1.0 REVIEW OF LITERATURE

===

This section deals with the available literatures regarding sugarcane and sugar production scenario, silicon element in nature, ancient review of silicon as a fertilizer, plant available silicon in soil and relationship with properties, role of silicon in sugarcane, applications of silicon in sugarcane and use of silicate solubilizing bacterial culture in sugarcane agriculture.

2.1 Sugarcane and Sugar production scenario

Sugarcane is an important cash crop of India. This industry is directly related to rural development and about 50 million farmers cultivating sugarcane on about 5.0 million hectares area in India. Maharashtra is leading sugarcane growing state in India contributing 30 to 35% of total sugar production in the country. The area under sugarcane, productivity, sugar recovery of Maharashtra and India is reported in Table 2.1.

The major problem and alarming situation in sugar industry of India in general and Maharashtra in particular is the stagnation in sugarcane productivity over the years. The highest cane productivity in the country was 71.7 t ha^{-1} in 2011-12, however it remained stagnant to around 70 t ha^{-1}, since last decade. Similarly in Maharashtra state, the highest sugarcane productivity was 92.30 t ha^{-1} in 1980-81 which was declined to 80 to 84 t ha^{-1} and remained stagnant since last ten years.

Table2.1: Area under sugarcane, sugarcane production, productivity and sugar recovery of Maharashtra state (MS) and India

Crushing season	Area under sugarcane (million ha)		Sugarcane Production (million tons)		Sugar Production (million tons)		Average sugarcane productivity (t ha^{-1})		Average Sugar Recovery (%)	
	India	MS	India	MS	India	MS	India	MS	India	MS
2004-05	3.66	0.327	237.08	19.45	12.69	2.20	64.8	73.0	10.22	11.43
2005-06	4.20	0.500	281.17	44.57	19.26	5.19	66.90	77.6	10.21	11.68
2006-07	5.15	0.848	355.52	79.88	28.36	9.10	69.00	74.9	10.16	11.39
2007-08	5.05	1.080	348.17	76.70	26.35	9.20	68.90	80.9	10.55	11.94
2008-09	4.41	0.768	285.03	40.02	14.54	4.57	64.60	79.0	10.03	11.46
2009-10	4.17	0.756	292.30	61.39	18.91	7.06	70.00	84.9	10.19	11.55
2010-11	4.88	0.964	342.38	80.21	24.39	9.05	70.10	84.9	10.17	11.31
2011-12	5.04	1.022	361.03	77.10	26.34	8.99	71.70	84.9	10.25	11.66
2012-13	4.99	0.938	341.19	70.04	25.14	7.99	68.30	74.6	10.03	11.43
2013-14	5.01	0.937	350.02	67.87	24.36	7.61	69.90	81.7	10.23	11.42

(Source: Anonyms, 2014)

It is reported that the potential yield of sugarcane is 600 t ha^{-1}, however some of the cane growers have harvested more than 350 t ha^{-1} but cane productivity of important cane growing states is not up to desired level. In tropical states, it is about 77 to 85 t ha^{-1} except Tamilnadu (109 t ha^{-1}) while in subtropical states it is 45 to 60 t ha^{-1}. In India, there is wide gap (figure 2.1.1) between the research farm yields, potential yield and the yield of sugarcane farms.

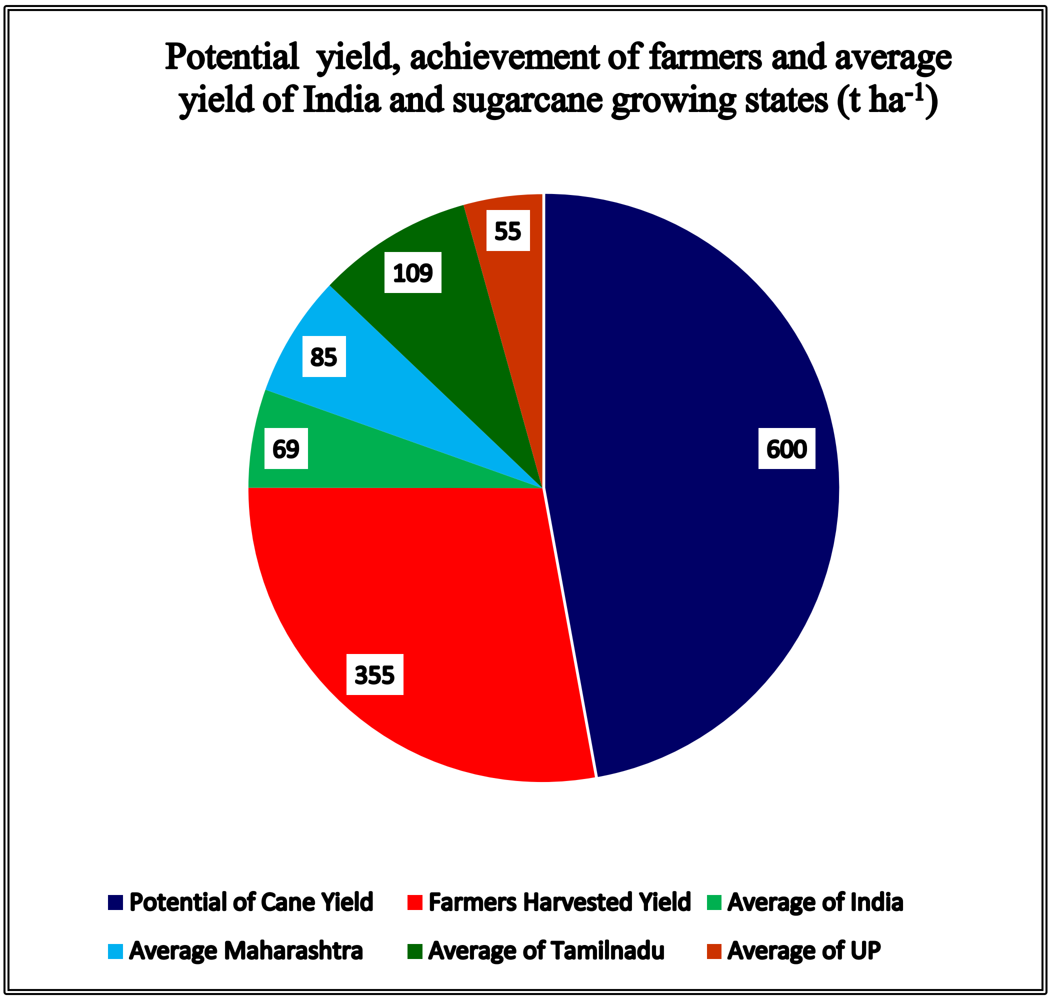

Figure 2.1.1: Potential yield, achievement of farmers and average yield of India and sugarcane growing states (t ha^{-1})

Considering the limitations of natural resources and requirement of other staple food crops, increasing the area of sugarcane is practically impossible. Therefore, increase in sugarcane productivity has prime importance, which urgently requires an effective and result-oriented time bound strategies for assured sugarcane productivity. Declining soil fertility is one of the important constraints to improve the cane productivity. It is reported that neither inorganic alone nor the organic sources exclusively can achieve the production sustainability under intensive cropping system. Sugarcane soils are found to be depleted in organic carbon, nitrogen, phosphate, sulphur, zinc, iron, boron in Maharashtra. Besides major and micro nutrients, silicon has great role in increasing sugarcane productivity, however, this issue is not still attended by systematic way in India. Therefore, an integrated nutrient supply system (INSS) involving essential and beneficial element like silicon in conjunction with organic manures and bio-fertilizers is very much essential in sugarcane agriculture.

2.2 Silicon in nature

Silicon is the eighth most common element in the universe by mass but very rarely occurs as the pure free element in nature. It is widely distributed in the form of silicon dioxide or silicates. Oxygen is the most prevalent element in the earth's crust and Si is the second most prevalent, comprising 25.7% by weight.

Silicon is a tetravalent cation (Si^{4+}) having atomic number 14, molecular weight 28.09, and oxidation states of +2, +4 and –4. It is not attacked by acids, except hydrofluoric acid. In the periodic chart, Si is surrounded by near neighbors B, C, N, O, P and S. It is interesting to note all those neighbors are recognized as essential elements while Si is recognized to only beneficial for plant species, because the criteria for proof as an essential element have not been met (Gascho, 1976).

Figure 2.1.2: Quartz in soils

Figure 2.1.3: Amorphous silica in soils

Most silicon is commercially used in Portland cement to make concrete, ceramics such as porecelian, traditional quartz based glass and synthetic polymers like silicone. In modern word, most free silicon is in steel refining, aluminum casting, chemical industries, semiconductor electronics and integrated circuits for computers on which modern technology is depend with a great deal.

Silicon is essential element in biology. In trace quantity it required by animals but various sea sponges and microorganisms like diatoms and radiolarian secrete skeletal structures made up of silicon. In plant life silicon often deposited in plant tissues in all parts of the most of the crops and plants in the universe.

Silicon is a functional nutrient though it is not considered as essential nutrient in plant crops, therefore a systematic survey of silicon status in soils and its relationship with soil properties, effect of applied silicon on growth, yield, juice quality, nutrient uptake, disease and pest resistance would be of practical importance. This review will provide scientific basis to conduct systematic research on silicon fertilizer management in sugarcane agriculture.

2.3 Ancient review of silicon

There are some evidences in old literature that vegetative ash improved soil fertility and it is considered as first complex mineral fertilizer used in ancient agriculture. Considering a great amount of amorphous silica in vegetative ash, it may be thought of as silicon fertilizer. Vergilian (Vergilius) was Rome Empire poet and scientist suggested to use plant ash for improving fertility of degraded soil. The technology developed by ancient Chinese scientists was to apply a part of rice straw into the soil. In China Empire, there were a few fertilizers that can be classified as silicon fertilizers and the plant ash was named as ‘Burning Manure’. Jons Jacob Berzelius discovered Si as element in 1824 and he was the first who studied Si-organic matter interaction in nature (Caron Mathew, 2004).

However, in recent era of Agriculture, several laboratory, greenhouse and field experiments have shown benefits for silicon fertilization of rice, corn, wheat, barley, sugar cane and other crops and benefits for maintaining a sustainable agriculture.

2.4 Soil Si and soil properties

Silicon is recognized as a major constituent of soils. It is present in the solid phase of soils as alumino-silicate clay minerals and crystalline minerals, and also in a number of amorphous forms such as plant phytoliths. In the soil solution, Si is present as mono- and poly-silicic acids, and also present as complexes with inorganic and organic compounds. While it is the mono-silicic acid component that is taken up by plants and has a direct influence on crop growth. The poly-silicic acids, and probably the inorganic and organic Si complexes, are important as sources of Si which can replenish the soil solution, following crop use. These complexes have a significant effect on soil properties such as improving soil aggregation and increasing soil water holding capacity and also increasing the exchange and buffering capacity of soils. It has also been suggested that the organosilicic compounds play a specific role in organic matter formation (Matichenkov and Bocharnikova, 1999).

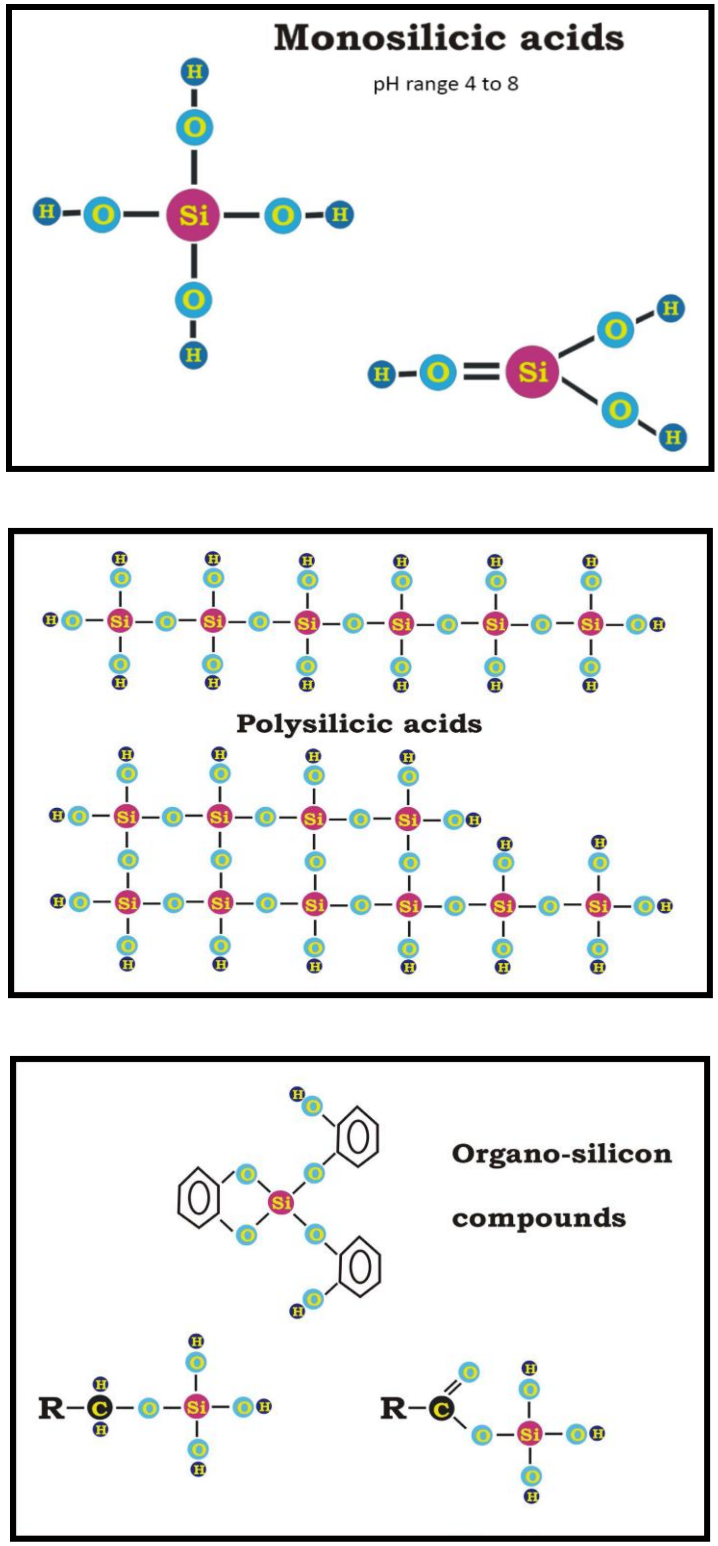

Figure 2.1.4: Chemical structures of monosilicic acid, polysilicic acid and organo-silicon compounds

It is opinion that Si element is mostly inert and slightly water soluble therefore cannot play an important role in the biological and chemical process. Silicon is released by the weathering of minerals, but only part is lost by leaching or in a crop ecosystem that is regularly harvested or burned. The following figure 2.1.5 indicates the main transformations influencing silicon in soil solution. (Savant *et al.*, 1997)

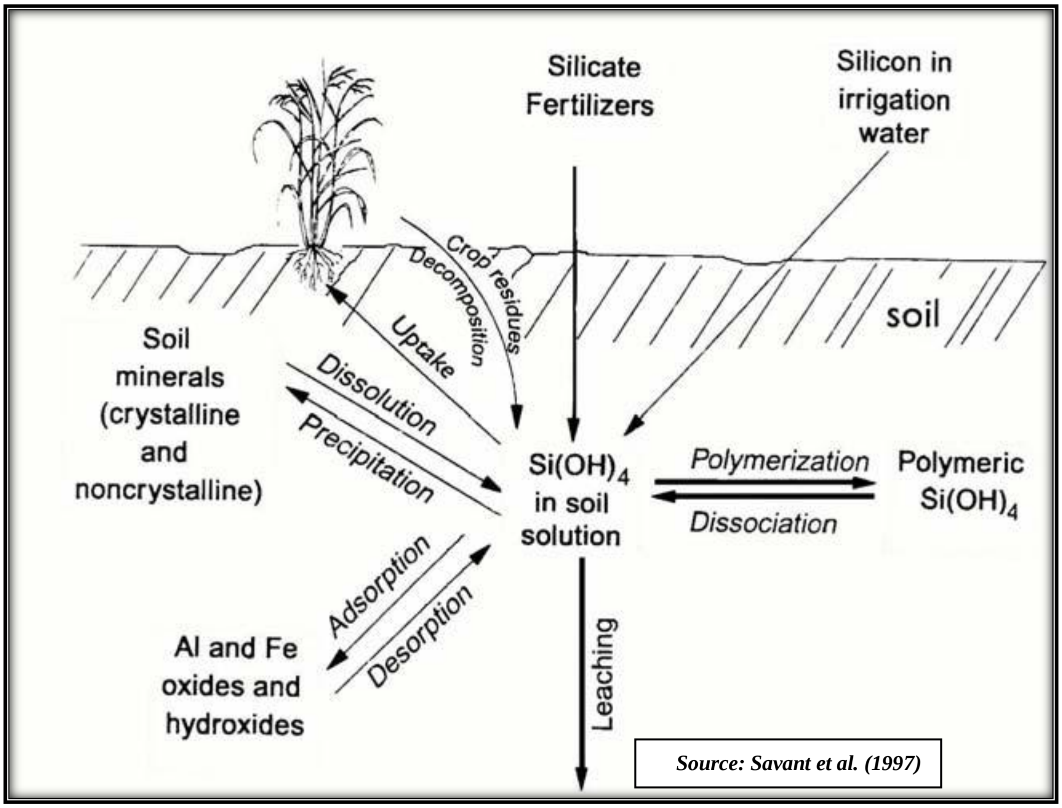

Figure 2.1.5: Silicon transformations influencing silicon in soil solution

Jones and Handreck (1963) showed that iron oxides and especially aluminum oxides were very effective in sorbing mono-silicic acid. Therefore, the solubility of Si in soils of the same pH was influenced by the free sesqui-oxides present. Silicon sorption in soils is pH dependent. Low pH results in less sorption, and greater sorption occurs at higher pH (McKeague and Cline, 1963).

The release of monosilicic acid into solution from soils has been studied (Beckwith and Reeve, 1964) under near-neutral and acid conditions. For all soils examined the final concentration of silica decreased with decreasing soil: solution ratio but larger total amounts were released into the larger volumes of extractant. The amount of silica extracted from any soil varied with pH in a manner similar to that reported previously for residual amounts of monosilicic acid added to soil suspensions, viz. release was minimal at pH 7-9 and increased continuously with acidity. Citrate ions promoted release of native silica from soils as well as partially preventing sorption of added monosilicic acid. Studies have also been made of the release of silica both from some clay minerals and from synthetic sesquioxides on which monosilicic acid was previously sorbed. The release of sorbed monosilicic acid from sesquioxides resembles release from soils in its dependence on pH; iron and aluminum oxides are considered to be responsible for most of the retention of monosilicic acid by soils. Much of the silica rapidly dissolved from soils by N hydrochloric acid is also believed to be derived from sorption sites. Suspensions of fine quartz or amorphous silica were partly converted to sorbed silicic acid in the presence of sesquioxides, and it appears that finely divided silica, even quartz, is not stable at near-neutral pH values in the presence of excess sesquioxides.

Ayres (1966) reported that addition of $CaCO_3$ to soil reduced Si solubility, mostly because of a change in pH of the soil. The effect of liming a soil decreased the uptake of Si by various plants including sugarcane. The relationship observed between Si in the sugarcane leaf and soil Si extracted by 0.5 N ammonium acetate (pH 4.0), implies that the plant uptake of Si is governed by the concentration of Si in the soil solution. If the concentration of monosilicic acid, although varying in soils of same pH, is being maintained at a steady level by soil reserves, the highly weathered soils are bound to become severely depleted in Si if continuously cropped with sugarcane.

Sticher and Bach (1966) explained the primary processes of chemical weathering of soil silicate are hydration, solution and carbonation; hydrolysis; chelation; oxidation and reduction.

Fox *et al.* (1967) reported calcium silicate slag increased sugar yields 12 t ha^{-1} are in a field where phosphate extractable soil silicon and trichloroacetic acid (TCA) extractable silicon of sugarcane (*Saccharum officinarum*) leaf sheaths were about 20 ppm. Large amounts of P or lime did not alleviate leaf freckle whereas slag did so to a marked degree. Acid solutions of phosphate, sulfate, acetate, and water can be used successfully as extractants for soil silicon. The general order for extractable silicon from soils developed on basalt and alluvium was: Humic Ferruginous Latosol < Humic Latosol < Low Humic Latosol < Dark Magnesium clay. This is also the order of decreasing weathering for these soils as indicated by total soil silicon and occurrence of secondary minerals. Leaf sheath silicon (TCA extractable) was especially well correlated with log extractable soil silicon (r = 0.97 for water extraction). Irrigation waters may contain much silicon and contribute greatly to the supply of extractable soil silicon and to plant silicon. It was also stated that as a result of dessilication, soils have distinct mineralogical systems that can be ranked with respect to Si-content and Si-solubility, as follows: 2:1 clays > 1:1 clays > Al and Fe oxides

A highly significant correlation (r=0.989**) was obtained by Wong You Cheong *et al.* (1968) using 4 different great soil groups, between extractable Si and pH. Many researchers believe that sesqui-oxides, especially Al oxides, are largely responsible for much of the capacity of soils to sorb soluble Si, with the maximum capacity between pH 8 and 10.

Crook (1968) as is demonstrated by the high rates of dissolution of soil Si, including quartz, in leachates containing organic matter, as complexes of Si-organic molecules.

According to Elgawhary and Lindsay (1972) solid amorphous Si in soil are more soluble than quartz and it controls Si in soil solution.

Lopes (1977) worked with six soils from different regions of Brazil and concluded that increase in pH of soil increased Si adsorption and that the adsorption of Si by the soils, decreased P adsorption, especially around pH 7.

Sadzawka and Aomine (1977) reported that humus protected soil Si from dissolution and at the same time prevented Si from adsorption by soils. These observations suggest that the role of soil organic matter in Si dissolution is rather complex. As particle size decreases or surface area of particles increases, the dissolution rate of Si minerals increases.

Douglas *et al.* (1984) did not find any correlation between the large concentrations of soluble organic carbon and mono-silicic acid movement in the leachate.

According to Drees *et al.*(1989) the dissolution kinetics of soil Si are influenced not only by nature of Si polymorphs but also by a myriad of soil factors such as organic matter, redox potential, metallic ions, phyllo-silicates, sesqui-oxides, surface area, surface coatings, and overall soil solution dynamics.

Oya and Kina (1989) stated that soluble Si in red, gray upland, gray lowland and dark red soils of Okinawa, Japan, under sugarcane cultivation, ranged from 0.9 to 46 mg Si 100 g^{-1} and was positively related to soil pH.

Baker and Scrivner (1985) reported the potential leaching losses of Si in the Menfro soil series (fine-silt, mesic Typic Hapludalfs) approximately 54.2 kg ha^{-1} yr^{-1}, which was approximately 200 times greater than the estimated losses for Al, 0.27 kg ha^{-1} yr^{-1}.

Gibson (1994) determined the kinetics of Si release from soils. He observed relatively rapid removal of Si from soil during the first hour of extraction with 0.01 M $CaCl_2$, which continued steady for 144 hours.

Matichenkov and Ammosova, (1996) reported that monosilicic acid loses water; it forms silica gel until the proper moisture content is reached. When the dissolved Si in soil solution exceeds 65 mg Si L^{-1}, polymerization of Si usually occurs and a mixture of monomers and polymers of $Si(OH)_4$ and Si-organic compounds found in soil solution. The solubility of Si both of crystalline and amorphous is essentially constant between the pH limits of 2 and 8.5, but increases rapidly above 9. The rapid rise in solubility above 9 is due to ionization of monosilicic acid.

Kovda (1973) reported silicon content in clay soils was 200 to 350 g kg^{-1} and in sandy soils 450 to 480 g kg^{-1}.

Berthelsen and Kordorfer (2003) stated that the total Si content of soils have relationship with soluble Si in soils, which is important component for plant growth. The concentration of soluble Si is dynamic and leaching plant uptake are important processes determining Si concentrations in soil. The equilibrium concentration is largely controlled by adsorption/desorption reactions.

Berthelsen *et al.* (2001) surveyed the area used for sugarcane production on wet tropical coast of north Queensland. He reported that more than 85 percent soils tested had sub-optimal or marginal soil Si levels (20 mg kg^{-1} Si). In all regions more than 50% had levels of plant available silicon sub optimal (< 10 mg kg^{-1} Si). The research work clearly demonstrated significant correlation between soil silicon and top visible dewlap tissue levels. He reported 0.01 M calcium chloride is appropriate extractant for measuring plant available Si in soils.

Matichenkov and Bocharnikov (2001) stated that soil minerals and organic matter control physical and chemical soil properties. Silicon is a basic mineral formatting element and Si fertilization increased soil exchange capacity, improved water and air regimes, transformation of P-containing minerals and formation of alumosilicates and heavy metal silicates. These effects were caused by the change in soil mineral composition that resulted from silicate addition and formation of new clay minerals, which has high biogeochemical activity. Due to large surface area, it adsorbs water, phosphates, potassium, nitrogen, aluminum and heavy metals. Adsorption may occur as chemosorptions or physical sorption. Cations (Al, heavy metals) usually are chemosorbed on Si-rich surface and lose their mobility. Phosphates and N are weakly adsorbed and remained in plant-available form. Amorphous silica, montmorillonite, and vermiculite represent the newly-formed minerals. These minerals affect the soil composition, and physical and chemical properties. The amounts of amorphous silica, monosilicic acids, and polysilicic acids in the soil are closely related to each other. Monosilicic acids regulate chemical properties of the soil solution and polysilicic acids effect on soil physical properties.

Kanamugire (2007) did comparison of soil extraction methods for predicting the silicon requirements for sugarcane. Since optimum crop production depends on the maintenance of adequate plant nutrients in the soil, there is a need for a reliable index for assessing the requirement for supplemental silicon (Si) in soils, particularly for reducing the risk of

Eldana saccharina stalk borer infestation in cane. He assessed Si availability in soils, to select a suitable Si extraction method and a critical value. Five acid soil groups under sugarcane production were used in in glasshouse of the South African Sugarcane Research Institute (SASRI) based at Mount Edgecombe. Sorghum was used as a plant crop and sugarcane as a ratoon crop because of their Si accumulator status. Three different Si sources: calmasil, slagment and wollastonite; with respectively 9.85, 15.20, and 5.25% Si content were applied at increasing rates of 0, 3 and 6 tons ha^{-1} as Si fertilizers. Silicon was extracted from untreated and treated soils by utilizing six different extractants, (1) 0.01M H_2S0_4 + $(NH_4)_2S0_4$; (2) Distilled water; (3) 0.025M H_2SO_4; (4) 0.5M CH_3COOH; (5) 0.5M CH_3COONH_4 pH 4.8; and (6) 0.01M $CaCl_2H_2O$. The amount of soil Si extracted followed the order: 0.025M H_2SO_4 > 0.5M CH_3COOH > 0.01M H_2S0_4 + $(NH_4)_2SO_4$ > 0.01M $CaCl_2H20$ > 0.5M CH_3COOH pH 4.8 > distilled water. Soil Si extracted by 0.025M H_2S0_4 was significantly correlated with soil exchangeable cations, CEC, clay content, cane biomass yield, cane Si uptake and increased rates of applied Si. Overall, the increase in dry biomass yield and Si uptake ranged from 18% to 54% for sorghum; and from 23% to 85% for cane respectively. There was no difference between different Si sources in their ability to influence cane biomass yield and Si uptake, and therefore the supply to the soils. Even though the lower and higher Si source rates were not differed from each other, they increased cane yield and Si uptake, indicating that Si was undoubtedly beneficial for sugarcane. The Si critical levels for different soils as estimated by 0.025M H_2S0_4 were 168 mg kg^{-1} for Arcadia; 64 mg kg^{-1} for Cartrel; 64 mg kg^{-1} for Glenrosa; 45 mg kg^{-1} for Longlands; and 67 mg kg^{-1} for Nomanci form soils.

Kebede (2009) studied silicon status and its relationship with major physico-chemical properties of vertisols of Northern highlands of Ethiopia. The study revealed that Si contents ranged from 79.8 to 87.5 g Si kg^{-1} in the cultivated vertisols of Adigudom, from 97.7 to 115.2 g Si kg^{-1} in Axum, from 113.7 to 117.2 g Si kg^{-1} in Maychew, from 130.0 to 133.9 g Si kg^{-1} in Shire and from 137.3 to 166.3 g Si kg^{-1} in Wukro. The highest concentration was found in Wukro where the sand content amounted to 50% whereas the lowest level was obtained from soils of Adigudom where the clay content exceeded 60%.

The Si contents were lower than the documented ranges of 200 and 300 g Si kg^{-1}. Significant correlation was found between silicon status and organic carbon 0.84*($p<0.05$), silt -0.84*($p<0.05$) and clay 0.84*($p<0.05$).

Tubana *et al.* (2014) conducted research to calibrate different soil extraction procedures for Si using selected soils from the Midwest and South USA. Bulk soil samples were collected from Indiana, Mississippi, Ohio, Michigan, and Louisiana. A total of twelve soil types were selected for this study. Pots were filled with approximately 2 kg of air-dried soils and applied with different rates (0, 1, 2, 4, 6, and 8 t ha^{-1}) of calcium silicate slag ($CaSiO_3$, 17% Si) before sowing ryegrass seeds (48 g seeds m^{-2}). Biomass was harvested every 30 days of growth for three months; a total of three samplings at 30 days after emergence (30 DAS), and 30 days of growth after the first (60 DAS) and second (90 DAS) samplings. Soil samples were also collected for each sampling period. Biomass, Si content and uptake were determined, as well as soil Si using different extraction procedures (0.5M acetic acid, 0.01M $CaCl_2$, distilled water, 0.5M NH_4CH_3COOH, 0.1N $NaCH_3COOH$, and 0.1M citric acid). Distilled water consistently extracted the lowest amount of Si across soil types while on average, both 0.5 M acetic acid and 0.1 N $NaCH_3COOH$ extracted the largest amount of Si. There were corresponding increases in soil extractable Si with increasing $CaSiO_3$ slag rates however, these changes were only reflected (at specific rates) to ryegrass biomass production and Si uptake on selected soils and if 0.5M acetic acid solution was used as extractant. The findings of this study documented that among the solutions, soil Si extracted using 0.5 M acetic acid provided the best estimate of plant-available Si.

Miles *et al.* (2011) measured extractable Si in 112 soils collected from sugarcane producing fields in South Africa. The regions sampled included the midlands, coastal areas and irrigated north. Extractants employed were 0.01 *M* $CaCl_2$ and 0.02 *N* H_2SO_4. Extractable Si levels varied widely in the soils, with lowest values being found in the midlands and coastal areas. Soils from the irrigated north and the Umfolozi area were high in extractable Si. Sugarcane leaf Si concentrations from 28 sites were related to soil extractable Si levels. The $CaCl_2$ soil test proved markedly superior to H_2SO_4 as a predicative test for leaf Si.

Miles *et al.* (2011) studied leaf Si concentrations from the 28 sites sampled ranged from 0.10% to 2.13%, with a median of 0.42%. Coefficients of determination for relationships between extractable Si in soil samples taken from these sites and leaf Si concentrations showed that of the four extraction methods employed, H_2SO_4 performed worst in terms of predicting leaf Si (R^2=0.478). Best fits were obtained with 0.01 M $CaCl_2$ and 0.001 M $CaCl_2$ with 16 h shaking (R^2=0.770 and 0.762, respectively).

Husnain *et al.* (2011) analyzed the available Si in soils of Indonesia which was ranged from 46 to 1,115 mg SiO_2 kg^{-1}. The distribution of available Si content in soil under rice field was varied. From total 194 sites of rice field, available Si was low in West Java and West Sumatra provinces. This trend might be related to the high precipitation and wet climate that enhances desilication process compare than eastern part of Java Island. The soil derived from volcanic ash contained high available Si while alluvial soil showed less available Si. Soils derived from volcanic ash contained higher Si compared to parent materials, including shale, quartz, granite and peat

2.5 Role of Silicon in sugarcane

Silicon has not been proven to be an essential element for plant crops but its multi functional role in crop growth has been reported in a wide variety of crops.

Deren *et al.* (1993) investigated genetic variability for plant-tissue silicon (Si) content in selected populations of commercial-type *Saccharum spp.* clones in the Canal Point (CP), Florida breeding programme. A total of 52 genotypes from the third and fourth stages of the breeding programme were evaluated for Si content in leaves. Clones were evaluated as plant cane in randomized complete-block experiments at 4 sites which varied in plant-available Si. Soils at 3 sites were organic histosols; the fourth was sand. The locations and the 40 stage III clones differed significantly in plant-tissue Si. Stage IV test sites also differed significantly but the 12 clones, which were of a narrower genetic base, did not. In both tests, CP72-1210, a very popular and high-yielding commercial cultivar, had the highest mean Si content. Results indicated that genotypic variability for Si content exists in elite, commercial-type sugarcanes. A greater range of Si content might be found in a more diverse array of genotypes.

Halais (1967) suggested critical level of Si 1.25 % in sixth leaf sheath.

Alexander (1968) suggested that sugarcane cultivars high in Si may also show enhanced sucrose synthesis, due to improved photosynthesis, as shoots are not as likely to become prostrate following wind and rain.

According to Samuels (1969) at 12 months the above ground parts of sugarcane contained 379 kg ha^{-1} of Si, compared with 362 kg ha^{-1} of K and 140 kg ha^{-1} of N.

Ross *et al*. (1974) reported the removal of 408 kg ha^{-1} of total Si from soil by sugarcane crop yielding 74 t ha^{-1}.

Silicon is an integral part of cell walls, and has a similar role to lignin, in that it provides compression-resistance and rigidity in cell walls, thus providing structural strength to the plant (Kaufman *et al.*, 1985; Adatia and Besford, 1986). An ample supply of Si has been reported to reduce lodging (drooping, leaning or becoming prostrate) in grass crops due to improved mechanical strength. The improved rigidity of the cell walls also promotes a more erect habit and disposition of the leaves, resulting in better light interception and photosynthetic efficiency.

Anderson *et al.* (1991) reported that older leaves of sugarcane may be affected with minute circular white leaf spots (freckles), poor tillering; premature aging of older leaves due to the silicon deficiency under the field conditions, in Florida. It was suggested that at least 1% Si is required for optimal cane yield. At 0.25% Si in leaves, the yield drops to about 50 percent.

(*Source: Anderson, 1991*)

Figure 2.1.6: Silicon deficiency symptoms in sugarcane

Liang *et al*. (1996) reported that adequate Si nutrition assist crops withstand the effects of drought conditions in areas reliant on rainfall, or declining water quality in irrigation areas. Plants with a well-thickened layer of Si associated with the cellulose in cell walls of epidermal cells have been observed to be less prone to wilting and have improved drought resistance. Silicon may also reduced stress to salt in a similar way that it alleviates water stress. Work with cereal crops suggest that Si can increase photosynthesis and decrease the permeability of plasma membranes of leaves of salt-stressed plants. In addition, Si has been shown to inhibit the uptake of Na and increase the uptake of K, thus alleviating the effect of salt toxicity and improving vegetative growth

Savant *et al.* (1999) published a review on Silicon nutrition and sugarcane production. He reported that Si is the most abundant elements found in the earth's crust, but is mostly inert and only slightly soluble. Agriculture activity tends to remove large quantities of Si from soil. Sugarcane absorbs more Si than any other mineral nutrient, accumulating approximately 380 kg ha^{-1} of Si, in a 12-month old crop. Sugarcane responses to silicon fertilization have been documented in some areas of the world, and applications on commercial fields are routine in certain areas. The reason for this plant response or yield increase is not fully understood, but several mechanisms have been proposed. Some studies indicate that sugarcane yield responses to silicon may be associated with induced resistance to biotic and abiotic stresses, such as disease and pest resistance, Al, Mn and Fe toxicity alleviation, increased P availability, reduced lodging, improved leaf and stalk erectness, freeze resistance, and improvement in plant water economy.

Epstein (1999) reported that plants deprived of Si are often weaker structurally and more prone to abnormalities of growth, development and reproduction and it is the only nutrient which is not detrimental when collected in excess.

Meyer and Keeping (2000) reviewed the research results and stated that with the exception of potassium, sugarcane take up more Si than any other mineral nutrient, with the potential to accumulate up to 400 kg ha^{-1} of Si in a 12 month old irrigated crop. He documented some of the outcomes of research into the Si requirement of sugarcane in countries such as Florida, Hawaii, Puerto Rico, Australia, Mauritius and South Africa. Field studies conducted in South Africa showed significant responses to the application of calcium silicate and these varied from 9 to 24 t ha^{-1}. Current research in South Africa is focused on the association between Si assimilation and host-plant resistance to the stalk borer. He reviewed some evidence which suggests that yield responses to Si may be attributed to a number of factors including, prevention of Al and Mn toxicities, and protection from pest and fungal disease, better water use efficiency, improved P nutrition, reduced lodging, and improved photosynthesis through the more effective use of sunlight. Recent evidence suggests that Si may reinforce plant pest and disease resistance by stimulating the expression of natural defense reactions through the production of low molecular weight metabolites, which include flavonoid phytoalexins.

Janaki and Chitra (2002) reported vital role of silica in increasing the cane yield, induced resistance in stress, disease and pest control, toxicity alleviation, water economy etc. It is also stated that application of silicate fertilizers viz. calcium silicate 120-200 kg ha^{-1} or potassium silicate 40-60 kg ha^{-1} correct the Si deficiency more rapidly.

Yongchao Liang (2006) reported that silicon (Si) is generally beneficial element for the growth of higher plants, especially for those grown under stressed environments. Recently, the mitigating role of Si in salt stress was observed worldwide attention. He studied the effects of Si on plasma membrane fluidity, phospholipids and H+-ATPase activity and reduced glutathione (GSH) concentration with two contrasting barley cultivars differing in their salt tolerance. The plasma membrane H+-ATPase activity decreased in leaves of plants treated with 120mM NaCl, and this reduction was more obvious in salt-sensitive cultivar (Kepin No. 7) than salt-tolerant cultivar (Jian 4). Under NaCl stress, plasma membrane fluidity decreased and the ratio of phospholipids to proteins in plasma membrane vesicles increased. GSH concentration decreased in leaves of plants exposed to 120mM NaCl in salt-sensitive cultivar. Inclusion of 1.0mM Si to the salt treatment increased plasma membrane H+-ATPase activity in both cultivars as compared with the plants treated with 120mM NaCl only. The addition of Si to salt treatment was also found to recover membrane fluidity to control level and decreased the ratio of phospholipids to protein. GSH concentration in leaves of salt-treated plants was increased by addition of Si. It is suggested that Si maintains the optimal membrane fluidity and increases GSH concentration which contributes to reducing oxidative damage to enzymes induced by active oxygen species and enhances plasma membrane H+-ATPase activity under NaCl stress.

Kvedaras *et al.* (2007) stated that Si improves resistance of plants to insect attack and enhances tolerance of water stress. Si-mediated host plant resistance to insect attack was augmented by water stress. Four sugarcane cultivars, two resistant and two susceptible to Eldana saccharina Walker were grown in a pot trial in Si-deficient river sand, with and without calcium silicate. To induce water stress, irrigation to half the trial was reduced after 8.5 months. The trial was artificially infested with E. saccharina eggs after water reduction and harvested 66 days later. Silicon treated, stressed and non-stressed plants of the same cultivar did not differ appreciably in Si content. The reduction in borer numbers and stalk damage in Si+ plants was greater for water-stressed cane than non-stressed cane, particularly for susceptible sugarcane cultivars.

Yongchao Liang (2007) reviewed the mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants. The key mechanisms of Si-mediated alleviation of abiotic stresses in higher plants include stimulation of antioxidant systems in plants, complexation or co-recipitation of toxic metal ions with Si, immobilization of toxic metal ions in growth media, uptake processes and compartmentation of metal ions within plants.

Heckman (2013) stated the functions of silicon in plants. Under controlled hydroponic conditions, Si does not meet the classical definition of an essential nutrient. However in plants exposed to multiple stresses, Si plays an important role in plant health. One major contribution of Si is reinforcement of cell walls by deposition of solid silica. It is translocated from the roots as silicic acid [$Si(OH)_4$] through the xylem until it deposits under the cuticle and in intercellular spaces. These silica bodies are called phytoliths or plant opal. These structures are very resistant to ecomposition. In addition to naturally occurring soluble Si in soil, many crops respond positively to additions of supplemental Si. Plants, especially grasses, can take up large amounts of Si where it contributes to their mechanical strength. Besides a structural role, Si helps to protect plants from insect attack, disease, and environmental stress. For some crops, Si fertilization of soils increases crop yield even under favorable growing conditions and in the absence of disease. A second mechanism for the beneficial effects of Si is its role in triggering a range of natural defenses. The presence of Si to stimulates the activity of active compounds such as chitinase, peroxidase, polyphenol oxidases, and flavonoid phytoalexins all of which can protect against fungal pathogens. Regardless of the mechanism, some benefits were observed due to Si that includes plant growth and yield through more upright growth and plant rigidity, suppression of plant diseases caused by bacteria and fungi and improved insect resistance. Silicon alleviates various environmental stresses including lodging, drought, temperature extremes, freezing, UV irradiation and chemical stresses like salt, heavy metals, and nutrient imbalances.

2.6 Application of Silicon in Sugarcane

Several laboratory and field experiments conducted at various locations in the world have shown benefits of silicon fertilization of rice, corn, wheat, barley, sugarcane and other crops for maintaining a sustainable agriculture. However, the research on use of silicon in sugarcane agriculture is very limited in India particularly in Maharashtra.

Ayres (1966) obtained increased tonnage of sugarcane amounting to 18% in cane and 22% in sugar for plant cane crop following the application of 6.2 t ha^{-1} of electric furnace slag in Latosols of Hawaii. It is also stated that application of silicate helps to increase the uptake of NPK, zinc, manganese, boron, copper and molybdenum.

Pan *et al.* (1979) incorporated bagasse furnace ash containing 28 % Si at rates of 12, 24, 36 and 48 t ha^{-1} into Malaysia soils before planting and observed highest cane yields of 119 and 127 t ha^{-1} at 36 and 48 t bagasse furnace ash per ha which were 13 and 20 % more than the control, respectively.

Silva (1971) investigated that application of silicate to Hawaiian soil of low P status resulted in high P in green top, suggesting silicate nutrition enhanced P mobilization in metabolically active tissues.

Anderson *et al.* (1987) observed that a single application of silicate slag to Terra Ceia muck prior to planting of rice increased production of rice and sugarcane in rotation, but to a lesser extent than the slag applied prior to cane planting. In multiyear studies, response of sugarcane to the application of 20 t ha^{-1} slag increased cumulative cane yield by 39% and sugar yield by 50% over three crop years.

Subramanian and Gopalswami (1990) published the results of a pot experiment conducted with various sources of silicate materials (sodium metasilicate, furnace slag and rice husk) at 500 ppm SiO_2 level and phosphate materials (superphosphate and rock phosphate) at 25 ppm P_2O_5 level in acid soils that showed increased available silicon and phosphorus content in soil due to the application of silicate and phosphate materials. The yield, nutrient contents and their uptake by rice also increased by the application of silicate and phosphate materials. Rice husk ranked first in increasing the availability of Si and P in soil and their nutrient content in plant as well as uptake by rice.

Raid *et al.* (1992) investigated the influence of cultivar and calcium silicate slag on foliar disease development in sugarcane hybrids. Severity of sugarcane rust was not affected by application of silicate slag. However, significant reduction in severity of ring spot was noticed with addition of the slag.

According to Rodrigues (1997) application of increased Si rate from 0 to 924 kg ha^{-1} using Wallastonite, resulted in substantial increase of Si content in the leaves from 0.7 to 1.93 and Si in the soil from 14 to 46 mg dm^{-3}.

Gascho and Korndorfer (1998) demonstrated the value of silicon (Si) application for rice (Oryza sativa) and sugarcane (Saccharum spp.) when soil soluble Si was low. The availability of silicon in sources were investigated for those crops in the Cerrado of Brazil, where response to Si was demonstrated. Total Si and Si extracted by 0.1 M citric acid were measured for five sources. An incubation study was conducted with four soil groups cropped in the Cerrado and a greenhouse experiment with rice using the soil of low soluble Si content. Experiments included five sources and several rates of silicon. After 60 days incubation, Si extracted by 0.5 M acetic acid ranged from 2.5 to 22 mg/kg for the four soils. Calcium silicate slag, wollastonite, and thermo-phosphate increased soluble Si significantly. A basic slag and magnesium metasilicate provided little soluble Si. In greenhouse experiment increased rate of wollastonite, increased Si concentration in rice. Calcium silicate slag, wollastonite, and thermo-phosphate application resulted in erect leaves, while rice plants without Si showed droopy leaves. At high rates of Si sources to rice plants also induced Fe deficiency, resulting in reduced dry weight. In addition to calcium silicate slag, thermo-phosphate - a fertilizer product that provides Si, P, and Mg - appears an excellent source for use in the Cerrado.

Kingston (1999) studied a role for silicon, nitrogen and reduced bulk density in cane yield response to sugar mill ash and filter mud ash mixtures at BSES, Bundaberg. He compared sugar mill ash fractions and filter mud/ ash mixture with various green cane trash management strategies to ameliorate the hard setting fine sandy loam surface of a grey podzolic soil. The experiment was established after plant cane harvest and results were obtained for the first and second ratoon crops. Sugar mill waste product reduced bulk density in the surface soil, but did not pre harvest soil moisture. Both mill products had large residual value for phosphorus and the ash increased both exchangeable and non exchangeable potassium in soil. Yield response to sugar mill waste was confounded with response to reduced bulk density and improved crop nutrition.

Jadhav *et al*. (2000) conducted trials on calcium silicate slag in suru and preseason sugarcane at Central Sugarcane Research Station, Padegaon (India). Soil application of 4 to 6 tons of calcium silicate slag to suru and preseasonal sugarcane increased the cane yield by 25 to 30 t ha^{-1}. Application of calcium silicate slag @ 6 ton/ha gave 179.5 t ha^{-1} cane in suru season and 193.3 t ha^{-1} in preseason as compared control (148.2 and 161.6 t ha^{-1}) in respective seasons. Application of calcium silicate slag also helped to increase the uptake of NPK.

Matichenkov and Kalvert (2002) reported that the direct effects of Si fertilizers on sugarcane have not advanced as rapidly as for rice. Silica concentration in cultivated plants ranged from 0.3 to 8.4%. A range of 210 to 224 million tons of Si or 70 to 800 kg ha^{-1} of plant available Si is harvested with sugarcane crop from the arable soils annually. Crop removal of Si by sugarcane exceeds those of macronutrients N, P and K. The concentration of Si in sugarcane leaves varies from 0.1 to 3.2%. Higher yield of sugarcane is associated with higher concentration of Si in leaves. Field and green house experiments conducted in USA and Mauritius demonstrated that application of Si fertilizers had a possitive effect on disease, pest and frost resistance of sugarcane. It was shown that sugarcane productivity increased from 17 to 30%, whereas production of sugar rose from 23 to 58 % with increasing Si fertilization.

Nagabovanalli *et al.* (2002) reported usefulness of silicate material in rice farming. The field experiment conducted to know the effect of Rice Hull Ash (RHA) as a source of silicon along with two sources of P on growth and yield of rice at Regional Research Station, Shimoga (India) for four consecutive seasons. Application of RHA at 2 and 4 t ha^{-1} without P source increased the cane yield of paddy over control. Application of RHA along with P source has further increased the grain yield of paddy during all the four seasons. The average grain yield of all four seasons showed that addition of RHA at 2 and 4 t ha^{-1} increased the cane yield by 65.51 and 65.80% respectively over control. Further, application of RHA at 2 and 4 t ha^{-1} with SSP as P source increased the yield to an extent of 89.92 and 99.42% and with RP as P source to an extent of 58.76 to 75.31 % respectively over control.

Jamil *et al.* (2004) studied impact of various rates of bagasse ash on Wheat (*Triticum aestivum* L.) in a calcareous soil. It was applied @ 0.1, 0.5, 1.0, 2.0, 5.0 and 10% along with a basal dose of 120, 90, and 60 kg ha^{-1} of NPK. The results showed that yield and yield components of wheat increased significantly with various rates of bagasse ash over control. However, significantly maximum plant height (102.8 cm), spike length (11.0 cm), number of productive tillers m^{-2} (333.5), number of grains $spike^{-1}$ (49.5) and grain yield (5.2 t ha^{-1}) were obtained where bagasse ash was applied @ 2.0%, respectively. While number of tillers m^{-2} (409.0) and straw yield (8.0 t ha^{-1}) was significantly higher with 10.0% bagasse ash and 1000-grain weight (41.20 g) with 1.0% bagasse ash. The overall response of wheat crop was significantly higher by the application of bagasse ash @ 2.0 % to the calcareous soil.

Kingston *et al.* (2005) conducted experiment in Queensland, Australia. The cane yield and CCS response to Si application was measured and diagnostic threshold values in soil and leaf tissue validated. The six rates of calcium silicate slag between 0 and 12 t ha^{-1} were tried. There was a 32% increase in cane yield at a rate of 9 t ha^{-1} ca-silicate. At Mossman a rate of 12 t ha^{-1} gave 35% total yield increase compared to the control. At Bundaberg, over a crop cycle of 4 years, 12 t ha^{-1} Ca-silicate resulted in a 45% increase in yield compared to the control. Silicon uptake by biomass increased with rate of applied slag, untreated controls acquired 77 kg Si ha^{-1} while cane treated with 6 ton slag ha^{-1}

acquired 166 kg Si ha^{-1}. Soil data from the Mossman and Innisfail sites showed significant increase in CEC in all treatments receiving Ca-silicate. A strong and significant relationship existed between relative cane yield and index leaf Si status (r2= 0.73).

Queiroz *et al.* (2005) in his studies concluded that a silicon source should have high levels of soluble Si, high Ca and Mg content, low level of contaminants and easy to apply in the field. A soil incubation experiment was carrying out using different silicon sources (200 mg kg^{-1} of Si) that were mixed with 250 g of two types of soils (sandy and clay). Soluble Si in the soil was determined by using acetic acid 0.5 mol L^{-1} and $CaCl_2$ 0.01 mol L^{-1} extractors. The clay soil, due to its mineralogical composition, presented greater silicon levels compared to the sandy soil. In both soils, Si level was greater when extracted by acetic acid 0.5 mol L^{-1}. The best sources for supplying silicon for the sandy soil were Siligran AWM® and for clay soils Wollastonite. Siligran®, Siligran AWM® and Wollastonite.

Khan and Qasim (2008) studied the effect of integrated use of boiler ash as organic fertilizer and soil conditioner with NPK in calcareous soils of Pakistan. Regular application of commercial fertilizers and increased crop yield, also degrade soils physically and chemically and increases the input cost. Therefore, in experiment sugar industry boiler ash was applied to wheat crop in pots having 20 kg soil @ 3, 12, 25,50, 125 and 250 t ha^{-1} and compared with control. Same doses of boiler ash were also applied to wheat crop in the field experiment. A basal dose of NPK, 120, 90, and 60 kg ha^{-1} respectively, was applied with boiler ash before sowing of wheat crop in both experiments. Boiler ash was rich in micronutrients like Fe, Mn, Zn and Cu and also contained sufficient amount of Ca, Mg, Na, S, K and P. Consequently, total porosity of soil, available P, S and K, Fe, Mn, Zn and Cu content in soil, increased with the levels of boiler ash application. On the other hand, dry bulk density declined which is a positive effect. ECe and pH of the soil was minutely increased. Yields and most of the yield components of wheat crop in pots, as well as in the field experiment, also increased due to boiler ash application. It is recommended that application of boiler ash @ 50 t ha^{-1} will result in enhanced yield of wheat in calcareous soil.

Camargo *et al.* (2009) evaluated silicon availability in soils and the relationship between availability and uptake by sugarcane. Dry matter yields of sugarcane cultivated in three soil types, with and without silicon fertilization. The experiment was set up with four silicon rates (0, 185, 370 and 555 kg ha^{-1} Si) through Ca-Mg silicate and three soils viz. Quartzipsamment (RQ), Rhodic Hapludox (LV) and Rhodic Acrudox (LVdf). All plots (100 L) received same Ca and Mg quantities with additions of dolomitic lime and or $MgCl_2$. The LVdf soil showed the higher soluble silicon concentration, followed by LV and RQ. Added Si increased the amounts of soluble Si content in all soils but Si uptake was increased to RQ and LV soils. However, addition of Si to the soils did not promote changes in dry matter yields and Si uptake on stalks of sugarcane.

Camargo *et al.* (2011) studied effects on soluble silicon in soil, uptake and occurrence of stalk borer. After harvest the best yield was obtained by 103.2 kg ha^{-1} Si (952 kg ha^{-1} silicate) supplied to cultivar B and no differences were observed in cultivar A. There was an increase of soluble Si in 0.5 mol L^{-1}acetic acid and 0.01 mol L^{-1} $CaCl_2$.The Si concentration in leaves were 3 g kg^{-1} in cultivar A and 2.18g kg^{-1} in B. In the stalks, best dry matter and Si uptake were obtained with 89 kg ha^{-1} Si, but no effect was observed on stalk borer damage.

Madeiros *et al.* (2010) studied beneficial effects of fertilization with steel slag in sugarcane. As Brazil is a great producer of this waste which if improperly discarded might contaminate soils and water. He demonstrated that the use of steel slag positively influences nutrient concentrations and silicon in soil and sugar cane.

Jagtap *et al.* (2011) conducted six field demonstration trials in pre-seasonal sugarcane (var. Co86032) in inceptisol and reported 153 t ha^{-1} cane yield due to 400 kg ha^{-1} silica compared to 123 t ha^{-1} in control. The cane yield increase was to the tune of 30 t ha^{-1} by application of 400 kg ha^{-1} silica. This increased sugarcane yield was due to increased cane weight and diameter of cane as result of silica application. It was noticed that silica application reduced attack of stem borer, wooly aphids and leaf freckling in sugarcane. The benefit: cost ratio increased from 2.71 to 3.03 as a result of silica application.

Camargo *et al.* (2011) evaluated silicon availability, uptake and recovery by three cycles of sugarcane in tropical soils with and without silicate. The experiments were conducted in pots with Si rates of 0, 185, 370 and 555 kg ha^{-1} Si in soils (Quartzipsamment-RQ, 6% clay, Rhodic Hapludox-LV, 22% clay and Rhodic Acrudox-LVdf, 68% clay) with four repetitions. The source of silicon was Ca-Mg silicate. Rates of Si increased Si availability and uptake in sugarcane with strong residual effect. The Si uptake increased with rates of Si and was higher in LVdf in all cycles.

Bokhtiar *et al.* (2011) highlighted the effects of silicon (Si), supplied as calcium silicate fertilizer on the productivity and Si accumulation in the sugarcane plant. Seven rates of Ca-silicate (0, 20, 40, 60, 80, 120 and 150 g pot-1) were applied with traditional fertilizers and plants were grown in a greenhouse. The added Ca-silicate increased photosynthesis, transpiration and stomatal conductance significantly over the non-amended treatment. Leaf tissue contents of phosphorus (P), sulfur (S), calcium (Ca), magnesium (Mg) and sodium (Na) did not differ remarkably. With increasing silicate application, iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) contents significantly decreased in both leaf tissue and soil contents. Si amended treatments significantly increased yield in dry matter (26 to 70%) and in cane yield (30 to 66 %) per pot over non-amended. The Si content up to 2.64% per dry mass was found in top visible dewlap (TVD) leaf tissues when amended with Ca-silicate fertilizer in our 12 months study. Soil pH, soil Si, and leaf tissues silicon content progressively increased with increasing rate of Ca-silicate. The available S, exchangeable potassium (K), Na, Ca and Mg increased more or less progressively as rate of Si application increased over non-amended. Nevertheless, the scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDAX) revealed that different rates of Ca-silicate responded differently in accumulation of Si and other elements in epidermal cells, silica cells and stomata cells.

Tubana *et al. (*2012) reported 1.5% silicon accumulation in sugarcane on a dry matter basis and has shown to respond to Si fertilization. Silicon content of flag leaf and stalk of cane variety HoCP96-540, on average, had 2.2% and 0.43% respectively, whereas the other varieties had >2.5% Si in flag leaf and >0.50% Si in stalk. $CaSiO_3$ application showed significant effect on sugarcane grown on silt loam but not on clay The experimental results showed that cane tonnage, sugar yield and Si removal rate were significantly increased by $CaSiO_3$ application for sugarcane grown on Commerce silt loam but not on Sharkey clay ($P<0.05$).

McCray and Shangning (2013) compared silicon sources for sugarcane on Mineral and Organic Soils in Florida. He reported **s**ilicon (Si) is a beneficial nutrient for sugarcane production with well documented yield responses with applications on Florida soils with low soluble Si. Evaluation of Si-containing amendments is important because of varying product availability and the substantial investment for applications. The objective of this study was to compare sugarcane tonnage and sucrose yield produced following application of various sources and application methods of Si available to growers in Florida. The study was conducted on a Margate sand and an Okeelanta muck. The Si materials compared were stainless steel calcium silicate slag (123 g Si kg^{-1}), electric furnace calcium silicate slag (198 g Si kg^{-1}), a mixed amendment containing electric furnace slag and magnesium sulfate/sulfite (Magslag: 172 g Si kg^{-1}), and magnesium silicate (Magnesil: 172 g Si kg^{-1}). Application methods consisted of broadcasting at 3.4 and 6.7 Mg ha^{-1} and banding at 1.1 Mg ha^{-1}. There were significant yield (tons sucrose ha-1) responses to the calcium silicate slag sources at each location, but there was no yield response to magnesium silicate. Leaf Si increases were greater with electric furnace slag compared to stainless steel slag, and leaf Mg was higher with stainless steel slag compared to electric furnace slag. The most effective source of Si was electric furnace slag; with stainless steel slag and Magslag being possible choices for supplying both Si and Mg. Growers should consider material costs in addition to the Si/Mg availability of the materials and Si/Mg soil requirements in selecting amendment sources and rates.

2.7 Role of silicon in disease and pest resistant

One of the earliest reports linking Si nutrient levels with stalk borer damage in cane is credited to Indian research (Rao, 1967). The author found that sugarcane varieties tolerant to the shootborer *Chilo infuscatelus* Snellen showed the highest density of Si per unit area in the leaf sheath.

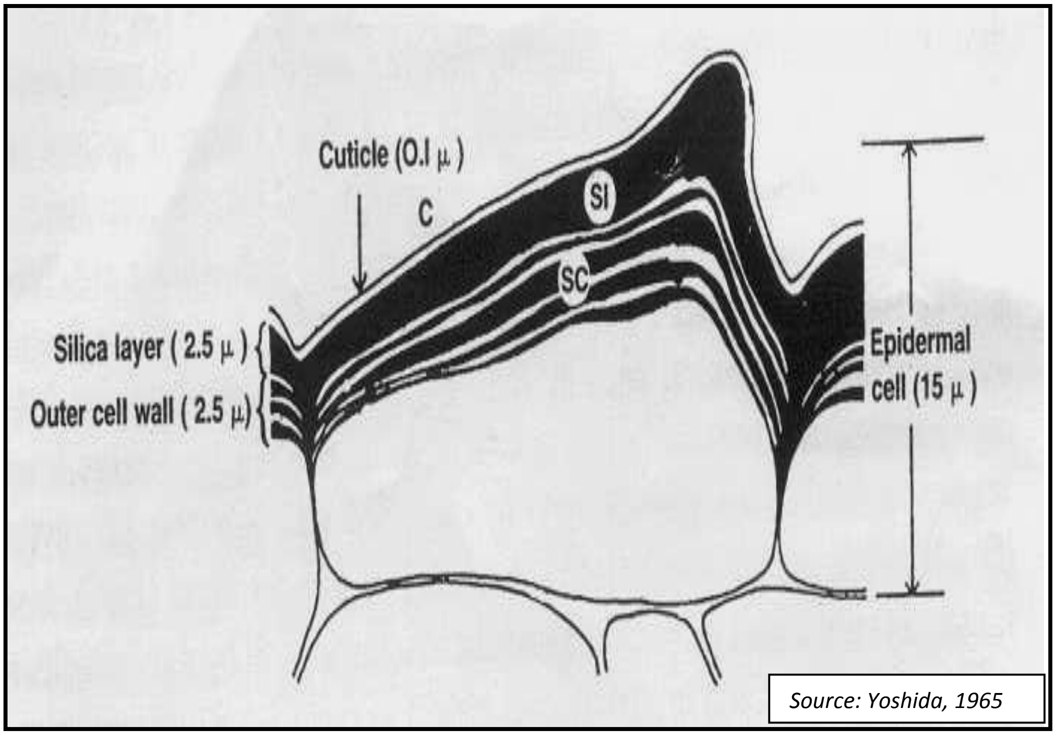

Figure 2.1.7: Silicon accumulation in cell wall of plant (Mechanical barrier hypothesis

In Taiwan, Pan *et al.* (1979) conducted an experiment where different forms of Si including bagasse furnace ash and silica slag were applied. The results showed that the incidence of borer damage in Si-treated sugarcane was less than in untreated control sugarcane.

In Florida, Elawad *et al*. (1982), found that by applying 20 t ha^{-1} of TVA slag to a muck soil, there was a significant decrease in leaf freckling in sugarcane. Furthermore, that with improved Si nutrition, there was an increase in the sugarcane resistance to the stem borer *Diatraea saccharalis* F. (Elawad *et al*., 1985).

McNaughton and Tarrants, (1983) stated that as most parasitic fungi penetrate the host by boring through the epidermal cell wall, Si in these walls may act as a mechanical barrier. In addition, Si may also protect the plant by its association with the cell wall constituents, minimizing the enzymatic degradation that accompanies the penetration of the cell wall by the fungal hyphae. The highly silicified leaves of grasses can not only make the plant more resistant to attack by pathogenic fungi, but also to attack by predaceous chewing insects, as they can suffer a high mortality when their mandibles and maxillae become worn down, rendering their mouthparts ineffective

Savant *et al*. (1997) commented that yield decline can be temporarily reversed by increasing N fertilizer rates to soil Si-depleted systems. However, for sustained yields, Si fertilization is required to balance applied nutrients, particularly N, when high rates can result in increased problems with lodging. Although Si additions are reported to improve P nutrition, conversely, continued use of superphosphate may have also resulted in accelerated depletion of soil Si reserves, since P effectively competes with Si for specific sorption sites, thereby resulting in the loss of Si through leaching.

Subsequent studies have confirmed the positive effect of silicon in increasing the resistance of sugarcane to this stalk borer (Anderson and Sosa, 2001).

In South Africa, recent studies (Keeping and Meyer, 2003) have focused on the association between silicon assimilation and host-plant resistance to *Eldana saccharina*. Greenhouse and field trials have been conducted to compare the efficacy of four silicon sources. In the greenhouse, sugarcane varieties were artificially inoculated with *E. saccharina* and treated with three doses (0, 2.5 and 5 t ha^{-1}) of calcium silicate. At 5 t ha^{-1} calcium silicate, there was a reduction of 30% in borer damage and 20% in borer mass. The most susceptible varieties showed the highest silicon uptake and the greatest response. Of the four carriers tested, stalk borer incidence declined as follows: local Namibian calcium silicate > imported USA calcium silicate > local Slagment > flyash. In the field experiment, similar results were recorded.

Keeping *et al.* (2011) stated that the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) is a major limiting factor in South African sugarcane production. One option to reduce the intensity of borer infestations has involved a reduction in nitrogen (N) fertilizer applications. Soil amendments with silicon (Si), where this element is deficient, can significantly increase plant resistance to *E. saccharina* and mitigate the effects of high plant N levels in promoting borer damage. A pot trial was established with three levels of N, two levels of Si (5 t ha^{-1}, 10 t ha^{-1}calcium silicate), and two levels of dolomitic lime (5 t ha^{-1}, 10 t ha^{-1}) as controls. The mass of washed river sand in which the plants were grown was 31 kg/pot and N was supplied in solution at rates of 4.5, 8.9 and 16.6 g/pot every 2 weeks, to provide the three N levels. The trial was artificially infested with *E. saccharina* eggs and survival of and stalk damage due to emerging larvae assessed after 2 months. Overall, increased levels of N significantly increased larval survival, percentage internodes bored and percentage stalk length bored, while calcium silicate at both application rates significantly reduced these compared with lime at both rates. A significant interaction between cultivar and N revealed that increasing N did not significantly affect larval survival in N27, but did increase it in N33. The interaction between cultivar and Si for percentage joints bored and percentage stalk length bored showed that Si significantly reduced stalk damage in N27 but did not do so in N33. The reduction in borer survival and stalk damage through Si application, at all levels of N, and in a 79 susceptible varieties. Under field conditions, sugarcane yields could still be optimized through adequate N fertilization, while reducing populations of *E. saccharina* to acceptable levels using an integrated pest management (IPM) approach that incorporates Si nutrition of the crop.

Berry, *et al.* (2011) studied the effect of silicon on a sugarcane nematode community in KwaZulu-Natal. Most of the research on the biotic influence of Si has dealt with insects and fungi, there being no proper studies on the effect of Si on plant-parasitic nematodes. To investigate this effect, a replicated field trial was planted with sugarcane in KwaZulu-Natal, comparing two Si carriers, fly ash and filter cake (both by-products of the sugar milling process), with other treatments and an untreated control. Applying the Si carriers to the soil was not always sufficient to increase levels of Si in the sugarcane leaves. Uptake of Si by sugarcane required a particular chemical balance in the soil. As a consequence, Si treatment, *per se,* had no effect on the nematode community. However, a comparison between Si-rich and Si-poor plots, selected independently of the treatments, showed that total numbers of plant parasitic nematodes and numbers of *Pratylenchus zeae* and *Helicotylenchus dihystera* in the soil were significantly lower in plots where foliar Si levels were higher. The same trend was true for the number of *P. zeae* in the roots, but the difference was not significant. In a pot experiment, root Si was found to be correlated with foliar Si. Multivariate analysis showed that while numbers of some of the nematodes in the soil were depressed in the higher Si plots, this was not so for the most pathogenic species able to feed on the deeper cells within the roots.

Naidoo *et al.* (2011) in the study focused on the uptake and deposition of Si in sugarcane as well as its effect on the severity of brown rust of sugarcane, caused by *Puccinia melanocephala* H. & P. Sydow. Trials consisted of 9 treatments i.e. 100, 200, 400, 800, 1200, 1600, 2000 mg L^{-1} potassium silicate (K_2SiO_3), applied once a week for 8 weeks and Calmasil®, a commercially available form of calcium silicate, applied at the recommended dosage of 52 g 5 L^{-1} incorporated in the potting soil at planting. The concentration of Si in the Calmasil® was calculated to be 1017 mg L^{-1}. For the disease severity trial, plants were naturally infected with *P. melanocephala* by placing them in a tunnel with brown rust-infected spreader plants. From 3 weeks after planting, plants were rated weekly for 5 weeks for percentage disease severity using a rating scale. Percent disease severity was reduced from 85% in the control to 64% in plants treated with Si at 2000 mg L^{-1}. The area of highest deposition of Si within the stem and leaf tissue will be assessed using energy dispersion X-ray (EDX) analysis with environmental scanning electron microscopy.

Sidhu *et al.* (2013) investigated the effect of silicon (Si) soil amendments on performance of sugarcane borer, *D. saccharalis*, on two rice cultivars, Cocodrie and XL723. There was a significant increase in the Si content of rice plants supplemented with calcium silicate as compared to non-treated plants. Soil Si amendment led to lower relative growth rates (RGRs) and reduced boring success of sugarcane borer larvae. Effects of soil Si amendments on borer success and RGR appeared to be more pronounced in 'Cocodrie', the cultivar relatively susceptible to borers, than in the moderately resistant cultivar, XL723. Soil Si amendment may contribute to the management of *D. saccharalis* through reduced feeding injury and increased exposure to adverse environmental conditions and natural enemies arising from reduced boring success.

2.8 Silicate solubilizing microorganisms

Silicon a biologically important element, required in living organisms in a very less amount. To the plants it provides multi functional role, hence silicon availability to the plants is very much important. Silicon is abundant element found on the earth, but its solubility in soil is a major concern. Therefore, identification of efficient bacterial strains which could solubilize silicate is of paramount importance. Moreover, solubilization of silica also releases several other essential nutrients in the soil.

A silicon cycle, comparable to nitrogen and carbon cycles, does not operate in the environment. The biological involvement in silicon mobilization-immobilization is represented by the solubilization of insoluble silicon, the release of the element from organic-silicon compounds and the immobilization of silicon by bacteria and fungi. In this respect, silicon is similar to phosphorus. The literature on the potential role of microbial processes in making silicon available to plants is almost non-existent; the exception being silicate solubilization. It is suggested that bacteria are concerned in rock decomposition. Similar to phosphate solubilizing bacteria, silicate solubilizing bacteria and its usefulness is well established.

Duff and Webley (1959) reported silicate dissolving action with a gram negative bacterium resembling *Erwinia*, with Bacterium *Herbicola* and with a few *Pseudomonas* strains. The transformation of polymerized silica into monomeric silica by *Proteus mirabilis* and *Bacillus caldolyticus* was shown clearly. The bacteria *Zooglea ramigera* and *Pseudomonas* were also found to enhance the dissolution rate of Bytownite, a calcium rich feldspar and quartz.

Jones and Handreck (1967) reported that bacteria solubilize the insoluble silicates by production of CO_2 organic acids and exo-polysaccharides. The solubilization of silicates was investigated using Kaolin quartz and sand as model substances. The chemical leaching of silicates was carried out using inorganic and organic acids as well as sodium hydroxide. The process was more effective in the alkaline than in the acid pH range on the other hand, microbiological influence on solubilization. The transformation of crystalline biotite, mica, vermiculite and certain rocks to amorphous state is due to the action of some organic products of microbial metabolism.

Karavaiko *et al*. (1988) reported most of the silicate solubilizers are common soil microorganisms, although a specialized silicon solubilizing bacterium, *Bacillus mucilaginosus,* has been described by Russian workers. Silicate-dissolving micro-organisms have been used to remove silicon from low-grade mineral raw materials, like bauxite, and to extract valuable metals from silicate and aluminosilicate ores and minerals.

Soomro (2000) showed that bacteria solubilize rock potash, releasing free silicon into the medium. The growth of a *Penicillium* sp.*in vitro* increased the solubilization of sodium silicate, but concentrations of free silicon decreased when the fungus was grown in the presence of silicic acid, presumably due to Si-immobilization by the fungus. Water-extractable silicon increased when silicic acid was added to all soils, under both aerobic and anaerobic conditions, Liming increased the release of soluble silicon from sodium silicate, silicic acid and rock potash, the effect being seen in all soil types. Addition of silicic acid generally decreased bacterial numbers in all soils, at least over the first days of the incubation period. Silicic acid had no effect on nitrification, while the addition of sodium silicate stimulated nitrate production; this effect is assumed to be largely due to the resultant marked increase in soil pH.7. The addition of silicic acid and rock potash also increased sulphur oxidation, It is clear that water-soluble silicon is released from insoluble silicon compounds following their addition to soil, and that such release is a combination of microbial and chemical-physical processes. The observed decrease in bacterial numbers, arylsulphatase activity, dehydrogenase activity and respiration can be regarded as being detrimental to soil fertility, while increases in sulphur oxidation can be seen as positive responses. The lack of effect of silicon compounds on nitrification can also be seen as being overall desirable; while increased nitrate following the addition of sodium silicate can be regarded a damaging because it leads to the, above-mentioned loss, of N from soils.

Raj (2004) identified silicate solubilizing bacteria from rice ecosystem (SSB) in a medium containing 0.25 per cent insoluble magnesium trisilicate and also reported that *Bacillus* sp. found to solubilize silicate minerals more efficiently under *in vitro* conditions.

Murali *et al.* (2005) isolated silicate solubilizers using modified Bunt and Rovira medium from soil samples collected from coconut palms. Majority of the silicate solubilizers are identified as *Bacillus* sp. and *Pseudmonas* sp.

Badr *et al*. (2006) reported bacteria capable of dissolving silicate minerals from feldspar samples.

Hu *et al.* (2006) reported K solubilizing strains from the soil and they were phenotypically and phylogenetically characterized and were effectively dissolve mineral potassium when they grown on Alekandrove medium which are rod shaped spore formers with a large capsule and formed slimy and translucent colonies.

Zhou *et al.* (2006) characterized and identified as *Bacillus mucilaginosus* which soluiblizes silicon from illite at 30°C, the bacterium is identified as gram-negative, rod shaped with endospore former and thick capsule.

Sheng (2008) isolated a silicate mineral-solubilizing bacterial strain Q12 from the surfaces of weathered feldspar and identified as *Bacillus globisporus* Q12 based on the 16S rDNA gene sequence analysis. Three silicate minerals (feldspar, muscovite, and biotite) were used to investigate potassium and silicon mobilization by strain Q12. In liquid cultures, the strain showed better growth on the biotite than on feldspar and muscovite. The biotite was the best potassium source for growth of the strain. Solubilization of potassium and silicon from the silicate minerals by the strain resulted mostly from the action of organic acids. Gluconic acid seemed to be the most active agent for the solubilization of the 3 silicate minerals. Gluconic and acetic acids were likely involved in the solubilization of feldspar. The strain could be acid or alkali and salt tolerant and temperature resistant.

Osman (2009) studied some microscopial, morphological and biochemical properties of two isolates of silicate bacteria isolated from Peat based silicate bacteria inoculants. The results revealed that silicate bacterial isolates are close to *Bacillus circulans* (transperant isolate) and *Bacillus mucilaginous* (milky white isolate). The results concluded that milky white isolate can tolerate high level of salinity, and more resistant to antibiotics in comparison to transparent isolate. Having a high capacity to grow in saline condition and resistant to antibiotics, are important characteristics that will help this isolate to compete and tolerate extreme soil salinity, particularly under arid conditions. Thus it can survive in such conditions and successfully mobilize potassium from silicate in soil.

Sheng *et al*. (2008) isolated a silicate mineral-solubilizing bacterial strain Q12 from the surfaces of weathered feldspar and identified as Bacillus globisporus Q12 based on the 16S rDNA gene sequence analysis. Three silicate minerals (feldspar, muscovite, and biotite) were used to investigate potassium and silicon mobilization by strain Q12. In liquid cultures, the strain showed better growth on the biotite than on feldspar and muscovite. The biotite was the best potassium source for growth of the strain. Solubilization of potassium and silicon from the silicate minerals by the strain resulted mostly from the action of organic acids. Gluconic acid seemed to be the most active agent for the solubilization of the 3 silicate minerals. Gluconic and acetic acids were likely involved in the solubilization of feldspar. The strain could be acid or alkali and salt tolerant and temperature resistant.

Fang *et al.* (2010) reported that there is plenty of total silicon in soil, but most of them were unavailable to plant. Silicate mineral-solubilizing bacteria can dissolve silicate minerals (such as feldspars and micas) and release the elements of potassium and silicon. The bacteria were isolated based on their plant growth-promoting characteristics and potential of feldspar-dissolution. The colonizing dynamics of the tested strains in paddy soil and their silicon-dissolving capacity in soil were studied. The study was also involved in the effects of the tested bacteria on the plant growth, available silicon in soil, and soil bacterial community in pot experiment. The strain was of high efficacy in silicate mineral-dissolution and production of IAA and siderophores. The results showed that strains N1-1R and NBT-R successfully colonized in paddy soil and the population of the strains reached to 103-104 cfu·g^{-1} soil after 48 days. The colonizing level of the strains in sterilized soil was higher than that of unsterilized soil. Strain NBT-R had the strongest colonizing ability in the tested stains. The inoculation with strain NBT-R increased the number of bacteria and actinomycetes, and the amount of fungi was reduced after 14 days. The efficacy of dissolving silicon of different forms in paddy soil showed that the content of water-soluble silicon in soil decreased apparently due to the inoculation of strains in 7-23 days. The content of active silicon in soil which strain NBT-R was inoculated, increased in 48days. The content of indefinite silicon was increased by 19.1% to 43.1% in 23rd day. Inoculants did not change the balance of silicon conversion. The content of available silicon was increased by 3.0% to 8.2% after 48 days and the content of available silicon in soil which inoculated of strain NBT-R was significantly increased compared with the control. The effects of the tested strains on the plant growth, available silicon in soil, and soil microorganism community in pot experiment were studied. The results showed that strains 7G2-gfp and NBT-R increased the content of silicon in rice and promoted rice growth apparently. The dry weights of shoots and roots of rice were increased by 43.0% to 61.2% and 48.4% to 70.6%. The content of silicon in shoots and roots of rice was increased by 12.9% to 36.0% and 9.2% to 23.2% compared to the un-inoculated control, respectively. The content of available silicon in soil which inoculated of strain 7G2-gfb was significantly increased by 17.3%. The inoculants increased the number of soil bacterial and produced an effect on soil bacteria community.

Vijayapriya and Muthukkaruppan (2010) conducted studies on isolation and screening of silicate solubilizing bacteria and its biocontrol nature against *yricularia oryzae.* Rice is siliceous plant a well known silicon (Si) accumulates and the plants benefits from silicon nutrition. The efficiency of the SSB on plant growth stimulation on the augmentation of ISR mediated biocontrol against *Pyricularia oryzae* added more advantages in the biotechnological application of the same to harness maximum plant growth and biocontrol benefits in rice. A range of 4.84 X 106 Cfu - 6.54x106 Cfu community population of SSB was recorded. Ten bacterial isolates were obtained from the soil sample, identified and characterized as *Bacillus mucilaginosus*. The isolate designated as SSB and numbered randomly. Among the ten isolates tested, four isolates, viz., SSB-3, SSB-5, SSB-8 and SSB-9 were found to be efficient in silicate solubilization and antagonistic activity against *Pyricularia oryzae*.

Balasubramaniam *et al.* (2011) was conducted an incubation experiment to study the release characteristics of silicon from native soil and applied sources *viz,* Fly Ash (FA), Silicate Solubilizing Bacteria (SSB) and Farm Yard Manure (FYM). The soil for incubation study was collected from Eastern block of Agricultural Engineering College and Research Institute which is low status of plant available silicon. The treatments consist of graded levels of FA *viz.*, 0, 12.5, 25, 37.5 and 50 g/kg of soil with and without SSB and FYM. The results revealed that among different treatments, addition of SSB + FYM resulted a consistent increase of N NaOAc (pH 4.0) extractable Si from 144.7 mg per kg to 272.2 mg per kg during 15th to 60th days after incubation, thereafter a slight decline in N NaOAc (pH 4.0) extractable Si was observed up to 90 days. Among the different treatments the application of SSB +FYM recorded the highest N NaOAc (pH 4.0) extractable Si of 272.2 mg per kg at 60th day followed by FYM (258.0 mg per kg) on 75th day of incubation. The control recorded the least N NaOAc extractable Si throughout the incubation period. Imposition of graded levels of fly ash and their interaction with various sources viz., SSB, FYM and SSB+FYM have shown significant variations in the N NaOAc (pH 4.0) extractable Si throughout the incubation period. Imposition of fly ash at 50 g kg^{-1} of soil with SSB + FYM resulted in more release at 15,30,45,60 and 75 days after incubation which was on par with addition of fly ash at 25 g kg^{-1} of soil at 90 days after incubation.

Kruger and Surridge (2011) studied solubilization of silica from fly ash and interaction with root exudates University of Pretoria, Pretoria South Africa and reported that fly ash from coal-fired power stations has successfully been used to ameliorate acid soil. The beneficial effect has been ascribed to the increase in pH, the dissolution of the amorphous silicate phase and the concomitant supply of elements required for plant growth over a protracted period. It is known that low molecular weight organic acids are exuded by the roots in rhizosphere as a means of assimilating nutrients. The interaction between a series of low molecular weight organic acids and fly ash has been investigated. Results showed the dissolution of the fly ash matrix and the solubilization of macro and trace minerals depends upon the specific low molecular weight organic acids and the composition of the glass phase of the particular fly ash. The results suggested that the application of fly ash to soil would raise the pH while providing a source of silica and trace elements beneficial to agricultural crops. It is suggested that the efficacy of fly ash as an alternative source of Si for sugarcane be studied especially in view of the simultaneous supply of essential trace nutrients.

Du *et al.* (2011) reported that the majorities of silicon in the soils are unavailable to plants. The major silicate fertilizers used widely in the world are slag-based fertilizers. However, the major disadvantages of such silicate fertilizers are their low solubility, high pH and inconveniency in use and transport due to their large application rates. Therefore, exploring novel silicate fertilizers is of crucial importance to the sustainability of agriculture. He obtained a novel silicate-dissolving bacteria strain with its preservation number of CGMCC NO.4667 by using microbial mutation technology. A three-day flask-shaking incubation experiment at $30^{o}C$ showed that this strain could effectively dissolve silicate from the powdered feldspar-containing culture medium. The water soluble silicon content in the culture media inoculated with the silicate-dissolving bacteria strain was 5.33 times as high as that in the control medium. Subsequently, he manufactured a compound bio-fertilizer containing the silicate-dissolving bacteria strain by fermenting and granulating. An 8-week incubation experiment with soils under saturation conditions at $25^{o}C$ showed that the available silicon content and water-soluble silicon content in the soils treated with the compound bio-fertilizer at the rate of 1.0 g kg^{-1} increased by 42% and 26%, respectively, compared with the control, suggesting that this compound bio-fertilizer could dissolve silicate in soil significantly. A pot experiment also showed increased tillering number and grain yield by 20% and 10.1%, respectively, in rice treated with the bio-fertilizer. In addition, total silicon, nitrogen, phosphorus and potassium contents were increased by 7.9%, 7.4%, 7.4% and 3.7%, respectively, compared with the control.

Vasanthi *et al.* (2012) reported that soil is the resource and reservoir of plant nutrients but it cannot sustain crop requirement continuously unless replenished by manures or fertilizers. To supplement chemical fertilizer inputs, biofertilizers for nitrogen fixation, phosphate solubilization and potash mobilization have been identified and widely used. A silicate solubilising bacterium *Bacillus* sp isolated from sugarcane field soil was found to release magnesium and calcium from dolomite, talc and magnesium trisilicate under *in vitro* condition and in soil amended with these minerals. The magnesium content in the soil solution from Talc amended soil increased from 9 to 24 ppm and 32 to 43 ppm in magnesium trisilicate amended soil. During the same period Ca increased from 32 to 64 ppm in talc amended soil, 40 to 72 ppm in dolomite and 32 to 72 ppm in Magnesium trisilicate. The studies revealed that silicate solubilising bacterium have potential of Mg, Ca, Si and also Zn solubilisation in soil.