# Chapter 148

# Benefits of the application of silicon in plants

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## ABSTRACT
Given the current context of the strong use of agricultural pesticides, sustainable forms are sought so that plants can create defense mechanisms for pathogenic fungi and insect pests. For this, it is necessary that they are in excellent nutritional status, being fundamental a nutrition with macro and micronutrients, and also with beneficial nutrients, according to the demand of each plant. Silicon is classified as a beneficial nutrient, which can confer greater stiffness to plant cells, greater resistance to bed, better tolerance to water stresses, salinity and toxicity of heavy metals, greater resistance fungi and insect pests , in addition to increasing the production of various trees. The element is generally available in the soil, but if necessary, fertilization via incorporated soil, foliar or fertigation may occur. Therefore, the objective of this work is to perform a bibliographic review on the influence of silicon on plant production. Furthermore, it is desired to verify the importance of silicate fertilization for large crops, resulting in economic and management benefits in agriculture. In view of the above, techniques that seek an efficient management in the s and sustainable cultures to the environment, such as the case of fertilization in a conscious way, are necessary in the search for higher yield, given the growing demand for food.

**Keywords**: Plant resistance , Insect pest , Pathogenic fungi, Soil fertility , Plant nutrition.

## 1 INTRODUCTION

In the current global context, the growing demand for food is noticeable, in addition to the rational consumption by the population, which seeks healthier and produced in a less harmful way to the environment. In addition, it is worth highlighting the low possibility of expansion in agricultural borders, which results in the need to increase productivity per unit of area.

Thus, the present agricultural sector seeks to increase income and sustainability. An example of this is adequate plant nutrition that seeks to strengthen the plant in the face of biotic and abiotic factors, avoiding or reducing yield losses. Among these, silicate fertilization is among the alternatives that have beneficial effects in many cultures, with Bakhat et al. (2018) consider it "almost essential", mainly under conditions of biotic and abiotic stress (ADREES et al., 2015; MAUAD et al., 2016) besides stimulating growth (ADREES et al., 2015), and when plants are in Si deficit, they are less resistant to pest and fungal attacks, they are subjects to and less tolerant to salinity, toxicity of heavy metals and water stress, respectively (VILELA, 2009; ISLAM et al., 2020; HUANG et al., 2021).

Silicon can also affect biochemical, physiological and photosynthetic processes and, consequently, reduce stress caused by water deficiency (MAUAD et al., 2016). In addition, it can benefit the availability of other nutrients and have an interaction with pH and heavy metals in the soil, which is positive to plants.

In the literature there is a diversity of information and contradictions about silicon, and some authors consider it as essential (nutrient), and others as a beneficial element. Benefits in the growth of some species are described, including sorgo (Sorghum bicolor L. 'Moench' Dekalb 540) and sunflower (Helianthus annuus L. 'Double Sungold'), observed by Calero Hurtado et al. (2020). Queiroz (2016) still mentions the increase in phytomass in soybean crop with silicon applications. This element is found naturally in many soils, being the second most abundant element, with a concentration of up to 30%, mostly found in minerals and rocks (ADREES et al., 2015; BAKHAT et al., 2018). However, over time, with high rates of exportation, it is necessary to replacement.

Silicon deficiency is unusual, since the element is common in most soils, being presented in situations of extreme soil exploitation, where the nutrient is exported through successive crops, or through leaching.

Thus, when necessary, silicon applications can occur in different ways, where plants will be used to stiffen the cell wall, as a mechanical form and barrier (CAMARGO et al., 2011). However, the mechanism of action of Si in plant resistance is still unclear (POZZA et al., 2015), where molecular and biochemical studies are needed to elucidate doubts about how the element acts on plant metabolism.

In view of what was observed, the review work aims to gather recent literature results in relation to the sources and benefits of silicon, as well as forms of application and future management perspectives , which, if carried out correctly, can be a viable alternative to solve some of the problems of current agriculture.

There are enormous perspectives regarding the application of silicon in various cultures, since it is a sustainable way to provide physical and biochemical reinforcements to plants in the face of biotic and abiotic factors. That is, with each harvest that passes it is possible to perceive greater tolerance or resistance of pathogens and, in addition, agriculture is prone to climatic variations, to which they can generate great economic losses. And so, silicon appears with a fertilization capable of circumventing and/or minimizing this damage.

## 2 SILICON AND ITS SOURCES IN NATURE

Silicon (Si) is a metalloid that is gaining worldwide attention from plant scientists due to its impact on improving plant growth and development (GAUR et al., 2020).

Most of the silicon in the soil is found in the form of silicon oxide ($SiO_2$) predominantly in the forms of quartz, opal ($SiO_2.nH_2O$) and other forms not available to plants, which formed during soil weathering processes (BARBOSA FILHO ; PRABHU, 2000).

According to Pereira et al. (2003), tropical soils are generally highly weathered, where easily weatherable primary minerals containing Si are almost non-existent. Schleier et al. (2014); Bakhat et al. (2020) claim that the element makes up about 27 to 30% of the earth's crust. And despite being the second element of greater abundance in the earth's crust, most soils lack the available form of Si to vegetables, i.e., sylícic acid (GAUR et al., 2020). Also, for Vilela (2009), although most soils contain considerable amounts of silicon, successive crops can reduce the level of the element, making replacement fertilization necessary.

In the biogeochemical cycle of silicon, the largest drain is the plant (rice cultivation being one of the most accumulating element in its structure), through the formation of amorphous silica, and the annual agricultural export of Si is estimated in 201-224 million tons of silicon, including in the calculation the amount dissolved and carried by watercourses (ZAMBOLIM et al., 2012).

## 3 ABSORPTION AND TRANSPORT OF SILICON IN PLANTS

According to Bakhat et al. (2018), silicon is absorbed by the roots and trans injured to the aerial part following transpiration flows, causing an accumulation capable of increasing polymerization in the intercellular system and below the cuticles, creating a barrier to infection of pathogens. Also, according to the authors, si soluble in the cytosol triggers metabolic pathways that result in the production of jasmonic acid and other organic compounds that have production induced in the plant by the consumption of herbivores, besides attracting natural predators and parasitoids during the occurrence of pests, which favors a biological control. However, the biochemical changes that Si causes in plants still need to be better elucidated. Thus, this combination of physical and biochemical defenses generates in the plant a form of defense in the face of biotic and abiotic adversities .

According to Gaur et al. (2020), Si absorption is an active process. The plants developed a well-optimized Si transport system, including various carrier proteins such as low silicon1 (Lsi1), low silicon2 (Lsi2), low silicon3 (Lsi3) and low silicon6 (Lsi6) in specific subcellular sites, together with the expression profile that creates a precisely coordinated network between these transporters, which also facilitates the absorption and accumulation of Si (GAUR et al., 2020).

Lsi1 is a permeable channel to Si, belongs to the subgroup of the main intrinsic protein similar to Nod26 (NIP) III of the aquaporin membrane protein family with a distinct selectivity, while Lsi2, an Si-flow transporter, belongs to a family of uncharacterized anion transporters (MA; YAMAJI, 2015). According to the same authors, these transporters are located in the plasma membrane, but in different plant species, they present different patterns of expression and cellular or tissue locations that are associated with different levels of Si accumulation.

However, according to Ma; Yamaji (2015), there is still a need for a molecular and physiological characterization of Si transporters in different plant species.

When absorbed by the plant, there is precipitation of SiO2, which provides stiffening to the plant, occurs mainly near the transpiration terminals, but can also occur in structures xylem vessels and root endoderm (RAVEN, 1983).

This precipitation is linked to increased cell wall resistance, plant resistance to the incidence of diseases and pests, regulation of evapotranspiration (water saving), increased structural stiffness (increased heating resistance), plant architecture improvement, lower shading of upright leaves, increased photosynthetic rate and tolerance to toxic elements, and finally, increased productivity (VILELA, 2009). The same author also presents the benefits to the environment: decreased use of fungicides and insecticides, maintains natural enemies against pests, improves water use and preserves the ozone layer (does not emit CO2 to the atmosphere).

## 4 IMPORTANCE OF SILICON IN PLANT GROWTH AND DEVELOPMENT AND SYMPTOMS OF DEFICIENCY

Si is not an essential element to plants from a physiological point of view, but is a beneficial element for plant growth and development, as well as to provide protection against various types of abiotic and biotic stresses, being the absorption, transport and accumulation of the element indispensable to plants (GAUR et al., 2020). Due to this context, the literature is rich in research results demonstrating adverse effects related to the growth, development and reproduction of some plants in conditions of extreme Si deficiency (BARBOSA FILHO; PRABHU, 2000). Barbosa Filho( Prabhu (2000) mention that it is found at levels ranging from 0.1 to 10% of plant mass, based on dry weight.

Still at, the element stands out for its potential to reduce the incidence and severity of diseases in many cultures (POZZA, et al., 2015), such as the works of Bakhat et al. (2018) that mention the resistance of plants with silicate supplementation to does how brown spot (Bipolaris oryzae), leaf spot (Cercospora kikuchii), mildew (Sphaerotheca juliginea), anthracnose (Colletotrichum spp. ) and rust (Phakopsora pachyrhizi), among others. In addition, IPNI Canada (2016) brings that several are the crops studied, such as cotton, beans, soybeans, vegetables and grasses (rice, sugarcane and wheat).

As for the reduction of the incidence of insect pests, there are already several studies associating the application of Si to reduce the genus Spodoptera in plants dand maize (GOUSSAIN, et al., 2002), potato (SILVA, 2010) and tomato (SANTOS et al., 2008).

According to Gaur et al. (2020), diseases in plants and insect pests are the main limiting factors, which reduce agricultural production worldwide, a point that further emphasizes the importance of plant defense mechanisms.

According to Menegale et al. (2015), this discussion cannot subdue its importance in the soil-plant system, given the benefits obtained in the application of this element, highlighting the use of calcium and magnesium silicates, providing positive responses to the crop and also to the reactions in the soil (increased P levels and reduction of some heavy metals), generating greater productive stability.

As symptoms of missing the element, silicon private plants are usually structurally weaker than silicon-filled plants with abnormal growth, development, viability and reproduction, more susceptible to abiotic stresses such as metal toxicity, and easier prey for pathogenic organisms and herbivores ranging from phytophagous insects to mammals (EPSTEIN, 1999), and many of these same conditions affect plants in soils poor in silicon.

In addition, Si deficiency may differ from plants properly nourished with Si in (i) chemical composition; (ii) structural characteristics; (iii) mechanical resistance; (iv) various aspects of growth, including income; (v) enzymatic activities; (vi) surface characteristics;

(vii) disease resistance; (viii) resistance to pests; (ix) resistance to metal toxicity; (x) salt tolerance; (xi) water relations; (xii) cold resistance; and probably additional resources (EPSTEIN, 2001). Taken together, evidence is impressive that silicon should be included among the elements that have the greatest influence on plant life (EPSTEIN, 1999).

When presented in excess, according to Etesami; Jeong (2018), silicon is not harmful, corrosive or polluting to plants, making the use of silicon-based fertilizers ecologically compatible and an environmentally "friendly" technique, capable of stimulating plant growth and relieving stresses.

## 5 FORMS OF FERTILIZATION SILICADA

The application of silicon can occur via soil (PEREIRA JÚNIOR et al., 2010) or leaf (MOREIRA, et al., 2010), depending on the fertilizer, however it is important to know that both obtain positive and satisfactory results. Furthermore, Si can be applied via fertigation (SILICON, IPNI Canada; IPNI Canada, 2011).

According to Lima Filho (2010), technology based on silicon application has enormous potential to reduce the use of chemical sand increase productivity through balanced and physiologically efficient nutrition, resulting in productive, efficient and vigorous plants.

Estesami; Jeong (2018), predict that the use of Si (mainly as industrial slag and straw and rice) will become a sustainable strategy and an emerging trend in agriculture to increase crop growth and relieve abiotic stress and biotic in the not-too-distant future.

## 6 APPLICATION OF SILICON IN LARGE CULTURES

Several crops, including corn, wheat, oats, pumpkin, cucumber, ornamental species, respond favorably to additions of Si under certain conditions; the best results being observed in sugarcane and rice (SILICON, IPNI Canada).

These as those of Oliveira Júnior et al. (2018) conclude that the applications of silicon doses do not interfere in the quality of wheat seeds, but improve the emergency performance and initial stand. Furthermore, different cultivars showed interesting agronomic characteristics, such as higher number of pen children, dry mass, chlorophyll A, B and total; and the electron transport rate, initial fluorescence and phytotoxicity were negatively influenced with the increase of leaf silicon doses (OLIVEIRA JÚNIOR, et al., 2018).

Also, according to studies by Moreira, et al. (2010), three applications of silicon via foliar in soybean crop, cultivated variety DB BRS FAVORITA RR, in phenological stages V8, R1 and R5.1, at a dose of 500 mL ha-1, increase the accumulation of dry phytomass and the growth rate of the crop, with effects responsible for the average increment of 19 bags.ha-1 (increasing not a-1 weight of grains, but rather the quantity produced). Furthermore, it was possible to observe that plants that received three Applications of Si had greater leaf thickness, supposedly by the accumulation of silicon in the epidermis, and consequently, greater dry mass index (MOREIRA, et al., 2010).

Moreover, the increase in the accumulation of dry phytomass and leaf area in plants was probably a reflection of the higher rate of liquid assimilation and relative growth of the crop, and the effect of the three silicon applications on the increase of grain production, even without having an effect on the mass ( MOREIRA, et al., 2010).

The application of silicon via soil, according to Oliveira et al. (2015), is beneficial for soybean crop, improving agronomic characteristics and increasing seed mass and vigor, being positively influenced at doses from 1.67 Mg.ha-1 to 2.32 Mg.ha-1, depending on the cultivar under analysis.

Pereira Júnior et al. (2010), working with different doses of Si applied in soybean sowing grooves, observed that the number of vegetables per plant increased significantly with the application of 200 kg ha-1 of silicate, which is an important component of yield. Also, it is noticed that the seed mass per plant also presented significant results only for the cultivar BMX Turbo RR (PEREIRA JÚNIOR et al., 2010).

According to Queiroz (2016), Si has the potential to increase nodulation in legumes, such as beans and soybeans, consequently increasing the N content in the aerial part of the plant. This is due to the increase in shoot and root part and, the more roots, the greater the site of rhizobial invasion infection, which increases nodulation and biological fixation of N2 of the atmosphere - FBN (QUEIROZ, 2016).

Given so many benefits, it is found that for the use of silicate fertilizers in agriculture, silicates (such as calcium silicate) are the main sources of Si. But in that way they can be applied, it is necessary that heavy metals be removed from the compound, a factor that can generate serious environmental damage (VILELA, 2009). Some of these metals, which can still be harmful to plants due to their toxicity, are Al and Mg (LIMA FILHO, 2009).

The characteristics considered ideal for a silicon source are high source of Soluble Si, good physical properties, ease of application mechanized, ready availability for plants, good ratio and qualities of calcium and magnesium, low concentration of heavy metals and low cost (VILELA, 2009). Pereira et al. (2003) mention other sources of Si: shales - essentially silto-clayey rock called "oils shales"; slags - basic steel, constituted basically and silicates of Ca and Mg; and thermophosphates - obtained by melting phosphate rock with serpentine (magnesium silicate) at 1,500ºC.

In addition to these, there are several industrial by-products that serve as silicon sources and that can be used in agriculture (CASTELLANOS et al., 2016), being an attractive possibility of destination of industrial waste and a source often little costly compost. One of these is rice husk ash, which is a byproduct of the rice industry that is obtained when the rice husk , extracted in the processing, is charred in ovens or special ovens at temperatures (CASTELLANOS et al., 2016). Therefore, studies are being conducted to identify the most efficient form of application of this erial mat (CASTELLANOS et al., 2016).

It is evident that the proper use of rice husk ash will result in benefit to the environmental conservation process (FOLETTO et al., 2005). As the ash contains high silica content (> 92%), this makes it a valued residue (FOLETTO et al., 2005), being an attractive source of silicon for agriculture.

Studies by Castellanos et al. (2016) indicate that rice husk ash as a source of silicon in wheat crop, up to the dose of 2000 kg ha-1 of SiO2, leads to an increase in the number of ears and seed weight per plant.

## 7 FINAL CONSIDERATIONS AND FUTURE PROSPECTS

In a sense, it is possible to notice that silicon is an element that generates many benefits to vegetables, such as resistance to fungi (such as Asian rust) and insect pests (such as caterpillars of the genus Spodoptera), stiffness and decrease to bedtime and greater tolerance to toxic elements. In addition, Si is also associated with greater resistance of plants to water deficit. It is also known that this element generates stiffness to the cell wall and other elements of the cell. Due to these and other factors, it is cited in the literature as a nutrient (essential) or beneficial element, depending on the authors.

Physiologically, Si is actively absorbed and transported to plant organs such as leaf and stem/stem. After, it precipitates and associates with the stiffening of the cell wall and then the benefits are achieved, such as greater resistance to biotic and abiotic factors, which usually cause physiological and yield damage.

As forms of application, liquid or soil applications are studied, and even fertigation application scans are mentioned in the literature. As main sources, silicates (such as calcium silicate) are highlighted, however, there are already studies with alternative sources such as rice husk, which is a by-product of the industry.

For large-scale application in commercial crops, studies are still needed in relation to the physiological effects that silicon promotes in vegetables, especially in large crops, in addition to the indication of dosages in front of fertilizer sources and forms of application.


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