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ANIBAL PACHECO DE ALMEIDA PRADO FILHO

MULTI-ELEMENT FOLIAR FERTILIZATION ASSOCIATED TO RIPENER IN SUGARCANE: ENZIMATIC ACTIVITY AND SUGAR AND ENERGY YIELD

Botucatu

2023

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Thesis presented to São Paulo State University - School of Agriculture, to obtain Doctor degree in Agronomy (Agriculture)

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Botucatu

2023

P896m

Prado Filho, Anibal Pacheco de Almeida
Multi-element foliar fertilization associated to ripener in sugarcane: enzimatic activity and sugar and energy yield / Anibal Pacheco de Almeida Prado Filho. -- Botucatu, 2023
88 p.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agronômicas, Botucatu
Orientador: Carlos Alexandre Costa Crusciol
Coorientadora: Letusa Momesso Marques

1. Fisiologia vegetal. 2. Nutrição de plantas. 3. Cana-de-açúcar. 4. Atividade enzimática. 5. Sacarose. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca da Faculdade de Ciências Agronômicas, Botucatu. Dados fornecidos pelo autor(a).

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: MULTI-ELEMENT FOLIAR FERTILIZATION ASSOCIATED TO RIPENER IN SUGARCANE: ENZIMATIC ACTIVITY AND SUGAR AND ENERGY YIELD

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Botucatu, 08 de dezembro de 2023

To my parents, Anibal e Mariângela, my sister Leticia and my nephew Breno, you are the foundation for everything in my life.

ACKNOWLEDGMENT

I thank God for all the blessings achieved, for the wisdom provided and for illuminating and guiding my path, always being with me, especially in moments of difficulty or uncertainty, comforting my heart and providing health to continue with the journey of life.

To my parents, Anibal Pacheco de Almeida Prado and Mariângela Capraro Suriano de Almeida Prado, for teaching me the importance and values of a family, for their support and unconditional love, for showing that we can´t achieve our goals without hard work, and not avoiding effort to ensure that your children have the best education possible, every achievement in my life is also yours.

To my sister, Letícia S. de Almeida Prado, of whom I am very proud, for partnership, encouragement and advice, I am very grateful for having each other in life, and for gifting our family with my nephew and godson Breno, who overflows our life with love and joy since he was born.

To my advisor, Prof. Dr. Carlos Alexandre Costa Crusciol, an excellent professional, of whom I am very proud and admire as a friend and person, for everything he taught me during these years, for his friendship and partnership, for all his time and dedication for advice and suggestions so that we could always develop brilliant work and therefore contribute so much at this stage of my life,

To my co-advisor and friend, Letusa Momesso Marques, for accepting this challenge and brilliantly contributed to the development of this work and for all the dedicated attention and willingness to help whenever I need it.

To my friend Cleber Hervatin, for the partnership and effort to help and carry out the work over these years, for the exchange of knowledge and friendship.

To my friend Gabriela Ferraz de Siqueira, for contributing so much to my academic and professional performance, being present at all stages of mine postgraduate studies, for the teachings and friendship that I will carry throughout my entire life.

To this Thesis evaluation committee, for their willingness to spend precious time reading and evaluating this work.

I would like to thank everyone who, in some way, contributed directly or indirectly to the development and completion of this great work, my thank you.

“Whoever you are, whatever social position you have in life, the highest or the lowest, always aim for strength, a lot of determination and always do everything with a lot of love and a lot of faith in God, that someday you get there, somehow you get there”

Ayrton Senna.

ABSTRACT

Brazil is the world´s largest sugarcane producer and it has been one of the main agricultural crops grown in the country and it is extreme important for the national economic scenario. Foliar fertilizers application can provide productivity gains and technological quality for the crop. However, its use at the ideal time and the impacts of this management on the development of sugar cane are still little explored. Therefore, two studies were conducted over three subsequent harvest years, between 2017 and 2019, aiming to evaluate the effectiveness of multi-nutrient foliar applications at vegetative and maturation sugarcane stage, associated or not with ripener. In first study, 18 experiments were conducted at early harvest season, with foliar application occurring 120 days before harvest (vegetative stage) and 35 days before harvest (maturation stage), at different locations, measuring growth parameters, quality, energetic potential, and sucrose metabolism enzymes activity. In second study, 21 experiments were conducted at middle and late harvest sugarcane season, within application of multi-nutrients occurring 150 and 60 DBH, respectively, for each season at vegetative stage, and 30 DBH at maturation stage, evaluating stalk and sugar yield, estimate energy and metabolites in leaves. The studies were conducted at different locations in São Paulo and Minas Gerais state, and treatments were defined considering all applications possible, following a pattern for both studies, which were: (*1*) control with no applications of multi-nutrient foliar fertilizer and ripener (Control), (*2*) multi-nutrient foliar fertilizer applied at sugarcane vegetative stage (V), (*3*) multi-nutrient foliar fertilizer applied at sugarcane maturation stage (M), (*4*) ripener applied at maturation stage (R), (*5*) multi-nutrient foliar fertilizer applied both vegetative and maturation stages (VM), (*6*) multi-nutrient foliar fertilizer applied at vegetative stage plus ripener application at maturation stage (VR), (*7*) multi-nutrient foliar fertilizer applied at maturation stage plus ripener application also in maturation stage (MR), (*8*) multi-nutrient foliar fertilizer applied both vegetative and maturation stages plus ripener application at maturation stage (VMR). In summary, considering the two studies carried out, the multi-nutrient foliar application provided increases in plant growth parameters (height, diameter and stalk yield), with emphasis on treatments with two foliar applications (VM and VMR). In both studies was applied the same foliar fertilizer, which composition is N, K, Mg, S, B, Mn, Zn e Mo. Sulfometuron-methyl and bispiribaque-sódio were the ripener used. The ripener applied treatments increased sucrose, TRS

and sugar yield, and its association with fertilizers enhanced the observed gains, also observed in energy results. Considering growth and quality results, VMR treatment showed highest values in tons of sugar per hectare, through all years and seasons. It was concluded that multi-nutrient foliar fertilization contributed with higher sucrose synthesis and its association with ripener could lead to greater content of sugar in plant, consequently achieving higher productivity and quality of sugarcane.

Key words: *Saccharum spp.;* ripening; nutrient foliar application; sugar yield; metabolites; sucrose; enzymatic activity; sucrose phosphate synthase;

FERTILIZAÇÃO FOLIAR MULTI-ELEMENTAR ASSOCIADA À MATURADOR NA CANA-DE-AÇÚCAR: ATIVIDADE ENZIMÁTICA E PRODUTIVIDADE DE AÇÚCAR E ENERGIA

RESUMO

O Brasil é o maior produtor mundial de cana-de-açúcar, sendo esta uma das principais culturas agrícolas cultivadas no país e de extrema importância para o cenário econômico nacional. Dessa forma, a aplicação de fertilizantes via foliar pode proporcionar ganhos de produtividade e qualidade tecnológica para a cultura. No entanto, sua utilização no momento ideal e os impactos desse manejo no desenvolvimento da cana-de-açúcar ainda são pouco explorados. Para tanto, dois estudos foram desenvolvidos, ao longo de três safras subsequentes entre os anos de 2017 a 2019, com o objetivo de avaliar a eficácia da aplicação foliar de nutrientes na fase de crescimento vegetativo da planta e também na fase de maturação, associados, ou não, ao maturador. No primeiro estudo 18 experimentos foram conduzidos na época de início de safra, com a aplicação na fase vegetativa ocorrendo com 120 dias, em média, e na fase de maturação com 35 dias antes da colheita, em diferentes localidades, analisando os efeitos nos parâmetros de crescimento da planta, qualidade, potencial energético e atividade de enzimas que atuam no metabolismo da sacarose. No segundo estudo, 21 experimentos foram realizados nas épocas de meio e final de safra, com as aplicações na fase vegetativa ocorrendo com 150 e 60 dias antes da colheita, respectivamente, para cada época, e 30 dias na fase de maturação, avaliando produtividade de colmos, qualidade tecnológica, produção de energia e teor de metabolitos nas folhas. Os experimentos foram instalados em diferentes localidades, divididos entre os estados de São Paulo e Minas Gerais e os tratamentos foram definidos considerando todas as possibilidades de aplicação, padronizados para os dois estudos, sendo eles: (1) controle sem nenhuma aplicação (C), (2) fertilizante foliar aplicado no estágio vegetativo da cana-de-açúcar (V), (3) fertilizante foliar aplicado no estágio de maturação da cana (M), (4) maturador isolado aplicado no estágio de maturação (R), (5) fertilizante foliar aplicado nos estágios vegetativo e de maturação (VM), (6) fertilizante foliar aplicado no estágio vegetativo e maturador aplicado no estágio de maturação (VR), (7) fertilizante foliar aplicado no estágio de maturação juntamente com maturador (MR) e (8) fertilizante foliar aplicado

no estágio vegetativo e também no estagio de maturação, associado com maturador (VMR). Em ambos os trabalhos, utilizou-se o mesmo fertilizante foliar, composto pelos seguintes nutrientes: N, K, Mg, S, B, Mn, Zn e Mo. Os maturadores utilizados foram o sulfometuron-methyl e bispiribaque-sódio. Em síntese, considerando os dois estudos realizados, foi possível observar que a aplicação foliar de nutrientes proporcionou incremento nos parâmetros de crescimento da planta (altura, diâmetro e produtividade de colmos), com destaque para os tratamentos que receberam duas aplicações de nutrientes (VM e VMR). Os tratamentos com aplicação de maturador proporcionaram incremento nos teores de pol, ATR e produtividade de açúcar e a associação com o fertilizante foliar potencializou os ganhos observados, sendo este padrão também observado nos resultados de produção de energia. Considerando os resultados de produção e qualidade, o tratamento VMR apresentou os maiores resultados em toneladas de açúcar por hectare, ao longo dos anos e épocas. Assim, concluiu-se que a adubação foliar contribui com maior síntese de sacarose e sua associação com a aplicação do maturador proporciona maior acúmulo de açúcar na planta, consequentemente resultando em ganhos de produtividade e qualidade da matéria prima.

Palavras-chave: *Saccharum spp.*; maturação; adubação foliar; produtividade de açúcar; metabólitos; sacarose; atividade enzimática; sacarose fosfato sintase;

SUMMARY

INTRODUCTION

Brazil is the largest sugarcane (*Saccharum* spp. hybrids) producer in the world, global leader in the production of sugar and its derivatives, and will remain by 2030 (OECD; FAO, 2021). Sugarcane predominantly grows in tropical and subtropical regions with well-distributed rainfall and can be harvested after 12 to 18 months in the first harvest and cultivated up to five consecutive years in the same area. The crop products allow flexibility to produce sugar and ethanol in the industry, as well as molasses or thick juice and the residue from sugarcane crushing (bagasse) to supply energy production (raw material for cogeneration for electricity) (BOARETTO; MAZZAFERA, 2013). However, its productivity is below the genetic potential (WACLAWOVSKY et al., 2010), caused by biotic and abiotic stresses during the entire phenological sugarcane stages (CHEAVEGATTI-GIANOTTO et al., 2011; DINARDO-MIRANDA; VASCONCELOS; LANDELL, 2008).

In south-central region in Brazil, one of the most important sugarcane producer areas, the harvest season usually begins in March to April, and ends in November and December, period that presents high temperatures and rainfall, in which climatic conditions promote the vegetative growth of the plant as well as sucrose accumulation (CASTRO, 2016).

For the adequate development of sugarcane, two climatic conditions are necessary. The first type of climatic condition refers to the occurrence of a hot and humid season to guarantee germination, root growth, tillering and complete vegetative development, which occurs with the beginning summer, covering the early harvest season. The second climatic condition is with low temperatures and water deficit aiming to stimulate, through stress to the plant, the physiological process of natural maturation, occurring in winter and beginning of spring, a period that encompasses middle and end-harvest season (CAPUTO et al., 2008).

Sugarcane greatest vegetative growth period occurs under high light intensity, high temperature and water availability, conditions that allow greater formation of leaves, stems, and root system, due to the use of photoassimilates for plant development (HUMBERT, 1984; VIANA, 2007). Therefore, at early harvest season, climatic conditions are favorable to sugarcane vegetative growth, this being the higher production crop period, where nutritional management drives increase in yield gains. On the other hand, at this season, the conditions for natural maturation are critic, thus,

the use of ripeners at early harvest season has become a frequently used practice in sugarcane cultivation, seeking to anticipate the plant maturation, promote improvements in the quality of the raw material, optimizing industry results and assisting in harvest planning (CAPUTO et al., 2008).

Ripeners, or also known as plant regulators, are defined as substances whose physiological effects are similar to those of some known hormones, in which are chemical compounds that modify plant morphology and physiology, interrupting or delaying the plant growth, changing its metabolism and directing the sucrose synthesized for storage in the sugarcane stems (LEITE et al., 2011).

Under opposite conditions to vegetative growth (low temperatures and low water availability), the plant stops its growth, and a change occurs in its metabolism, which directs the sucrose synthesized in the leaves to accumulate in the vacuole of the parenchyma cells of the stem (ALEXANDER, 1973; DEUBER, 1978; ANDRADE; CARDOSO, 2004). In the mid-late sugarcane season in southeastern Brazil, the reduction of temperatures, drought and reduction nutrients uptake from the soil is frequent, thus impairing the activity of enzymes responsible for the photosynthetic process and consequently the growth and development (SCUDELETTI et al., 2021), requiring further studies during this harvest season.

New and advanced agricultural technologies and management need to be promoted and implemented to mitigate stress caused by environment and improve the production and quality of raw materials. Some studies highlight that micronutrient application is a great option to promote gains in crop productivity and quality (JAMRO et al., 2002; PROM-U-THAI et al., 2020; STEWART et al., 2020; ZEWAIL et al., 2020), but information on the use of foliar fertilization of a multi-nutrient complex is scarce in sugarcane.

Foliar fertilizer application has been used to protect the photosynthesis process through regulation of primary plant metabolism to increase productivity and quality gain, but this is a rule due to the limitations imposed by the stress of extreme heat, cold, drought and high incidence of light (WANG et al., 2003; HEFFERNAN, 2013; TEIXEIRA et al., 2013; SLAMA et al., 2015; SOLIMAN et al., 2019; ELSHEERY et al., 2020; GUPTA, RICO-MEDINA, CANO-DELGADO, 2020; SOLIMAN et al., 2020).

Knowing the many metabolic and structural functions of nutrients and their requirements throughout the crop cycle, as well as the right moment that plants need them most, can facilitate management and provide improvements in crop quality and

productivity (EPSTEIN; BLOOM, 2005; MARSCHNER, 2012). The maintenance of the photosynthetic apparatus and osmoprotector production and accumulation by the foliar fertilization of a multi-nutrient complex seems to be an interesting strategy to mitigate stresses and increase the productivity and quality of sugarcane.

In this scenario, the efficiency of applying foliar nutrients at vegetative and in the maturation crop stage through different harvest seasons, combined or not with ripener, looking for improvements in technological quality and productivity as well as its impact on plant metabolism, has not been widely recognized in sugarcane.

The hypothesis raised in study was that a multi-nutrient foliar fertilizer applied at final vegetative and maturation development stages of sugarcane can promote improvements in growth and quality yield; foliar fertilizer combined with ripener application may provide higher theoretical recuperable sugar and sugar yield than only ripener application; energy production must be greater with multi-nutrient foliar application; and foliar fertilization applied both vegetative and maturation stage could lead to higher growth parameters results.

In order to evaluate this hypothesis, as there are different agronomic managements for each harvest season, this thesis is composed by two chapters with several experiments applying nutrient and ripener to sugarcane in three harvest seasons (early, middle and late harvest seasons). Following similar management of nutrient and ripener, first chapter focused in sugarcane in the early harvest (March-April) that plant has high yields and most common cultivated; however, it is far from achieving the sugarcane potential yield production and still needs information about sugarcane metabolism. The second chapter aimed to evaluate the sugarcane response in the middle and late harvest seasons (Winter-Spring) that are lack of knowledge in technology of multi-nutrient foliar applications and in which stage of plant development could potentially provide greater results, especially because the sugarcane harvest at these two seasons has low yields and requires more studies in its metabolism improvements.

GENERAL CONSIDERATIONS

Foliar multinutrient fertilizer composed by N, K, Mg, S, B, Mn, Zn and Mo, and ripener applications in sugarcane field production efficiently raise plant growth, sugar yields, energy production and favoured enzymes activity in sucrose metabolism, especially when fertilizer applied at vegetative and maturation stages combined with ripener application. This management proved to be a great alternative to increase sucrose synthesis, contributing to higher plant development as well as increasing quality for industry.

Considering the results found in this study, it should be noted that use of ripener is an essential tool to enhance theoretical recoverable sugar and sucrose accumulation in sugarcane, mainly in early harvest season, when the climate conditions are not favorable to natural maturation, and the association with multi-nutrient foliar contributes to achieving greater results in tons of sugar per hectare (sugar yield).

It has been clear the positive effect of multinutrient fertilization mainly in the vegetative stage, on average of 120 DBH at early harvest season, 150 and 60 days at middle and late harvest, respectively, which enhanced sugarcane growth through a longer period. The combined effects of nutrient supply by fertilizer at early development stage (vegetative) and at late stage (maturation) to complement the necessary nutrients for reactions, were reflected in improvements in productivity, mainly stalk and sugar yields, emphasizing the importance of an adequate supply of nutrients to crops. Furthermore, due to the capacity of the leaves to absorb nutrients, foliar applications represent an excellent fertilization strategy to improve the internal concentration of required nutrient at the period of greatest demand in plants.

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