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Silicon Fertilization for Crop Stress Management

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Silicon is non-essential but beneficial element to plants as it has pivotal role in stress environment. A very large quantity of silicon is present in the soil as silicates and silicon dioxide, but the actual concentration of bio available ortho-silicic acid is very less. Si supplementation significantly ameliorated a range of biotic and abiotic stress symptoms. Therefore, use of silicate-containing fertilizers in agricultural crop production system is needed to improve plant performance and productivity.

Introduction

There are Seventeen elements that are needed by plants to complete their life cycle. However, a few non-essential elements also provide some benefits to plants, silicon (Si) is one among them. Silicon is basic mineral formatting element and most plants grow in soil medium dominated by it. It is required for normal cell growth and imparts structural benefits to diatoms and some sponges and enhances physical and chemical defense power of plants. It is second most abundant (27%) element in earth crust followed by oxygen (48%). Being extremely insoluble, only a minute amount of Si is available to plant (0.1-0.6 mM). Si fertilizer is applied to crops in several countries for increased productivity and sustainable production.

Occurrence in Soil

Silicon is found in soil in solid, liquid and adsorbed phase. Ninety percent of the earth's crust is comprised of silica compounds. The most prevalent Si compound is silica, primary and secondary silicate minerals. In addition, biogenic Si obtained from phytolith and Si rich plants, also contribute to soil Si pool. The weathering of silicate-containing minerals releases soluble silica into the soil solution with variable contents of 0.1-0.6 mM. Young, less weathered and mineral soils usually supply more Si than completely weathered acidic and organic soils.

Agricultural Role

Silicon is a wonderful nutrient to plant as it has potential to protect the crop from several stresses. It is having following functions in plant safety:

a) Biotic stress: Silicon polymerization in shoot epidermis generally provides a protective layer against penetration of biotic entities like fungi and bacteria. It also promotes production of antibacterial and antifungal compounds known as phytoalexins. Due to enhanced rigidity, palatability and digestibility of plants, Si protects the crop from herbivore attack. Therefore, Si could be employed in integrated disease management for reducing fungicide use. Cucurbit growers, often add silicon to irrigation water to increase the plant's resistance to powdery mildew.

b) Abiotic stresses: Si generally has a pivotal role in stress environment. Silicon immobilizes heavy metals and removes them from rhizosphere through precipitation and improves plant resistance against heavy metals (Al, Fe, Cu, Zn, Mn *etc*.) toxicities. Further, exogenous Si application raises soil pH and decreases solubility and thus availability of toxic metals. Si stimulates root exudation of phenolic compounds which form complexes with Al ions and make them immobile. Thus, Si impart metal toxicity by increasing soil pH, metal immobilization in the growth media and also by changing metal distribution inside the plant. Under high incidence of solar radiation, Si bodies efficiently release infra-red thermal radiation and overcome heat stress. Presence of silicic acid in soil matrix reduces the salinity load on plants to some extent. Thick leaves surface due to Si deposition in cuticle, hamper transpiration mediated water loss in plants and improve water use efficiency. Moreover, Si polymerization in plant body also improves root resistance in dry soil. Thus, Si alleviates moisture stress in plants to a great extent.

c) Crop lodging and photosynthesis: Accumulation of Si bodies in plant vacuole increases mechanical strength and rigidity of stem and reduces crop lodging. Further, silicification also causes leaf erectness, thus, directly improves light interception and indirectly increases photosynthesis efficiency.

d) Nutrient use efficiency: Si is having synergetic interaction with P. Si establishes a buffer system for phosphorous as Si fertilization improves phosphate availability to plants in low phosphorous soils and vice-versa. Si increase available P in soil either by reducing P adsorbing capacity or by replacing P from adsorb site. In addition, the beneficial effect of Si under phosphorous deficiency is attributed to increased levels of organic phosphoesters, thereby improved utilization of phosphorous inside plant body.

Plant Uptake

Cultivation of crops especially cereals remove large quantity of silicon from soil. Rice, wheat and sugarcane extract 500, 100 and 300 kg Si/ha/year, respectively. This amount is much higher than uptake of primary nutrients. The ash of rice and wheat straw contains ca. 80% and ca.70% SiO_2, respectively. According to an estimate, as much as 90% of total Si uptake are deposited in the cell wall of hulls and leaf epidermal cells and constitute up to 10% of dry weight in grass shoots. Rice-growing soils of India are becoming deficient in Si because of intensive cultivation without addition of Si fertilizers, particularly when the rice straw is not incorporated in the field. As a result, Si depletion due to intensive rice cultivation resulted in Si deficiency in many rice growing region. Silicon deficiency is assumed one of the reasons for yield stagnation of rice. Based on Si uptake plants has been categorized into following three groups:

- Accumulators (>1.5 % Si): Fern, mosses, equisetum, monocots (rice, sugar cane)
- Intermediate (0.5-1.5 % Si): Wheat, cucumber, pumpkin, chrysanthemum
- Non-accumulators (<0.5 % Si): Dicots (sunflower, tomato, gerbera, geranium, begonia *etc*.)

Silicon Deficiency

Although soil mass is having 28.8% share of Si but only a trace amount of it released by bio-chemical process. Further, some natural and anthropogenic activities permanently remove the plant-available Si from soils. Tropical regions are generally deficient in plant usable Si due to intensive weathering and leaching. Soils having low base saturation, acidic pH and rich in organic matter are also deprived in available Si content. In addition, intensive crop cultivation and mono-cropping of Si loving and high yielding crops can deplete Si from soil reservoir. Rice-sugarcane continuous rotation on organic sandy soil removes huge amount of Si. As a result, these soils are generally low in plant-available Si. Plant husk, leaves and stem are major sink for Si accumulation. For example, rice straw contains about 86% of total Si uptake after harvesting of crops. Farmers generally remove straw from field and thus huge amount of Si is lost from the field.

Deficiency Symptoms (Fig. 1)

- Symptoms appear as minute circular white leaf spot (Freckles) mostly on older leaves.
- Leaves and culms become soft and droopy thus increasing mutual shading.
- Reduces photosynthetic activity
- Severe Si deficiency reduces the number of panicles and the number of filled spikelets per panicle.
- Deficiency of Si in gramineous plants hamper silicification at epidermis cells which results in stalk weakness and crop lodging.

Corrective Measures

1. For more rapid correction of Si deficiency, granular silicate fertilizers like calcium silicate 120-200 kg/ha or potassium silicate 40-60 kg/ha should be applied.
2. In the long term, Si deficiency is prevented by not removing the straw from the field following harvest. Recycle rice straw (5-6% Si) and rice husks (10% Si).
3. Avoid applying excessive amounts of N fertilizer, which increases yield and total uptake of N and Si, but also decreases the Si concentration in straw because of excessive biomass growth.
4. Where possible, apply calcium silicate slags regularly to degraded paddy soils or peat soils at a rate of 1-3 t/ha.

Fig 1: Silicon deficiency symptoms in rice and sugar cane

(Sources: IRRI, 2013 and Hussain, 2013, respectively)

Sources of Silicon

Supplementation of Si fertilizers can alleviate almost abiotic and biotic stresses. However, use of Si-containing fertilizers & minerals are really needed for Si-loving crop especially under harsh environment. Sources of mono-silicic acid are irrigation water, desorption from the soil matrix and weathering of Si-containing soil minerals.

a) **Silicon based fertilizer:** For external supplementation of Si, readily available, cost effective and soluble-Si enriched materials are suitable (Table 1).

Table 1: Commercially available silicon fertilizers

Type	Fertilizer	Nutrient content	Remark
Solid fertilizer	Calcium silicate	24% Si, 31% Ca	○ Most important sources for soil applications ○ Supply macro-nutrient 'Ca' to crop ○ Act as liming material to ameliorate acidic soils.
	Potassium silicate	18% Si 50% K	○ Feed the crop with primary nutrient potassium ○ It is used in nutria-culture for disease control in high value crops.
	Sodium silicate	23% Si 38% Na	○ It is used to supply Si in research and high value crops. ○ Sodium act as dispersant and degrade soil structure so sodium silicate is not considered as good source of Si.
	Calcium magnesium silicate	17% Si	○ Feed the crop with Ca, Mg and Si ○ Application method: Solid fertilizer can easily apply by mixing with NPK fertilizers.
Liquid fertilizer	Silicon acid or silicic acid, and silicon conditioners	29-30%	○ These are mainly used for foliar application, as plants can only absorb silicon in silica acid form. It helps plants to fight diseases such as powdery mildew, septoria and eye-spot, insect pests and others. ○ Application method:Liquid fertilizers can be used as soil application through drip irrigation/fertigation system and as foliar spray.
Silicon-nano fertilizer			○ Increases fertilizer efficiency ○ Significantly reduced root mortality, decay and yield losses due to *Pythium ultimum.* ○ Application method: a) Drenching: Mix 1-2ml nano fertilizer in 1 litter of water and drench in root zone. b) Spray: Mix 1-2ml nano fertilizer in 1 litter of water and spray on foliage.

Caution: *Silicon fertilizers being alkaline increase the pH of the stock solution and reduce the solubility of micronutrients and silicon can form precipitates in the stock tank. So, it is better to have separate stock tanks for a silicon fertilizer and other fertilizers.*

b) Silicon solubilizing bacteria (*Bacillus flexus, B. mucilaginosus, B. megaterium* and *Pseudomonas fluorescens*): Microbe produces organic acids as part of its metabolism that has a dual role in silicate weathering. They supply H+ ions to the medium and promote hydrolysis and the organic acids like citric acid, oxalic acid, keto acids and hydroxy carbolic acids which form complexes with cations and make the silica available to the plant in an assimilable form. It plays crucial role in the release of the plant nutrients like potassium, calcium and magnesium from the silicates.

Application methods

- Seed Treatment: Mix 10 g of Si biofertilizer with 10 g of crude sugar in sufficient water to make slurry and coat 1 kg of seeds. Dry the seeds in shade and sow/broadcast/dibble in the field.

- Seedling treatment: Mix 100 g of Si biofertilizer with sufficient quantity of water and organic manure to form slurry. The seedlings are dipped in this slurry for 30 minutes prior to planting so that the bacteria get attached to the roots.
- Soil application: Mix 3-5 kg/acre of Si biofertilizer with compost and apply to an acre of soil.
- Drip Irrigation: Mix 3 kg/acre of Si biofertilizer in drip stream.

c) Rice straw recycling: Rice straw is generally not preferred as livestock feed due to its high Si content. Rice contain 2-10% Si (average-5-6%) in leaves & stem and up to 10% Si in husk. So, the straw can be incorporated into soil to recycle the Si.
d) Industrial by-products: Smelting of wollastonite, Fe and Mg ores, electrical production of P are economic and commercial sources of Si. Slags, (by-products from iron and alloy industries) consist of alkaline calcium silicate and magnesium silicate and thus neutralize acidic soils besides supplying Si.
e) Fly ash: Fly ash is a coal combustion residue of thermal power plants. Fly-ash has great potentiality in agriculture due to its efficacy in modification of soil health and crop performance. Further, it is rich source of Si (75% Si) also. In India alone, 112 mt fly-ash is produced every year and only 38% of it is utilized. So, the remaining 62% can be used in agriculture as Si fertilizer and soil ameliorant.
f) Diatomaceous earth (DE): It is the fossilized remains of salt or freshwater diatoms which are predominantly composed of amorphous silica (SiO_2). Amorphous DE silica is good source of plant-available Si as it more solubilized than other forms.

Future Perspective

Adaptation of silicon as a nutrient will be higher in tropical and rice-growing regions like India, China and Japan. New farming technologies such as hydroponics and floriculture provide new opportunities for the growth of liquid silicon fertilizers in the market. Since it's a natural element, silicon-based fertilizers can be used by all farmers, under conventional or organic farming or under integration of the both.

Conclusion

Silicon fertilizers help to resist diseases and insect attack, unfavorable climatic conditions and improve physical & chemical soil properties as well as maintain nutrients in plants. These are used in different crops such as barley, wheat, maize, sugarcane, cucumber, citrus, tomato and other crops for increased productivity along with sustainable production. Although benefits obtained by plant are impressive, but the relative high cost of the Si fertilizers could make Si application unprofitable in some areas of the world. So, alternate Si-sources like straw recycling, DE and industrial by-products may serve the purpose.

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