Chapter 10

Sugarcane: Organo-Mineral Fertilizers and Biostimulants

Emmerson Rodrigues de Moraes,
José Geraldo Mageste, Regina Maria Quintão Lana,
Rodrigo Vieira da Silva and Reginaldo de Camargo

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Abstract

The combined application of organic fertilizer with mineral fertilizer increases the yield of sugarcane. It promotes greater residual beneficial effect in relation to the use of each fertilizer in isolation. The organo-mineral fertilizer presents gradual solubilization during the period of development of the crop. Thus, when compared to soluble mineral sources, its agronomic efficiency may be higher. Various types of organic material can be used, such as pig manure, poultry litter, filter cake and sewage sludge, among others. Organic matter is responsible for maintaining and increasing soil porosity to improve water retention and to ensure soil microbial balance. The efficiency in nourishing the sugarcane crops or availing the available nutrients is maximized. The use of biostimulants in world agriculture has achieved significant growth rates in the last decades. Hormone compounds ensure the sustainability of crops. It can be an alternative to improve plant nutrition, support of abiotic and biotic stresses. They act in the activation and potentiation of the metabolism of the cells, give more vigor to the immune system and help to enable the physiological processes in the different stages of development. The emergence and use of new technologies is the way to achieve greater productivity, sustainability and profitability.

Keywords: *Saccharum* spp., nutrition, nutrient cycling, plant hormones, sustainability

1. Introduction

Sugarcane (*Saccharum* spp.) is a species of plant in semi-perennial grass in the Poaceae family. It presents itself as an important culture providing not only food but also renewable energy. With all the existing technological package for the cultivation of sugarcane, it is possible to envisage an even more promising future economically, socially and environmentally for the planet. Energy cogeneration, that is, the production of energy by employing more than one process, such as second-generation ethanol or cellulosic ethanol, is a great example. In this scenario, where the adoption of new agricultural practices and techniques has been done in an accelerated way, often passing the scientific production, it is necessary to produce knowledge that helps producers in the adoption of sustainable and economically viable technologies.

The quality and longevity of a cane field is related to soils of good chemical, physical and biological properties. A soil fertility management program is also a requirement for forming productive reeds. Thus, the addition and/or maintenance of organic matter in the soil as well as adequate levels of nutrients is necessary to obtain high productivities. Organo-mineral fertilizers contribute to the addition and maintenance of organic matter in the soil. Physiological factors associated with nutrition contribute considerably to the development of sugarcane plants [1].

In modern agriculture, additional techniques with the aim of obtaining the maximum productivity of sugarcane are being used. Among them is the use of biostimulants, regulators of plant or bioregulators. They act to activate the metabolism of cells, assist and confer greater vigor to the immune system, help to enable physiological processes at different stages of development, stimulate root growth due to the higher rate of cell development and induce the formation of new shoots, resulting in the potentialization of the quality and quantity of production [2].

Thus, this chapter aims to emphasize an adoption of sugarcane cultivation technologies such as the use of organo-mineral fertilizers and biostimulants. In this way, many studies have shown the great environmental, economic and sustainable benefits. The adoption of nutrient cycling from agricultural and urban waste can be an alternative and necessity in the present day.

2. Organo-mineral fertilizers in sugarcane

The great agricultural development in the twenty-first century increased the residues discarded. Thus, farmers began to reuse or cycling in larger proportions, realizing the great benefits of organic fertilizers and the advantages of mineral fertilizers have been combined. However, the economic feasibility of applying large volumes of organic fertilizers over large areas is still low. The addition of mineral components enriches the biofertilizer, providing high volume and cost reduction. Obstacles such as logistics, availability of raw material suitable for mineral source enrichment and production infrastructure are real problems that farmers and companies on the industry have to face. The knowledge of the composition and the handling of the residues constitute barriers that hinder the process.

The organo-mineral fertilizers are a mixture formed by fertilizers of organic and mineral fraction, characterized by a texture suitable for the supply to the crops. Existing information of specifications and minimum guarantees to know the best management and quantities to be used in each type of soil is necessary.

In Brazilian legislation, there are rules about its use and guarantees about its quality. It says that solid organo-mineral fertilizers should have a minimum of: 8% organic carbon; 80 $mmol_c\ kg^{-1}$;

10% isolated primary macronutrients (N, P, K) or a mixture (NK, NP, PK, NPK); 5% of secondary macronutrients; 1% micronutrients and 30% maximum moisture.

At European Union (EU), there are not maximum permitted levels of metallic elements on the composition of fertilizers. The European Commission (EC) is discussing the proposal to review the 2003/2003 regulation in order to impose limits on the content of minerals, heavy metals and organic fertilizers. The European regulation does not yet address environmental concerns arising from soil contamination from fertilizers. But, USA defends the imposition of limited values for As, Cd, Cr, Pb, Hg and Ni that are inserted on fertilizers [3].

Organo-mineral fertilizers significantly improve soil agronomic and environmental components for society. When it is applied in mulch fertilizers, they help to avoid high volatilization levels of ammonia (NH_3). In the other hand, mineral fertilizers have great solubility and are readily available to plants. The management of them should follow aimed criteria of their efficiency, economy and environmental sustainability.

The sources of the biofertilizers have great resistance to changes in its composition. This characteristic is transferred to soils that receive organic matter, allowing greater balance on the plant nutrition. The availability of organic carbon in the soil increases the microbial biomass, which improves the efficiency and release of nitrogen on the plants.

Organo-mineral fertilizers promote the union of the characteristics of chemical fertilizers with organic fertilizers [4]. Antille et al. [5], studying the effects of organo-mineral fertilizer derived from biosolids, granulated biosolids and urea, established that soils with ryegrass (Lolium perenne L.) that had the application of organo-mineral and organic biosolids had changes on the levels of P and increased its raise during 3 consecutive years. They also pointed out that there was a slow release of P with the application of this organo-mineral fertilizer. This release may work for several years from then.

The combined application of organic and mineral fertilizer improves the yield of sugarcane [4] and promotes greater residual benefits that will affect the relation on the use of each fertilizer singly. In this sense, the organo-mineral fertilizer presents reactive chemical potential relatively inferior to the mineral fertilizer. Its solubilization is gradual during the period of development of the culture, but when compared to soluble mineral sources, its agronomic efficiency may be higher.

After the homogenization, fractions of organic and mineral fertilizers can be extracted to a pallet capable of being supplied to the plants (**Figure 1**). Pelletizing is the process that fertilizer passes through a short period of time due to high pressure, humidity and temperature in order to reduce its size and turns it handling easier [6]. The production of the pellets (**Figure 2**) is objected to a high degree of hardness depending on the production process of the company, varying from 3.0 to 8.0 kgf cm^{-2}.

Carvalho et al. [7] state that organo-mineral fertilizers can improve the agronomic efficiency of fertilizers. These reduce the natural process of fixation of the labile phosphorus in the soil, being readily available to the plants for a longer time. Also, very mobile mineral components in the soil, such as nitrogen and boron, have its release slowed down by the organo-minerals, allowing its better leveraging by plants.

Figure 1. Organo-mineral fertilizer pallets. Source: Authors.

Some of the materials that can be used on the mixing or processing of organo-mineral fertilizer are sewage sludge, chicken litter or manure, bovine and porcine manure, castor bean cake, filter cake from the processing of ethanol and sugar, green manures, peat, organic compounds and fruit-processing residues.

de Sousa [9], doing a research about the use of organo-mineral fertilizer quotes in the production of sugarcane, concluded that there is higher efficiency on the use of nutrients applied through organo-mineral fertilizer than with mineral fertilizer. The same author also reports that organo-mineral fertilizer was more efficient in cane planted in the first year

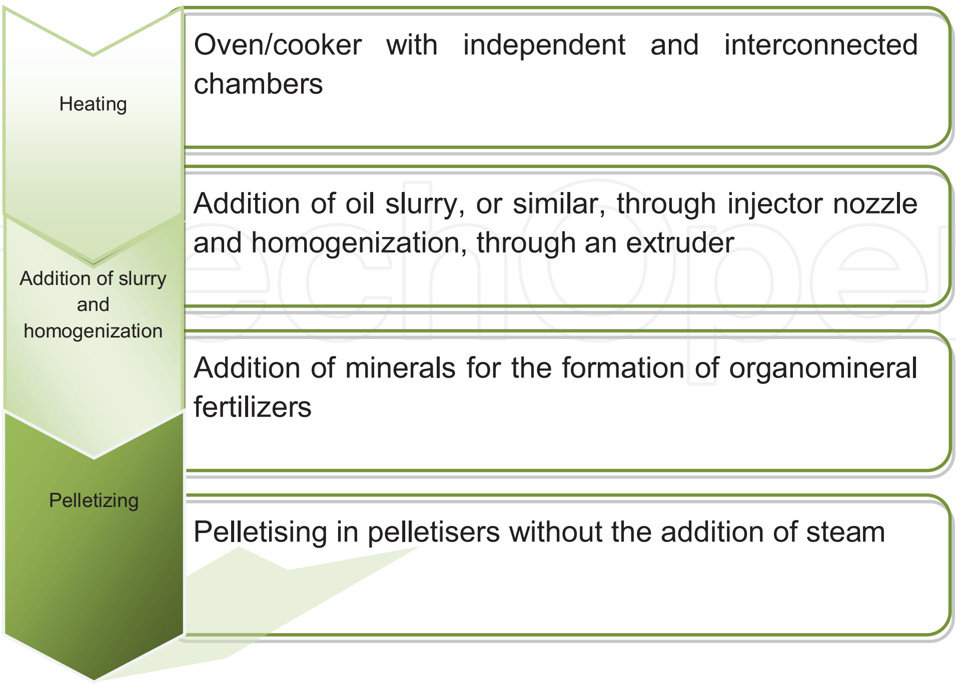

Figure 2. Flowchart of the physical-chemical-mechanical process of digestion and avian bed pelletization for the production of organic compound and organo-mineral fertilizers. Source: de Oliveira [8].

than in cane budded after the first year. This fertilizer can substitute the mineral fertilizer, because it can increase efficiency up to 24% of stem production. In another study, Teixeira et al. [10] also observed great efficiency in phosphorus doses provided by organo-mineral fertilizer in the sugarcane crop. de Sousa [9] comments about some "sustainable benefits of organo-mineral fertilizers," and some of these benefits are recovering capability of the microbial flora, the reduction of soil acidification and the gradual release of nutrients. Such benefits will influence the best development of root system, lower fixation of phosphorus to soil colloids and better water retention. It also worth nothing to the operational cost of crop. This use reduce operations for fertilization with mineral and organic fertilizer together throughout the crops.

Gurgel et al. [11] studied BIOFOM (an organo-mineral biofertilizer formulated with concentrated vinasse, filter cake, boiler ash and chimney soot and complemented with mineral fertilizers), a technology for the reuse of trash from the sugarcane agroindustry and pelletized organo-mineral fertilizer, and they concluded that organo-mineral can replace the partial or total fertilization of sugarcane crop. Another major benefit is the reduction of the production and accumulation of industry trash.

3. Biostimulants in sugarcane

The use of biostimulants in world agriculture has achieved significant growth rates in the recent decades. There are estimations that by 2018 this market will move US$ 2.2 billion. It means a growth rate of 12.5% from 2013 to 2018 [12]. There are products that promote sustainability of crops and can be an alternative to improve plant nutrition, support of abiotic and biotic stresses and is efficient in integrating pest and disease control. Some biostimulants have indirect pest control properties that do not fit in the insecticide regulation. Others have indirect fertilizer properties containing micronutrients that are better to foliar fertilization.

Most of the biostimulants contain synthetic plant hormones and fertilizers. Vegetable hormone is a natural compound produced in the plant with organic characteristics. Synthetic vegetable hormones, also called plant regulators or bioregulators, are artificially produced compounds with organic characteristics and can be supplied to the vegetable.

Vegetable stimulants or biostimulants are mixtures formed between plant regulators and other biochemical compounds, such as amino acids, nutrients and other active ingredients, which can contribute to plant development [13].

It is known that plants are influenced by internal and external factors. We can cite the external factors such as light, temperature, rainfall, photoperiod, soil type, fertility and so on. Internal factors of a chemical nature regulate plant growth. The mechanism of regulating and/or controlling the development of animals and plants depends on information passed between cells, tissues and organs. These metabolisms control substances that emit chemical signals that are called hormones [13, 14].

The plant hormones can be produced in a tissue and transported to another part of the vegetable where its action will take place. Some of these hormones are called phytohormones, and they are produced in the vegetable in tiny quantities and very small proportions. The same hormone can trigger different responses or reactions in different organs and stages of development of the plant. In plant hormones, there are interactions since they hardly act isolated. The auxins, cytokinins, ethylene, abscisic acid and gibberellins (GAs) are traditionally the five most well-known phytohormones. Brassinosteroids, salicylic acid, jasmonic acid and sistemin are other substances that also emit recently researched chemical signals [14].

The biostimulants are the mixture of hormones with different plant regulators or with nutrients that can provide better performance for plants. The presence of plant hormones promotes vital and structural changes in the plant. Thus, there will be better cellular development and tissue growths. On an objective way, organs such as leaves, stems and roots can develop in larger size and number reflecting on the plant's production potential. On a positive way, nutrients combined in/or association will have better effects. The biggest potential production joining with the available nutrients can promote greater effect on the productivity of crops such as sugarcane.

In a study of the productivity and technological quality of sugarcane ratoon with the objective of application in the plant growth regulator and liquid fertilizers, Silva et al. [15] observed that genotypes respond differently to the use of biostimulants in the absence or presence of foliar fertilizers in sugarcane after the first year of harvest.

The application of 0.09 g dm^{-3} of kinetin, 0.05 g dm^{-3} of 4-indole-3-ylbutyric acid and 0.05 g $dm^{-3}$of gibberellic acid and liquid fertilizers has no effect on the technological quality of sugarcane juice. The use of the hormonal mixture in the absence and presence of liquid fertilizer increases the yield of sugarcane and the amount of sugarcane. Raposo et al. [16], in evaluation of different foliar fertilizers on the crop production of sugarcane associated with biostimulants, concluded that the association of micronutrients plus biostimulants is increased by 17% in sugar yield.

3.1. Auxin

Charles Darwin and his son Francis, in their book published in 1881, mentioned studies involving growth regulators. Some years later, in 1926, Frits W. Went designated the substance that involved his studies of auxin, being the first hormone described in the literature [14]. Meristematic tissues of plants are the main production sites, either in the airways or underground. Depending on the tissues or production sites, there are large variations in the quantities produced [13].

Auxin indole-3-acetic acid (IAA) is one of the major plant hormones (**Figure 3**) produced in the plant that has great capacity to influence on its growth and initiation of exchange activity and apical dominance [17]. The IAA regulates cell division and expansion, vascular differentiation, lateral root development and apical dominance [18]. Indole-3-butyric acid (IBA), 4-chloroindole-3-acetic acid (4-Cl-IAA) and phenylacetic acid (PAA) may also be referred to as the auxins of plants [19]. Lisboa et al. [20] verified a viable result for the development of sugarcane corns using 0.125 mg/l of 2,4-D and concluded that auxin decreases the diameter of the cell and its nucleus.

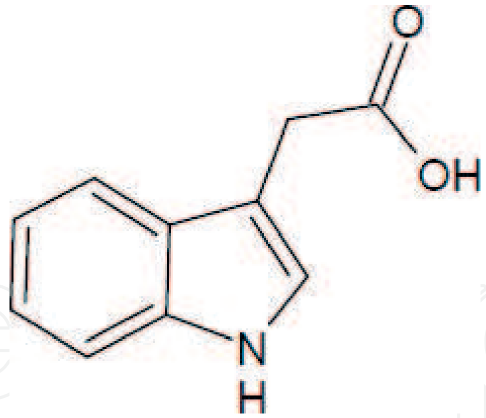

Figure 3. Indole-3-acetic acid (AIA) which is the main naturally occurring auxin. Source: Raven [14].

3.2. Kinetin

Cytokinins (**Figure 4**) began to be discovered by Johannes van Overbeek around 1941 when he observed that coconut water (Cocos nucifera) promoted embryonic development and growth of cells and tissues. The natural cytokinins are 6-*N*-substituted purine [21], and their isolated use has little or no effect. Its action is closely related to auxins and acts as a stimulant of cell division. With the union of the two hormones, there is a fast division of cells forming a large number of small and undifferentiated cells. But everything will depend on the concentrations and proportions of both hormones. At high concentrations of auxins, there will be a great root formation. When in high concentrations of kinetin, there will be gem growth. In equal concentrations, there will be production of meristematic cells. Cytokinins are also involved in the establishment of functional root nodules, which influence the nutritional status of the plant and may interfere with flowering time.

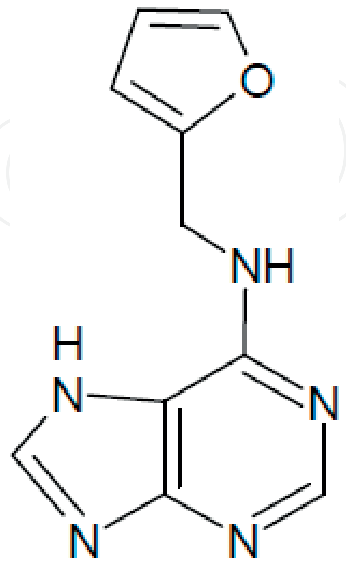

Figure 4. Molecule of kinetin that probably does not occur naturally in plants. Source: Raven [14].

Controlling the rate of differentiation and cell division, the cytokinin determines the size of the meristem root. Thus, there is a balance of auxin effects that is responsible for controlling cell division [14]. The cytokinins still delay the aging of the leaves, avoid their senescence and prolong their useful stage in the plant. Raposo et al. [22] comparing media productivity of sugarcane noticed that the addition of kinetin to coconut water promotes cell regeneration and growth of sugarcane.

3.3. Gibberellin

Gibberellins (GAs) were discovered by Japanese scientists in 1926 (**Figure 5**). These substances are present in practically all plants being found in 136 natural gibberellins. GAs are a class of phytohormones that regulate various sites and stages of plant development. The main actions in the plant such as stem elongation, germination, flowering and fruit development can be mentioned [23].

Gibberella acid is the most studied gibberellin produced by the fungus *Gibberella fujikuroi*. It promotes cell division and stretching and causes noticeable stretching of stems, roots, leaves and fruits. They are efficient to overcome dormancy and promote seed germination [14]. Alcantara et al. [24] studied about shoot multiplication, elongation and rooting in vitro of clones of sugarcane under different concentrations of 6-benzylaminopurine and gibberellic acid and concluded that the gibberellic acid in the elongation of the seedlings varies according to the genotype; for the clones RB036152 and RB036066, it promotes the formation of larger seedlings.

3.4. Humic acids (HA)

The decomposition of animals or plants is a part of an organic cycle. Humic substances (HS) are produced when it happens. Some researchers argue that HS improves the biological, chemical and physical quality of soil and the physiological development of plants. There is a difficulty in understanding the HS action on plants due to the complexity of the chemical mixture. The improvement in nutrient absorption efficiency has been the most widely held idea. They may increase permeability of the cell membrane favoring the ionic transport in the cell. There is also a higher efficiency in the products generated from the Krebs cycle (ATP) as a result of the increasing of respiration and the speed of enzymatic reactions. This

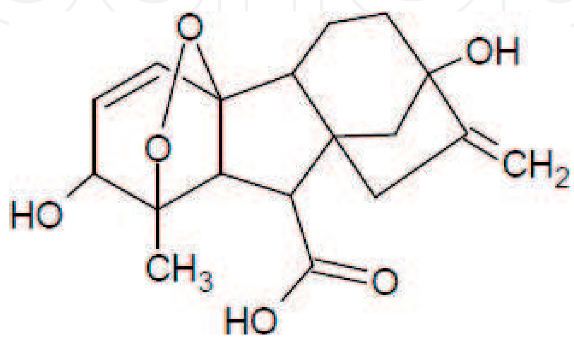

Figure 5. Molecule of gibberellic acid that is more abundant in fungi and the most biologically active in many tests. Source: Raven [14].

directly influences the development of the plant. Morozesk et al. [25] explained that the increase on the efficiency of nutrient absorption is related to the activation of $H^+ - ATPase$ (proton pump activity). Thus, products such as humic acid (HA) can interfere positively on physiological phases and guarantee better efficiency in plant nutrition, especially in the early stages [26].

Marques [27], using humic acids and diazotrophic endophytic bacteria in the production of sugarcane, obtained increases of up to 23% in the productivity of foliar application in sugarcane variety RB867515. Civiero et al. [28], in the study application of humic substance and L-glutamic amino acid in different sizes of 1-bud set of sugarcane, noticed superiority of the humic substances to L-glutamic acid and control for the variable root length, root surface area, dry mass of root system and dry mass of aerial part. Leite [29] concluded that in general, urea + HS doses promoted a significant increase of 6% yield of sugarcane stalks and a 4.5% increase in sugar production (Mg ha^{-1}), comparing only to the application of urea doses.

3.5. Fulvic acids (FA)

There is a division of different categories of humic substances between humic acids, already cited and fulvic acids (FAs). There are commercial types of biostimulants divided between two types of acids. In general, [12] cite some authors that discuss about the size of the molecules. FAs are considered larger molecules with higher molecular weight. The fulvic acids are the organic fraction of the soil soluble in acid and basic solutions. Also, they have higher acidity and carboxylic groups, conferring an important characteristic such as the better capacity in the exchange of cations. Other important characteristics are the abilities of chelation and mobilization of metallic ions, mainly Fe and Al. Yet, AFs do not have selectivity of plasma membrane different from humic acids.

Exposed this large amount of characteristics, the authors [12] reported that in corn plants (Zea mays) there is greater root development, reduced transpiration and Al toxicity, in soil with high Al concentrations, increase in the production of biomass and nutrient absorption and better performance under Water stress. In wheat crop (*Triticum aestivum*), higher growth and plant weight, improved nutrient uptake, higher amount of chlorophyl, reduction of water stress, and increases the absorption of phosphorus can be observed. In rice (*Oryza sativa*) can be noticed a greater efficiency in the absorption of iron. Common bean (Phaseolus vulgaris) improved the development of adventitious roots and reduction of lead toxicity in the exposure of high loads of this. There were no reports of specific effects of fulvic acids in sugarcane.

3.6. Silicon as biostimulant

Silicon as a biostimulant has a good availability in soils in the form of oxides of silicon. Then, it can be concluded that the lack of silicon is not limited to the cultures. However, the majority of the sources present in the Earth's crust are poorly soluble and insoluble in water. So it is difficult to find readily soluble sources that are economically viable. In the other hand, there are industrial wastes on the extraction of silicates, which have been studied and shown efficient use as fertilizer and/or stimulator. This requires special care, mainly because of the risk of contamination with heavy metals, fact unwanted for the crops. The use of these residues should occur only with the removal of these contaminants or with the purification of the silicon source. The other problem is the very low mobility in the phloem of plants.

Some plants, like the dicotyledons, do not accumulate this nutrient on the tissues. But, in the other hand, sugar cane and other grasses have ease of absorption and accumulation of Si (**Figure 6**). The effects of biostimulants are a result from deposition within the tissues, specifically in the cell wall which increases the thickness, stiffness and lignification of cells. This confers better resistance to biotic and abiotic stresses. They are also physical benefits to the barriers of silica on the fabrics, giving best architecture to plants with leaves more upright and reducing shading which improves photosynthetic efficiency, since there is a reduction in the rates of transpiration.

Lower transpiration implies less demand of water by plants and reduction in levels of damage caused by fungi and insects phytophagous Lepidoptera. In another analysis [31], the plants are submitted to several physiological and metabolic diseases. There are many other discoveries that show interference in the activity of some enzymes, reducing the antioxidant capacity of some oxidative compounds, interfering in relations of water in the plant, photosynthesis, absorption of nutrients, mobility of ions inside of the plant tissues, hormone balance and in gene expression. It reports that Si increases the concentration of some metabolites nonenzymatic acting and defensively against oxidizing agents.

The use of fertilization facilitates the action of the plant to regulate the nutritional balance. Besides the ability to regulate the absorption of Zn in the presence of high levels of P, can be prevented the onset of symptoms of deficiency of Mn and B; reduces the absorption of Na in plants exposed to high concentrations; reduces the toxicity of heavy metals and Al forming a link themselves metal. From the physiological point of view, there is a great efficiency of Si in avoiding or reducing the permeability and selectivity of the plasmatic membrane at the input and output of ions under

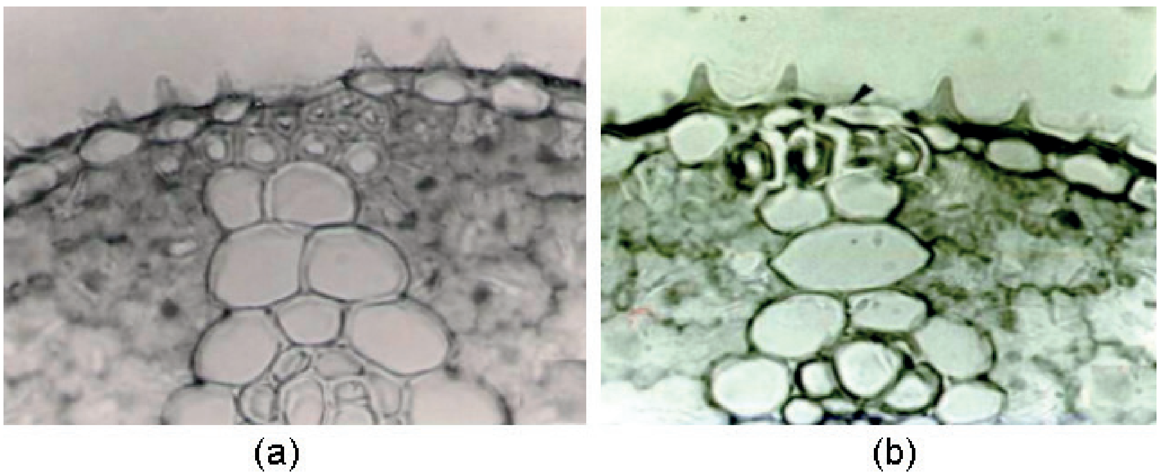

Figure 6. Transverse cuttings of leaf blade limb of rice plants (Oryza sativa L.). (A) Detail showing projection of the external wall of the epidermis on the adaxial side (×1000) of the leaf limb treated with 5 mg of N and zero of SiO_2 (×400). (B) Detail showing projection of the external wall of the epidermis on the adaxial side (×1000) of the leaf limb treated with 5 mg of N and 400 mg of SiO_2 (×400). The tip of the arrow at B indicates spherical silica bodies. Source: Mauad et al. [30].

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conditions of stress. The supply of Si enhances the extension of the cell wall, and root system may cause an increase in the rate of absorption of nutrients. Other studies have shown that the presence of other biostimulants influences on the final amount of plant hormones. In soybean plants, stressed with higher salt concentration, the levels of gibberellin increased with the objective of supplying themselves needs. In another study cited by Savvas and Ntatsi [31], the Si has reduced the levels of jasmonic acid and salicylic acid in rice plants exposed to the stress of heavy metals. The abscisic acid can also cause negative or positive effects in the presence of each other. These phytohormones play an important role in the regulation of physiological processes and in the control of biotic and abiotic influences. Lately, it has cause a great improvement in the understanding of the features of Si in the interior of the plants. However, there seems to be a need to improve these skills.

4. Conclusion

The proper nutrition of sugarcane is very important to obtain high production of the crop. With the use of organo-mineral biostimulants and fertilizers in association, the global importance of the improvement of this technology stands out. The productivity gains in sugarcane plantations are notorious. The big gains come from building and maintaining a fertile soil to the cycling of essential nutrients that are discarded as trash. There is, also, a reduction of the contamination of fountains and subsoil, reduction of the emission of gases that cause greenhouse effect, and reduction of proliferating environments of diseases and their respective vectors.

The environmental, economic and social gains are great when this agricultural practice in the cultivation of sugarcane is used. The emergence and use of new technologies are ways to achieve greater productivity, sustainability and profitability. Several technologies on the use of plant hormones, especially synthetic ones, have contributed to these goals.

Author details

Emmerson Rodrigues de Moraes[1]*, José Geraldo Mageste[2], Regina Maria Quintão Lana[2], Rodrigo Vieira da Silva[1] and Reginaldo de Camargo[2]

*Address all correspondence to: emmerson.moraes@ifgoiano.edu.br

1 Federal Institute of Education, Science and Technology Goiano, Morrinhos, Goiás, Brazil

2 Institute of Agricultural Sciences, Federal University of the Uberlândia, Uberlândia, Minas Gerais, Brazil

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