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A review article on: Plant response to silicon fertilization

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Abstract

Silicon has been established as beneficial element for growth, development and yield of many plants. Silicon has numerous functions on plant physiology, and its most significant effects are focussed on cell wall. The presence of silicon in the cell wall increases their strength, resistance to salinity, drought tolerance, and photosynthetic activity. It supports root and foliage growth and leads to prevention of oxidative stress by antioxidant enzymes. Exogenous application of silicon was effective in mitigating several responses of biotic and abiotic stress damages by improving the plant water uptake and transport. Silicon nutrition is responsible for better light capturing by plants, thereby an increase in photosynthetic activity in plants. Silicon in a combination with oxygen, is the basic non metallic components of all rocks and considered as a trace element only in respect to its biochemical functions. In the lithosphere it is the most stable element, preferable at +4 oxidation state and occurs mainly as SiO_2. However, under specific conditions it can be dissolved and transported mainly in colloidal phase. Quartz, SiO_2 is very resistant mineral in all terrestrial environment and is basic part of all silicates (e.g. feld-spar, quartz) and aluminium silicate minerals. Nonsilicate mineral containing Si is silicon car-bide (Carborundum) SiC.

Key Words: Silicon, Plant growth, Nutrient, Yield, Drought tolerance

Si is the most abundant element in the earth crust but its availability to plants is in limited extent. Silica and alumino silicates are the main source in the soil which have lower solubility. Moreover, Silicon uptake in higher concentration in plants does not create any toxicity or abnormal symptoms (Ma *et al.* 2006). If soils contain low availability of silicon and further intensive cropping system can reduce the levels of plant available silicon to such a point that supplemental silicon fertilization is critically required for maximum production (Hattori *et al*. 2005). Long period of intensive cultivation decreases the available soil silicon. Depletion of available Si in the soil could be one of the possible limiting factor contributing to rice yields. Major causes of low availability of silicon may be as:

(i) Severe and frequent soil erosion and sediment transport
(ii) uptake by plants equal to the concentration of macronutrients
(iii) Occurrence of desilication and leaching.

Sub-tropical and tropical soils are generally low in available Si and therefore, silicon fertilization will be beneficial for these soils.

Silicon plays an effective role in preventing lodging of rice crop by increasing the thickness of the culm wall and the size of the vascular bundles, thereby, enhancing the strength of the stem. Silicon can reduce the transpiration losses and enhances the water use efficiency of the crop. Miyake and Takahashi (1978) revealed that the tomato plants deficient in Si have shown the poor reproductive growth in the culture solution. Silicon in the form of H_4SiO_4 is readily absorbed by higher plants and is deposited as a solid amorphous Si opal. It may be taken up in a form of monosilicic acid, amorphous silica and as organic complexes. The Si absorption depends on its concentration in solution, soil water percentage and pH. Though all the plants contain silicon in their tissues. It is considered as plant nutrient anomaly because there is no evidence recognizing that silicon is involved in the metabolism of plants and not been established as essential nutrient element. Silicon has several beneficial roles in plant growth and development and sufficient supply of silicon to rice crop can favour the better growth and yield. Moreover, Si appear to interact favourably with other fertilizer nutrients like N, P and K and enhances their efficiency. Silicic acid or orthosilicic acid are the plant available forms of silicon in soils. Rice plant absorbs Si by the roots in the form of ortho silicic acid (H_4SiO_4) along with water and translocated to the shoots. In the shoots, with the loss of water through transpiration, silicic acid is concentrated and polymerised to silica (SiO_2) and finally deposited on the different tissues (Yoshida, 1975).

The cuticle with Si layers can obstruct the infection of disease causing organisms. The deposition of silica on epidermal layers builds a physical barrier to pests. Most of the Si minerals are largely insoluble, though low levels of mono – and polysilicic acid are invariably found dissolved in the soil solution. Plants assimilate Si mainly as monosilicic acid or orthosilicic acid which are very unstable and changed to unavailable form (polymeric silicic acid) or forms complex with other compounds to make metasilicates (Maichenkov and Calvert , 2002; Rodrigue and Dantoff, 2005). Concentrations of monosilicic acid in the soils found in the range of 0.1- 0.6 mm. The ability of soils to supply Si depend on its presence in soluble form in the soil solution. Once absorbed Si is deposited as amorphous silica (SiO_2 –nH_2O) throughout the plant, mainly in the cell walls, where it combines with pectin and polyphenols and enhances cell wall rigidity and strength. It is not considered as an essential or functional plant nutrient, but it is considered as an absolutely useful element for a large variety of plants (Hayaska *et al*, 2008, Nakata et al, 2008). It has been showed that Si is beneficial to plants, especially graminae family plants like – rice, wheat, barley, maize, sorghum, sugarcane, etc. The beneficial response of plants to silicon application was reported under various conditions of biotic stresses – plant disease / insects damage and abiotic stresses – Al toxicity, salinity stress, drought and high temperature stress.

Rice is a high Si accumulator plant absorbs 150-300 kg Si/ha. Silicon is deposited mostly in cell walls, but sometimes as silica bodies in the lumen of cells (Lanning *et al*, 1958). Silica content in rice increases with an increase in age of the crop from transplanting to harvest (Nayar *et al,* 1982). In rice, oat, rye and wheat seed coat accumulates most of the silica and grain the least (Gallo *et al,* 1974). Silicon is involved in several major roles in rice – carbohydrate synthesis, grain yield, phenolic synthesis and plant cell wall protection (Van ,2006). Silicon makes plant more rigid and erect, tolerant to pest and diseases. Silicon is probably the only nutrient element which is able to enhance the resistance to multiple stresses.

Soil:

The chemistry of silicon is complex. The common form of Si available to plants is monosilicic acid and other minerals in soils such as polysilicic acid (Mckeague and Cline 1963, Raven 1983). Silicon is also adsorbed on and precipitated with aluminium, iron and manganese to become source for replenishment of available Si to plants. Aluminium oxides are more efficient to bind Si through adsorption process than Fe oxides. Concentration of $Si\ (OH)_4$ in soil solution has been measured to be as high as 112 mm (Jones and Handreck 1967), but normal concentration ranges of Si are 0.1-0.6 mm (Epstein, 1994)). It ranges from 200 to 300 g Si/kg in clay soil and 450 g Si/kg in sandy soil (Matichenkov and Calvert, 2002).

Silicon is the most abundant element in soil, averages 54 %, but in some soils its content is much higher, (Takeda *et al,* 2004) stated that average SiO_2 content was 43 % in Andosol, 56% in Cambisols, 63 % in Gleysols and 66% in Aridisol. Quartz, SiO_2 is the most resistant mineral in soils and is also known to occur in a non crystalline form opal, which is presumable of a biological origin. In soils, amorphous silicates apparently contribute to anion adsorption process, and it has been suggested that silicate and phosphate ions compete for site on mineral soil particles .Tiller advocated that the presence of monosilicic acid in solution increases the sorption of trace cations as Co, Ni and Zn by clays. A part of Si is released from minerals into soil solution and this process is controlled by both soil and climatic factors. (Carlisle *et al*, 1974) reported that Si (mainly as H_4SiO_4) in the soil solution ranges from 1 mg /l to about 200mg /l. Soil pH has a significant effect on Si concentration in solution. Usually, Si is more mobile in alkaline soils. Several interactions between Si and other ions as P, Al, Ca and Fe may occur in soil and modify the behavior of Si. In acid soil, silicate and phosphate ions form insoluble precipitates that, may fix several other cations e.g. Fe and Al oxides. Presence of Soil organic matter in large amount in flooded soil may induce a higher Si mobility due to reduction of Fe hydrous oxides, which release adsorbed monosilicic acid.

Plants:

In plants, Si is absorbed by roots but accumulation is more in above ground parts. Its content in plants ranges from 0.1 -10 percent on dry weight basis, this amount is equivalent or even more than several macronutrient contents present in plants (Ma and Takahashi, 2002 and Kamenidou *et al* 2009). Some plants uptake more silica than its requirement and this become deposited on tissues. Its content is found in increasing order Legumes < Fruit crops< vegetables< grasses < grain crops (Thiagalingam *et al,* 1977). Based on the Si concentration levels in the plant tissue, the plants can be grouped into three categories viz; I Dicotyledons with less than 0.1 % on dry weight basis II Dry land grasses – oat and rye with 1.5 % and III Wet Land Grasses and Paddy with Si content 5 % or higher (Jones and Hendreck, 1967).

Once Si is absorbed by roots and transported across plasma membrane, it is translocated exclusively in the xylem (Epstein 1994) and is freely moved from roots to shoots. Wallace (1993) reported that application of Si reduced the Fe toxicity and also improves and accelerate the aeration to leaves, stem and roots of the plant. The better aeration improved the oxidative power of rice roots and resulted in oxidation of ferrous ions to ferric ions of iron and minimized the iron toxicity in the soil. It has been reported that, soil application of calcium silicate @ 4g/ kg soil was superior to foliar application of potassium silicate. The Fe and Mn contents in grain and straw were decreased with application of Si. Wallace (1993) reported Si responded on plant growth and he said it may be due to effects of Si on the increased uptake of P and Mo as well as Mn transport within plant. Si has antagonistic relation with B, Mn and Fe uptake by plants. Si balance the harmful effects of As, as well as reduce the internal phyto toxicity caused by Al and Mn (Foy *et al*, 1978, Rogall and Romheld, 2002).

The presence of high amount of silicon in the plant increases the proportion of air filled spaces in the shoots and roots which allows increased transport of O_2 to the roots. Si deficiency leads a soft and droppy leaves resulting in reduced photosynthesis and lower grain yield. In rice, typical symptoms of Si deficiency are necrosis of the older leaves and wilting associated with a higher rate of transpiration (Mitsui and Takatoh, 1963). Si reduces absorption of Na (Liang *et al*. 1996) by rice and enhances resistance to salinity (Okada and Takahashi, 1965). The only biochemical role Si in plant suggested is its involvement in biosynthesis of lignin (Weiss and Herzogg, 1978).

Si has antagonistic relationship with Zn and Fe and reduces the bio availability of Zn and Fe in rice plant. A number of possible mechanisms are proposed by which Si can increase the resistance of plants against salinity stress which is a major yield limiting factor in arid and semiarid areas include: stimulation of antioxidant systems in plants, complexation or co-precipitation of toxic metal ions with Si and compartment of metal ions within plants (Liang *et al*. 2006). Sodium content was higher in wheat cultivars grown under saline irrigation water; however Si application significantly reduced Na content in grain of two wheat cultivars. (Liang *et al*. 2006) reported a significant increase in K uptake and decrease in Na uptake under salt stress when Si was included because of increasing activity of plasma membrane H-ATPase. Silicon is known also to reduce Na uptake. Silicon application enhanced K/Na selectivity ratio in wheat cultivars thus enhancing biological and grain yields. Silicon when deposited in exodermises and endodermis of roots reduced Na uptake in plants (Gong et al. 2003). Though the amount of silicon in soil in large quantity but only a small fraction is soluble and available for plant acquisition. In many soils the available silicon content is sufficient to obtain a satisfactory crop yield without external application of silicon. Silicon can help better crop growth and higher yield and indirectly reduce the biotic and abiotic stress.

The availability of Si to plants, however, depends largely on how rapidly weathering takes place, bringing Si into soil solution. Silicon concentration in higher plants species varies from one percent to more than ten percent of tissue dry weight basis. Monocots typically accumulate more Si in their tissues than dicots. Although Si is not considered an essential nutrient for plant growth, its beneficial effects on crop plants is well documented. Silicon provides lodging and drought resistance to crop plants. In addition, Si have positive influence on some enzymes involved in photosynthesis and leaf senescence (Sawant *et al*,1997). Silicon increases the oxidation power of rice roots in flooded soils (Datnoff *et al*.2007) by increasing Fe^{2+} precipitation on root surfaces, thereby reducing Fe toxicity.

In certain organic Histosols of the florida Everglades low in plant –available Si, silicon fertilization has been shown beneficial to rice. When these soils are amended with Si as calcium silicate slag, rice yields increased significantly, due to reduce level of disease severity in rice plant. By the addition of plant available Si to Si deficient soils, disease such as brown spot (Bipolaris oryzae) and blast (Pyricularia grisea) are greatly reduced. Another possible effect of Si on rice grown on Everglades Histosols may be that it counteracts some of the detrimental effects of N fertilization. Silicon application have been observed to improve rice plant phenotype characters and photosynthesis. In West and Central Africa, rice is often grown on freely drained upland soils in high –rainfall forest areas. The highly weathered ultisols and oxisols have lost most of their silicon and probably have insufficient Si to satisfy the requirements of the crop (Winslow, 1992). Application of Si to an upland Ultisol soil at in Nigeria increased rice yields and reduced damage from diseases. The association between Si deficiency and disease raises the possibility of increase disease resistance by breeding cultivars with higher Si contents. Some investigators also reported correlation in blast resistance and high –Si genotypes (Deren *et al.* 1992, Winslow1992).

Deren et al (1994) reported that, rice genotypes differed in Si concentration and disease severity at several locations and Si fertilizer treatments. Among genotypes, disease severity was negatively correlated with Si concentration in plant tissue. Increases in yield with added Si were attributable to a greater number of grains per panicle, whereas weight per 100 seed and panicles per square meter were less affected. Poor silicification of rice epidermal cells increases susceptibility to such fungal diseases as rice blast and helminthosporium leaf spot. Many workers feel that silicate in leaf epidermis prevent physical penetration of fungi (Ou, 1985). Silicification of cell wall is also linked with K nutrition. According to Nogushi and Sugawara (1996), K deficiency reduces the accumulation of SiO_2 in the cells of leaf blades, thus increasing the susceptibility to rice blast. Wheat and barley powdery mildew was effectively controlled with the application of Silicon. Hence, improved Si management is necessary to increase yield and sustain crop production in temperate and tropical regions.

Silicon fertilizers common in agriculture use are calcium silicate (14-19%), potassium silicate (14% Si 17 % K), blast furnace slag (14-19 %) and fused magnesium phosphate (9 % Si and 9 %P, 7-9 % Mg). Rice straw and its compost is the easiest organic source of Si to the farmers. Rice responded well to application of organic siliceous residue like rice straw, rice husk and black ash @ 5 t/ha. Microorganisms are capable of degrading silicates and aluminum silicates. Combining Silicate solubilizing bacteria (SSB) with these residues further resulted in increased plant growth and grain yield. This enhancement is due to increased dissolution of silica and nutrients from the soil.

Silicon fertilizers has a double effect on the soil –plant system as under (i) improved plant –Si nutrition reinforces the plant – protective properties against diseases, insect-pest attack, and unfavorable environmental conditions, (ii) soil application with bio geochemically active silicon substances enhances soil fertility through improved soil moisture availability, improved physical and chemical properties of soil and content of available nutrients (Meena *et al,* 2014). Supply of appropriate amount of Silicon to the plant cultivated in Si deficient soils could considerably improve the rate of plant growth as well as its resistance against biotic and abiotic stresses. Increased application rate of silica fertilizers (0, 250, 500 kg/ ha) increased silica concentration in shoots, leaves and panicle of rice (Fallah *et al,* 2011). Rice crop with a grain yield of 5 ton/ ha normally uptakes 234 – 470 kg Silicon/ ha (500 - 1000 kg SiO_2 / ha).

Source of Silicon:

The first attempt to investigate the applicability of industrial by-products containing Si as fertilizers was conducted in China during late 1950's. Subsequently, Si application as fertilizers has increased significantly since 1970, and Si fertilizers have been applied continuously to improve rice production by reducing insect and disease incidence. As a fertilizer, it must provide sufficient water – soluble Si with relatively high Si content to meet the plant requirements, available in low cost, have a physical nature suitable to easy storage and application and should not have any substance that will pollute the soil. (Gascho, 2001). Many potential sources meet the required fertilizers characteristics for soil and plant system. Crop residues, especially of Si accumulating plants, such as rice, are used as Si source however, the crop demand for Si generally exceeds that it was supplied by crop residues. Inorganic materials, although may not be applied due to poor solubility of Si like quartz, micas and feldspar. Calcium silicate, obtained from steel and phosphorus industry is one of the most widely used Si fertilizer. Potassium silicate is costly but highly soluble in nature and suitable for hydroponics. Other sources that have been common in use are calcium silicate, silica gel and thermo- phosphate (Gascho, 2001).

Table 1: different sources of Silicon

S.No.	Source	Chemical formula	Si content (%)
1	Silicic acid	$H_4Si\ O_4$	29
2	Calcium silicate slag	-	18-21
3	Calcium silicate	$CaSiO_3$	24
4	Potassium silicate	$K_2\ SiO_3$	18
5	Sodium silicate	$Na_2\ SiO_3$	23
6	Quartz sand (Finely grind)	SiO_2	46
7	Diatomaceous Earth (DE)	-	63.7 SiO_2

Source: Meena *et al* (2014)

International Rice Research Institute (IRRI) reported that Si deficiency can be amended by the application of calcium silicate –slag at the rate of 120-200 kg/ha. The Si content of different part of the rice plant was found in the order of descending –Hull, leaf, leaf sheath, culm and root (Zhu, 1985).

Table 2: Silicon content in different part of rice plant

S. No.	Plant Part	Si content (g per kg)
1	Polished rice	0.5
2	Rice bran	50
3	Rice straw	130
4	Rice Hull	230
5	Rice spikelets	350

Source: Van (2006)

Application of potassium, magnesium and calcium silicate increases the rice yield. On an average 10-30% increase in yield were recorded with silicate application (Gascho 2001). Application of siloxol granules at the rate of 37.5 kg per ha along with 100% RDF showed its superiority over others for panicles per square meter, filled grain per panicle, test weight and grain and straw yields of rice (Jawahar *et al.* 2015).

References

Carlisle, E. M.; Mc Keague, J, A, Siever, R. and Van Soest, P. J. (1974). Silicon in Geochemistry and the Environment.Vol 2 Hopps, H C ed N A S, Washington, DC 54.

Dantoff, L. E., Rodrigues, F A, Seebold K W, (2007). Silicon and plant disease. In : Mineral Nutrition and Plant Disease .(Eds.) Dantoff, L E , Elmer, W.H. and Huber, D.M. St Paul, M N USA: The American Phytopathological Society, pp233-246.

Deren, C, Dantoff, L E, Synder, G Hand Martin F G. (1994). Silicon concentration disease response and yield components of rice genotypes grown on flooded organic histosols. Crop Science, 34:733-737.

Deren, C, Dantoff, L E, Synder, G. (1992). Variable silicon content of rice cultivars grown on everglades histosols. Journal of plant nutrition. 15 (11): 2363-2368.

Epstein E. (1994). The anomaly of silicon in plant biology. Proc. Natl. Acad. Sci. U. S. A. 91:11–17.

Fallah, A,Osko, T, Khosravi, V.Mohammadian, M and Rosttami,M.(2011). Reduction of chemical pesticides by using of silicate fertilizer in paddy soils. (In): Proceeding of the 5th International Conference on Silicon in Agriculture, 13-18 September Beijing, China pp 46.

Foy, C D, Chaney, R L and White, M C. (1978). The physiology of metal toxicity in plants. Annu. Rev. Physiology, 29, 511.

Foy, C D. (1992). Soil Chemical factors limiting plant growth. Advances in Soil Science, 19:97-149.

Gallo,J, R, Furlani, P, R, Bataglia, O, C. and Hiroce, R.(1974).Silicon content in grass and forage crops. Cinecia cultura, 26:282-293.

Gascho G, J. (2001). Silicon sources for agriculture. *In*: Silicon in Agriculture, Vol. 8, Studies in plant science. Datnoff L. E., Snyder G. H., Körndorfer G. H. (eds.). Amsterdam, the Netherlands: Elsevier, 197–207.

Gong, H, Zhu X and Chen K. (2005) .Silicon alleviates oxidative damage of wheat plants in pots under drought .Plant Sci 169-:313-321.

Hattori T, Inanaga S, Araki H, An P, Morita S, Luxuva M and Lux A. (2005). Application of silicon enhanced drought tolerance in *Sorghum bicolor*. Physiol. Plant. 123:459–466.

Hayaska, T, fujji, H and Ishiguro, K. (2008). The role of silicon in preventing apersorial penetration by rice blast fungus. Phytopathology, 98(9):1038-1044.

Jawahar, S, Vijaya, K D, Bommera R and Jain, N. (2015). Effect of siloxol grainules on growth and yield of rice. International Journal of Current Research Academic Review, 3(1): 168-174.

Jones, L H P and Handreck, K A. (1967). Silica in soils, plants, and animals. Adv. Agron. 19:107–149.

Kamenidou, S, Cavins,T J. and Marek, S.(2009). Evaluation of silicon as a nutritional supplement for greenhouse zinnia production. Scientia Hortticulture. 119(3):297-301.

Lanning, F C, Ponnaiya, B W X. and Crumpton, C F. (1958). The chemical nature of silica in plants. Plant Physiology, 85:339-343.

Liang,Y C. and Ding, R X, (2002). Influence of silicon on micro distribution of mineral ions in roots of salt – stressed barley as associated with salt tolerance in plants. Sience in China Series C: Life Sciences, 45(3):298-308.

Ma, J F, Tamai, K, Yamaji, N, Mitani, N, Konishi, S, Katsuhara, M, Ishiguro, M, Murata, Y and Yano, M. (2006). A silicon transporter in rice. Nature. 440: 688–691.

Matichenkov, V V. and Calvert, D V. (2002). Silicon as a beneficial element for sugarcane.Journal American Society of Sugarcane Technologists, 22:21-30.

McKeague J A. and Cline M G. (1963). Silica in soil solutions. I. The form and concentration of dissolved silica in aqueous extracts of some soils. Can. J. Soil Sci. 43:70–82.

Meena, V D, Dotaniya, M L, Coumar, V, Rajendiran, S, Kundu, S. and Rao, A S. (2014). A case for silicon fertilization to improve crop yields in tropical soils. Proceedings of the National. Academy of Sciences, India Section. B: Biological Sciences, 84(3): 505518.

Mitsui, S and Takatoh, H. (1963). Nutrition study of Si in graminaceous crops. Soil Sci Plant Nutr.9:49-53.

Miyake, Y and Takahashi E. (1978). Silicon deficiency of tomato plant. Soil Sci Plant Nutr :24, 175.

Miyake, Y and Takahashi, E. (1978). Silicon deficiency of tomato plants. Soil Sci. Plant Nutr.24:175-179.

Mnzies, J G, Ehret, D L, Glass, A D M, Helmer,T, Koch, C and Seywerd, F.(1991). Effect of soluble silicon on parasitic fitness of Sphaerothecia fulginea on Cucumis sativus. Phytopathology, 81:84-88.

Nakata,Y, Ueno, M, Kihara, J ,Ichii, M,Taketa ,S and Arase, S. (2008). Rice blast disease and susceptibility to pest in a silicon uptake deficient mutant. Crop Protection .27:865-868.

Nayar, P K, Mishra, A K. and Patnik, S. (1982). Silica in rice and flooded rice soils – effects of flooding on extractable silica in soil and its relation with uptake by rice .Oryza, 19:34-40.

Okuda, A and Takahashi, E. (1965). The role of silicon.p.126-146. The mineral nutrition of Rice Plant, John Hopkins, Baltimore, MD, USA.

Ou, S H. (1985). Rice Diseases: 2nd Edition. Commonwealth Mycological Institute, Kew, England.

Raven, J A. (1983). The transport and function of silicon in plants. Biol. Rev. 58:179–207.

Rodrigues, F A. and Dantoff, L E. (2005). Silicon and rice disease management. Fitopatologia Brasileira 30, 457-469.

Rogal, H. and Romheld, V. (2002). Role of leaf apoplast in silicon – mediated manganese tolerance of cucumis sativua L. Plant Cell Environ. 25:549-555.

Savant, N, K, Datnoff, L, E. and Snyder G H. (1997) Depletion of plant-available silicon in soils: A possible cause of declining rice yields. Commun. Soil Sci. Plant Anal. 28:1145–1152.

Savant, N, K, Snyder G, H. and Datnoff L, E. (1997). Silicon Management and Sustainable Rice Production. Adv. Agron. 58:151–199.

Takeda, A, Kimura, K. and Yamaski, S, I. (2004). Analysis of 57 elements in Japanese soils with special reference to soil group and agricultural use. Geoderma 119:291-307.

Thialingam, K, Silva, J, A. and Fox, R, L. (1977). Effect of calcium silicate on yield and nutrient uptake in plant growth on a humic ferruginous latosol. (In): Proceedings in Conference of Chemistry and Fertility of Tropical Soils,5-10 November, Kualalampur, Malaysia, Malaysian.pp:149-155.

Tiller, K, G. (1968) The interaction of some heavy metal cations and silicic acid at low concentrations in the presence of clays .in trans. 9th Int. Soil Sci Congr, part 2, Adelaide, 567.

Van, S, P, J. (2006). Rice straw, the role of silica and treatments to improve quality. Animal Feed Science and Technology, 130(3):137-171.

Wallace, A. (1993). Participation of silicon in cation-anion balance as possible mechanism for aluminum and iron tolerance in some gramineae. J. Plant Nutr. 16:547–553.

Weiss, A and Herzog, A. (1978). Isolation and characterization of a silicon –organic complex from plants.p.109-127. In Biochemistry of silicon and related Problems (G. Bendz and Lidqvist, l. Eds.), Plenum, New York.

Winslow, M, D. (1992). Silicon disease resistance and yield of rice genotypes under upland cultural conditions. Crop Science ,32(5):1208-1213.

Yoshida (1975). The physiology of silicon in rice. Tech. Bull. No 25, ASPAC Food & Fert. Technol. Centre, Taipei.

Zhu, H.J. (1985). Rice Soil. Agricultural Publishing Press, Beijing, China.pp161.