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Silicon Nutrition of Crops with Special Reference to Rice

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Although silicon (Si) is the second most abundant element both on the surface of the Earth's crust and in soils, it has not yet been listed among the essential elements for higher plants. However, the beneficial role of Si in stimulating the growth and development of many plant species has been generally recognized. Silicon is known to effectively mitigate various abiotic stresses such as manganese, aluminum and heavy metal toxicities, and salinity, drought, chilling and freezing stresses. However, mechanisms of Si-mediated alleviation of abiotic stresses remain poorly understood. In this review, the role of Si in conferring resistance to multiple stresses is described.

Introduction

Silicon is the second most abundant element in the earth's crust. Average concentration of Si in the lithosphere is about 27.6 percent and in soils normally ranges between 23 and 35 percent. It is a principal soil component lost during weathering and the conversions of silicon to secondary minerals are most important mechanisms of soil formation. It is well known that silicon is present in primary silicate minerals, secondary aluminosilicates and various forms of SiO_2.

Si is a tetravalent (Si^{4+}) element, which is not found in free state. It occurs as the oxide silica, $Si0_2$ in various forms like quartz, agate and flint. In soil solutions the prevailing form is monosilicic acid $Si(OH)_4$, which is in equilibrium with quartz (SiO_2) and the concentrations in the soil solution are usually ranging from 14 to 20 mg l^{-1} Si.

All soil-grown plants contain Si. However, the Si concentration of plant shoots varies greatly between plant species, ranging from 0.1 to 10% Si on a dry weight basis. Silicon has not considered as essential element, but is a beneficial element for crop growth, especially for poaceae crops. Silicon plays a crucial role in amino acid and protein metabolism.Silica strengthens the plant, protects the plant against disease, insect and fungi, increases crop production and quality, stimulates active immune systems of plants, increases plant nutrition, increase plant salt resistance and neutralizes Al toxicity in acid soils.Therefore, a continued supply of this element would be required particularly for healthy and productive development of plant during all growth stages.

Silicon in soils

Silicon undergoes various transformations in soils like conversion of soluble forms to insoluble through adsorption reactions, change in soil reaction, and also reacts with various soil components like clay minerals, amorphous and crystalline oxides ofFe^{3+}, Al^{3+} and Mn^{4+} and organic matter which may modify the solubility of silicon in soils. Iron and aluminium oxides of soil components have the capacity to absorb a considerable amount of silicon (Si) on their surfaces. The concentration of Si in soil solutions of waterlogged conditions increases slightly after flooding and then the amount of the same gradually decreases. Soils with a high amount of organic matter regardless of pH, gave the highest increase. The concentrations of Si in natural waters have been recorded to be much less than 120mg l^{-1}. Nagula *et al.* (2015a) revealed that the soil and foliar application silicon and boron had a synergistic effect on the availability of nutrients (P, K and Ca) in the soil. Sadgrove (2006) reported that Si controls the chemical and biological properties of soil with reduced leaching of phosphorous (P) and potassium (K), improved microbial activity, increased stability of soil organic matter, improved soil texture, improved water holding capacity, increased stability against soil erosion and increased cationic exchange capacity (CEC).

Role of Silicon in Rice

Rice is a high silicon accumulating plant. Si is a beneficial element for plant growth and is agronomically essential for improving and sustaining rice productivity. Besides rice yield increase, Si has many fold advantages of increasing nutrient availability (N, P, K, Ca, Mg, S, Zn), decreasing nutrient toxicity (Fe, Mn, Al) and minimizing biotic and abiotic stress in plants. Silica is not much mobile in plants, therefore a continued supply is required for long term sustainable rice production. Hence the application of Si to soil or plant is practically useful in laterite derived paddy soils, not only to increase yield but also to alleviate the iron toxicity problems. Increased mechanical strength of the culm helps reduce crop lodging (Savant *et al*., 1997). The critical level of Si in soil 40 mg kg^{-1} and the critical level of Si in rice (leaf and straw) 5%.

In wetland rice lacking Si, the vegetative growth and yield are drastically reduced and deficiency symptoms like necrosis of older leaves and wilting of plants may occur. The other symptoms; Soft and droopy leaves and culms, increased occurrence of disease, keep leaves erect, reduction in the number of panicle and filled spikelet's per panicle, smaller grain yield, and lodging.

Effect of Silicon on Biotic Stresses

Silicon has been found to suppress many plant diseases and insect attacks. The effect of silicon on plant resistance to pests is considered to be due either to accumulation of absorbed silicon in the epidermal tissue or expression of pathogensis-induced host-defence responses.

Table 1. Insects and other pests suppressed by silicon in rice

S. No.	Pest	Insect	Source
1	Stem borer	*Chilosuppressalis* *Scirpophagaincertulas*	Savant *et al.*, 1994
2	Green leaf hopper	*Chloropsoryzae*	Maxwell *et al.*, 1972
3	Brown plant hopper	*Nephotettixbipnctatuscinticeps*	Sujathata*et al.*, 1987
4	Leaf spider	*Tetranychus*spp.	Savant *et al.*, 1994

Table 2. Diseases suppressed by silicon in rice

S. No.	Disease	Pathogen	Source
1	Brown leaf spot	*Helminthosporiumoryzae*	
2	Brown spot (husk discoloration)	*Cochiobolusmiyabeanus* (*Bipolarisoryzae*)	Hegazi*et al*., 1993. Hegazi*et al*., 1993.
3	Grain discoloration	*Fusarium*, *Epicoccum*, etc.	
4	Leaf and neck blast	*Magnaporthagrisea* (*Pyriculariagrisea)* (*Pyriculariaoryzae*)	Bazilevich, 1993. Yamaguchi and Winslow, 1987.
5	Leaf scald	*Gerlachiaoryzae*	
6	Sheath blight	*Thanatephoruscucumeris* (*Rhizoctoniasolani*) *Magnaporthesalvanii*	Yamaguchi and Winslow, 1987 Rodrigues *et al*., 2003.
7	Rice Stem rot		Elaward and Green, 1979.

Effect of Silicon on Abiotic Stresses

Silicon alleviating Fe toxicity*:* In humid tropical and subtropical area such as South Asia, Fe^{2+} toxicity is one of the major physiological disorders that limit rice growth (Zhang *et al*., 2011). Fe^{2+} toxicity injures plants by inhibiting the elongation of rice roots. Batty and Younger (2003) indicated that iron plaque on the surface of rice roots was harmful to the roots. It decreases root activity and inhibited nutrient uptake (Zhang *et al*., 2011). Moreover, the epidermal and cortex cells within rice roots died when iron plaque was formed (Zhang *et al*., 2011). Silicon enhanced the oxidative power of rice roots, resulting in enhanced oxidation of Fe from ferrous iron to insoluble ferric iron. Therefore, excess Fe uptake was indirectly prevented by Si application (Qiang*et al*., 2012; Nagula, 2014).

Silicon alleviating Mn toxicity: In rice, Si reduced Mn uptake by promoting the Mn oxidizing power of the roots. Nagula, (2014) reported that when silicon levels in tissue are low, Mn^{2+} tends to be distributed non-homogenously and accumulates to toxic levels in leaves. However sufficient levels of Si seem to prevent the toxic levels of Mn^{2+}.

Silicon alleviating Al toxicity: Al toxicity is a major factor limiting crop production in acid soils. Ionic Al inhibits root growth and nutrient uptake (Ma *et al.*, 2001b). Alleviative effect of Si on Al toxicity has been observed in sorghum, barley, maize, rice, and soybean. The alleviative effect was more apparent with increasing Si concentration. Concentration of toxic Al^{3+} was found to decrease by the addition of silicic acid. These results suggest that interaction between Si and Al occurs in the solution, presumably by the formation of Al-Si complexes, a non-toxic form.

Alleviation of salt stress: The Na concentration in the shoots of rice was decreased by addition of Si. This was attributed to Si-induced reduction in transpiration rate and to the partial blockage of the transpirational bypass flow (Yeo *et al.*, 1999). The increased uptake and transport of K^+ and decreased uptake and transport of Na^+ from roots to shoots in barley was thought to be attributable to Si-induced stimulation of the root plasma membrane H^+-ATPase under salt stress (Yeo *et al.*,1999).

Alleviation of water stress: Drought stress usually causes a decrease in crop production. It inhibits the photosynthesis of plants, causes changes of chlorophyll contents and components and damage of photosynthetic apparatus. It also inhibits the photochemical activities and decreases the activities of enzymes in the Calvin cycle. With respect to drought stress, relevant work is limited. Ma *et al*. (2001a) reported that silicon could decrease the transpiration rate and membrane permeability of rice under water deficit induced by polyethylene glycerol.

Effect of Silicon on Crop Growth and Yield

Ahmad *et al*. (2013) reported that increase in level of applied silicon enhanced the number of productive tillers and total number of tillers m^{-2}. Reduction in kernel sterility due to silicon application might be due to balanced nutrition, optimum metabolic activities or nullification of stresses.

Research conducted in 16 provinces of China during 1979-1999 showed yield increases from 0 to 400 %, due to silicon application depending on the severity of Si deficiency (Wang *et al.*, 2004). Silicon and boron significantly improved kernel weight, biological yield, protein content and starch content in grain (Ahmad *et al*., 2013). Nagula *et al*. (2015b) reported combined application of potassium silicate 0.5% spray + borax 0.5% spray was significantly superior with respect to yield (grain and straw) and yield attributes of rice.

Conclusion

It is obvious that most of the effects of Si were expressed through Si deposition on the leaves, stems, and hulls. The more Si accumulated in the shoots, the larger the effect. However, Si accumulation in the shoot varies considerably with the plant species and most plants are unable to accumulate high levels Si in the shoots. The difference in Si accumulation was attributed to the ability of the roots to take up Si. Therefore, although Si is abundant in soil, since most plants especially dicots are unable to take up a large amount of Si from soil, they do not benefit from Si. One approach to enhance the resistance of plants to multiple stresses is to genetically modify the Si uptake ability. Rice is a typical Si-accumulating plant and elucidation of the uptake system of Si in rice roots may provide valuable information for the genetic modification of root Si uptake ability. Most of the previous research on Si has concentrated on highly weathered temperate region soils, mostly acidic in nature

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