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ARIANI GARCIA

INTERACTION OF MAGNESIUM WITH POTASSIUM IN SUGARCANE

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I dedicate this thesis to my parents José and Osmarina,

my brother Alessandro and my niece Raissa,

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RESUMO

Objetivou-se avaliar o efeito do fornecimento de concentrações de Mg^{2+}e K^+, e da aplicação foliar de Mg^{2+} no desenvolvimento da raiz e parte aérea, bem como possíveis alterações no estado nutricional e na partição de carboidratos em plantas de cana-de-açúcar. Para tanto, três estudos foram conduzidos: i) avaliação do efeito de concentrações de Mg^{2+} (controle e deficiente) no desenvolvimento de plantas de cana-de-açúcar; ii) alterações metabólicas e nutricionais na cana-de-açúcar decorrentes do desequilíbrio de Mg^{2+} causado pelo alto nível de K^+; iii) eficiência da aplicação foliar de Mg^{2+} em plantas de cana-de-açúcar cultivadas em nutrição variada de K^+ e Mg^{2+}. Os experimentos foram conduzidos em casa de vegetação e as plantas cultivadas em solução nutritiva. Foram avaliados: o teor de clorofila nas folhas, parâmetros morfológicos das raízes (comprimento e diâmetro radicular), produção de matéria seca das partes da planta, composição nutricional e partição de amido, sacarose e açúcares redutores nas diferentes partes da planta. No geral, o adequado fornecimento de Mg^{2+} levou a maior produção de matéria seca, concentração de sacarose nos colmos e relação raiz/parte aérea. Clorofila *a*, *b* e carotenoides foram menores em plantas deficientes em Mg^{2+}. Ademais, foi observado maior concentração de amido e açúcares solúveis nas folhas e menor concentração de sacarose nos colmos destas plantas. Além disso, plantas deficientes em Mg^{2+} tiveram menor comprimento radicular e maior diâmetro, do que as quais apresentaram maior concentração de K^+ na raiz e maior translocação deste cátion para a parte aérea. O aumento da concentração de K^+ na solução nutritiva reduziu a concentração de Mg^{2+} nas raízes, folhas novas, folhas velhas e colmos da cana-de-açúcar, mesmo nas plantas controle de Mg^{2+}. Independente da nutrição com Mg^{2+}, no maior nível de K^+, todos os parâmetros biométricos avaliados neste estudo foram reduzidos. Plantas cultivadas sob deficiência de Mg^{2+} obtiveram maior concentração de amido nos colmos em altas concentrações de K^+. A aplicação foliar de Mg^{2+} aumentou o conteúdo de sacarose nos colmos e reduziu o de amido, independentemente do nível de K^+ avaliado. Além disso, foi observado plantas maiores com a aplicação foliar e alto nível de K, em ambos níveis de Mg^{2+} avaliados. Para os parâmetros biométricos, com ou sem aplicação foliar, a deficiência de Mg^{2+} pareceu afetar mais as plantas de cana-de-açúcar do que os altos níveis de K^+.

Palavras-chave: *Saccharum* spp.. Partição de carboidratos. Produção de clorofila. Estado nutricional. Nutrição de plantas. Potássio.

ABSTRACT

The aim of this study was to evaluate the effect of Mg^{2+} and K^+ concentrations, and Mg^{2+} foliar application on the root and shoot growth, as well as to check the alterations on the nutritional status and carbohydrates partitioning in sugarcane plants. For this purpose, three studies were conducted: i) evaluation of the effect of Mg^{2+} concentrations (adequate and deficient) on the sugarcane plants development; ii) metabolic and nutritional alterations in sugarcane due to Mg^{2+} imbalance caused by K^+ high level; iii) efficiency of the Mg^{2+} foliar application in sugarcane plants grown under varied levels of K^+ and Mg^{2+}. The experiments were estabilished in greenhouse and the plants grown in nutrition solution. The evalutions were: leaf chlorophyll content, root morphological parameters (length and root diameter), dry matter production of plant parts, nutritional composition and starch, sucrose and reducing sugars partitioning in the different plant parts. In general, the adequate supply of Mg^{2+} resulted in higher dry matter production, sucrose concentration in the stalks and root/shoot ratio. Chlorophyll *a, b* and carotenoids were lower in Mg^{2+} deficient plants. Moreover, higher concentration of starch and soluble sugars were observed in the leaves and lower starch concentration in the stalks of these plants. Besides, Mg-deficient plants had shorter root length and larger diameter, which presented higher K^+ concentrations in the root and higher translocation of this cation to the shoot. Increase in K^+ concentration in the nutrition solution reduced Mg^{2+} concentration in the roots, young leaves, old leaves and stalks of sugarcane, even in Mg^{2+} control plants. Regardless Mg^{2+} nutrition, at the highest level of K^+, all the plant growth parameters evaluated in this study were reduced. Plants grown under Mg^{2+} deficiency obtained higher starch concentration in the stalks at higher K^+ level. Magnesium foliar application raised the sucrose concentration in the stalks and reduced the starch, regardless the K^+ level evaluated. In addition, bigger plants were observed with foliar application and high K^+ level, at both Mg^{2+} levels. For the plant growth parameters, with or without foliar application, Mg^{2+} deficiency seemed to greater affect the sugarcane plants than the high levels of K^+.

Keywords: *Saccharum* spp.. Carbohydrate partitioning, Chlorophyll production, Nutritional status. Potassium

SUMMARY

GENERAL INTRODUCTION

The worldwide demand for ethanol from renewable sources combined with large cropping areas and favorable soil and climate conditions for sugarcane has made Brazil the largest producer of sugarcane and an important country for the export of sugar as a commodity (CONAB, 2018). The sugarcane production estimate for the 2018/19 cropping season is 615.84 million tons, which is 2.8% lower than that of the previous cropping season. With respect to ethanol, the expectation is an increase of 18.6% during this season due to the increased need for total recoverable sugar production for anhydrous ethanol, with a production of 32.3 billion liters (CONAB, 2018).

Vinasse is a residue derived from the alcohol production process. This residue is generated in amounts ranging from 10 to 18 L L^{-1} ethanol and is rich in potassium (K^+) and organic matter. When applied at the correct ratio and at the correct timing, this subproduct offers great rational and economical possibilities with respect to incorporation into the soil (NICOCHELLI et al., 2012; DEL NERY et al., 2018).

As regard to sugarcane, in addition to crop yield, the quality of the raw material is highly important for industrial purposes. The use of vinasse in sugarcane fields has undoubted benefits from agronomic and economic perspectives, since vinasse-treated fields yield the most tons of sugarcane per hectare (SILVA; BONO; PEREIRA, 2014). However, these fields can present low economic returns due to low sucrose concentrations within the stalks.

Potassium is directly correlated with the ash content in sugarcane juice (RODELLA; FERRARI, 1977; SILVA et al., 1978; FREIRE; CORTEZ, 2000). This ash content is an important factor in the industrialization process due to the negative effects of sugar crystallization. In plants, high K^+ level can induce the production of potassium saccharate instead of sucrose, reducing the amount of total recoverable sugar per ton of sugarcane produced (RODRIGUES, 1995; FREIRE; CORTEZ, 2000). Furthermore, high concentrations of K^+ in sugarcane juice seems to be strongly correlated with trans-aconitic acid contents in the stalks. Clarke and Brannan (1983) reported that this acid can be used as an indicator of the maturity level of sugarcane, since as the plant matures, the content of trans-aconitic acid decreases. Therefore, this acid might be another important indicator of the relatively lower sugar concentrations in sugarcane stalks grown in vinasse-treated fields.

According to Oliveira et al. (2014), the inclusion of vinasse during fertigation supplies the nutritional needs of sugarcane beginning from the second harvest; however, vinasse inclusion results in lower agroindustry quality parameters such as Brix value, sucrose and total recoverable sugar due to an increase in mineral fertilization from fertigation.

Compared with magnesium (Mg^{2+}) concentrations, K^{+} concentrations are relatively high in vinasse (NUNES; VELLOSO; LEAL, 1981), suggesting that a deficiency in this divalent cation can be induced by continual applications of large volumes of vinasse, especially in Mg-deficient soils (NUNES; LEAL; VELLOSO, 1982).

Although the ionic radius of Mg is smaller than that of K, the radius of the hydrated ion of Mg is larger, indicating the need for ion-specific transport proteins. Moreover, the easy mobility of K^{+} throughout the xylem is associated with the strong interaction of Mg^{2+} with the negative charges of the xylem vessels, and the apoplast can slow Mg^{2+} translocation to shoots (MARSCHNER, 1996; CAKMAK; YAZICI, 2010; GRANSEE; FÜHRS, 2013). At a very early stage of deficiency, photoassimilate phloem loading is severely impaired and occurs before any visible changes in shoot growth, chlorophyll concentrations or photosynthetic activity (CAKMAK et al., 1994a, b; HERMANS et al., 2005; CAKMAK; KIRKBY, 2008).

Reduced photosynthate transport from source to sink organs caused by Mg^{2+} deficiencies in plants may affect the amount of sucrose in stalks (GERENDÁS; FÜHRS, 2013), mainly because adequate Mg^{2+} nutrition is needed during the preripening stage to maintain and maximize source-to-sink transport (CAKMAK; KIRKBY, 2008).

Although antagonism between K^{+} and Mg^{2+} is well documented for other crop species, such as barley (JAKOBSEN, 1993), maize (MEURER; FONSECA, 1997), common bean (TUMA et al., 2004), rice (DING et al., 2008), safflower (FARHAT et al. 2013) and tomato (LI et al., 2018), this phenomenon as well as its impact on plant metabolism has not been widely recognized in sugarcane.

The present study presents the following hypotheses: a) Mg^{2+} deficiency causes changes in root morphological parameters (diameter and length) as well as in carbohydrate partitioning in the sugarcane roots and shoots due to impaired sucrose export in the phloem and reduced carbohydrate supply to the roots, causes accumulations of starch and soluble sugars in the leaves, with lower amounts of these carbohydrates allocated to the stalks, and reduces chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoid contents due to reduced Mg concentrations and increased accumulation of starch in the leaves; b) High K^+ levels decrease Mg^{2+} uptake by the roots by reducing the affinity of this ion for plasma membrane transporters, decrease Mg^{2+} translocation from the roots to the shoots, and affect sugarcane photosynthetic metabolism as well as the partitioning and translocation of starch and sucrose, resulting in reduced accumulations of this polysaccharide in the stalks; and c) Mg^{2+} foliar applications may rescue the effects caused by high K^+ levels on the Mg^{2+} uptake by roots.

Therefore, we aimed to evaluate the effects of K^+ and Mg^{2+} concentrations in nutrient solutions and the foliar applications of Mg^{2+} on root and shoot development of sugarcane as well as on the possible nutritional and metabolic alterations in the plants.

GENERAL CONSIDERATIONS

Sugarcane is a crop specie with great socioeconomic importance in Brazil. Vinasse has been used in an increasingly intense way as an organic fertilizer. With respect to mills, vinasse is seen as a product of economic value in the production of sugar and alcohol because applications of this natural product through fertigation results in increased agricultural productivity and reduced fertilization and irrigation costs.

However, the sugarcane productivity of vinasse-treated fields is still below the genetic potential of the varieties. This fact can be attributed to the internal Mg concentration imbalance in the plants caused by the high K concentration in the vinasse, making acquisition of this nutrient by plant roots difficult.

Due to the complex role of Mg in chlorophyll and protein biosynthesis, negative impacts are expected not only on final crop yields but also on the qualitative parameters of sugarcane under Mg deficiency. Since several plant organs (roots, stalks and gems) are not able to satisfy their demand for photoassimilates (sugars, amino acids, etc.), their demands are compensated by the direct transport from the source leaves to the sink organs, mediated by phloem. Although not entirely clarified, Mg seems to play a key role in the phloem loading of sucrose from source leaves, emphasizing the importance of an adequate supply of this nutrient to crops. In addition, due to the ability of the leaves to absorb nutrients, Mg foliar applications represent an excellent fertilization strategy to improve the internal concentration of this nutrient in plants. Thus, additional studies should be carried out to elucidate the mechanisms of K and Mg interaction as well as alternatives to Mg supply in combination with vinasse use, since several benefits occur in response to the use of this product.

REFERENCES

CAKMAK, I.; YAZICI, A. Magnesium: a forgotten elemento in crop prodution. **Better Crops**. v.94, p.23-25, 2010.

CAKMAK, I.; KIRKBY; E. A. Role of magnesium in carbon partitioning and alleviating photoxidative damage. **Physiology Plantarum**, v. 133, p. 692–704, 2008.

CAKMAK, I; HENGELER, C; MARSCHNER, H. Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. **Journal of Experimental Botany**. v. 45, p. 1245–1250, 1994a.

CAKMAK, I.; HENGELER, C.; MARSCHNER, H. Changes in phloem export of sucrose in leaves in response to phosphorus, potassium and magnesium deficiency in bean plants. **Journal of Experimental Botany** v. 45, p. 1251–1257, 1994b.

COMPANHIA NACIONAL DE ABASTECIMENTO- CONAB. **Acompanhamento da Safra Brasileira Cana-de-Açúcar Safra 2016/2017, primeiro levantamento, dez/2018**. Brasília, 2018. 66 p. Disponível em: <http://www.conab.gov.br/conabweb/>. Acesso em: 18 janeiro 2019.

CLARKE, M.A.; BRANNAN, M.A. Rapid analyses of lactic acid, an indicator of sugarcane deterioration, and aconitic acid, an indicator of sugarcane maturity by high performance liquid chromatography. **Journal of the American Society of Sugar Cane Technologists**, v. 2, n. 88, 1983.

DEL NERY, V.; ALVES, I.; DAMIANOVIC, M. H. R. Z.; PIRES, E. C. Hydraulic and organic rates applied to pilot scale UASB reactor for sugar cane vinasse degradation and biogas generation. **Biomass and Bioenergy**, v. 119, p. 411-417, 2018.

DING, Y. C.; CHANG, C. R.; LUO, W.; WU, Y. S.; REN, X. L.; WANG, P.; XU, G. H. High Potassium Aggravates the Oxidative Stress Inducedy by Magnesium Deflciency in Rice Leaves1. **Pedosphere**, v. 18, n. 3, p. 316-327, 2008.

FARHAT, N.; RABHI, M.; FALLEH, H.; LENGLIZ, K.; SMAOUI, A;, ABDELLY, C; LACHAA, M.; KARRAY-Bouraoui, N. Interactive effects of excessive potassium and Mg deficiency on safflower. **Acta physiologiae plantarum**, v. 35, n. 9, p. 2737-2745, 2013.

FREIRE, W.J.; CORTEZ, L.A.B. **Vinhaça de cana-de-açúcar**. Guaíba: Agropecuária, 2000. 203 p.

GRANSEE, A.; FÜHRS, H. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. **Plant and Soil**, v. 268, n. 1-2, p. 5-21, 2013.

HERMANS, C.; BOURGIS, F.; FAUCHER, M.; DELROT, S.; STRASSER, R.J.; VERBRUGGEN, N. Magnesium deficiency in sugar beet alters sugar partitioning and phloem loading in young mature leaves. **Planta**. v. 220, p. 541–549, 2005.

HORIE, T.; BRODSKY, D. E.; COSTA, A.; KANEKO, T.; SCHIAVO, F. L.; KATSUHARA, M.; SCHROEDER, J. I. K^+ transport by the $O_sHKT2;4$ transporter from rice with atypical Na^+ transport properties and competition in permeation of K^+ over Mg^{2+} and Ca^{2+} ions. **Plant Physiology,** pp-110, 2011.

JAKOBSEN, S. T. Interaction between plant nutrients: III. Antagonism between potassium, magnesium and calcium. **Acta Agriculturae Scandinavica B-Plant Soil Sciences**, v. 43, n. 1, p. 1-5, 1993.

LI, H. X.; CHEN, Z. J.; ZHOU, T.; LIU, Y.; ZHOU, J. B. High potassium to magnesium ratio affected the growth and magnesium uptake of three tomato *(Solanum lycopersicum* L.) cultivars, **Journal of Integrative Agriculture***,* v. 17, p. *60345-7,* 2018.

MARSCHNER, H.; KIRKBY, E. A.; CAKMAK, I. Effect of mineral nutritional status on shoot–root partitioning of photoassimilates and cycling of mineral nutrients. **Journal of Experimental Botany,** v.47, p.1255–1263, 1996.

MEURER, E. J.; FONSECA, J. A. Inibição da absorção de magnésio pelo potássio em plântulas de milho em solução nutritiva. **Revista brasileira de ciência do solo**, Campinas, SP, v. 21, p. 47-50, 1997.

NICOCHELLI, L. M.; NASCENTES, R.; LIMA, E. B. N. R.; SOARES, F. S. Sorção de potássio em amostras de solo submetidas à aplicação de vinhaça. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 16, n. 7, p. 754-760, 2012.

NUNES, M. R.; VELLOSO, A. C. X.; LEAL, J. R. Efeito da vinhaça nos cátions trocáveis e outros elementos químicos do solo. **Pesquisa Agropecuária Brasileira**, v.16, n.2, p.171-176, 1981.

NUNES, M.R., LEAL, J.R. AND VELLOSO, A.C.X. Effect ofland disposal of vinasse on the leaching of soil nutrients III. Potassium, Calcium and Magnesium. **Pesquisa Agropecuária Brasileiria**, v. 17, n. 3, p. 371-374, 1982.

OLIVEIRA, W. S.; BRITO, M. E. B.; ALVES, R. A. B.; SOUZA, A. S.; SILVA, E. G. Cultivo da cana-de-açúcar sob fertirrigação com vinhaça e adubação mineral. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, v. 9, n. 1, p. 01-05, 2014.

RODELLA, A.A.; FERRARI, S.E. A composição da vinhaça e efeitos de sua aplicação como fertilizante na cana-de-açúcar. **Brasil Açucareiro**, v. 90, n. 7, p. 380-387, 1977.

RODRIGUES, D.J. **Fisiologia da cana-de-açúcar**. Botucatu: UNESP, 1995. 100 p.

SILVA, A. P. M.; BONO, J. A. M.; PEREIRA, F. A. R. Aplicação de vinhaça na cultura da cana-de-açúcar: Efeito no solo e na produtividade de colmos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.18, n.1, p.38-43, 2014.

SILVA, G.M.A. Efeitos da aplicação da vinhaça como fertilizante em cana-de-açúcar. **Boletim Técnico Copersucar**, v. 7, p. 9-14, 1978.

TUMA, J., SKALICKY, M., TUMOVA, L., BLÁHOVÁ, P., & ROSULKOVA, M. Potassium, magnesium and calcium content in individual parts of Phaseolus vulgaris L. plant as related to potassium and magnesium nutrition. **Plant Soil and Environment**, v. 50, n. 1, p. 18-26, 2004.