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DANIELE SCUDELETTI

**THE SUGARCANE DEVELOPING AS A FUNCTION OF MICROORGANISM
ADOPTION TO POTENTIALIZE THE PRODUCTION**

Botucatu

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Advisor: Prof. Dr. Carlos Alexandre Costa Crusiol

Co-advisor: Prof. Dr. Brenda Servaz Tubaña

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ADOPTION TO POTENTIALIZE THE PRODUCTION

AUTORA: DANIELE SCUDELETTI

ORIENTADOR: CARLOS ALEXANDRE COSTA CRUSCIOL

COORIENTADORA: BRENDA SERVAZ TUBAÑA

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(AGRICULTURA), pela Comissão Examinadora:

Prof. Dr. CARLOS ALEXANDRE COSTA CRUSCIOL
Produção Vegetal / Faculdade de Ciências Agrônomicas de Botucatu - UNESP

Dr. GUSTAVO SPADOTTI AMARAL CASTRO
Gestão Territorial Estratégica / Embrapa Territorial

Dr. SÉRGIO GUSTAVO QUASSI DE CASTRO
/ Laboratório Nacional de Ciência e Tecnologia do Bioetanol

Pesquisadora Dr.ª ELISA FIDÊNCIO DE OLIVEIRA
Três Lagoas/MS /

Dr. MARCELO ROCHA CORRÊA
/ TechField Assessoria & Consultoria Agrícola e Ambiental

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*To my beloved parents,
Leucina and Mauricio,
I dedicate.*

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ABSTRACT

The use of microorganisms has contributed to the greater optimization of agricultural areas by increasing productivity, as they may contribute to some mechanisms related to plant growth, biological nitrogen fixation and attenuation of water stress. Thus, the objectives were divided into two studies (Chapters 1 and 2). In Chapter 1, the study aimed to evaluate the efficacy of doses and inoculation modes of *Azospirillum brasilense*, on biometric, physiological and technological parameters, as well as improvements in the absorption of nutrients and productivity of sugarcane. The study was carried out in an experimental area belonging to Raízen Mill, located in the municipality of Santa Maria da Serra - SP, in two crop seasons (2015/2016 and 2016/2017), in which the doses of the inoculant containing *Azospirillum brasilense* and the method of inoculation were evaluated. In general, the application of the dose of 15 and 20 × 10¹⁰ UFC ha⁻¹ of the inoculant *Azospirillum brasilense*, mainly stimulated the biometric characteristics, reflected in the higher productivity of stalks, sugar and economic return. As for the mode of inoculation, further investigation of the impact of weather conditions on microbial shelf life and on the efficiency of the use of the inoculant is necessary, guaranteeing the most appropriate time and method of application to minimize potentially adverse conditions. In Chapter 2, the objective of the study was to evaluate the inoculation of *Trichoderma asperellum* in the absence or presence of drought stress in the biometric, physiological, biochemical and enzymatic parameters, and in the physico-chemical characterization of leaf sugars and the possible improvements in sugarcane conditioning. sugar in situations of drought stress. The experiment conducted in a greenhouse at College of Agricultural Science (FCA-UNESP) and the response of plants by association with *Trichoderma asperellum* under conditions of drought stress in sugarcane was evaluated. The use of this microorganism provided better results, contributing significantly to the conditioning of plants under drought stress and improving the biometric, physiological, biochemical, enzymatic parameters, as well as the physicochemical characterization of leaf sugars. In summary, both experiments found benefits from microorganisms: *Azospirillum* stimulates the growth and development of sugarcane, reflecting in increased productivity and greater economic return from sugarcane production; and *Trichoderma* improved the physiological parameters, the activation of the enzyme nitrate reductase and the antioxidant metabolism, providing better growth, development, tillering and the productivity of sugarcane, mainly under drought stress conditions.

Keywords: *Azospirillum brasilense*. *Trichoderma asperellum*. *Saccharum* spp.
Productivity.

RESUMO

O uso de microrganismos tem contribuído para a maior otimização das áreas agricultáveis por meio do aumento da produtividade, pois podem contribuir para alguns mecanismos relacionados ao crescimento das plantas, fixação biológica de nitrogênio e atenuação do estresse hídrico. Assim, os objetivos foram divididos em dois estudos (Capítulos 1 e 2). No Capítulo 1, o estudo visou avaliar a eficácia de doses e os modos de inoculação do *Azospirillum brasilense*, sobre os parâmetros biométricos, fisiológicos e tecnológicos, bem como as melhorias na absorção de nutrientes e na produtividade da cana-de-açúcar. O estudo foi realizado em área experimental pertencente à Usina Raízen, localizada no município de Santa Maria da Serra - SP, em duas safras (2015/2016 e 2016/2017), nos quais foram avaliados as doses do inoculante contendo *Azospirillum brasilense* e o modo de inoculação. Em geral, a aplicação da dose de 15 e 20 × 10¹⁰ UFC ha⁻¹ do inoculante *Azospirillum brasilense*, estimulou principalmente as características biométricas, refletiu na maior produtividade de colmos, açúcar e retorno econômico. Quanto ao modo de inoculação, é necessária uma investigação mais aprofundada do impacto das condições meteorológicas na vida de prateleira microbiana e na eficiência do uso do inoculante garantindo tempo e o método de aplicação mais apropriados para minimizar condições potencialmente adversas. No Capítulo 2, o objetivo do estudo foi avaliar a inoculação de *Trichoderma asperellum* na ausência ou presença de estresse hídrico nos parâmetros biométricos, fisiológicos, bioquímicos e enzimáticos, e na caracterização físico-química dos açúcares foliares e as possíveis melhorias no condicionamento da cana-de-açúcar em situações de estresse hídrico. O experimento foi conduzido em casa de vegetação na Faculdade de Ciências Agrônômicas (FCA-UNESP) e foi avaliada a resposta das plantas inoculadas com *Trichoderma asperellum* sob condições de estresse hídrico na cana-de-açúcar. O uso deste microrganismo proporcionou melhores resultados, contribuindo significativamente para o condicionamento de plantas sob estresse hídrico e melhorando os parâmetros biométricos, fisiológicos, bioquímicos, enzimáticos, bem como a caracterização físico-química dos açúcares foliares. Em resumo, ambos os experimentos encontraram benefícios advindos dos microrganismos: o *Azospirillum* estimula o crescimento e o desenvolvimento da cana-de-açúcar, refletindo no aumento da produtividade e maior retorno econômico da produção de cana-de-açúcar; e *Trichoderma* melhorou os parâmetros fisiológicos, a ativação da enzima nitrato redutase e o metabolismo antioxidante, proporcionando melhor crescimento, desenvolvimento, perfilhamento e a produtividade da cana-de-açúcar, principalmente em condições de estresse hídrico.

Palavras-chave: *Azospirillum brasilense*. *Trichoderma asperellum*. *Saccharum* spp.
Produtividade.

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GENERAL INTRODUCTION

Climate change and increasing climate variability are affecting agricultural productivity, food production, and natural resources, with impacts on food systems and rural livelihoods, including a decline in the number of farmers and steady growth of people living in urban areas (FAO, 2019). The world population today is 7.7 billion and in 2050 it will surpass 9.7 billion people. These numbers represent a 26% growth from 2020 to 2050 (EMBRAPA, 2020). The increase in population, life expectancy and purchasing power, implies greater consumptions of water, energy, food and fiber. All of this leads to major changes in the way food is produced, distributed, and consumed worldwide (FAO, 2019), causing consequently new challenges with the need to increase world agricultural production due to population growth.

Brazil is an important producer and one of the main global food suppliers. Among the main crops produced in Brazil, sugarcane (*Saccharum* spp.) stands out for being one of the activities that generate more jobs in the agribusiness sector, generates income helping in the trade balance for the production of sugar, ethanol, and bioenergy, being considered one of the main alternatives within this sector by the great production potential.

Between 1975 and 2019 the production of sugarcane increased from 91.5 million tonnes to 668 million tonnes, occupying just over 1% of the national territory (EMBRAPA, 2020). According to CONAB (2020), the estimated area for sugarcane production in the 2020/2021 harvest is close to 8,605 thousand hectares, which represents a increase of 1.9% concerning the last harvested area. The estimated average productivity of stalks is approximately 77 t ha^{-1} , a relatively low value when compared to its production potential (380 t ha^{-1}) (WACLAWOVSKY et al., 2010). Increase production and plant adaptation to stress conditions is a great challenge for current agriculture since the increase in production cannot be based solely on the increase in the cultivated area, but also on the improvements in the productivity of the area consolidated agriculture (VAN REES et al., 2014; LIZANA et al., 2006). However, the production approach nowadays is different from the agricultural model adopted since the Green Revolution (increase in productivity, expansion of agricultural frontiers, intensive soil use, reduction of biodiversity, etc.). The

concern about socio-economic and environmental importance is necessary for the development of sustainable practices to ensure greater productivity.

Thus, it is necessary to use new technologies that can provide productivity improvements. The intensification of research with the use of some microorganisms has shown to be a promising technology. In this context there are potential alternatives: the use of diazotrophic bacteria, such as *Azospirillum*, are capable of carrying out biological nitrogen fixation (BNF) and can also produce growth-promoting substances in plants, consisting of a promising technology, which can benefit crop growth and productivity; the use of the fungus *Trichoderma asperellum* are also an option that acts in the pathogens defense, contributing plant development and growth nutrients and stress resistance (OLIVEIRA et al., 2006; SCHULTZ et al., 2012, 2014, MENDES, R. et al., 2011; COLEMAN-DERR et al., 2014; COMPANT, S. et al., 2010; de SANTI FERRARA et al., 2012).

Diazotrophic bacteria are bridges in the production of growth regulators, obtaining greater development of the root system, which makes the absorption of water and nutrients more efficient (SPAEPEN et al., 2007; CASSÁN et al., 2014). The promotion of plant growth occurs because these bacteria stimulate the production of phytohormones, solubilization of phosphates, zinc and can also contribute to the induction of resistance to diseases, competition with pathogens, or even induction of water stress, by providing resistance to stresses (DOBBELAERE et al., 2003; ARENCIBIA et al., 2006; SARAVANAN et al., 2007).

Several diazotrophic bacteria were found and associated with sugarcane (SOUZA et al., 2016). Various species have been described, obtained from different parts of the plant (stalk, root and leaves), such as *Gluconacetobacter diazotrophicus* (CAVALCANTE; DÖBEREINER, 1988), *Herbaspirillum* (BALDANI et al., 1996), *Azospirillum* (BALDANI et al., 1997), *Burkholderia* (REIS et al., 2004), *Microbacterium* (LIN et al., 2012) and *Raoultella* (LUO et al., 2016). The selection of strains, that is, the efficient lineage of growth promotion can increase biomass and sugar (SCHULTZ et al., 2012, 2014), it can also promote other indirect benefits, such as protection against pathogens (BLANCO et al., 2005; ARENCIBIA et al., 2006; SCHULTZ et al., 2017).

Trichoderma spp. in addition to acting as a pathogen control due to the ability to produce antibiotics and enzymes (HOYOS-CARVAJAL et al., 2009), they can produce morphological and biochemical changes in the host plant, contributing to the solubilization or sequestration of inorganic nutrients such as phosphate solubilization and other minerals making them available to the plant or even contributing to stress tolerance (HARMAN, 2000; VITERBO et al., 2002). This fungus has shown benefits in the seed germination process (ALTOMAR; TRINGOVSKA, 2011), as well as the metabolic production with activities analogous to plant hormones (HOYOS-CARVAJAL et al., 2009), which consequently activates the growth of plants, which has been observed in several cultures (KLEIFELD; CHET, 1992; OUSLEY et al., 1994; ALTOMARE et al., 1999; HARMAN, 2000; YEDIDIA et al., 2001).

The use of bacteria, and the fungus adoption (*Trichoderma* spp.) has versatility and mechanism of action, used as biological control of nematodes, and as a plant stimulator, which makes it very attractive, being one of the most researched fungi in laboratories and tested in greenhouses (WIJESINGHE et al., 2011; TRUSHINA et al., 2013; FILHO et al., 2008). Some isolates can act in the phosphate solubilization and other minerals, making them available to the plant (HARMAN, 2000). Another feature is the determination of auxin synthesis, favoring root growth, and shoot growth (HOYOS-CARVAJAL et al., 2009). Among the mechanisms of action exercised can be highlighted: competition, parasitism, and predation, in addition to inducing morphological and biochemical changes in the host plant and stress tolerance (VITERBO et al., 2002; LORITO et al., 2010).

Thus, the study was divided into two chapters. The first chapter consists of the inoculation of *Azospirillum brasilense* as a growth promoter in sugarcane, where the effectiveness in its methods of inoculation and doses of inoculant during two agricultural harvests in two crops cycles were evaluated through the evaluations of biometric and technologies with the objective of possible improvements in soil nutrient absorption and productivity. In the second chapter, the topic addressed was the use of microorganisms as attenuators of water stress in sugarcane. Thus, the inoculation of *Trichoderma asperellum* was evaluated as a water stress conditioner, through biometric, physiological, biochemical, enzymatic evaluations, physicochemical characterization of leaf starches, and the possible improvements provided by bacteria under water stress conditions. This

research had as a main interest to address and clarify the effects of growth and conditioning to drought stress that microorganisms can and provide for sugarcane crop.

GENERAL CONSIDERATIONS

The inoculation of microorganisms in sugarcane has the purpose of enhancing productivity, by increasing the production of photoassimilates, improving the metabolism of the plant mainly in situations of water stress, consequently favoring the growth and development of the plants, contributing to the profitability for the producer.

The use of doses 15 and 20 × 10¹⁰ CFU ha⁻¹ of the inoculant containing bacteria *Azospirillum brasilense* provided better crop development, tillering and thus higher stalk production, sugar, trash and bagasse yields and energy production of sugarcane. However, there was no pattern of results from effect of the inoculant application time. Therefore, the use of this microorganism in high rates provides greater sugarcane yields, as well as being an alternative to maximize the agronomic and economic return to the sugarcane sector; and the application of the inoculant is not related to the stage of the sugarcane, but to the climatic conditions.

Trichoderma asperellum also showed positive effects when inoculated on sugarcane plants under water stress. These findings were observed on greater crop nutrition, concentration of chlorophylls and carotenoids by increases in the rate of photosynthesis, stomatal conductance and water use efficiency on inoculated sugarcane compared to uninoculated plants. In addition, the antioxidant metabolism was also affected, increasing the activities of the enzymes SOD, POD, proline and the portioning of sugars; these effects result in the potentiation of root and stalk development of sugarcane, which *Trichoderma asperellum* inoculation is an important tool to reduce the negative effects of drought stress in sugarcane.

For these aspects, consolidating the use of microorganisms in agriculture is an innovative alternative, and its benefits are greater plant growth, stress tolerance (biotic and abiotic), as well as increases in productivity. In addition, application of microorganisms inoculants in plants favors the environment for being an important sustainable strategy economically viable.

REFERENCES

- ALTOMAR, C.; TRINGOVSKA, I. Beneficial soil microorganisms, an ecological alternative for soil fertility management. In: Lichtfouse, E. (Ed.) - **Genetics, biofuels and local farming systems**. Heidelberg, Springer, p. 161-214, 2011.
- ALTOMARE, C., NORVELL, W.A., BJÖRKMAN, T., HARMAN, G.E. Solubilization of phosphates and micronutrients by the plantgrowth-promoting and biocontrol fungus *Trichoderma harzianum* Rifai 1295-22. **Applied and Environmental Microbiology** v. 65, p. 2926–2933, 1999.
- ARENCIBIA, A.D.; ESTEVEZ, Y.; VINAGRE, F.; BERNAL, A.; PÉREZ, J.; CARMONA, E.; SANTANA, I. Induced resistance in sugarcane against pathogenic bacteria *Xanthomonas albilineans* mediated by an endophytic interaction. **Sugar Tech.**, v. 8, n. 4, p. 272–280, 2006.
- BALDANI, J.; CARUSO, L.; BALDANI, V.L.D.; GOI, S. R.; DÖBEREINER, J. Recent advances in BNF with non-legume plants. **Soil Biology and Biochemistry**, v. 29, n.5/6, p. 911–922, 1997.
- BLANCO, Y.; BLANCH, M.; PIÑÓN, D.; LEGAZ, M.; VICENTE, C. Antagonism of *Gluconacetobacter diazotrophicus* (a sugarcane endosymbiont) against *Xanthomonas albilineans* (pathogen) studied in alginate-immobilized sugarcane stalk tissues. **Journal of Bioscience and Bioengineering**, v. 99, p. 366–371, 2005.
- CASSÁN, F.; VANDERLEYDEN, J.; SPAEPEN S. Physiological and agronomical aspects of phytohormone production by model plant bacteria-promoting rhizobacteria (PGPR) belonging to the genus *Azospirillum*. **Journal Plant Growth Regul.** v. 33, p. 40-59, 2014.
- CAVALCANTE, V.A., DÖBEREINER, J. A new acid tolerant nitrogen-fixing bacterium associated with sugarcane. **Plant Soil**, v. 108, p. 23–31, 1988.
- COLEMAN-DERR, D.; TRINGE, S. G. Building the crops of tomorrow: advantages of symbiont-based approaches to improving abiotic stress tolerance. **Frontiers in Microbiology**, v. 5, p. 1–6, 2014.
- COMPANT, S.; CLÉMENT, C.; SESSITSCH, A. Plant growth-promoting bacteria in the rhizo- and endosphere of plants: Their role, colonization, mechanisms involved and prospects for utilization. **Soil Biology and Biochemistry**, v. 42, p. 669–678, 2010.
- CONAB - Companhia Nacional de Abastecimento. Acompanhamento da safra brasileira. Cana-de-açúcar. V.7 Safra 2019-20. 3º levantamento, Dezembro 2020. ISSN 2318-7921 – Brasília, p. 1-58. Monitoramento Agrícola. Available in: www.conab.gov.br. Acess in 16th December 2020.
- de SANTI FERRARA, F. I.; OLIVEIRA, Z. M.; GONZALES, H. H. S.; FLOH, E. I. S.; BARBOSA, H. R. Endophytic and rhizospheric enterobacteria isolated from sugar

cane have different potentials for producing plant growth-promoting substances. **Plant Soil**, v. 353, p. 409–417, 2012.

DOBBELAERE, S.; VANDERLEYDEN, J.; OKON Y. Plant growth promoting effects of diazotrophs in the rhizosphere. **Critical Reviews in Plant Sciences**, v. 22, n. 2, p.107-149, 2003.

EMBRAPA. **Embrapa em números**. Embrapa, Secretaria Geral, Gerência de Comunicação e Informação. Brasília, DF, 2020.

FAO, **The State of Food Security and Nutrition in the World 2019**. Food and Agriculture Organization of the United Nations, Rome, FAO, 2019.

FILHO, M. R. C.; MELLO, S. C.M.; SANTOS, R. P.; MENÊZES, J. E. Avaliação de isolados de *Trichoderma* na promoção de crescimento, produção de ácido indolacético in vitro e colonização endofítica de mudas de eucalipto. Boletim de pesquisa e desenvolvimento, 226. Brasília, **Embrapa Recursos Genéticos e Biotecnologia**, 2008.

HARMAN, G. E. Myths and dogmas of biocontrol – Changes in perceptions derived from research on *Trichoderma harzianum* T-22. **Plant Disease**, v. 84, n. 4, p. 377-392, 2000.

HOYOS-CARVAJAL, L.; ORDUZ, S.; BISSETT, J. Growth stimulation in bean (*Phaseolus vulgaris* L.) by *Trichoderma*. **Biological Control**, v. 51, n. 3, p. 409–416, 2009.

KLEIFELD, O.; CHET, I. *Trichoderma harzianum*—interaction with plants and effect on growth response. **Plant and Soil**, v. 144, n. 2, p. 267–272, 1992.

LIN, L.; GUO, W.; XING, Y.; ZHANG, X.; LI, Z.; HU, C.; LI, S.; LI, Y.; AN, Q. The actinobacterium *Microbacterium* sp. 16SH accepts pBBR1-based pPROBE vectors, forms biofilms, invade roots, and fixes N₂ associated with micropropagated sugarcane plants. **Applied Genetics and Molecular Biotechnology**, v. 93, p. 1185–1195, 2012.

LIZANA, C.; WENTWORTH, M.; MARTINEZ, J. P.; VILLEGAS, D.; MENESES, R.; MURCHIE, E. H.; PASTENES, C.; LERCARI, B.; VERNIERI, P.; HORTON, P.; PINTO, M. Differential adaptation of two varieties of common bean to abiotic stress. I. Effects of drought on yield and photosynthesis. **Journal of Experimental Botany**, v.57, p.685-697, 2006.

LORITO, M.; WOO, S. L.; HARMAN, G. E.; MONTE, E. Translational research on *Trichoderma*: from 'omics to the field. **Annual review of phytopathology**, v. 48, p. 395–417, jan. 2010.

LUO, T.; OU-YANG, X.Q.; YANG, L.T.; LI, Y.R.; SONG, X.P., ZHANG, G.M., GAO, Y.J., DUAN, W.X., AN, Q. *Raoultella* sp. strain L03 fixes N₂ in association with micropropagated sugarcane plants. **Journal of Basic Microbiology**, v. 56, p. 934–940, 2016.

MENDES, R.; KRUIJT, M.; de BRUIJN, I.; DEKKERS, E.; van DER VOORT, M.; SCHNEIDER, J. H. M.; PICENO, Y. M.; RAAIJMAKERS, J. M. Deciphering the rhizosphere microbiome for disease-suppressive bacteria. **Science**, v. 332, p. 1097–1100, 2011.

OLIVEIRA; A.L.M.; CANUTO, E.L.; URQUIAGA, S., REIS, V.M.; BALDANI, J.I. Yield of micropropagated sugarcane varieties in different soil types following inoculation with diazotrophic bacteria. **Plant Soil**, v. 284, p. 23–32, 2006.

ONU, United nations, department of economic and social affairs The United Nations, Population Division, **Population Estimates and Projections Section**, 2012.

OUSLEY, M.A.; LYNCH, J.M.; WHIPPS, J.M. Potential of *Trichoderma* spp. as consistent plant growth stimulators. **Biology and Fertility of Soils** v. 17, p. 85–90, 1994.

REIS, V. M.; ESTRADA DE LOS SANTOS, P.; TENORIO-SALGADO, S.; VOLGEL, J.; STROFFELS, M.; GUYON, S.; MAVINGUI, P.; BALDANI, V. L. D.; SCHMID, M.; BALDANI, J. I.; BALANDREAU, J.; HARTMANN A.; CABALLERO-MELLADO, J. *Burkholderia tropica* sp. nov., a novel nitrogen-fixing, plant-associated bacterium. **International Journal of Systematic and Evolutionary Microbiology**, v. 54, p. 2155-2162, 2004.

SARAVANAN, V.S.; MADHAIYAN, M.; THANGARAJU, M. Solubilization of zinc compounds by the diazotrophic, plant growth promoting bacterium *Gluconacetobacter diazotrophicus*. **Chemosphere**, v. 66, n.9, p. 1794-1798, 2007.

SCHULTZ, N.; DE MORAIS, R. F.; DA SILVA, J. A.; BAPTISTA, R. B.; OLIVEIRA, R. P.; LEITE, J. M.; PEREIRA, W.; CARNEIRO JÚNIOR, J. de B.; ALVES, B. J. R.; BALDANI, J. I.; BODDEY, R. M. Avaliação agronômica de variedades de cana-de-açúcar inoculadas com bactérias diazotróficas e adubadas com nitrogênio **Pesquisa Agropecuária Brasileira**, Brasília, v. 47, n. 2, p. 261-268, fev. 2012.

SCHULTZ, N.; PEREIRA, W.; SILVA, P.A.; BALDANI, J.I.; BODDEY, R.M.; ALVES, B.J.R.;URQUIAGA, S.; REIS, V.M. Yield of sugarcane varieties and their sugar quality grown in different soil types and inoculated with diazotrophic bacteria consortium. **Plant Production Science**, v. 20, p. 366–374, 2017.

SCHULTZ, N.; da SILVA, J. A.; SOUSA, J. S.; MONTEIRO, R. C.; OLIVEIRA, R. P.; CHAVES, V. A.; PEREIRA, W.; SILVA, M. F.; da REIS, V. M.; URQUIAGA, S. Inoculation of sugarcane with diazotrophic bacteria. **Revista Brasileira de Ciência do Solo**, [S.l.], v. 38, n. 2, p. 359-371, 2014. Available in: DOI: 10.1590/S0100-06832014000200005. Access in 16th December 2020.

SPAEPEN, S.; VERSÉES, W.; GOCKE, D., PO; L. M.; STEYAERT, J.; VANDERLEYDEN, J. Characterization of phenylpyruvate decarboxylase, involved in auxin production of *Azospirillum brasilense*. **Journal of Bacteriology**, v. 189, n 21, p. 7626–7633, 2007.

TRUSHINA, N.; LEVIN, M.; MUKHERJEE, P. K.; HORWITZ, B. A. Pac and pH-dependent transcriptome of the mycotrophic fungus *Trichoderma virens*. **BMC genomics**, v. 14, n. 1, p. 138, jan. 2013.

VAN REES, H.; MCCLELLAND, T.; HOCHMAN, Z.; CARBERRY, P.; HUNT, J.; HUTH, N.; HOLZWORTH, D. Leading farmers in South East Australia have closed the exploitable wheat yield gap: prospects for further improvement. **Field Crops Research**, v. 164, p. 1-11, Aug.2014. Available in: DOI: 10.1016/j.fcr.2014.04.018. Access in 10th December 2020.

VITERBO, A.; RAMOT, O.; CHERNIN, L.; CHET, I. Significance of lytic enzymes from *Trichoderma* spp. in the biocontrol of fungal plant pathogens. **Antonie van Leeuwenhoek**, v. 81, n. 1-4, p. 549–56, ago. 2002.

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. Available in: <http://dx.doi.org/10.1111/j.1467-7652.2009.00491.x>. Access in 10th December 2020.

WIJESINGHE, C.J.; WILSON WIJERATNAM, R.S.; SAMARASEKARA, J.K.R.R.; WIJESUNDERA, R.L.C. Development of a formulation of *Trichoderma asperellum* to control black rot disease on pineapple caused by (*Thielaviopsis paradoxa*). **Crop Protection**, v. 30, n. 3, p. 300–306, mar. 2011.

YEDIDIA, I., SRIVASTVA, A.K.; KAPULNIK, Y.; CHET, I. Effect of *Trichoderma harzianum* on microelement concentrations and increased growth of cucumber plants. **Plant and Soil**, v.235, p. 235–242, 2001.