SILICON NUTRITION IN RICE - A REVIEW

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ABSTRACT

Present trends toward intensive rice cultivation by growing more than one crop of fertilizer responsive high-yielding cultivars in a year may result in a decrease in plant available Si in the soil. Silicon has been described as being absorbed actively and passively by roots. Large amount of Si as monocilicic acid is absorbed by the rice plant. Si nutrition has direct and indirect beneficial effects on rice growth largely due to its unique physiological role. Silicon promoted growth attributes, photosynthetic activity of the lower leaves and improved leaf and stalk erectness of rice. Silicon improved the plant resistance to biotic and abiotic stresses such as soil aluminium (Al) manganese (Mn) and iron (Fe) toxicities alleviation, plant pests and disease resistance and increased phosphorus availability. Application of Si with nitrogen has been found to raise the optimum nitrogen dose from its existing level due to its synergistic effect and addition of nitrogen enhances lodging because of enhanced plant growth while Si as well as high N has greater resistance to lodging. The review covers the relationship of silicon to rice crop production, including growth, yield attributes, yield, quality and nutrient uptake.

Rice is a known silicon accumulator (Takahashi et al., 1990) and the plant is benefited from Si nutrition (Yoshida, 1975; Takahashi, 1995). Consequently there is a definite need to consider Si as an agronomically essential element for increasing and/or sustaining rice production (Takahashi and Miyake, 1977; Yoshida, 1981). In 1955, Si was first recognized as a fertilizer in Japan and since then 1.5 to 2.0 t ha⁻¹ of silicate fertilizer have been applied to silicate deficient paddy soils. As a result a 5 to 15 per cent increase in rice yield has been reported (Takahashi et al., 1990). Nowadays silicate fertilizers are also applied in South Korea, Taiwan and Hawaii and more recently in China. Silicon has several potential benefits and its sufficient supply in soil is required for healthy growth and productive development of the rice crop. Apparently applied Si seems to interact favourably with other applied fertilizer nutrients (namely N, P and K) and offers the potential to improve their agronomic performance and efficiency in terms of yield response. Si amended rice plants possess varying degrees of ability to tolerate biotic stresses, such as attack of insect, pests and fungal diseases and abiotic stresses like toxicity of soil Al, Fe, Mn and excessive salts (Yoshida, 1975; Sistani et al., 1997 and Savant et al., 1999). Si supply also helps to reduce cuticular transpiration and to some extent crop lodging caused by excessive N supply (Savant et al., 1997).

Silica is an essential minor element for plant is not yet firmly established but improved growth in the presence of silica were reported by Yoshida (1975). The decline in rice production may be due to decreased availability of phosphorus (P) and potassium (K) levels in intensive cropping system Epstein (1994). Flinn and De Datta (1984). However, recent studies suggests that the depletion of available silica (Si) in soils under intensive rice cultivation as a reason for reduction in rice yield (Savant et al., 1997). The rice plant absorbs silica in the form of orthosilicic acid. Transpiration increases the concentration of this form which is practically immobile in the plant. Silica is present in leaves just beneath the cuticle gives a more erect leaf habit than in its absence and

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thus it improves photosynthesis and transpiration rate. The resistance to lodging is increased due to silicon application mainly due to the rigidity of the stalk (Idris et al., 1975; Zhao and Jiang, 1987; Liang et al., 1994; Hossain et al., 1998). Symptoms of plant grown without Si or under low Si (deficiency) have been shown malformation of young leaves, chlorosis of mature leaves and leaf senescence (e.g. cucumber); leaf tracking (e.g. Sugarcane); yellowing and/or browning of lower leaves with necrotic spots, poor tillering wilted and dried leaf tips and small panicles with high sterility (Gascho, 1977; Miyake and Takahashi, 1983; Takahashi and Miyake, 1982; Marschner et al., 1990; Savant et al., 1997 and Singh et al., 2000). 

Zang and Wang (1986) observed that the soil available Si was deficient, the functional rice leaves senescenced immediately after heading and the tolerance of the plants to rice blast disease and to pests was lower. Rice hulls a major byproduct of rice milling, contains about 8% Si and can be recycled for use in a sustainable rice cultivation system. Silicon is also known to reduce plant diseases in rice (Datnoff et al., 1997 and Seebold et al., 2001).

**Silicon on growth**

Plants for which Si has been considered essential or Si accumulators containing high amounts of silicon are *Equisetum arvense*, *Cladophora glomerata*, *Synura petersenii*, *Oryza saliva* and *Saccharum officinarum* and these plants do not perform normal growth when deficient in Si while other plants benefit from addition of Si to the growing medium (Chen and Lewin, 1969; Elawad et al., 1982; Epstein, 1994; Klaveness and Guillard, 1975; Moore and Traquair, 1976). Silica promoted crop growth by increasing number of tillers, leaf area and photosynthetic activity of the lower leaves (Takahashi, 1961; Sadanandan and Varghese, 1968). The photosynthetic activity is improved by more erectness of rice which is ultimately provided by silica. Silica nutrition has direct and indirect beneficial effects on rice growth largely due to its unique physiological role (Okuda and Takahashi, 1965; Yoshida, 1975; Takahashi et al., 1990). Silicon application after transplanting increased tiller number (IRRI, 1965; Kim et al., 1985; Liang et al., 1994).

Silicon is responsible for improved growth in rice (Lewin and Reimann, 1969). Pawar and Hegde (1978) also observed that foliar spray of 100-400 ppm Si applied twice per week to rice seeding upto the booting stage increased tillering, vegetative growth and photosynthetic efficiency. silica in the soil increased dry matter yield and hastened heading. Maximum dry matter yield was found at > 40 ppm Si with drooping leaves cultivar showed a greater response to Si than those with erect leaves (Kang, 1981; Kang and Stutte, 1982; Kang, 1985).

Cheng (1982) and Savant et al. (1997) noted beneficial effects of Si on plant growth in terms of increased number of leaves, tillers, and alleviation of disorders like bronzing and ‘Akiochi’ in rice. Ma et al. (1989) observed that addition of 100 ppm SiO₂ as silicic acid during the reproductive stage markedly increased straw yield.

The maintenance of photosynthetic activity due to Si fertilization could be one of the reasons for the increased dry matter production (Agaric et al., 1992). The application of black to gray ash of rice hulls (at 0.5-2.0 kg m⁻²) made rice seedling healthy and strong and increased their biomass (Sawant et al., 1994). Addition of 100 mg Si kg⁻¹ soil increased plant height, dry matter production and leaf area ratio (Rani et al., 1997). Plant grown with added Si also maintained or had enhanced photosynthesis, translocation of carbon to panicles/seed, water use efficiency, transpiration and advanced from vegetative to reproductive growth (Savant et al., 1997).
Silicon on yield attributes

Application of silicon in rice is found to increase the grain yield by increasing spikelets number panicles\(^1\), mature grain percentage and 1000 grain weight (Takahashi, 1961; Tasman, 1988; Miah et al., 1990). Zang and Wang (1986) also reported 0.2-2.6 g higher 1000 grain weight with Si application over control. Addition of Si during the reproductive stage is also increased the percentage of filled spikelets by about 15% (Ma et al., 1989 and Singh et al., 2002). However, 1000 grain weight was very little influenced by the addition of Si regardless of the growth stage. Deren et al. (1994), Liang et al. (1994), Pershin (1995) and Hossain (1998) reported that spike number, filled grain percentage and grain shoot\(^1\) ratio markedly increased with the silica treated rice. Rani et al. (1997) found that silica application significantly increased grain yield by increasing the number of panicles plant\(^{-1}\), spikelets panicle\(^{-1}\), mature grains panicle\(^{-1}\), test weight and harvest index. Zhao et al. (1998) noted that Si application increased panicle length (0.4 cm) seed setting (2.65%), 1000 grain weight (0.23 g) of dry raised rice. The main effect of adding silicon was to increase the percentage of filled grains (70.4, 70.8% with 150 and 300 kg Si ha\(^{-1}\) respectively than control (65.%). (Zhu et al., 1999). Si application increased productive panicles and grains per panicle (Wang et al., 1999; Zhiquan et al., 1999). Vchimura et al. (2000) reported that silicon application increased the yield by increasing the percentage of ripened grains.

Silicon on yield

Increase in rice yield due to Si fertilization has been reported from various countries like Sri Lanka (Radrigo, 1964), Thailand (Takahashi et al., 1980), Indonesia (Burbey et al., 1988), India (Datta et al., 1962; Sadanandan and Varghese, 1968; Subramaniam and Gopalswamy, 1990), China (Liang et al., 1994) and U.S.A. (Datnoff et al., 1991). Zang and Wang (1986) reported that Si application increased rice yield by 10.1-20.1% in whitish and sandy soils. Rao et al. (1986) obtained respectively 2.2 to 5.1% and 10-14% increase in rice grain yield due to silicon application. Liang et al. (1994) reported that Si application increased the rice yields by 4.6-20.7 per cent. Pershin et al. (1995) found that 2-4 g SiO\(_2\) NH\(_4\)O/kg soil increased rice grain yield by 13-42 per cent. Lee et al. (1998) reported that rice hull ash with 91% Si applied at 11.25, 22.25 and 44.50 t ha\(^{-1}\) increased rough rice yields. Application of Si increased grain yield by 6.14 per cent (Zao et al., 1998; Ding et al., 2000). Zhu et al. (1999) reported that effect of commercial silica fertilizer (25% SiO\(_2\), 35% CaO) on the yield of hybrid rice. Yield increase of 8.52 and 14.72 per cent were achieved with 150 and 300 kg Si ha\(^{-1}\) respectively. Additional benefits are to be gained by amending soils with silicon as a standard production practice to increase rough rice yields (Lee et al., 2000). Silica application significantly increased grain yield up to 150 kg Si ha\(^{-1}\) (Singh et al., 2002 a).

Silicon on quality

Russian studies suggested a possible role of Si in protein synthesis (Aleshin and Avakyan, 1983; Aleshin, 1988). Silicon application affected grain ripening, hull formation as well as grain quality (Seo and Ota, 1983; Lee et al., 1990). Supply of Si also influenced carbohydrates, protein and phenol contents in rice plants and these changes varied slightly with the stage of the crop and plant part (Rani et al., 1997). The palatability of the rice grown with silicon application tended to superior to that of the rice grown without silicon application. Silicon application lowered the protein contents in milled rice and increased the maximum viscosity (Vchimura et al., 2000).

Silicon on Nutrient Uptake

Nitrogen: Silicon application
enhanced more optimal use of nitrogen (N) applied to rice (Savant et al., 1997) but N may also have decreased acquisition of Si, especially by NH₄-N applied during early growth compared to NO₃-N (Cheng, 1982). Growth showed greater promotion due to applied Si with intermediate and high N than with low N (Kang and Stutte, 1982). N fertilization tends to make rice leaves droopy, since leaves are generally longer, wider, thinner and have more area, while leaves of plants receiving added Si generally remain erect, less curved, more vertical and thicker (Cheng, 1982; Savant et al., 1997). Kang (1985) also reported that ethylene evolution decreased with N and Si application in field experiments. In erect type rice plants ethylene evolution decreased because of N whereas in droopy type it reduced due to N and SiO₂ application. Addition of N particularly enhanced lodging because of enhanced growth whereas plant grown with Si as well as high N showed greater resistance to lodging (Lee et al., 1990) and decreased N acquisition was attributed to high Si (Deren, 1997). However, Zhiquan et al. (1999) found that silicon promotes nitrogen uptake by rice raising it by 2.95 kg/mu (1mu = 0.067 ha) and the percent uptake by 14.8%.

Phosphorus: Si increased P in grain and straw in rice grown without P and the enhanced P was attributed to enhanced translocation of P from roots to shoots (IRRI, 1965; 1966). Si application increased Si and P uptake (Rani and Narayanan, 1994; Wang et al., 1999).

Potassium: Potassium deficiency reduced Si accumulation in the epidermal cells of the leaf blades leading to increased susceptibility to blast (Noguchi and Sugawara, 1966). Schelhass and Muller (1977) also found that application of CaSiO₃ resulted in a strong increase of Si uptake, but significant effect on yield was only obtained at high levels of Si and K. Similarly silica application (140 and 250 kg Si ha⁻¹) increased upland rice yield to applied K (Burbey et al., 1988).

Other nutrient: Many of the mineral nutrients were affected by added Si depending on plant and growth conditions. Added Si increased P, Ca and Mg (Islam and Saha, 1969) and Zn (Lewin and Reiman, 1969) in rice. However, it decreased Fe translocation and increased the movement of Mn from straw to grain (Verma and Minhas, 1989).

Silicon uptake

Silicon has been described as being absorbed actively and passively as well as excluded by roots (Epstein, 1994; Hodson and Evans, 1995; Savant et al., 1997). However, silicon absorption by rice roots has been considered to be active because of its accumulation against such high concentration gradients and linkages with aerobic respiration and anaerobic glycolysis (Savant et al., 1997).

Nayar et al. (1982) and Singh et al. (2002b) found that silica content in the harvested straw was less than 11%, the reported critical limit for optimum growth and yield of rice was obtained as 3.7% Si in rice straw. The silica content of the leaf blade, culm and whole plant increased with progress of growth and was low during the vegetative period and high after flowering. Silica absorption was slow during the initial growth stage but increased with the onset of reproductive growth period. Zang and Wang (1986) also found that production of 1 t rice grain receded 130 kg silica. Zhao and Jiang (1987) considered that silicon content in culms, leaves and sheaths was 8.8-10.2, 16.8-22.0 and 14.4-20.6 per cent respectively. Ma et al. (1989) reported that effect of addition and removal of 100 ppm SiO₂ as silicic acid during vegetative, reproductive and ripening stages on plant growth. About 66% of Si in whole plant and 70-75% of that in the leaf blades was absorbed during the reproductive stage. About 75% of the Si in
the panicle was absorbed during the vegetative and reproductive stages was present in the leaf blades, where as only 20-30 per cent of that absorbed during the ripening stage was present in the leaf blades. Silicon content of different plant species is related to their ability to silicon uptake (Takashi et al., 1990). Three modes of silicon uptake are recognized i.e. active (rice plant), passive (cucumber plant) and exclusive (tomato plant). Although the active Si absorption by rice starts after tillering stage (Kato and Owa, 1990) or after stem elongation (Chen, 1990). Silicon concentration of leaves increased with supplied silicon and was closely correlated with the silica bodies per unit leaf area in the epidermal system (Agarie et al., 1996).

REFERENCES


