

Silicon nutrition

of graminaceous crops

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Silicon (Si) is the second most abundant element on the surface of the Earth. It is not generally considered to be essential for plant survival. However, Si is probably the only element which is able to enhance the resistance to multiple stresses. It has been shown that Si promotes the growth of plants as well as provides protection against the detrimental effects of abiotic and biotic stresses. Recent studies have demonstrated that Si is a beneficial or 'agronomically essential' element for higher plants, particularly for cereal crops.

Keywords: Abiotic stress, Biotic stress, Growth, Silicon

SILICON (Si) is a ubiquitous element and the second most abundant after oxygen in the soil, comprising approximately 28 % of the earth's crust. It ranges from 200-300 g Si kg⁻¹ in clay soil and 450 g Si kg⁻¹ in sandy soils and its content in soil varies from 1-45% by dry weight. Despite this, most sources of Si in soil are present as crystalline aluminosilicates, which are insoluble and not directly available for plants. Plants assimilate Si solely as monosilicic acid (H₄SiO₄) which are highly unstable and convert to unavailable form. Concentrations of mono-silicic acid in the soil ranges from 0.1–0.6 mM roughly, two orders of magnitude higher than the concentrations of phosphorus (P) in soil solutions. However, its content in plants ranges from 0.1–10% on dry weight basis. Despite its ubiquity and abundance in both soils and plants, Si has not yet been considered an 'essential' mineral element of any terrestrial higher plant taxon. However, studies have shown that Si improves the growth and quality of plants as well as provides protection against the detrimental effects of abiotic and biotic stresses and known

as beneficial or 'agronomically essential' element for higher plants, particularly for cereal crops.

Si removal and requirement of different crops

Uptake of Si also varies from plant to plant. Among plants, sugarcane, rice, and wheat absorb the largest amount of Si, with 300-700, 150-300, and 50-150 kg Si ha⁻¹, respectively. Generally, Si uptake in cereal plants is much higher than its uptake in other plant species. For example, rice is a common Si-collector that absorbs Si in active progression, as other graminaceous plants do include wheat, barley, maize, and some *cyperaceous* plants. The majority of dicotyledon plants, such as cucumbers, melons, strawberries, and soybeans absorb Si inertly. Nonetheless, some plants especially di-cotyledon, such as tomatoes, beans, and other plants, are not able to absorb Si from the soil.

Role of Si in improving growth, yield and quality of crops

It has been well documented that Si is effective in enhancing the growth and yield of many crops. Si fertilization is proven not only to

enhance crop growth and yield but also to improve crop quality. The major crops that are widely reported to positively respond to Si fertilization include some monocotyledonous crops such as rice, wheat, maize, barley and sugarcane that actively absorb and accumulate high amount of Si in their organs.

Silicon is an essential component of rice plants and its accumulation helps in maintaining sustainable production. Silicon nutrition improves the light receiving posture of the plants, thereby stimulating photosynthates production in plants. Studies reported that with the increase of Si levels, the dry weight of the plant will increase together with its height and number of tillers, increased leaf area led to enhanced photosynthetic rate and prevents the destruction of chlorophyll. The beneficial effects of Si may be attributed to an increase in water use efficiency (WUE) and maintenance of photosynthetic activity. Several studies have suggested positive growth effects of Si nutrition on biomass, yield and pollination. It is reported that a high correlation exists between straw silica content and yield of grain up to about

12% silica in the straw. Brown rice, milled rice and head rice recovery is higher in Si-treated rice than in the Si-untreated rice while, chalky grain and chalkiness are lower.

Wheat is another staple food crop that is widely reported to positively respond to Si fertilizers. It has been reported an obvious yield increase in wheat ranging from 10 to 20% following the application Si fertilizers. Silicon increases the number and mass grain production of wheat by stimulating shoot and root biomasses ultimately enhances the wheat growth and yield especially when applied in water-stressed conditions. Si application enhances the content of wet gluten, flour water absorption and paste fracture time, and the extension quality of the paste. The residual effect of Si fertilization also plays a great role in enhancing the quality parameters of grain like hectoliter weight, sedimentation volume and grain hardness index.

Maize growth and yield are also highly responsive to Si fertilization. Si application in maize enhances the yield by 10-12%. It has been observed that yield of summer maize receiving Si fertilization is increased by 473–900 kg ha⁻¹. The application of Si fertilizer increases concentrations of N, P, Zn and Mn in maize plants. Thus, the yield response to Si may be related to improved uptake of these nutrients.

Sugarcane is a Si-accumulating plant species and the second most Si-responsive crop after rice. It has been well documented that Si nutrition has a definite agronomic role in sugarcane crop cultivation, especially on highly weathered tropical soils. It is reported that the above ground parts of 12-month-old sugarcane plants contained 379 kg ha⁻¹ of Si, compared to 362 kg ha⁻¹ of K and 140 kg ha⁻¹ of N. Several researchers reported that application Si increases sugarcane yield ranging from 10 to 50%. Si fertilization gives positive responses to sugarcane to a number of factors including prevention of aluminium and manganese toxicities in highly weathered acid soils, improves WUE, protection from fungal and insect pest damage, improves phosphorus nutrition,

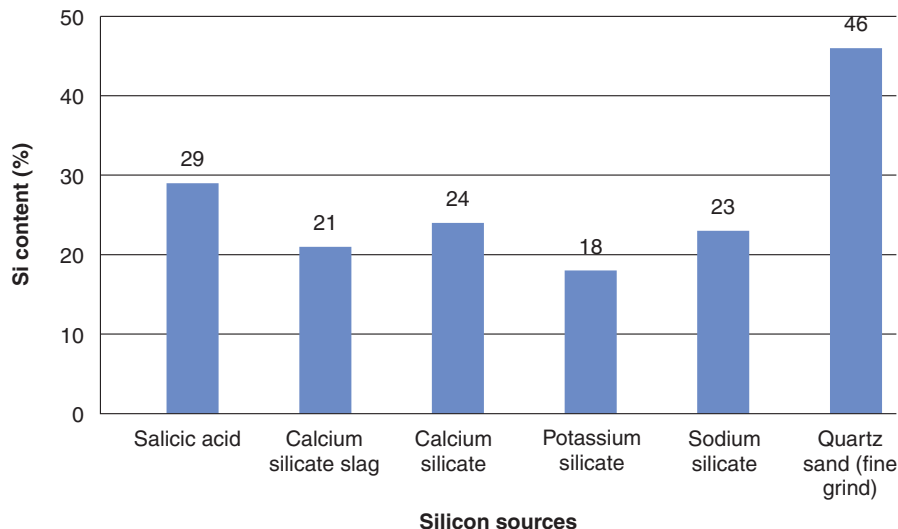


Fig. 1. Different sources of silicon fertilizers and their content

mechanical strength and photosynthesis through better use of sunlight.

Si application could increase the chlorophyll content and activity of nitrate reductase of lower (old) leaves of sugarcane, prolong the leaf functional period and increase the leaf area index. Si also increases the export of photosynthetic products from middle and lower leaves at night. Application of Si can influence the availability of nutrients in the soil and nutrient concentrations in sugarcane plants. It has been found that Si promoted the translocation of 11 nutrients including N, P, K, Mg, Ca, Mn, Zn, Cu, Fe, Mo and B to the growing parts of the plant, which could enhance the growth of sugarcane, as well as sugar synthesis and accumulation. Si may play a role in the synthesis, storage and retention of sucrose in sugarcane plants. Si application decreases the activities of acid invertase in mature leaves but increases the activities of neutral

invertase at elongation and maturity stages. Si-mediated changes facilitated sucrose accumulation in the cane. Application of Si improves sugarcane juice quality characteristics like Brix (% soluble solids in juice), Pol (% sucrose in juice), commercial cane sugar and sugar recovery.

Sources of Si fertilizers

As a fertilizer, it must provide sufficient water-soluble Si with relatively high Si content to meet the plant needs, should be cost effective, have a physical nature that facilitates storage and application, and does not contain substances that will contaminate the soil. Many potential sources meet the first requirement (Fig. 1), however, only a few meet all of these requirements. Crop residues, especially of Si accumulating plants, such as rice, are used as Si sources. However, the crop demand for Si generally exceeds that supplied by crop residues. Inorganic materials, such as quartz, clays, micas, and

Table 1. Disease suppression by Si in different crops

Crops	Pest	Scientific name
Rice	Small Brown hopper	<i>Laodelphax striatellus</i>
	Green rice caterpillar	<i>Naranga aenescens</i>
	Leaf roller	<i>Cnaphalocrocis medinalis</i>
Wheat	Green bug	<i>Scizaphis graminum</i>
	Aphid	<i>Sitobion avenae</i>
Maize	Fall armyworm	<i>Spodoptera frugiperda</i>
	Leaf aphid	<i>Rhopalosiphum maidis</i>
Sorghum	Central shoot fly	<i>Atherigona indica</i>
	Green bug	<i>Scizaphis graminum</i>
Sugarcane	Stem borer	<i>Diatraea saccharina</i>
	Stalk borer	<i>Eldana saccharina</i>
	Spittlebug	<i>Mahanarva fimbriolata</i>

Table 2. Pest suppression by Si in different crops

Crops	Disease	Pathogen
Rice	Blast	<i>Pyricularia oryzae</i>
	Brown spot	<i>Bipolaris oryzae</i>
Wheat	Powdery mildew	<i>Blumeria graminis</i>
	Spot blotch	<i>Bipolaris scrokiniana</i>
Sugarcane	Sugar rust	<i>Puccinia melanocephala</i>
Barley	Powdery mildew	<i>Blumeria graminis</i>
Pearl millet	Downy mildew	<i>Sclerospora graminicola</i>
Sorghum	Anthraxnose	<i>Colletotrichum graminis</i>

Table 3. Mitigation of abiotic stresses by Si in different crops

Abiotic stress	Crops	Mechanism of Si
Lodging	Wheat	Increase strength of stem
	Rice	Increase rind thickness
Drought	Wheat	Increase in leaf water potential
	Sorghum	Increase in CO ₂ assimilation
Freezing	Wheat	Increase in photosynthetic rate
High temperature	Rice	-
UV radiation	Rice	Forming a cuticle- Si double layer in leaf blades which act like a glass layer and decrease the further transmission of UV radiation from the epidermis
	Wheat	
Flooding	Barley	Decreases the intensity of reactive oxygen species (ROS) destruction in barley roots
Salinity	Sugarcane	Decrease in osmotic potential and increase in turgor potential
	Sorghum	
Cadmium toxicity	Maize	Reduction in uptake and translocation
Aluminium toxicity	Wheat	Reduction in uptake and translocation
Arsenic, Iron, manganese toxicity	Rice	Reduction in uptake and translocation

feldspars, although rich in Si, are poor silicon-fertilizer sources because of the low solubility of the Si. Calcium silicate, obtained as a by-product of steel and phosphorus production, is one of the most widely used Si fertilizer. Potassium silicate, though expensive, is highly soluble and can be used in hydroponic culture. Other sources that have been used commercially are calcium silicate

hydrate, silica gel and thermophosphate. International Rice Research Institute (IRRI) research indicates that Si deficiency can be rectified by the application of calcium silicate slag @ 120-200 kg ha⁻¹.

Role of Si in mitigating biotic stresses

The beneficial effect of Si is more evident under stress conditions. This is because Si is able to protect plants

from biotic stresses. Si depleted soils have been associated with lower resistance to insect-pests and fungal diseases. Recent evidence suggests that Si may re-inforce plant pest and disease resistance by stimulating the expression of natural defence reactions through the production of low molecular weight metabolites, which include flavonoid, phytoalexins. The beneficial effect of Si has been demonstrated on many diseases and fungal attacks: powdery mildew, stalk rot, blast, *Fusarium* wilt and leaf spots (Table 1). Silicon increases the thickness of cell wall below the cuticle, which imparts mechanical resistance to the penetration of pathogenic fungi. The beneficial effects of Si have been thought to be due to the precipitation of amorphous silica in plants which acts as a mechanical barrier. The beneficial effect of Si has been proven on attacks by many insects like; yellow borers, leafhopper, aphids and shoot fly. Silicon deposited in the plant tissues, which provides a mechanical barrier against probing and chewing by insects and pests (Table 2).

Silicon nutrition also alleviates many abiotic stresses including physical stress like lodging, drought, radiation, high temperatures, freezing, UV and chemical stress like salt, metal toxicity, nutrient imbalance and many others (Table 3). The beneficial effects are attributed to Si deposition in cell walls of roots, leaves, culms and hulls. Accumulation of Si in plant imparts toughness and integrity to cell walls and reduces

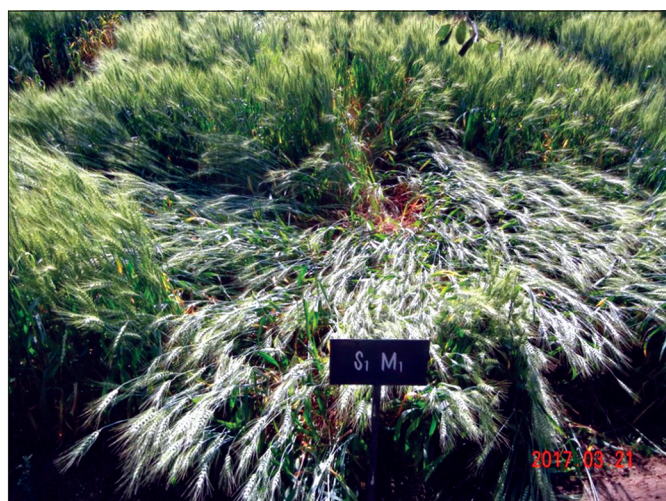


Fig. 2. Lodging in wheat due to without Si application



Fig. 3. No lodging in wheat with Si application

transpiration and, hence, making the plant resistant to lodging, temperature and water stresses. A study conducted at ICAR-Indian Agricultural Research Institute, New Delhi, revealed that application of Si at 120 kg ha⁻¹ reduced the lodging by 100% (Fig. 3) as compared to the control plot without Si application (Fig. 2). Si minimizes water and salt stresses due to its antioxidant defence abilities. Si deposition in roots reduces the binding sites for metals resulting in decreased uptake and translocation of salts and toxic metals from roots to

shoot. Further, accumulation of Si in the roots decreases non-living flow and creates attachment locations for heavy metals and simultaneously minimizes the uptake and finally translocation of harmful heavy metals and salts.

CONCLUSION

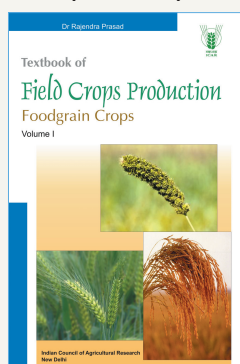
Silicon is not considered as essential component for crop growth. However, it is one of the most versatile elements in nutrient management. Application of Si not only improves productivity but also

mitigates biotic and abiotic stresses. The beneficial effect of Si is more evident under stress conditions. Thus, it can be concluded that Si may a boon for improving productivity as well as the quality of the graminaceous crops particularly under.

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Textbook of *Field Crops Production* – Foodgrain Crops

(Volume I)



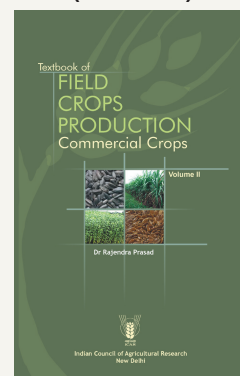
The first edition of Textbook of Field Crops Production was published in 2002 and there has been a heavy demand for the book. This book is now being brought out in two volumes. The chapters cover emerging trends in crop production such as System of Rice Intensification (SRI), export quality assurance in the production technology of commodities like Basmati rice, organic farming, resource conservation technologies, herbicide management etc. Good agronomic practices must judiciously inter-mix the applications of soil and plant sciences to produce food, feed, fuel, fibre, and of late nutraceuticals while ensuring sustainability of the system in as much possible environment and eco-friendly manner. The advent of hydroponics, precision farming, bio-sensors, fertigation, landscaping, application of ICT, GPS and GIS tools, micro-irrigation etc. is in the horizon. The textbook covers both the fundamentals of the subject and at the same time inspire and prepare both teachers and students for the emerging frontiers.

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(Volume II)



Availability of high-yielding varieties/hybrids and increased irrigated facilities have resulted in the development of production-intensive cropping systems in several parts of India, and this has catalyzed further agronomic research based on the cropping-system approach. Many changes have also taken place in the crop-production technologies. And this necessitated the revision of the earlier publication brought out in 2002. The revised textbook is in two volumes: First is covering Foodgrains and second is on Commercial Crops.

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