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Foliar fertilizer management for tolerance to water drought in sugarcane

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Abstract. Currently, Brazil is the world's largest sugarcane producer, with a planted area of approximately 8.59 million hectares. For being a crop of great prominence in the world economy, sugarcane has been widely researched, especially in the study of the causes that limit its productivity, with emphasis on water availability, an important factor to be considered in Brazil, because much of the cultivation takes place in drought regions, and the producing locations are limited to seasonal rainfall. However, sugarcane may present certain mechanisms for tolerance to water stress, especially with the use of foliar fertilization for that tolerance. Therefore, this study aimed to analyze the effects of foliar fertilization as a form of tolerance to water deficit in sugarcane crop. Water stress is the responsible factor for promoting physiological changes in the crop, enabling structural and functional alterations at various organizational levels of the plant. Furthermore, another approach to minimize the effects of water stress in sugarcane is to explore the plant's defense mechanisms, especially with the use of foliar fertilization as an alternative to tolerance to water deficit, considering the several benefits caused by this application method. Plant regulators are a viable option for reducing the negative physiological causes of water stress in plants, besides helping the plant to maintain physiological processes with a rapid recovery after overcoming water stress.

Keywords: *Saccharum* spp., foliar fertilizers, deficit.

Contextualization and analysis

An important aspect to be considered when analyzing the panorama of climate change is related to the availability of water for irrigation use, being this, a source that has been becoming limited, and this resource may be reduced in regions with high rates of temperature, which is notorious in semi-arid locations (Oliveira et al., 2015). Among the irrigated crops, sugarcane stands out, being the effects of climate change dubious and, in some cases, discordant. In contrast, Carvalho et al. (2015), states that even though sugarcane is well adapted to the various regions of the country, climate change may reduce its potential yield.

Nowadays, Brazil is the world's largest producer of sugarcane, with a planted area of approximately 8.59 million hectares (CONAB 2019). The crop belongs to the Poaceae family and the Saccharum genus, with high economic value and extreme relevance due to its uses, and can be used in natura as fodder for animal feed, as well as making use of the raw material itself for the production of ethanol and sugar, among other uses as sources of organic fertilizers through vinasse and filter cake (Pinto et al., 2020).

Because it is a crop of great prominence in the world economy, sugarcane has been widely researched, especially in the study of the causes that limit its productivity, with emphasis on water availability, an important factor to be considered in Brazil, because much of the cultivation takes place in dryland regions, and the producing locations are limited to seasonal rainfall (Marin & Jones, 2014). However, sugarcane can present certain mechanisms for tolerance to water stress, mainly with the use of foliar fertilization for this tolerance (Vieira et al., 2014).

The methodology of preparation of this work consists of a literature review based on bibliographic references obtained from articles published in national and international journals, internet sites and annals of scientific events, In addition, probable topics for future research are also highlighted with the approach of foliar fertilization as tolerance to water stress in the culture of regionalized sugarcane and points that still lack consensus and that remain poorly developed in research already produced with this methodology.

Therefore, the objective was to review the effects of foliar fertilization as a form of tolerance to water deficit in sugarcane crop.

Sugarcane metabolism and responses to water deficit

According to Taiz & Zeiger (2017), water deficit can be presented as a water material being of a tissue or cell, which is lower than the higher water content that is shown by the plant in a favorable hydration state. In this sense, water deficit is a common cause to the production of several crops, being able to manifest several negative impacts on the development of the plant.

According to Silva et al. (2013), when studying the impacts of climate change, they stated that the changes caused by the increase in air temperature rates and the decrease in rainfall, cause significant decreases in agricultural areas with little climatic risk for the sugarcane crop, with crops in the Northeast region of Brazil. However, the crop when subjected to water stress, changes occur in its physiology caused by the reduction in water potential, which results in several modifications in metabolic processes (Souza, 2019).

Taiz & Zeiger (2017), state that different plants have adaptive capacity, such as the photosynthetic types C4 and CAM, which allow them to explore more arid environments, and also plants have acclimatization mechanisms, which can be awakened when in response to water deficit.

Sugarcane water requirement according to variety and phenological stage

The physiological alterations in the sugarcane crop, as well as in the various plants, are linked to the partial closure of stomata, decrease in photosynthetic rate, decrease in height and diameter of the stalk, increase in leaf water potential and increase in tillers (Bezerra, 2015). In this sense, the use of resistant and tolerant varieties are alternatives to reduce the productivity losses related to water deficit (Campos et al., 2014).

The phenological stages of crops are factors responsible for acting on evapotranspiration. In the first and second phenological stage, characterized by the sprouting and establishment of the plant, the crop presents the lowest values of evapotranspiration, being phase three the stage in which the crop reaches its maximum point due to its high leaf development, resulting in a larger area of evapotranspiration (Silva et al., 2015).

According to Andrade Júnior et al. (2018), when studying the water demand of sugarcane, they reported that in phase four of the crop, known as the physiological maturation phase, the plant does not need a high-water demand, but the ETc or evapotranspiration values of the crop increase.

In this way, water stress is the factor responsible for promoting physiological changes in the crop, enabling structural and functional changes in the various organizational levels of the plant (Sobrinho et al., 2019). In this sense, according to Irriger (2013), the use of methods through appropriate management in sugarcane cultivation sites is feasible and entails significant advantages to the productivity and development of the crop. Depending on the sugarcane variety, the stomata present in the leaves are mostly on the abaxial side, where the occurrence of fine lignified hairs is much lower, thus reducing the deleterious causes related to the absorption of solutes via the leaf (Castro, 2016).

According to Boaretto et al. (2014), they observed that drought-resistant varieties of sugarcane developed a high increase in the expression of genes related to cellular organization, protein metabolism, antioxidant systems and cell signaling, in which these factors contribute to an effective response of the crop when subjected to water stress conditions, mitigating the deleterious consequences of drought.

Although many scholars seek to understand the mechanisms of response to water stress in sugarcane, the development of new varieties with characteristics of greater resistance is still a challenge, requiring years of research due to the great genetic complexity of this crop, such as the high number of chromosomes and polyploidy (De La Fuente et al., 2013). Thus, the main strategies to increase the levels of tolerance to water stress in sugarcane concern the selection of superior varieties or the genetic modification of cultivars (Ferreira et al., 2017), using the selection of genotypes with resistance to water deficit, transgenic techniques, and gene editing (Kumar & Jain, 2014).

Furthermore, another approach to mitigate the effects of water stress in sugarcane is to explore the plant's defense mechanisms, especially with the use of foliar fertilization as an alternative to tolerance to water deficit, given the various benefits caused by this means of application.

Foliar fertilization as an alternative of tolerance to water deficit in sugarcane crop

In the environment where the sugarcane crop is grown, plants are constantly subjected to inappropriate external situations, which end up causing stresses that cause negative effects on their growth and productivity (Bianchi et al., 2016). When plants are subjected to drought situations, they undergo osmotic adjustment at the cellular level, synthesis and concentrate non-toxic metabolic compounds of low molecular weight, which are called osmotically active solutes (Santos, 2015).

Moreover, plant responses to the effect of drought are related to the period of occurrence of this factor and severity of display to stress, age and phenological stage of the crop in dry periods, as well as the organ and cell type (Gao et al., 2013).

The first symptoms of water stress are visualized by leaf wilting, caused by the effect of dehydration and loss of leaf turgor (Taiz & Zeiger, 2013). Foliar fertilization, in turn, reduces the damage caused by water stress to sugarcane, in which the crop activates its morphological defense mechanisms such as root deepening, leaf curling, leaf abscission, and the closure of stomata, the latter being controlled by the concentration of potassium and chloride in the guard cells, which, when deficient, causes limited control over the loss of plant water (Castro, 2016).

Furthermore, phosphorus is an essential nutrient for the crop because it is required in many chemical reactions and is essential in the energy link between ADP and ATP, as well as in CO2 absorption (Castro, 2016).

Zambrosi & Mesquita (2016), when studying the use of foliar fertilization of phosphorus in plants, obtained positive responses regarding the increase in dry matter of the aerial part and roots, as well as internal concentration in these organisms. Nevertheless, in old roots as also under water stresses, production of a thick suberin layer occurs, increasing the thickness of the suberized layer of the roots, preventing water loss (Fagan et al., 2016).

According to Pincelli (2010), tolerance to water stress usually manifests itself in four ways: limitation in growth, morphological and physiological adaptations, as well as also metabolic changes. The use of foliar fertilizers for tolerance to water deficit brings several benefits for the plant and for the environment because it is theoretically less harmful to the ecosystem, as well as having a faster result and being more directed towards the objective of the study when compared to soil fertilization, considering the high capacity of nutrient absorption of the leaf tissues during the critical phenological stages of plant growth (Fernández et al., 2015).

Foliar fertilizers are an alternative for reducing the negative effects of nutrient deficiency and water stress caused to the crop, thus improving plant performance through physiological and biochemical changes (Teixeira, 2015). Thus, tolerance to water deficit allows sugarcane to maintain its growth and metabolism, even with a decrease in soil water potential (Ravandi et al., 2014).

In different researches with the sugarcane crop, the leaf water potential and relative water content have shown a high connection with high tolerance to drought stresses, making them considered potential physiological indicators in the selection of varieties (Silva et al., 2014). Also, according to the authors, when the plant is exposed to conditions of water stress, other components of the photosynthetic process are affected, such as inhibition of the biosynthesis of chlorophylls and the restriction of the efficiency of absorption of light energy.

According to Mellis et al. (2016), sugarcane is capable of responding positively to the use of micronutrient-based foliar fertilizers because they play essential roles in plant metabolism. Thus, foliar fertilization aims to correct probable nutritional deficiencies that are not met by soil fertilization, because nutrients penetrate the leaves easily depending on factors such as environmental conditions and soil fertility management (Lira, 2018). In addition to nutrition, according to Mesquita et al. (2019), foliar application of nutrients has benefits in protecting plants from diseases and tolerance to water deficit.

Thus, the sugarcane crop throughout its growth when subjected to water restrictions, has smaller increments in its development and consequently in productivity.

With the application of foliar fertilization, nutrients such as potassium (K) are essential for the opening and closing of stomata, as well as protein synthesis, the generation of ATP and the transport of photo-assimilates, besides the fact that potassium plays an essential role in the transport of carbohydrates, and this nutrient is used to indicate stress due to its contribution in osmotic adjustment (Wu et al., 2018). Moreover, plants when subjected to water stress and supplemented with potassium, these have the ability to possess a greater development in the root system (Romheld & Kirkby, 2010), as can be observed in their work (Figure 1).

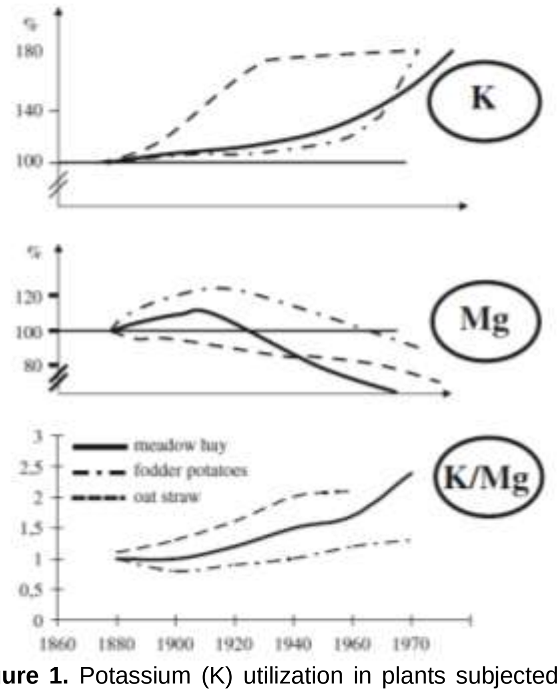

Figure 1. Potassium (K) utilization in plants subjected to water stress. Source: (Romheld & Kirkby, 2010).

Another essential nutrient when it comes to foliar fertilization for tolerance to water stress in sugarcane is Phosphorus (P), which is fundamental in the adaptability of the plant when submitted to stress conditions, which will allow the plant metabolism to perform new physiological as well as morphological configurations, which will permit the preservation of energy resources (Lanza, 2021). Moreover, phosphorus contributes to the maintenance of membrane structures, synthesis of biomolecules, formation of high energy molecules, cell division and enzyme activation and inactivation (Malhotra et al., 2018). Thus, foliar fertilization with these nutrients has the ability to help the crop in tolerance to water stress.

Sulphur (S), in turn, is another nutrient that can contribute to crop productivity even under stress conditions (Samanta et al., 2020). Magnesium (Mg) also plays an important role in this tolerance because it is the central atom of the chlorophyll molecule in the light-absorbing complex of the chloroplasts and contributes to the photosynthetic fixation of CO2. It is also responsible for the activation of a wide range of enzymes (RNA polymerases, ATPases, protein kinases, phosphatases, glutathione synthases and carboxylases) (Lanza, 2021).

Therefore, when foliar fertilization is used in sugarcane with these elements in the correct phenological phase of the crop, it is possible to grant the plant a greater tolerance to water stress. Thus, implementing these strategies by means of foliar fertilization makes the plants more capable of withstanding water stress.

Effect of foliar application on growth and yield of sugarcane under dryland conditions

The nutrients are applied to plants through the soil as well as foliar applications. The way in which nutrient solutions enter the leaves can be balanced by certain abiotic factors (Lira, 2018). Also, according to the author, several agricultural areas have nutrient deficiencies, which points to the need for fertilizers in sugarcane plantations so that they can have better results throughout the crop cycle, and may be an economically viable practice due to the elevation in leaf photosynthetic quality, the productivity of canes and technological quality.

The leaves of the plants have the capacity to rapidly absorb the nutrients from foliar fertilizers in the form of a solution on their surface, being a means of supplementary fertilization to soil fertilization due to the high capacity of use of this nutritional medium by the plants when compared to base applications, with the results being obtained quickly and with greater uniformity, increasing crop growth and consequently productivity with the action of macronutrients, and improving the enzymatic processes by means of micronutrients (Nicchio et al., 2016).

The main environmental causes that induce the growth and productivity of sugarcane are the air temperature, which affects several metabolic processes of the plant, as well as intervening in the demand for evapotranspiration, and water availability, which can lead to a decrease in tillers and their leaf area, and stimulate senescence (Vianna & Sentelhas, 2014). Also, according to the authors, because sugarcane is spreading to various regions of the country where cultivation is not traditional, the productivity of the crop has suffered adverse impacts due to the climatic factors of these locations, in which water deficit is the main factor, making research that evaluates these problems caused by this abiotic factor essential for the preparation of new areas of sugarcane plantations.

In this sense, the use of foliar fertilizers is essential to the culture of sugarcane, because this fertilization reduces the time delay between the application and absorption of nutrients by the plant, being essential throughout a phase of rapid growth, besides being able to bypass the process of absorption of a nutrient in the soil, such as iron, manganese and copper, acting quickly when applied via foliar application (Taiz & Zeiger, 2013).

Foliar nutrition contributes to the increase in productivity and improves the conditions of the photosynthetic apparatus, which in turn is the result of the functions of the nutrients that act in the metabolism of the plant, such as nitrogen, which is made up of all amino acids, amides, proteins, nucleic acids, nucleotides and polyamides, as well as other nutrients that also participate directly or indirectly in metabolic processes (Buchanan et al., 2015).

According to Rossi (2015), the distribution of nutrients via the foliar route causes the oldest leaves of the plant to remain metabolically active for a certain extended time, and consequently, more productive. Lira et al. (2017), state that the increase in productivity in sugarcane was due to the maintenance of the active photosynthetic rate of the leaf, increasing the life of the plant and delaying leaf senescence, which may promote an increase in production variables.

Another beneficial factor is the possibility of using these fertilizers in mixture with pesticides, which in turn reduces the costs of application, an advantageous practice that can increase crop production in a viable manner and contribute to reducing the degrading effects of the lack of nutrients that are essential for the development of the crop (Maróstica & Feijó, 2013).

Use of foliar biostimulants in the development and tolerance to drought in sugarcane

In the market it is possible to find several products consisting of plant hormones that are used to increase the productivity of many crops, including sugarcane, and these constituents are called biostimulants, or plant stimulants, which through their compositions are able to modify the growth and development rates of plants (Batista et al., 2013). Research by Ferreira et al. (2013) found that the use of biostimulants accelerated the growth and initial development of the main and secondary tillers of sugarcane crops.

Biostimulants consist of bioregulators related to other chemical substances such as amino acids, nutrients, mineral salts and various other compounds (Jardin, 2015). Some biostimulants have the capacity to contain hormones, which act as signaling molecules originally present in plants in low concentrations, and able to induce or modify their growth and development (Taiz et al., 2017).

In this sense, biostimulants promote the action in the hormonal control of the plant that favours its genetic potential, and consequently, increases the vegetative parts of the plant, through cell division (Bulgari et al., 2015), which will originate in plants with high vigour and improve their root development and productivity, promoting high tolerance to drought in critical periods (Zilliani, 2015).

Also, according to Zilliani (2015), the biostimulants when applied to the plant in its early development phase, these products have a high capacity to stimulate greater root growth of the plant, allowing greater resistance to water and nutritional stresses, and, when used in different dosages, these products favour plant development. In this respect, the use of biostimulants in sugarcane crops has the capacity to elevate production and productivity, increasing the sucrose content of the plant (Santos et al., 2020).

Plant regulators are a very viable option for decreasing the negative physiological causes of water stress in plants, besides helping the plant to maintain physiological processes with a rapid recovery after overcoming water stress (Aroca, 2012). Cavalcante et al. (2020), in their study, stated that the use of biostimulants proved effective in promoting a greater capacity to withstand periods of water deficit.

The use of plant regulators in sugarcane is not recent, and their use may lead to a quantitative and qualitative increase in crop production (Silva, 2010). According to the author, the application of biostimulants promotes cell division, increasing the absorption of water by the plant's roots, which results in a great advantage for the plant when cultivated in areas of water deficit, because it will favour the use of the nutrients applied by foliar fertilizer and thus increase the plant's tolerance. In this way, the use of plant regulators has aroused the interest of producers and technicians, with a great increase in their use in sugarcane plantations and an innovative market in the agribusiness chain.

Thus, the viability of using biostimulants in sugarcane cultivation should be linked to physical productivity and economic analysis, and it is essential for the producer to make a decision so that the application of the plant regulator offers a viable and desirable financial return by improving productivity, so that there is no increase in operational costs and a low economic return.

Conclusion

The use of foliar fertilization for tolerance to water stress in sugarcane crop is feasible;

The use of plant regulators promotes tolerance to water deficit in sugarcane;

The use of foliar fertilization increases the productivity of sugarcane under dryland conditions;

The use of biostimulants in the foliar tissue is feasible and increases the productivity of sugarcane.

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