Agri. Reviews, **35** (1) : 14-23, 2014
DOI- 10.5958/j.0976-0741.35.1.002

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
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SILICON IN CROP PRODUCTION AND CROP PROTECTION - A REVIEW

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Received: 18-07-2012 Accepted: 28-03-2013

ABSTRACT

Silicon is accumulated in plants higher than the essential major nutrients. Although it is not considered as an essential element it is accepted as an agronomically beneficial element as it confers rigidity and strength, resistance against pests and diseases, improves water economy by reducing transpiration rate, alleviates the ill effects of abiotic stresses and enhances crop yield. Its continuous removal from soil by cropping is left unreplenished and hence the demand for silicon by crops escalates when other fertilizers are applied. As silicon nutrition reverses the succulence induced by high nitrogen and enhances crop growth and yield silicon fertilizers based on silicate minerals, ashes and slags have come into vogue. Solubilisation of silica in situ in soil by silicate solubilising bacteria to supplement crop need is also made. The role of silicon nutrition in crop production and crop protection are reviewed.

Key words: Crop growth, Disease control, Pest suppression, Silicon role.

Silicon (Si) constitute 27.8% (w/w) in earth's crust which occurs as silica (SiO_2) and silicates (SiO_3) but not in its elemental form (Ehrlich,1981). Silicon content in soil ranges from < 1 to 45% by dry weight (Sommer *et al.*, 2006) while the silica (Si to SiO_2 - 2.1; Si to SiO_3 - 2.6) constitute 50-70% of the soil mass varying from less than 20% to almost 100%. All plants rooting in soil therefore contain silicon. Yet it is considered as a plant nutrient "anomaly" as its essentiality for plants is not yet established (Epstein,1994). But soluble silicon was found to enhance plant growth and yield of many crop plants, protect them from pests and diseases and hence accepted as an agronomically beneficial element (Epstein, 1999). Rice removes 230-470 kg Si/ha and sugarcane removes as much as 500-700 kg Si/ha. The quantity of silicon removed from the world arable soils is estimated as 210-224 million tons annually (FAO, 1998). Its role in soils, plants and animals (Jones and Handreck, 1967) and silicon nutrition effect in rice (Savant *et al.*,1997) and sugarcane production (Savant *et al.*,1999) were highlighted. The usefulness of silicon in different spheres of human life was well elucidated (Vasanthi *et al.*, 2012). The present review restricts to the role of silicon in crop production and crop protection.

Silicon in plants: Ever since silicon was first observed in plants (de Saussure,1804) its role is debated. Plants absorb more silica then they need but once deposited on tissues it cannot be excreted. It is largely restricted to primitive life forms and plants of Poaceae, Cyperaceae, Commenllinaceae in monocots and Urticaceae and Cucurbitaceae in dicots. Plants of the families of Poaceae, Equisitaceae and Cyperaceae accumulate high silicon (> 4% Si), the Cucurbitales and Commenllianaceae exhibit intermediate levels (2-4%) while most other species accumulate (> 2%) less silicon (Curie and Perry,2007). The silicon content of plant ranges from 0.1 to 10% of dry weight. Silicon levels increased fromlegumes< fruit crops< vegetables < grasses < graincrops (Thiagalingam *et al.*,1977). The aerial parts accumulate more silicon than roots. The silicon content of shoots tend to decline in the order of liverworts> horsetails> club mosses> mosses> angiosperms> gymnosperms and > ferns. The mean shoot silicon concentration of certain plant species indicate a wide variation with lowest in *Amaranthus viridis* and highest in bamboo *Arundinaria gigantea* (Hodson *et al.*,2005).

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Rice absorbs silicon in the form of *ortho*-silicic acid (H_4SiO_4 or Si (OH_4) along with water by diffusion and also by transpiration induced root absorption by mass flow (Yoshida, 1975). But silicic acid present in soil solution is only in the range of 0.1–0.6 mM (3.5–40 mg Si l^{-1}). Because of continued absorption and transpiration, the silica concentration increases due to loss of water and at higher levels *ortho*-silicic acid polymerizes into silica gel ($SiO_2.nH_2O$) through a non-enzymatic reaction. In rice leaf blades 90% or more of silicic acid exists as silica gel (polysilicic acid) and 0.5% as low molecular weight silicic acids (largely composed of *ortho*-silicic acid). Rice accumulate 4-20% silica in straw with an average of 11% and almost every part of rice contains silica (Ishizuka,1971). The silica content of rice plant increased with the age of the crop from transplanting to harvest (Nayar *et al.*,1982a). The silica content of rice straw at harvest ranged from 4.8–13.5% in dry season and from 4.3–10.3% in wet season (Nayar *et al.*, 1982b). The genotypic variation in the shoot Si concentration within the same species was also observed. However this is not as large as that occurs between species. The variation in the shoot Si concentration among the cultivars of barley (Ma *et al.*, 2003) and sugarcane (Deran, 2001) were also reported. Rice varieties of Japonica type showed a higher Si than indica varieties (Deran *et al.*, 1992).

Silicon uptake by plants: Plants are classified as (1) silicon accumulators (2) intermediate accumulators and (3) silicon excluders (Takahashi *et al.,* 1990). This difference is attributed to the difference in the ability of plant roots to absorb Si from soil solution. Active, passive and rejective modes of Si uptake were recognised by comparing Si uptake with water uptake. An active Si uptake is similar to water uptake and a rejective mode is slower than the water uptake. Investigations with two rice mutants, one defective in root hair formation and another in the formation of lateral roots showed that the lateral roots contribute to the Si uptake and not root hairs (Ma *et al.*, 2001). The uptake is mediated by a specific transporter in rice roots (Okuda and Takahashi, 1962). Through studies with a rice mutant defective in Si uptake, two genes (Low Silicon rice 1- LSi-1 and LSi-2) encoding Si transporters were identified in Japonica rice varieties (Ma *et al.*, 2002; 2006). The gene LSi 1 is an influx transporter from external solution to root cells and is mainly expressed in roots. LSi 2 is an efflux transporter mediating Si transport from root cells to the apoplast. These two transporters are expressed in roots and their activity decreases with Si supply (Ma *et al.*, 2007). Ma and Yamaji (2006) investigated the Si uptake mechanism in rice, cucumber and tomato that accumulate high, medium and low levels of Si. It was found that the transport of Si from the solution to cortical cells were almost similar in all the three species but the density of the transporter differed. The transport of Si from cortical cells to xylem (xylem loading), was higher in rice with increased Si level in xylem sap than the other two. Xylem loading in rice was mediated by a transporter but in cucumber and tomato this was mediated by diffusion. The low level of accumulation of Si in cucumber and tomato might be due to lower density of the transporter and a defective or absence of transporter to transport Si from cortical cells to xylem.

Silica is deposited as 2.5mm layer beneath the cuticle forming a double layer of silica – cuticle in rice. The silica structures vary with plant species (Lanning *et al.*, 1958). Globular, fibrous and sheet like micro structural forms of silica are observed in plants of Poaceae and Equisetaceae. Silica cells, dumb bell shaped cells on epidermis and vascular bundles, silica bodies in bulliform cells, guard cells and subsidiary cells of stomata are seen in plants of Poaceae. In roots silica is found in all tissues. Silica bodies are opal phytoliths (phyto= plant; litho= rock) produced by plants and range from 10–30mm size (Neethirajan *et al.*, 2009). Silicification is most common in monocots and is comparable with the secondary thickening and lignifications of sclerenchymatous cells which offers strength to dicotyledons plants.

Role of silicon in plants: Silica deposition confers rigidity and strength to the culms and erectness to leaves and thereby facilitates non- lodging, enhanced interception of sunlight and photosynthesis. Silicon supply was found to increase the photo assimilation of carbon and also promoted the assimilated carbon to rice panicle (Tisdale *et al.*, 1985). Its nutrition reduces transpiration and improves water balance resulting in water economy (Gao *et al.*, 2004). Low silica content results in succulence and increases the transpiration rate creating poor water-use efficiency. The thick silica – cuticle double layer formed in rice leaves render them difficult for the sucking and chewing pests for feeding and for penetration by pathogenic fungi. Silicon nutrition reduces chaffiness and shattering of grain and enhances grain yield (Jones and Handreck,1967). It plays a role in phosphorus nutrition and there is an interrelationship with phosphorus (Silva, 1971). Silicon in soil improves phosphorus availability and uptake by competing with phosphorus fixation sites in soil (Ma and Yamaji,2006).

Although no biochemical role has been positively identified for silicon in plants, it has been proposed that enzyme silicon complexes are found to protect or regulate photosynthesis. Silicon was found to suppress the activity of certain enzymes and suppression of invertase resulted in greater sucrose production in sugarcane and the reduction in phosphatase provided a greater supply of essential high energy precursors needed for optimum growth. Silicon deficiency decreases the synthesis of proteins and chlorophyll. It was also suggested that silica in plants filter harmful ultraviolet radiation reaching leaf surface with leaf cells acting as 'windows' transmitting the light energy to photosynthetic mesophyll and cortical tissues beneath epidermis, than that would occur if silica was absent (Tisdale *et al.*, 1985).

Silica reduces pest incidence: The use of ashes to control aphids in lab lab is an age old practice. The role of silicon in pest control was reviewed recently (Laing *et al.*,2006). A cursory perusal of the available literature indicate that a higher silica content reduced the incidence of several crop pests (Table 1). Sucking pests and leaf eating caterpillars have a low preference for the silicified tissues than low silica containing succulent parts. Both physical and /or biochemical defence systems might operate. The rice plants grown in nutrient solutions containing 0.47 and 47 ppm Si concentration exhibited a difference in the time taken for penetration by the first instar larvae of yellow stem borer, *Scirpophaga incertulas*. The penetration time increased from 2.8 min in plants grown in 0.47 ppm Si to 21.2 min in plants grown in 47 ppm Si. When seedlings in the nursery was fertilized with silicon through black-grey ash of burnt rice hulls the stem borer damage (dead heart) was reduced in the transplanted rice. The incidence of stem maggots, green leaf hopper, brown plant hopper and white backed plant hopper, leaf folder etc. were reduced due to silicon nutrition. Application of silicon to corn affected the biological development of the *Spodoptera* . In wheat and sorghum silicon negatively affected the preference and reduced reproduction rates of the green bug *Schizaphis graminum* (Gomes *et al.*, 2005; Carvalho *et al.*, 1999). Silicon decreases the food intake, growth longevity, fecundity and population growth of xylem feeding white backed plant hopper *Sogatella frucifera* (Salim and Saxena,1992). Soluble silicon reduces off spring production and population fitness of phloem feeding aphids *Myzus persicae* in potato, wheat and white fly (*Bemisia tabaci*) in cucumber. Both soil and foliar application of calcium silicate increased the mortality of nymphs of white fly in wheat (Correa *et al.*, 2005). In sugarcane the hardness of cane due to a higher silica reduced the shoot borer attack (Rao, 1967).

Suppression of non insect pests: Silica accumulation reduces nematode infection and the attack of mites in crop plants (Table 2). Roots of rice varieties containing high silica was found to resist

TABLE 1: Reduction of pest incidence in crops due to silica content

Rice:	Stem maggot Chlorops oryzae; Green leaf hopper Nephotetix bipunctatus cinticeps; Brown plant hopper Nilaparvata lugens; White backed plant hopper Sogatella furcifera ; Stem borer Chilo suppressalis; African striped borer Chilo zacconius; Yellow stem borer Scirpophaga incertulas; Leaf folder Cnaphalocracis medinalis; Gall midge Oresolia oryza.
Wheat:	Green bug Schizaphis graminum; Hessian fly Phytophaga destructor; White fly Bemisia tabaci.
Maize:	Stalk borer Chilo zonellus; Borer Sesamia calamistis; Leaf aphid Rhapalosiphum maidis; European corn borer Ostrinia nutitali; Army worm Spodoptera frugiperda.
Sorghum:	Green bug Schizaphis graminum.
Sugarcane:	Shoot borer Cholo infuscatelus; Stem borer Diatraea saccharalis; African stalk borer Eldana saccharina .
Musk melon:	Fruit fly Daucus cucurbitae .
Zinia:	Aphids Myzus persicae.

the infection of root- knot nematodes (Swain and Prasad, 1988). A reduction in nematode infection due to a high silica content was also observed in coffee and cucumber (Silva *et al.*,2010; Dugui *et al.*, 2010). Mites were also reduced by a higher silica content in plants (Tanaka and Park,1966).

Suppression of pests in stored products: The development of resistance to insecticides and the pesticide residues in food commodities led to the use of safer, inert, chemically unreactive dusts to combat pests in storage. Sand or Soil has been used to cover the top of stored grains for centuries by the aboriginal people in North America and Africa to control insect pests in stored grains. The use of ash in India is known since ancient times. Diatomaceous earth, a pure from of silica from fossilized diatoms, has been used from ancient times in the control of household pests by incorporating it in the walls, floors and ceilings of home and barn because of its low mammalian toxicity, but possess insecticidal, repellent and ovicidal properties. This prevents infestation by ants, white ants, earwigs, bed bugs, flies, silver fish, fleas, chicken lice, mites and ticks. Clays, activated clays, rice husk ash, wood ash, lime, rock phosphate, silica- pyrethroid mixtures, silica aerogels and silica nano particles are in use (Abd El-Aziz,2011; Debnath *et al.*, 2011). Several commercial formulations based on silica or diatomaceous earth like Grasil 23 D, Aerosil R 972, Dryacide, Insecto, Protect- it, Silico-sec etc have come into the market in several countries. The inert dusts are safe and act on pests by (1) dehydration and desiccation (2) impairing the digestive tract (3) blocking spiracles and tracheae (4) by absorbing lipids from cuticle (5) by damaging the wax layer and / or (6) causing weight loss. The efficacy of these dust formulations vary with the insect species and also between instars of larval development and adults. The storage pests controlled by silica application are listed in Table 3.

TABLE 2: Suppression of non insect pests by silica.

Nematodes:	
Meloidogyne sp	Rice
Meloidogyne exigua	Coffee
Meloidogyne incognita	Cucumber
Pratylenchus zeae, Helicotylenchus dihystera	Sugarcane
Mites:	
Leaf spider mite Tetranychus sp	Rice
Red Spider mite Tetranychus urticae	Brinjal

Silicon in disease suppression: Silicon nutrition suppressed the leaf and neck blast, brown spot, sheath blight, leaf scald, grain discoloration, stem rot and bacterial leaf blight infection in rice (Gangopadhyay and Chattopadhyay, 1975; Winslow,1992; Datnoff and Rodrigues,2005). Silicon application at 1000kg/ha through calcium silicate reduced neck blast by 30.5% and brown spot by 15.0% over the control (Datnoff and Rodrigues, 2005). It was found to suppress ring spot in sugarcane, root rot and powdery mildews in cucumber (Menzies *et al.*, 1991) powdery mildew of wheat (Belanger *et al.*, 2003) (Table 4). The accumulation of silica induces resistance by (1) playing a mechanical role as a barrier for the invading pathogen either by reducing the rate of progress of the disease or by restricting the lesion size and production of spores for secondary infection (Seebold *et al.*, 2001) and (2) by inducing host resistance by enhancing the levels of preformed inhibitors like phenolics or by mediating the synthesis of post infectionally formed antifungal phyotalexins or by activating oxidative enzymes (Fauteux *et al.*,2005).

The cuticle-silica double layer mechanically impede penetration of fungi and thus disrupt the infection process in rice (Yoshida *et al.*, 1962). In rice-blast system increased resistance due to Si application was associated with the density of silicified bulliform, long and short cells in leaf epidermis which acted as a barrier and decreased the number of blast lesion. It was also postulated that Si might form complexes with the organic compounds of cell walls of epidermal cells, thus increasing their resistance to enzymes elaborated by

TABLE 3: Pests of stored products controlled by silica formulations

Rice husk ash:	Callosobruchus analis
Wood ash:	Callosobruchus analis, C. chinensis, C. maculatus
Silica:	Tribolium confusum, Sitophilus granarius, Rhyzopertha dominica, Tenebrio molitor, Plodia interpunctella, Coleomegilla maculata, Leptinotarsa decemlineata
Silica nanoparticle:	Sitophilus oryzae
Silica aerogel:	Prostephanus truncates, Oryzaephilus mercator

TABLE 4: Silicon induced suppression / resistance against plant diseases.

Rice:	Rice blast *Pyricularia oryzae,* Grain discoloration *Bipolaris, Fusarium* Brown spot *Cochliobolus miyabeanus,* Leaf scald *Monographella albescens* Sheath blight *Rhizoctonia solani,* Stem rot *Magnaporthe salvinii,* Bacterial leaf blight *Xanthomonas oryzae* pv *oryzae.*
Wheat:	Powdery mildew *Erysiphe graminis, Oidium monilioides, Blumeria graminis sp.tritici,* Leaf spot *Mycosphaerella pinodes.*
French Bean:	Cow pea rust *Uromyces phaeseoli typia.*
Soybean:	Stem canker *Diaporthe phaseolorum f.sp.meridiunalis,* Soybean sudden death syndrome *Fusarium solani,* Seedling damping off *Fusarium semitectum* Downy mildew *Peronospora manshunica,* Frog's eye spot *Cercospora sojina.*
Sugarcane:	Sugarcane rust *Leptosphaeria Sacchari***,** Ring spot *Puccinia melanocephala.*
Banana:	Panama wilt *Fusarium oxysporium f.sp.cubense,* Root rot *Cylindrocladium spathiphylli.*
Carrot:	Cercospora blight *Cercospora carotae,* Alternaria blight *Alternaria dauci.*
Cucumber:	Powdery mildew *Sphaerotheca fuliginea,* Crown and root rot *Pythium ultimum.*
Melon:	Fruit decay *Alternaria alternate, Fusarium semitectum, Trichothecium roseum.*
Coffee:	Frog's eye spot *Cercospora coffeicola.*

the pathogen (Volk *et al.*, 1958). The soluble Si can produce phenolics and phytoalexins in response to infection. The antifungal phyotalexin momilactones that accumulate in Si amended rice plants acted against blast pathogen (Rodrigues *et al.*, 2004). Silicon induced cell wall fortification in rice leaves as a mechanism of resistance to blast was also shown (Kim *et al.*, 2002). In cucumbers Si enhanced the activity of chitinases, peroxidases and polyphenol oxidases when their roots were colonized by *Pythium* (Cherif *et al.*, 1994). Silicon mediated accumulation of flavonoid phytoalexin rhamnetin in cucumber which acted against the invading powdery mildew pathogen *Sphaerotheca fulginea* (Fawe *et al.*,1998). A higher level of chitinase and ß- 1,3-glucanase and consequent less susceptibility to *Mycospharella pinodes* was observed in pea seedlings grown in elevated silicon levels (Dann and Muir,2002). The foliar application of talc (silica) based formulations of biopesticides and biocontrol agents may also induce host resistance by triggering biochemical reactions of the host besides directly controlling the invaders.

Silicon in alleviating abiotic stress: Silicon nutrition alleviates many abiotic stresses (Table 5) including physical stress like lodging, drought, UV radiation, high temperatures, freezing and chemical stress like salt, metal toxicity, nutrient imbalance (Epstein, 1994; Ma and Yamagi,2006). Si may increase salinity tolerance to plants by improving water status, increased photosynthetic activity, stimulation of antioxidant system, by reducing salt uptake and increasing K uptake (Tahir *et al.*, 2006). The hydrophilic nature of silica could retain more water, dilute salts and protect tissues from physiological drought (Romero-Arnada *et al.*, 2006).). Lodging, a phenomenon of succulence and tender growth due to increased nitrogen supply and water logging is also off set by silicon nutrition (Idris *et al.*, 1975). Silicon treatment was found to render rice leaves resistant to UV-B radiation (Li *et al.*, 2004). 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 (Li *et al.*, 2008). The metal toxicity in acid soils can be counteracted with the application of soluble silica. It was also found that foliar application of silica reduced the cadmium accumulation in rice grains (Liu *et al.*, 2009)

Si alleviated effects have been associated with an increase in antioxidant defence abilities. It is a common feature to observe oxidative stress in plants subjected to abiotic stresses due to the production of active oxygen species (AOS) or reactive oxygen species (ROS) like superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), hydroxyl radicals(OH^-) that are cytotoxic (Mc Cord, 2000). These reactive oxygen species cause oxidative damage to membrane lipids, proteins and nucleic acids thereby affecting growth. Plants respond to abiotic stresses by activating antioxidants like ascorbate, glutathione, a-tocopherol and carotenoids and detoxifying enzymes like superoxide dismutase (SOD), catalase (CAT), peroxide and enzymes of ascorbate and glutathione cycle that scavenge the free radicals resulting due to stress (Zhu *et al.*, 2004). Silicon nutrition increases the antioxidants and the enzymes involved in detoxification of the free

TABLE 5: Silicon nutrition and mitigation of the abiotic stress in crops

Physical stress:	
Lodging, Drought, High temperature, Freezing, UV Radiation etc.	
Chemical stress:	
Salinity:	Rice
	Wheat
	Mesquite
	Maize
Mn toxicity:	Cucumis
	Bean
Al toxicity:	Rice
Cu toxicity:	Arabidopsis
Fe toxicity:	Sugarcane
Cd toxicity:	Rice
	Maize
Zn toxicity:	Maize

radicals. Copper toxicity in plants enhances the phenylalanine ammonia lyase (PAL) similar to pathogenic invasion. Silicon nutrition increases phenolic compounds in plants which form silicon phenol complexes that may reduce PAL activity in copper stressed plants (Li *et al.*, 2008).

Silicon nutrition and crop response: The response of crops to silicon application particularly rice and sugarcane have been extensively investigated both in solution and soil culture (Padmaja and Verghese, 1972). The oxidizing power of rice roots and accompanying tolerance to high levels of iron and manganese was found to be dependent on silicon nutrition. By maintaining a higher root oxidase activity and by decreasing the slow down of its activity at later stages of growth through silicon, a healthy crop and a higher yield could be achieved (Yuan and Chang,1978). Supplemental silicon has been proved to be beneficial when silica concentration falls below 1% in straw and to avoid this problem silicon bearing materials have been recommended for field application (Tisdale *et al.*, 1985). Application of silicate to rice was found to increase the grain yield under both upland and water logged conditions (Datta and Shinde, 1985). The application of silicate not only augmented its absorption by rice plant but had a significant interrelationship with the other nutrients as well. With adequate silicon, the uptake of nitrogen was increased (Okamoto, 1969; Sadanandan and Verghese, 1969). However, a decrease in nitrogen content was also reported in rice in response to silicon addition to solution culture (Islam and Saha, 1969). Realizing the agronomically beneficial nature of silicon, silicate minerals, ashes from furnaces and slags from smelters have been used as soil amendment / conditioner to enhance crop yield. Justus von Leibig (1840) suggested the use of sodium silicate as a silicon fertilizer as early as in 1840 and conducted green house experiment with sugar beet. A field experiment started in 1856 in Rothamsted Experiment Station and continued beyond a century and a half revealed the favourable effect of silicates on grass productivity. A patent for silicon slag as a fertilizer was also given in 1881 (Zippicotte, 1881). The ashes from conventional household chulas using fire wood and dried cow dung cake were rich in silica and potash and used for field application. The traditional practice of application of tank silt to cultivated fields in summer supplied silica in the form of silt with a small amount of organic matter. In river deltas of South India, sand is applied to rice fields at 2–3 tons/acre during summer once in 2 or 3 years. It has been thought that this is applied to loosen the heavy clay. But in reality sand (pure quartz) replenished the soil with silicon that is continuously removed by the silicocolous rice plant in large quantities. In United States farmers in Texas, Lousiania and Florida use organically certified green sand containing iron, potassium and silicates to get higher yields. Application of cured press mud to sugarcane fields and incorporation of straw and stubbles to rice fields offer organic matter, silica and other nutrients. In the context of declining productivity in deltaic areas of the World new innovative technologies like silicon fertilization to boost crop yield is important. Products based on silicates either for soil application or for foliar spray are now available in the market. Several naturally occurring minerals rich in silica like wallostonite, basalt, feldspar and industrial wastes rich in silica like silicate slag, steel slag, electric furnace slag, Tennessee Valley association slag, Poha industry waste ash, baggase furnace ash, lignite fly ash, cola fly ash, rice hull ash and rice straw have been used to increase the yield as a source of silicon (Ayres, 1966; Savant *et al.*, 1999; Dikshit *et al.*, 2001; Kalra *et al.*, 2003) (Table 6).

Silicon nutrition was found to benefit the rice seedlings in nursery by increasing the biomass, dry matter and by keeping the seedlings strong and healthy (Savant *et al.*, 1994). The number of leaves, tillers and panicle, number of spikelets, grain weight and yield were increased due to silicon fertilization

TABLE 6: Silicon fertilizers used to augment the yield in different crops

Rice:	Calcium silicate, Ca-Mg silicate, Sodium meta silicate, Silicate slag, Rice hull, Rice hull ash, Rice straw, Poha industry waste, Lignite fly ash, Coal flyash.
Sugarcane:	Calcium silicate, Calcium meta silicate, Ca- Mg silicate, Silicate slag, Electric furnace slag, Steel slag, Tennessee Valley Authority (TVA) slag, Bagasse furnace ash, Basalt, Cement
Wheat:	Silicic acid, coal fly ash, Poha industry waste
Maize:	Coal fly ash
Soybean:	Poha industry waste
Mustard:	Coal fly ash
Potato:	Lignosilicon
Cucumber:	Sodium metasilicate

in both lowland and upland rice (IRRI, 1965; Liang *et al*., 1994). The laboratory, green house and field experiments conducted in solution and soil cultures under controlled conditions revealed the beneficial effects of silicon for rice, barley, wheat, cotton, cucumber, tomato, pumpkin, citrus and ornamental crops (Savant *et al*., 1997; 1999; Matichenkov *et al*., 1999; Aziz *et al*., 2002; Matichenkov and Calvert, 2002; Singh *et al*., 2008; Gorecki and Danielski-Busch, 2009; Abro *et al*., 2009). The yield responses to silicon fertilization in rice (Elawad and Green, 1979) in sugarcane (Plucknett, 1972) and cotton (Aziz *et al*., 2002) were clearly established.

Silicate solubilising bacteria (SSB) occurring in soil and rhizosphere, solubilise silica and render it available to plants. Inoculation of SSB with organosiliceous rice straw, husk and husk ash (black char/ash) to rice was found to enhance the growth, chlorophyll content, thousand grain weight, matured grains, biomass and yield (Muralikannan,1996). The SSB inoculation along with fly ash to rice reduced the incidence of stem borer, leaf folder and gall midge and increased the yield (Chandramani *et al*.,2010).

CONCLUSION

The role of silicon as a nutrient for plant growth was overlooked because of its natural abundance. But with the application of more nitrogenous fertilizers, crops become succulent, prone to lodging and increased incidence of pests and diseases resulting in demand for more silicon than the soil could sustain. Silicon nutrition enhances host resistance to pests and diseases and also alleviate abiotic stresses thus protecting the crops. In the context of organic farming the application of siliceous materials and silicon sources to not only cereals, millets, sugarcane etc but also to cucumber, vegetables and pulses may pave way for increasing the yield and reducing the use of chemical fertilizers, pesticides and fungicides. The ashes from agro industries and industrial slags free from heavy metals will find future source of silicon fertilizers in future to protect the crops and to boost the yield .

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