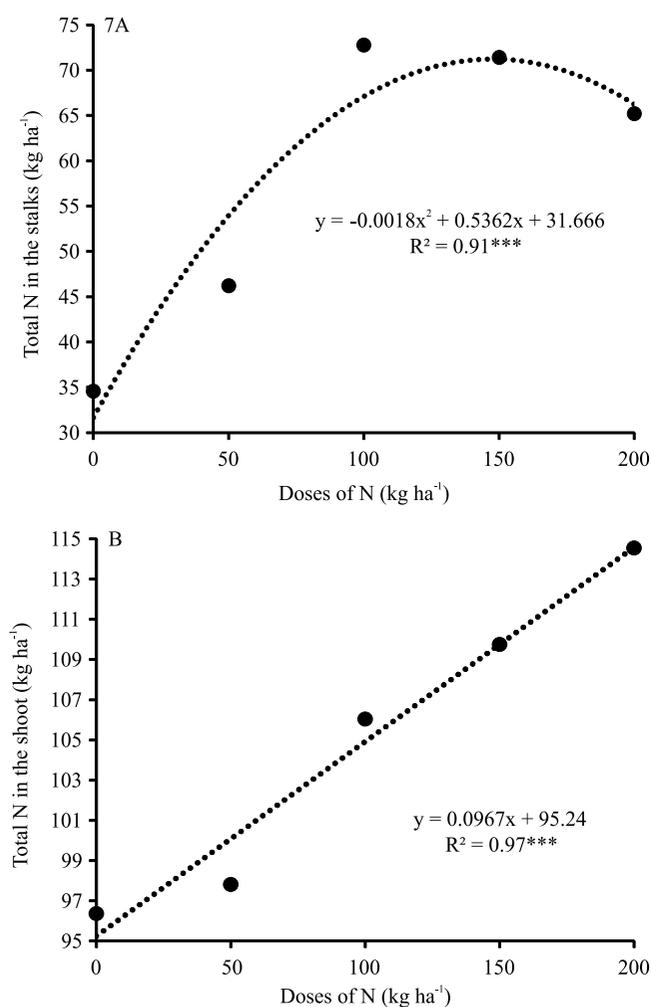
representing an important source of nutrient reserves for subsequent regrowth (Figure 7). Mariano et al. (2016) compared the effect of ammonium chloride with that of other N sources at the dose 100 kg ha^{-1} on sugarcane shoot yield and nutrient accumulation on two soil types – Typic Hapludox and Typic Eutrustox. The authors found that, in a single crop year, ammonium chloride did not increase plant dry matter on both soils; however, it increased N content in the shoot when compared with the control on a Typic Hapludox. Vieira-Megda et al. (2015) evaluated N contribution from fertilizers at the dose 100 kg ha^{-1} N using the

Figure 6. Nitrogen accumulation in the stalks (A) and in total shoot (stalks, dry leaves, and pointers) (B) of sugarcane (*Saccharum* spp.) as a function of the application of N doses as ammonium chloride (NH$_4$Cl) in the second sugarcane ratoon, in the 2010/2011 harvest. ***Significant at 1% probability.
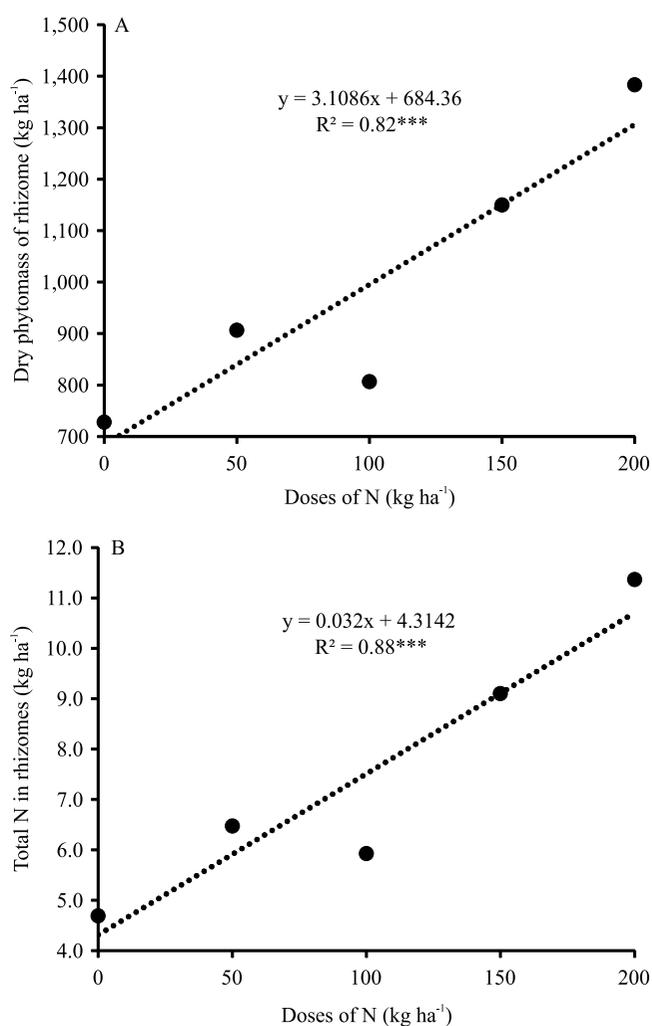
Figure 7. Dry phytomass of rhizomes (A) and total N in rhizomes (B) of sugarcane (*Saccharum* spp.) as a function of the application of N doses as ammonium chloride (NH$_4$Cl) in the second sugarcane ratoon, in the 2010/2011 harvest. ***Significant at 1% probability.

^{15}N tracer technique and reported no difference between sources regarding dry shoot and roots and N accumulation in these compartments during the first ratoon cycle. According to the latter authors, further studies are necessary to better understand the effect of ammonium chloride as a N source for sugarcane.

Conclusions

1. The increase in ammonium chloride doses as a source of nitrogen for sugarcane (*Saccharum* spp.) excessively increases the electrical conductivity of the soil solution, with consequent uptake by the crop and accumulation of chloride in the shoots.

2. The application of ammonium chloride does not affect the development of the root system of sugarcane, nor, consequently, N uptake and shoot dry matter accumulation.

3. High doses of nitrogen applied as ammonium chloride in consecutive cycles of the sugarcane crop result in a decrease in the yield of stalks for processing.

Acknowledgments

References

ACOMPANHAMENTO DA SAFRA BRASILEIRA [DE] CANA-DE-AÇÚCAR: safra 2016/17: quarto levantamento, v.3, n.4, abril 2017. Available at: <https://www.conab.gov.br/info-agro/safras/cana/boletim-da-safra-de-cana-de-acucar>. Accessed on: Aug. 12 2017.

ALVES, F.A.L.; FERREIRA-SILVA, S.L.; SILVEIRA, J.A.G. da; PEREIRA, V.L.A. Efeito do Ca^{2+} externo no conteúdo de Na^+ e K^+ em cajueiros expostos a salinidade. **Revista Brasileira de Ciências Agrárias**, v.6, p.602-608, 2011. DOI: https://doi.org/10.5039/agraria.v6i4a1257.

ASHRAF, M.Y.; ALVI, A.K.; SARWAR, G.; QURESHI, M.S.; ASHRAF, M.; HUSSAIN, M. Effect of ammonium chloride on the growth and nutrient uptake by cotton grown in alkaline soil. **Agrochimica**, v.49, p.153-164, 2005.

BETHKE, P.C.; DREW, M.C. Stomatal and nonstomatal components to inhibition of photosynthesis in leaves of *Capsicum annuum* during progressive exposure to NaCl salinity. **Plant Physiology**, v.99, p.219-226, 1992.

BÖRJESSON, P. Good or bad bioethanol from a greenhouse gas perspective – what determines this? **Applied Energy**, v.86, p.589-594, 2009. DOI: https://doi.org/10.1016/j.apenergy.2008.11.025.

CARDOZO, N.P.; SENTELHAS, P.C. Climatic effects on sugarcane ripening under the influence of cultivars and crop age. **Scientia Agricola**, v.70, p.449-456, 2013. DOI: https://doi.org/10.1590/S0103-90162013000600011.

FORTES, C.; TRIVELIN, P.C.O.; VITTI, A.C.; FERREIRA, D.A.; FRANCO, H.C.J.; OTTO, R. Recovery of nitrogen (^{15}N) by sugarcane from previous crop residues and urea fertilisation under a minimum tillage system. **Sugar Tech**, v.13, p.42-46, 2011. DOI: https://doi.org/10.1007/s12355-011-0074-4.

FRANCO, H.C.J.; OTTO, R.; FARONI, C.E.; VITTI, A.C.; OLIVEIRA, E.C.A. de; TRIVELIN, P.C.O. Nitrogen in sugarcane derived from fertilizer under Brazilian field conditions. **Field Crops Research**, v.121, p.29-41, 2011. DOI: https://doi.org/10.1016/j.fcr.2010.11.011.

FRANCO, H.C.J; TRIVELIN, P.C.O.; FARONI, C.E.; VITTI, A.C.; OTTO, R. Stalk yield and technological attributes of planted cane as related to nitrogen fertilization. **Scientia Agricola**, v.67, p.579-590, 2010. DOI: https://doi.org/10.1590/S0103-90162010000500012.

FURLANI, A.M.C. Nutrição mineral. In: KERBAUY, G.B. (Org.). **Fisiologia vegetal**. Rio de Janeiro: Guanabara Koogan, 2004. p.40-75.

INMAN-BAMBER, N.G.; SMITH, D.M. Water relations in sugarcane and response to water deficits. **Field Crops Research**, v.92, p.185-202, 2005. DOI: https://doi.org/10.1016/j.fcr.2005.01.023.

JACOBS, D.F.; TIMMER, V.R. Fertilizer-induced changes in rhizosphere electrical conductivity: relation to forest tree seedling root system growth and function. **New Forests**, v.30, p.147-166, 2005. DOI: https://doi.org/10.1007/s11056-005-6572-z.

LEITE, J.M.; CIAMPITTI, I.A.; MARIANO, E.; VIEIRA-MEGDA, M.X.; TRIVELIN, P.C.O. Nutrient partitioning and stoichiometry in unburnt sugarcane ratoon at varying yield levels. **Frontiers in Plant Science**, v.7, art.466, 2016. DOI: https://doi.org/10.3389/fpls.2016.00466.

MALAVOLTA, E.; VITTI, G.C.; OLIVEIRA, S.A. de. **Avaliação do estado nutricional das plantas**: princípios e aplicações. Piracicaba: Potafos, 1997. 319p.

MARIANO, E.; LEITE, J.M.; MEGDA, M.X.V.; TORRES-DORANTE, L.; TRIVELIN, P.C.O. Influence of nitrogen form supply on soil mineral nitrogen dynamics, nitrogen uptake, and productivity of sugarcane. **Agronomy Journal**, v.107, p.641-650, 2015. DOI: https://doi.org/10.2134/agronj14.0422.

MARIANO, E.; LEITE, J.M.; VIEIRA-MEGDA, M.X.; CIAMPITTI, I.A.; VITTI, A.C.; FARONI, C.E.; FRANCO, H.C.J.; TRIVELIN, P.C.O. Biomass and nutrient content by sugarcane as affected by fertilizer nitrogen sources. **Crop Science**, v.56, p.1234-1244, 2016. DOI: https://doi.org/10.2135/cropsci2015.06.0349.

MARIANO, E.; TRIVELIN, P.C.O.; VIEIRA, M.X.; LEITE, J.M.; OTTO, R.; FRANCO, H.C.J. Ammonia losses estimated by an open collector from urea applied to sugarcane straw. **Revista Brasileira de Ciência do Solo**, v.36, p.411-419, 2012. DOI: https://doi.org/10.1590/S0100-06832012000200010.

MEGDA, M.X.V.; MARIANO, E.; LEITE, J.M.; MEGDA, M.M.; TRIVELIN, P.C.O. Chloride ion as nitrification inhibitor and its biocidal potential in soils. **Soil Biology & Biochemistry**, v.72, p.84-87, 2014. DOI: https://doi.org/10.1016/j.soilbio.2014.01.030.

MEGDA, M.X.V.; TRIVELIN, P.C.O.; FRANCO, H.C.J.; OTTO, R.; VITTI, A.C. Eficiência agronômica de adubos nitrogenados em soqueira de cana-de-açúcar colhida sem queima. **Pesquisa Agropecuária Brasileira**, v.47, p.1681-1690, 2012. DOI: https://doi.org/10.1590/S0100-204X2012001200002.

MUNNS, R.; TESTER, M. Mechanisms of salinity tolerance. **Annual Review of Plant Biology**, v.59, p.651-681, 2008. DOI: 10.1146/annurev.arplant.59.032607.092911.

OTTO, R.; SILVA. A.P.; FRANCO, H.C.J.; OLIVEIRA, E.C.A.; TRIVELIN, P.C.O. High soil penetration resistance reduces sugarcane root system development. **Soil and Tillage Research**, v.117, p.201-210, 2011. DOI: https://doi.org/10.1016/j.still.2011.10.005.

OTTO, R.; TRIVELIN, P.C.O.; FRANCO, H.C.J.; FARONI, C.E.; VITTI, A.C. Root system distribution of sugar cane as related to nitrogen fertilization, evaluated by two methods: monolith and probes. **Revista Brasileira de Ciência do Solo**, v.33, p.601-611, 2009. DOI: https://doi.org/10.1590/S0100-06832009000300013.

RAIJ, B. van; ANDRADE, J.C. de; CANTARELLA, H.; QUAGGIO, J.A. (Ed.). **Análise química para avaliação da fertilidade de solos tropicais**. Campinas: IAC, 2001. 285p.

ROBINSON, N.; BRACKIN, R.; VINALL, K.; SOPER, F.; HOLST, J.; GAMAGE, H.; PAUNGFOO-LONHIENNE, C.; RENNENBERG , H.; LAKSHMANAN, P.; SCHMIDT, S. Nitrate paradigm does not hold up for sugarcane. **PLoS ONE**, v.6, e19045, 2011. DOI: https://doi.org/10.1371/journal.pone.0019045.

SANTANA, M.J. de; CARVALHO, J. de A.; SOUZA, K.J. de; SOUSA, A.M.G. de; VASCONCELOS, C.L.; ANDRADE, L.A. de B. Efeitos da salinidade da água de irrigação na brotação e desenvolvimento inicial da cana-de-açúcar (*Saccharum* spp) e em solos com diferentes níveis texturais. **Ciência e Agrotecnologia**, v.31, p.1470-1476, 2007. DOI: https://doi.org/10.1590/S1413-70542007000500030.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; CUNHA, T.J.F.; OLIVEIRA, J.B. de. **Sistema brasileiro de classificação de solos**. 3.ed. rev. e atual. Brasília: Embrapa, 2013. 353p.

SOIL SURVEY STAFF. **Keys to soil taxonomy**. 12th ed. Washington: Usda, 2014. 372p.

TAIZ, L.; ZEIGER, E.; MØLLER, I.M.; MURPHY, A. **Fisiologia e desenvolvimento vegetal**. 6.ed. Porto Alegre: Artmed, 2017. 888p.

VIEIRA, M.X.; TRIVELIN, P.C.O.; FRANCO, H.C.J.; OTTO, R.; FARONI, C.E. Ammonium chloride as nitrogen source in sugarcane harvested without burning. **Revista Brasileira de Ciência do Solo**, v.34, p.1165-1174, 2010. DOI: https://doi.org/10.1590/S0100-06832010000400016.

VIEIRA-MEGDA, M.X.; MARIANO, E.; LEITE, J.M.; FRANCO, H.C.J.; VITTI, A.C.; MEGDA, M.M.; KHAN, S.A.; MULVANEY, R.L.; TRIVELIN, P.C.O. Contribution of fertilizer nitrogen to the total nitrogen extracted by sugarcane under Brazilian field conditions. **Nutrient Cycling in Agroecosystems**, v.101, p.241-257, 2015. DOI: https://doi.org/10.1007/s10705-015-9676-7.

WACLAWOVSKY, A.J.; SATO, P.M.; LEMBKE, C.G.; MOORE, P.H.; SOUZA, G.M. Sugarcane for bioenergy production: an assessment of yield and regulation of sucrose content. **Plant Biotechnology Journal**, v.8, p.263-276, 2010. DOI: https://doi.org/10.1111/j.1467-7652.2009.00491.x.