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Use of silicon in rice crop in coastal region of Maharashtra: A review of research

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Abstract
Silicon (Si) is a tetravalent element and the second most abundant element after oxygen in soil which comprises about 28% of the earth's crust. Silicon is required by the every crop but the role of silicon is not specific in every crop that's why the application of the silicon and essentiality of the silicon is not specified yet with the crop and soil. If we think about the water storage, we are now a days taking tube wells at different depths and accordingly, we are opposing the practice of boring the tube wells because it is our very basic need and without which we cannot survive so we are trying to conserve the water by reducing the practice of boring. At the same time, if we think about the crop cultivation, we are cultivation different crops without application of the silicon to it but when we analyse the yield of plant and residue of the plant in that residue and yield components silica is present at varying level from the silica accumulator to less silica accumulator. The things are just telling that the continuous mining without application of the silicon to the soil it may hampers the content of silicon in the earth crust which has been approximately 28% since I am studying but I am not sure about that the same per cent of silicon is present today also in the earth crust. So I tried to point out the importance of silicon in agriculture in this review article along with the different forms of the silicon present in the soil and different methods by which different scientist have been analysed till today.

Keywords: Silicon, silicic acid, forms, available silica

Introduction
Silicon (Si) is a tetravalent element and the second most abundant element after oxygen in soil which comprises about 28% of the earth's crust (Elawad and Green, 1979; Epstein, 1991 and Singer and Munns, 1987) [11, 43]. Total silicon content in the soil ranges from 25 to 35 per cent. But the most sources of Si in soil are present as crystalline alumino silicates, which are insoluble and not directly available for plants (Richmond and Sussman 2003) [36]. The highly weathered soils such as latosols or latosolic red soils in the tropics where desilification and fersialization process are extremely active, Si can be low as < 1 % and its availability in soil depends on soil forming processes and consequently on soil types. The plant-available form of Si is monosilicic acid (H4SiO4) which is present in the soil solution. Si is observed in varying amounts in all plants ranging from 0.1 to 10 %.
As per as the desilification is concerned, this process is less in Mollisols which are dominant in Feldspars, vermiculites etc. These process increases the availability of the silica. In this type of soil, soil silica sesquioxide ratio is more. There is an arrangement of soil orders which reflects the process of desilification is given as followed Oxisols> Ultisols> Alfisols> Inceptisols> Vertisols> Mollisols. It clearly indicates that the silica sesquioxide ratio increases the availability of the silica as the minerals get weathered with acids.
The available Si in soils are monosilicic acid form in soil solution and some part of the silicate components that can be easily converted into monosilicic acids such as polymerized silicic acid, exchangeable silicates and part of colloidal silicates. If we consider, the availability of silica at various pH ranges. The pH 2–9, Si in soil is mainly present in mono- silicic acid form and conversion of monosilicic acid into ionic silicates is possible only at pH above 9. There are many factors of Si availability or Si-supplying power which influences the availability of silica are types of soil and parent material which are the major factors and some factors like historical land-use change, soil pH, soil texture, organic matter (Kawaguchi and Kyuma 1977; He and Li 1995; Cai *et al.* 1997; Sumida 2002; Husnain *et al.* 2008; Struyf *et al.* 2010) [24, 45, 8, 46, 18, 45]. Silicon abundance shows its importance in the processes of soil formation and properties of soils Even though it has long been neglected by ecologists/physiologists, as it is not considered an essential nutrient for plants.

However, the different studies showed that it is beneficial for the growth of many plants including major crops such as rice, wheat and barley. For instance, Si has been found to enhance the resistance against pests, pathogens and abiotic stresses such as salts, drought, cold and storms. Silicon also plays an important role in the development of 'sustainable' rice production systems with lower input of harmful pesticides. As we know now a day, there is trend of premium pricing for the organic product or low residue produces. Accordingly, silica application may be helpful for reducing the residue in agricultural produces with the minimum applications of the pesticides and fungicides.

The soluble Si helps in improving the growth, development, yield and other secondary metabolic activities of several plant species like rice, sugarcane, wheat and some dicotyledonous species. If we consider the coastal belt of the India, rice is the major growing cereal because most of the regions are having heavy rainfall in the *kharif* season. However, we can focus majorly on the rice crop for more production in coastal belt. Rice is known as silicon accumulator. Silica accumulator crop means the crop which is having Si above 1% of dry weight. There is a need to consider silicon as an agronomically essential element for increasing rice production (Takahashi and Miyake, 1977; Yoshida, 1981) [48, 51].

In rice, Si accumulation is about 108% greater than that of the nitrogen. It is estimated that a rice crop producing a total grain yield of 5000 kg ha^{-1} will remove Si at 230 to 470 kg ha^{-1} from the soil (Savant *et al.* 1997) [38]. The content of Si in rice shoots cannot be accounted for only by diffusion and transpiration (Elawad and Green, 1979) [11]. The concentration of Si in the xylem of rice is usually many times higher than that of the soil solution; indicating that the uptake of Si might be metabolically driven (Takahashi, 1995) [47]. In rice, additive and non-additive genes seem to be involved in the mechanism of Si absorption (Majumder *et al.* 1985) [29]. Silicon is deposited in the form of silica gel or opal as amorphous $SiO_2 \cdot nH_2O$ in cell walls and intercellular spaces of root and leaf cells also in bracts the silica get accumulated (Lanning, 1963; Yoshida, 1965; Yoshida *et al.* 1962) [26, 50, 52]. Silicon also can be found in the form of monosilicic acid, colloidal silicic acid, or organosilicon compounds in plant tissues (Inanaga *et al.* 1995; Yoshida *et al.* 1962) [19, 52].

There are so many beneficial effects of Si to plants under biotic and abiotic stresses which have been reported to occur in rice by so many researchers. Silicon application increases resistance to lodging and drought in rice crop which increases the dry matter accumulation (Epstein, 1991; Lee *et al.* 1981) [12, 27]. Silicon can positively affect the activity of some enzymes involved in the photosynthesis in rice (Savant *et al.* 1997) [38] as well as reduce the senescence of rice leaves (Kang, 1980) [22]. Silicon can lower the electrolyte leakage from rice leaves and therefore, promote greater photosynthetic activity in plants grown under water deficit or heat stress (Agarie. *et al.*1998) [1]. Silicon increases the oxidation power of rice roots, decreases injury caused by climate stress such as typhoons and cool summer damage in rice (Hodson and Sangster, 2002; Savant *et al.* 1997) [16, 38]. Silicon reduces the toxicity effects of the elements such as manganese, iron and aluminum to roots of plants of rice and also increases the rice resistance to salt stress (Horiguchi, 1988; Savant *et al.* 1997) [17, 38].

In warm sub-humid and humid tropical eco-regions, a high degree of weathering, mainly as desilication, has resulted in the development of soil orders rich in iron and aluminum oxides and low in nutrient bases and Si (Juo and Sanchez, 1986) [21]. As a result of Si leaching, the soluble Si content of tropical soils, such as Ultisols and Oxisols, is generally less than in most temperate soils (Foy, 1992) [13]. This might be one of the unidentified causes of lower rice productivity of many tropical/subtropical soils compared to with that of temperate soils (Savant *et al.* 1997) [38]. Although most soils can contain considerable levels of Si, repeated cropping can reduce the levels of plant-available Si to the point that supplemental Si fertilization is required for maximum production. Silicon depletion can occur in traditional rice soils from the continuous monoculture of high yielding cultivars with intensive cultivation practices (Miyake, 1993) [30] especially if farmers are not replacing the silicon removed by rice.

Konkan, coastal region of Maharashtra is mono-cropped with rice and it is the only crop grown during *kharif* season. The soils of the *Konkan* region can broadly be grouped into lateritic and medium black. The region has a long sea coast and because of this, some area is covered under coastal saline and coastal alluvial soils. Out of the nine agro-climatic zones of Maharashtra, the Konkan region covers three zones *viz.*, very high rainfall lateritic zone, very high rainfall non-lateritic zone and ghat zone. The very high rainfall lateritic and non-lateritic zones are important for cultivation of crops. The annual rainfall in the region varies from 3000 to 4000 mm with a mean temperature of about 20^0C throughout the year.

Every single crop of rice grown on medium black, coastal saline and lateritic soils of Konkan region removes about 550 kg ha^{-1} of silica (Dhane, 2005) [10]. Because of heavy rainfall, warm and humid climate and high degree of weathering of Konkan region, desilication naturally occurs resulting in the depletion in the level of available silica in the soils. Under the circumstances, in the absence of addition of silica fertilizers, it is feared that the continuous mono-cropping of rice for a prolonged period in Konkan region might further deplete the available soil silica content. This might be one of the unidentified reasons for stabilizing/decreasing yields of rice in Konkan region.

The research is reviewed in respect of silica content, its uptake and significance in coastal region of Maharashtra.

Silica content in soils of Konkan

Phonde (1987) [34] studied lateritic soils from very high rainfall lateritic zone (VRL) at Dapoli, Wakavali, Awashi, Shirgaon, Lanja and Phodaghat locations and found 48.98 per cent of total silica, while in medium black soils from very high rainfall non-lateritic zone (VRN) at Dahanu, Palghar, Karjat, Pargaon (Panvel), Roha and Repoli (Mangaon) and found 55.90 per cent of total silica. Dhamapurkar (1999) [9] reported that the water soluble silica (SiO_2) content in typical lateritic soil at Dapoli was 22 kg/ha.

Dhane (2005) [10] reported total (hydrochloric acid insoluble) silica content in medium black soils (VRN zone) and lateritic soils (VRL zone) ranged from 44.5 to 60.7 and 37.72 to 50.9 with an average values of 53.03 and 49.64 per cent, respectively. The coastal saline soils from very high rainfall non-lateritic zone (VRN) had total SiO_2 content in the range of 47.3 to 64.5 with an average value of 56.88 per cent, while available (water soluble) silica content in medium black soils (VRN zone) and lateritic soils (VRL zone) ranged from 13.07 to 53.04 and 14.04 to 50.60 with an average values of 30.74 and 25.92 kg/ha, respectively. The coastal saline soils from very high rainfall non-lateritic zone (VRN) had available SiO_2

content in the range of 20.99 to 31.54 with an average value of 26.05 kg/ha.

Parchure, (2011) [32] reported the (water soluble) available silica content of medium black soil of Konkan at Regional Agricultural Research Station, Karjat varied from 36.98 to 59.27 kg ha^{-1} with mean value of 45.80 kg ha^{-1} and it was also revealed that the application of the rice husk ash with balance nutrient application improves the availability of silica as compare to other treatments. More, (2014) [31] estimated the available silica (water soluble) content from lateritic soils of *Konkan* region of Maharashtra which was varied from 48.10 to 66.27 kg ha^{-1}.

Silica content in rice husk, rice husk ash and rice straw

Rice husk, a major by-product of rice milling, contain about 8% Si depending on the variety, it can be recycled for use in a sustainable rice cultivation system. Rice straw contain about 8 to 10% Si, is other source of Si which can also be recycled within the farm. Silica content of rice straw of seventeen varieties/cultures released by Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (Maharashtra) was determined from the plant samples (straw only) collected at maximum tillering, panicle initiation and harvesting stage and it was observed that, silicon uptake by rice seedlings increased continuously from maximum tillering to harvesting stage in all the varieties/cultures. Silica content ranged between 7.15 to 8.30 per cent at maximum tillering stage, 8.70 to 10.05 per cent at panicle initiation stage and 10.05 to 11.50 per cent at harvesting stage in the various varieties/cultures (Anonymous, 1995) [1].

Kumbhar and Nevase (1995) [25] reported 81.0% SiO_2 content in black to grey rice husk ash prepared by burning rice husk in open field, it was amorphous in nature. Only the amorphous form of SiO_2 can be absorbed by plants. Crystalline SiO_2 from white or pink RHA is not available for plant. Further, the blackish-grey RHA prepared by burning husks in the open field for the field experiment at Karjat contained 34.0% Si, amorphous in nature, were reported by Savant and Sawant (1996) [7].

In Konkan, under very high rainfall non-lateritic zone, silica (SiO_2) content in rice straw of Palghar, Karjat and Roha locations was 8.78, 6.11 and 7.53 per cent, respectively. The silica content in straw, grown in coastal saline soils at Panvel was in between 4.28 to 9.49 per cent with an average value of 7.86 per cent. While in very high rainfall lateritic zone, the average silica content at Dapoli, Lanja and Phondaghat locations was 7.06, 7.87 and 9.07 per cent, respectively.

Effect of silicon on uptake, growth and yield of rice

Sawant and Patil (1994) [42] reported that rice husk ash (RHA) applied @ 1 kg per m^2 increases SiO_2 content of seedlings and reduces dead hearts in transplanted rice in medium black clay loam soils of Karjat. A Field experiment was conducted at Karjat revealed that application of RHA @ 1 or 2 kg m^{-2} seed bed alone or in combination with the application of rice straw @ 2.5 t/ha applied at the time of transplanting produced significantly superior grain yield over control. Similarly, application of RHA alone or in combination with rice straw minimized the stem borer incidence significantly (Anonymous, 1995) [2].

Talashilkar and Chavan (1996) [46] studied the effect of rice husk ash on yield, silicon uptake pattern and phosphorous uptake by 17 cultivars of rice. It was observed that, silicon uptake by all varieties increased with the stage of the crop as the crop age increased the silica content increased in the crop. It was also observed that addition of RHA significantly increased silicon content of rice at all three growth stages of rice. Response of silicon to P uptake was significantly influenced by all the cultivars. The straw and grain yield of rice increased significantly with an application of the (RHA) rice husk ash.

Savant and Sawant (1996) [7] conducted an experiment on nutrient composition of rice seedlings as influenced by application of rice husk ash (RHA) to seedlings in medium black clay loam soils of Karjat which showed that the increase in P, K and Si content with incorporation of RHA (Prepared by burning of husk in open field contained 34.07% Si and it was amorphous in nature) upto about 10 cm soil depth in raised beds before sowing seeds of rice variety Jaya, can make the rice seedlings more productive and help in reducing the incidence of leaf blast in the nursery and stem borer (dead hearts) after transplanting.

Rice straw–urea briquettes management consisting of incorporation of rice straw at 2 t ha^{-1} before transplanting and deep placement of urea briquettes immediately after transplanting had the potential to increase the productivity of small paddy fields in the warm sub-humid tropical region of Maharashtra (Bulbule *et al*. 1996) [7].

An experiment was conducted to study the effect of application of silicon on grain yield of rice on medium black soils of Karjat using RHA as a source of Si consisting three levels of Si (0, 25 and 50 kg SiO_2 ha^{-1}) with three rice varieties (Jaya, Palghar-1 and TKM-6). It was found that, the application of RHA @ 50 kg SiO_2 ha^{-1} applied at the time of transplanting produced significantly superior grain yield of rice variety Palghar-1. However, the application of RHA either 25 or 50 kg SiO_2 ha^{-1} has not affected the grain yield in case of rice variety TKM-6 and Jaya (Anonymous, 1997) [3]. In other field experiment, the significant highest grain yield (79.25 q ha^{-1}) of hybrid rice was recorded under the treatment UB-DAP + RHA @ 10 t ha^{-1} + Glyricidia @ 3 t ha^{-1} (Anonymous, 1998) [4]. The research experiment was carried out on silicon nutrition of rice as influenced by calcium silicate slag (45% SiO_2) in lateritic soils inferred that the integrated use of silicon in the form of calcium silicate slag, a by-product of steel industries, with deep placement of UB-DAP increased grain yield of rice with 4 t ha^{-1} calcium silicate slag (Anonymous, 1999) [6].

An investigation was done on the effect of silica application on yield of rice variety Karjat-3 on lateritic soils of Pangari Block, Wakawali using straw, rice husk ash and 'Super Harvest' a commercial Si content fertilizer (47.5% Si), as a source of Si, showed that highest grain yield (50.54 q ha^{-1}) was received with the application of 50 kg Si ha^{-1} through 'Super Harvest' along with recommended dose of NPK (Anonymous, 2005) [6].

Parchure, (2011) [32] reported the uptake of silicon as affected by different sources of fertilizers and manures applied with and without RHA as a source of silica. The silica uptake in various treatments varied from 59.60 to 330.57 kg ha^{-1} in grain, 107.63 to 643.58 kg ha^{-1} in straw and total uptake varied from 167.23 to 974.15 kg ha^{-1}. Maximum uptake (330.57 kg ha^{-1}) of silicon by grain was registered in the treatment where 2.5 t of glyricidia + UB-DAP+RHA were applied which was followed by the treatment where 2.5 t of glyricidia + Urea-Suphala briquettes+ RHA (323.60 kg ha^{-1}) was added. The same ranges of silicon uptake were also reported by Dhane (2005) [10]. The results revealed that total uptake of silicon by grain and straw increased significantly with the application of the rice husk ash as a source of silicon. The data clearly indicated that application of rice husk ash in combination with briquettes and RDF showed increase in silicon uptake by grain. Ma and Takahashi (1989) [28] reported that higher silicon uptake by grain and straw with the higher rate of silicon application.

Salvi *et al.* (2017) [37] reported that the grain and straw yield of rice were found to be significantly influenced by the application of glyricidia green manure, different formulations of briquettes and RDF through straight fertilizer with and without RHA. The grain (24.91 q ha^{-1}) and straw (28.77 q ha^{-1}) yield were recorded in absolute control. The grain and straw yield of rice increased significantly by the application of NPK fertilizer over control. The application of fertilizer in combination with RHA still produced higher grain and straw yield as compared to application of fertilizer alone. Increase in the yield due to application of silicon was also reported by Singh *et al.* (2006) [44]. Similarly, a three years trial conducted at Agricultural Research Station, Phondaghat showed that the treatment receiving rice hull ash green manuring 10 t ha-1+controlled transplanting and Urea DAP briquettes increased grain yield (61.28 q ha-1) and straw (62.00 q ha- 1) of Sahyadri rice (Savant and Sonar, 2010) [38]. The effect of silicon and SA on enhancing growth and nutritional status of the trees surely reflected on improving the yield. These results are in agreement with these obtained by Kanto (2002) [23] and Gad El-Kareem (2012) [13] on silicon.

Rane, (2017) conducted an experiment on various nitrogen and silica levels in the lateritic soil of *Konkan* region in paddy crop in which the grain yield of rice varied from 15.85 q ha^{-1} (control) to 44.94 q ha^{-1}. It was revealed from the experiment that, the highest grain yield of rice (35.99 q ha^{-1}) was recorded by the treatment in which 80 per cent RDN through KAB was applied which found statistically superior over rest of all the treatments. Regarding the application of different levels of silica, it was found that the highest grain yield of rice (31.21q ha^{-1}) was recorded in the treatment where silica @ 100 kg ha^{-1} was applied. There was huge difference between control and silica treated plot because at grain filling stage, pollen were washed out due to the high rainfall during 34 to 38 meteorological weak of 2017 but higher percentage of grain filled observed in silica treated plot. The same trend was observed in case of straw yield of rice. The straw yield of rice varied from 31.89 q ha^{-1} in control to 51.44 q ha^{-1}. It was observed that the application of different levels of nitrogen showed significant results with respect to straw yield of rice. The maximum straw yield (48.24 q ha^{-1}) was recorded in the treatment where 80 per cent RDN through KAB was applied which found significantly superior over rest of all the nitrogen treatments. It may be due to higher N rates, which primarily increased the chlorophyll concentration in leaves and there by higher photosynthetic rate and ultimately plenty of photosynthates available during grain development (Patil *et al.* 2015) [33].

The grain yield response to silicon application may be due to increased leaf erectness, decreased mutual shading caused by dense planting and high nitrogen application, nitrogen increases susceptibility to various diseases the occurrence of diseases in rice (Yoshida *et al.* 1962) [52]. Silicon fertilizer application decreased blank spikelet number in rice and that caused plant not to have enough carbohydrates to fill up all spikelet produced as the silicon fertilization produced as the silicon fertilizer level increased contribution to decrease the number of blank spikelet and to increase filled spikelet percentage. Patil *et al.* (2015) [33] reported that Si fertilization increased rice straw and grain yield.

Recent study on bio-efficacy of ‘Silixol’ (Stabilized silicic acid in liquid form) on rice in medium black soils of Karjat indicated that the application of silica in the form of Silixol spray containing 4.5% Si, is beneficial for increasing rice yield. The highest grain yield (83.16 q ha^{-1}) and straw yield (86.63 q ha^{-1}) was obtained with the treatment i.e. four sprays of Silixol at 20, 40, 60 and 80 days after transplanting @ 20L Silixol ha^{-1} (i.e. 0.05mL/sq.m./spray) with application of potash. But in further investigation on application of silica through ‘Silixol’ spray and silica containing briquettes (3.5% Si), the highest grain yield (52 q ha^{-1}) and straw yield (66.67 q ha^{-1}) was obtained with application of silica through briquettes.

Summary

The different reviews showed that the application of the silicon to the rice crop give beneficial effects in crop production and also overcome the biotic and abiotic stresses. The role of silicon not only as an essential nutrient but also as a beneficial nutrient was unnoticed because of its natural abundance. But if the application of more nitrogen was done then the crops become more succulent, prone to lodging and increased the incidence of pest and diseases which can be overcome by the application of silicon by which soil could be sustain. The plant available Si in soil is an important soil-related factor which may be closely associated with progressive yield declines experienced in Konkan. To the period of the issue of Si nutrition in rice production remains largely unknown. Identifying and implementing strategic Si nutrition management strategies may very well play a critical role for reversing deteriorating yield trends in Konkan a coastal region of Maharashtra. Si has been shown to affect the availability of phosphorus in the soil. There should be development and standardization of different sources of silicon and quantify the amount of different sources for the rice crop.

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