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MICRONUTRIENT NUTRITION IN SUGARCANE: A BRIEF REVIEW

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ABSTRACT - Sugarcane is a crop of worldwide economic value used in sugar, electricity, and alcohol production. This review demonstrates the importance of the main micronutrients and their respective effects on the development and yield of sugarcane. Micronutrient deficiency is one of the limiting factors in sugarcane productivity in producing regions. This deficit is related to several aspects, such as fertilizer use with low micronutrient levels, increased agricultural productivity, and decreased productivity levels of soil organic matter. Thus, proper fertilization management can circumvent the limiting factors such as the foliar application of boron and soil fertilization of zinc, both resulting in greater stem production. Molybdenum increases biological nitrogen fixation in sugarcane and contributes to the accumulation of N in the plant. Iron and manganese are involved in chlorophyll content and dry matter accumulation in sugarcane. In this review, we show the contributions of fertilization with microelements to the development of the sugarcane sector. In this perspective, more research is needed on micronutrient fertilization to increase sugarcane productivity in different soil and climate conditions.
Keywords: *Saccharum* spp., nutrition, production.

NUTRIÇÃO COM MICRONUTRIENTES NA CANA-DE-AÇÚCAR: BREVE REVISÃO

RESUMO - A cana-de-açúcar apresenta valor econômico a nível mundial, sendo utilizada na produção de açúcar, energia elétrica e álcool. Portanto, objetivou-se demonstrar à importância dos principais micronutrientes e seus respectivos efeitos sobre o desenvolvimento e rendimento da cana-de-açúcar. A deficiência de micronutrientes é um dos fatores que limitam a produtividade dessa cultura nas regiões produtoras, sendo este déficit relacionado a vários aspectos, como o uso de fertilizante com baixos níveis de micronutrientes, aumento da produtividade agrícola, diminuição dos níveis de matéria orgânica do solo. Dessa forma, vale ressaltar que o manejo adequado pode contornar os fatores limitantes, pois a aplicação de boro via foliar resulta em maior tonelada de colmos, e com relação ao zinco, aplicado via solo também é benéfica à produção de colmos. O molibdênio aumenta a fixação biológica de nitrogênio na cana-de-açúcar e contribui com o acúmulo de N na planta. O ferro e o manganês ambos estão envolvidos no teor de clorofila e acúmulo de matéria seca da cana-de-açúcar. O estudo expõe as contribuições da adubação com microelementos para o desenvolvimento do setor canavieiro. Nessa perspectiva, mais pesquisas são necessárias sobre a fertilização de micronutrientes para impulsionar a produtividade da cana-de-açúcar em diferentes condições edafoclimáticas.
Palavras-chave: *Saccharum* spp., nutrição, produção.

INTRODUCTION

Sugarcane (*Saccharum* spp.) is a crop of great worldwide economic value used mainly for the production of sugar, electricity, and alcohol (SILVA et al., 2014), with global productivity of approximately 1.5 billion tons per year (SOBRINHO et al., 2019). In Brazil, the estimated 2021/22 harvest points to a total sugar production of 36.9 million tons and 25.8 billion liters of ethanol (CONAB, 2021). Hence, the cultivation of sugarcane is of significant importance to Brazil, which is considered the largest producer and exporter globally, followed by India (SILVA; BARBOSA, 2021).

Proper nutritional management increase sugarcane production. However, studies have shown that traditional fertilization methods are often based on empirical data from the farmer, with fertilization practices that do not consider variability and the soil conditions, which are associated with the low availability or absence of micronutrients impair the maximum crop yield (PACHÓN et al., 2017).

Micronutrient deficiency is called “hidden hunger” and can cause disorders in plant metabolism, visually expressing itself in the form of chlorosis, necrosis, and defoliation (NOREEN et al., 2018). In soil, the availability of microelements for crops depends on several factors, such as soil texture, soil reaction, organic matter, clay content, and nutrient interactions, among others (KUMAR et al., 2016).

Microelements, in turn, play several essential roles in plant metabolism, either as part of components necessary for metabolic and/or phenological processes and enzymatic activators. However, the lack of knowledge about their impacts on sugarcane reflects the low use of these elements in the sugarcane sector (SANTOS JUNIOR; RUIZ, 2019).

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Therefore, we aimed to demonstrate the recent findings on the main micronutrients and their respective effects on sugarcane yield and development.

DEVELOPMENT

Micronutrients availability in sugarcane

Sugarcane needs micronutrients for its development, which are involved in synthesizing compounds necessary for plant development. In addition, they promote yield increment and sap quality (MADHURI et al., 2013; MELLIS et al., 2016). Thus, the export of micronutrients most required by this crop has the following order: iron (Fe) > manganese (Mn) > zinc (Zn) > copper (Cu) > boron (B) > molybdenum (Mo) (FORLI et al., 2017), which are readily available when the soil has a pH near 5.0, except for molybdenum (FAGERIA et al., 2002; KUMAR et al., 2016). However, in sugarcane planting, liming is usually performed to neutralize Al+3, typical of highly weathered soils (ROSSETTO et al., 2004; FINK et al., 2016), where it can sometimes become a problematic practice for the uptake of micronutrients by plants since they have low availability under excess carbonates (RIAZ et al., 2020).

Microelements deficiency is one of the limiting factors in sugarcane productivity due to several aspects, such as soil alkalinity, the use of fertilizers with low micronutrients levels, increased agricultural productivity, decreased level of soil organic matter, and intense cultivation in low-fertility areas (FAGERIA et al., 2002; RIAZ et al., 2020).

In addition, producers lack knowledge of the requirements and effects of microelements on plants and that they may have beneficial effects on the maximum performance of the crop. Because of this, some fertilization programs are showing the importance of micronutrients in terms of the quantities extracted from the soil, where these, although low (g ha^{-1}), are of great importance for the crop cycle and can, under deficit conditions, be detrimental to plant development (VAZQUEZ; SANCHES, 2010). Thus, adequate macro and micronutrients fertilization is necessary to achieve high yields and food quality (RUTKOWSKA et al., 2014).

Micronutrient fertilization can be performed either in the form of salts, chelates, mixtures with macroelements, or in the form of aerosols applied to the leaf surface (MIKULA et al., 2020). In sugarcane, micronutrient fertilization occurs directly in the planting furrow. In this process, some aspects must be considered, such as the form and nutrient dose required by the crop, to reduce environmental impact. The foliar supply of nutrients is recommended over the soil's direct fertilization because it is environmentally correct (NIU et al., 2021). This application may result in different outcomes in sugarcane depending on plant age, soil type, and plant variety (BENETT et al., 2013).

Effect of micronutrients on sugarcane

Boron (B)

There is evidence that boron promotes RG II (rhamnogalacturonan II) cross-links in the cell wall and drives cell elongation and plant hormonal responses (TAIZ et al., 2017). Thus, some authors point out the importance of this element in the productivity and production of sugar, which is considered the most mobile element in the soil among the microelements (VIDAL et al., 2019).

The effect of boron fertilization on sugarcane fields is variable. Franco et al. (2009) showed no effects of boron on sugarcane productivity and found even a negative effect using B doses greater than 2 kg ha^{-1} (FRANCO et al., 2011). Nevertheless, Mazhar (2016) reported a positive effect on sugarcane productivity and recovery when zinc and boron were applied in the soil at the dose of 1.5 kg ha^{-1} of boron. Marangoni et al. (2019), working in soil with low clay and organic matter content in Southeast Brazil, described that the application of B in the form of soluble salt (boric acid) in the planting furrow decreases sugarcane productivity in the first and second crop cycle. However, Mangrio et al. (2020) reported that foliar application of boron resulted in a higher ton of stem (119.0 t ha^{-1}) and soluble solids content (ºBrix) of 23.0%.

Copper (Cu)

Copper is associated with enzymes such as plastocyanin, which is involved in electron transfer during light-dependent reactions in plants (TAIZ et al., 2017). In sugarcane, Su et al. (2015) observed the effects of different concentrations of Cu on its development and showed that it could tolerate up to 269.15 mg kg^{-1} of Cu in the soil with no adverse effects on its growth and productivity. Oliveira et al. (2012) evaluated the effect of fertilization with copper and manganese on sugarcane and found no influence in the variables analyzed, probably due to their high adsorption in soil organic matter.

Tamez et al. (2019) evaluated the use of copper nanomaterials in sugarcane and observed that copper concentrations in root tissues increased in a dose-dependent manner in almost all treatments. However, there was no evidence of copper translocation in the aerial plant tissue. The following year with the same experiment, Tamez et al. (2020) reported that mature plants were able to mitigate exposure to copper-based compounds/nanomaterials better than immature sugarcane plants.

Iron (Fe)

Iron is one of the essential microelements for plant growth and plays a direct role in the primary process of photosynthesis. Based on this, Lana et al. (2014) described that this element is necessary for synthesizing chlorophylls, a fundamental constituent of cytochromes. Rakkiyappan et al. (2002) described an increase in sugarcane chlorophyll content, stalk yield, and sucrose content with foliar application of iron sulfate. Mishra et al. (2014) studied the effect of micronutrients on the sugarcane plant-ratoon system, particularly iron and manganese, and obtained the highest sugar productivity (10.73 and 9.25 t ha^{-1}) by foliar application, with 1% of $FeSO_4$ and $MnSO_4$, respectively, with three sprays.

Cavalcante et al. (2016) evaluated the effect of Fe concentrations in the nutrient solution on growth, green color index, and dry matter production of sugarcane and found an increase in the accumulation of the element in the seedlings and the green color index. These authors obtained a satisfactory dry matter production best growth with the same element concentration (184 μmol L^{-1} of Fe). In general, information on iron and its effect on stalk productivity is scarce, despite being among the most exported microelements in sugarcane plants, an element commonly found in Latosols and Ultisols, rich in iron and aluminum oxides, in approximately 170 million hectares in 72 countries and 50% of all terrestrial agriculture in the world (FINK et al., 2016).

Manganese (Mn)

Manganese is the second most extracted micronutrient from the soil by sugarcane plants and, when provided at adequate levels, can contribute to productivity and improvements in technological quality (BENETT et al., 2016). According to Taiz et al. (2017), decarboxylases and dehydrogenases, which are involved in the citric acid cycle (Krebs cycle) are specifically activated by manganese. The photosynthetic activity and chlorophyll production also depends on this nutrient (MISHRA et al., 2014).

Benett et al. (2013), evaluated the effect of five doses and three sources of manganese applied in the planting furrow of sugarcane and its residual effect on ratoon cane, in the Northwest region of the State of São Paulo, Brazil, and found that the manganese sources and doses influenced the accumulation of macro and micronutrients and stem dry matter in plants and ratoon cane. However, manganese doses and sources in any plant stages did not affect stem productivity. Yang et al. (2016) suggested that the recommended levels of manganese should be within 0.2-0.4 g kg^{-1} for production in latosol and that this micronutrient also provides resistance to water stress.

Huang et al. (2016) described that the decrease in chlorophyll concentration in ratoon cane tillers was possibly due to manganese excess in the soil. However, Mesquita et al. (2019) observed that foliar supplementation with Mn reduced symptoms and benefited the functioning of sugarcane leaves infected by the orange rust fungus.

Molybdenum (Mo)

Plant molybdenum content depends not only on its availability in the soil but also on the relationship with other nutrients, which is associated with better use of nitrogen, given its direct action on the activity of the enzyme (nitrogenase) responsible for converting N_2 into NH^{4+} (MANUEL et al., 2018). Because of this, some studies aim mainly at reducing applications with high amounts of nitrogen in the cultivation of sugarcane.

Santos et al. (2018) evaluated the levels of Mo in the soil, roots, and leaves of sugarcane fertilized with N and Mo and the quality of the technological attributes for sugar and alcohol and found that fertilization with molybdenum promoted an increase in the Mo content in the surface and subsurface soil layers. In addition, the agricultural and sugar yield of the variety RB867515 increased with this fertilization.

In a study with molybdenum and nitrogen in the leaves and roots of two commercial sugarcane varieties during the first crop cycle, Santos et al. (2019b) observed that the application of molybdenum increased the Mo content in the leaves and roots of the plants, and stimulated the activity of nitrate reductase, with maximum activity occurring approximately at 100 days after planting (DAP), showing to be the best period for nutritional studies with nitrogen.

Santos et al. (2019a) studied the effect of Mo fertilization on biological nitrogen fixation (BNF), nitrogenase activity, naturally abundant N isotopes, and N accumulation in different genotypes (RB867515 and RB92579) of sugarcane fertilized with nitrogen and reported that fertilization with Mo contributed to biological nitrogen fixation and increased N accumulation in both genotypes. Also, according to the same authors, fertilization with molybdenum should be recommended for fertility management, especially in soils with low N content, or as an alternative to reduce the use of nitrogen fertilizers in sugarcane.

Zinc (Zn)

Zinc may be required for chlorophyll biosynthesis in some plants, and its deficiency is characterized by reduced internode growth, with plants showing a rosette growth habit (TAIZ et al., 2017). In sugarcane, it potentially increases productivity and tillering when supplied in low fertility soils (NAVARRETE et al., 2017; NICCHIO et al., 2020). According to Costa Filho and Prado (2008), zinc is one of the most important micronutrients for productivity increase in tropical soils. In their research, they evaluated the effect of zinc doses on the growth and production of sugarcane at the third ratoon stage cultivated in a Red Yellow Latosol and observed that the application of zinc was efficient to increase the zinc contents in the soil (0.6 to 1.2 mg dm^{-3}) and in the leaf (9.8 to 25 mg kg^{-1}). However, it did not affect stem growth and yield.

Teixeira Filho et al. (2013), evaluated the effect of doses and sources of zinc applied in the planting furrow in sugarcane (plant cane and 1st ratoon) cultivated in a sandy textured soil with low Zn content and found that based on technological quality indicators, such as apparent sucrose mass (pol), soluble solids (°Brix) and total sugar recovered (ATR), from the 1st ratoon cane, it would be interesting to apply 4.0 to 5.0 kg ha^{-1} of Zn in the planting furrow, in the form of Zn chelate or sulfate.

Marangoni et al. (2019) reported that the application of Zn in the sugarcane planting furrow potentially increased productivity in the second crop cycle (residual effect) and also in the sugarcane quality (pol and fiber content), with maximum yields obtained at the dose of 3.9 kg ha^{-1} of Zn.

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CONCLUSIONS

Studies have shown that micronutrients fertilization in different doses results in changes in the sugarcane's technological attributes, with beneficial and adverse effects. In this perspective, more research is needed on micronutrients to increase sugarcane productivity under different soil and climate conditions.

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