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Silicon nutrition to rice alleviates iron, manganese and aluminum toxicity in laterite derived paddy soils

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ABSTRACT

The beneficial role of silicon (Si) in alleviation of abiotic stress is well established. Toxicity of iron, manganese and aluminium are widespread in laterite derived paddy soils of Kerala. Plants undergo severe abiotic stress due to the toxicity of these elements. The aim of our work was to investigate the influence of silicon application to rice on alleviating toxicity of Fe, Mn and Al in laterite derived wet land paddy soils of northern Kerala. A pot culture experiment was laid out in completely randomised design replicated thrice with nine treatments using Aishwarya as the test variety. The results of the study indicated a significant decline in available Fe content (120 mg kg^{-1}) in soil in treatments receiving silicon compared to control (181 mg kg^{-1}). Decline was to the tune of 31% due to the foliar application potassium silicate @ 0.5% spray + borax 0.5%. Similar results were obtained with respect to available Mn and exchangeable Al content in soil. Higher silicon content (44.58 mg kg^{-1}) in soil was obtained with the soil application of calcium silicate @ 4 g kg^{-1} soil which was superior to foliar application of potassium silicate. The Fe and Mn content in straw and grain were decreased with application of silicon while its uptake in plant alone was significantly increased. Application of potassium silicate @ 0.5 % spray + borax 0.5 % spray thrice recorded maximum plant height (131.6 cm), number of productive tillers plant^{-1} (23.33), thousand grain weight (27.16 g), grain yield (68.30 g pot^{-1}) and straw yield (88.79 g pot^{-1}).

Key words: *Silicon, iron, rice, manganese and aluminium toxicity*

Rice is one of the most important staple crops in many countries. Rice yields are decelerating / stagnating / declining in post green revolution era mainly due to imbalance in fertilizer use, soil degradation and lack of suitable rice genotypes for low moisture adaptability and disease resistance (Prakash, 2010). Crop production in laterite soils has been found to be low due to several constraints. However, there is considerable scope for improving the productivity of soils through proper land management.

The mid land rice fields of northern Kerala mainly constitute the drainage basins of hills and hillocks. These basins usually accumulate all the leachates wash down from the hills. The soils being lateritic in nature the extent of reduced form of iron accumulating in such soils are high. These soils are acidic, generally having low levels of plant nutrients, low cation exchange capacity, deficient in Ca, Mg, B, Si and having toxic concentration of Fe, Mn and Al (Ma *et al*., 2001). This creates soil stress and the yields of rice crop grown in these soils are reduced, far below the yield potentials.

The prevailing form of silicon in soil solution is monosilicic acid (H_4SiO_4) (Ma and Takahasi, 2002). Hydrated, amorphous silica is deposited in cell lumens, cell walls, and intercellular spaces. It also accumulates in external layers below and above the cuticle of the leaves. Silicon is present in roots, leaves, and the inflorescence bracts of cereals, especially in rice, wheat, oats and barley. Silicon is the only element known that does not damage plants with excess accumulation. Rice is a high Si accumulator plant and this element has been demonstrated to be necessary for healthy growth and stable production. For this reason, Si has been recognized as an "agronomically essential element" in Japan and silicate fertilizers have since then been applied to rice soils (Ma *et al*., 2001). Iron and aluminum oxides of soil have the capacity to adsorb a considerable amount of silicon (Si) on their surfaces. Aluminum oxides are more effective in binding silicon through adsorption mechanism than iron oxides (Farmer *et al*., 2005).

Rice is a high silicon accumulating plant (Savant *et al*., 1997). Silicon is a beneficial element for plant growth and is agronomically essential for improving and sustaining rice productivity (Epstein, 1999). Besides increase in rice yield, Si has many fold advantages of increasing nutrient availability (N, P, K, Ca, Mg, S & Zn), decreasing nutrient toxicity (Fe, Mn & Al) and minimizing biotic and abiotic stress in plants (Ma, 2004). Hence the application of Si to soil or plant is practically useful in laterite derived paddy soils not only to increase yield but also to alleviate the iron toxicity problems. Therefore, the experiment deals with silicon application to rice on alleviating toxicity of Fe, Mn and Al in laterite derived wet land paddy soils of northern Kerala.

MATERIALS AND METHODS

A pot culture experiment was conducted at College of Agriculture, Padannakkad. The experiment was laid out in complete randomized design replicated thrice with test crop of rice variety Aishwarya. There were 9 treatments *viz.* T_1- Control- No Si and B, T_2- Calcium silicate @ 4 g kg^{-1} soil, T_3- Potassium silicate @ 0.5% spray thrice , T_4- Borax @ 0.5 g kg^{-1} soil, T_5 - Borax 0.5% foliar spray thrice, T_6- Calcium silicate @ 4 g kg^{-1} soil + borax @ 0.5 g kg^{-1} soil, T_7- Calcium silicate @ 4 g kg^{-1} soil + borax 0.5% spray thrice, T_8- Potassium silicate @ 0.5% spray + borax 0.5% spray thrice and T_9- Potassium silicate @ 0.5% spray thrice + borax @ 0.5g kg^{-1} soil.

Laterite derived paddy soil (10 kg) was filled in each pot for conducting pot culture experiment. The experimental soil was sandy clay belonging to the taxonomical order Inceptisol having pH 4.7, EC 0.16 dsm^{-1}, CEC 7.5 c mol (p$^+$) kg^{-1}, organic carbon 3.6 g kg^{-1} soil, available nitrogen 200.9 kg ha^{-1} available P_2O_5 15.68 kg ha^{-1}, available K_2O 152.32 kg ha^{-1}, available Fe 178.2 mg kg^{-1}, available Mn 38.5 mg kg^{-1}, exchangeable Al 340 mg kg^{-1} and available Si 24 mg kg^{-1}. Nitrogen, P and K fertilizers were applied as per package of practices recommendations (POP) of KAU (2011). Collected soil samples were analyzed for available N, P (Bray and Kurtz 1945) and K using standard methods (Jackson, 1973). Fe, Mn and exchangeable Al by atomic absorptions spectrophotometer and Si was analysed by photo colorimetry method (Korndorfer *et al*., 2001). Plant samples were analyzed for N by Kjeldahl method. Phosphorus was analyzed in diacid digest by vanadomolybdate yellow colour method, K by flame photometer. Total Fe and Mn were determined by atomic absorption spectrophotometer and Si by blue silicomolybdous acid method (Ma *et al*. 2003). Biometric observations *viz.,* plant height, number of productive tillers plant^{-1}, thousand grain weights, grain and straw yield were recorded. The results obtained were statistically analyzed using statistical analysis software (SAS).

RESULTS AND DISCUSSION

The results obtained from the present investigation revealed a significant reduction in HCl extractable iron and manganese content in soil for the application of silicon both as soil and foliar application (Table 1). Foliar application of potassium silicate @ 0.5% spray + borax 0.5% spray thrice (T_8) was superior to other treatments in reducing iron toxicity (120 mg kg^{-1}). But this did not affect the iron nutrition of rice as indicated by the absence of any significant decrease in total iron uptake by rice. Instead the uptake of iron in grain and straw were enhanced. Hence, it can be concluded that the treatment could reduce iron toxicity in the soil because

Table 1. Effect of silicon on content of Fe, Mn and Al in soil

Treatments	HCl extractable Fe (mg kg^{-1})	HCl extractable Mn(mg kg^{-1})	Exchangeable Al(mg kg^{-1})
T_1	181.0	38.20	340.6
T_2	135.0	25.96	227.6
T_3	139.6	26.53	248.0
T_4	178.3	36.26	290.3
T_5	170.0	35.76	304.0
T_6	121.0	25.60	248.3
T_7	122.3	27.90	260.0
T_8	120.0	25.70	235.3
T_9	136.3	28.76	264.6
CD (P<0.05)	17.3	1.16	36.1

application of silicon improves the air passages in the leaves and stem of the plant and permits the passages of air for the leaves to the stem and finally to the roots. This enhances the oxidative power of rice roots and results in enhanced oxidation of iron from ferrous iron to ferric iron which reduces the toxicity of iron in soil as reported by Wallace, 1992.

The available Mn content of soil was significantly reduced by the application of silicon as both soil and foliar sprays (Table 1). Application of calcium silicate @ 4 g kg^{-1} soil + borax @ 0.5 g kg^{-1} soil (T_6) (25.60 mg kg^{-1}) was superior. This may be due to the influence of silicon in improving the oxidizing power of the rice roots as reported by Wang *et al.*, 1994.

Application of calcium silicate @ 4 g kg^{-1} soil (T_2) was superior in reducing the toxicity of Al in soil (227.6 mg kg^{-1}) (Table 1). The silicon applied to soil would have formed complexes with Al which would have reduced the concentration of Al in the soil (Wallace, 1992).

The silicon availability showed a concomitant increase with application of silicon as soil and foliar spray (Table 2). The silicon availability increased from maximum tillering stage to flowering stage and then decreased at harvesting stage. This decrease may be due to increased absorption of silicon by the plant at vegetative and reproductive stages. At flowering stage significantly higher available silicon was observed in the treatment receiving calcium silicate @ 4 g kg^{-1} (T_2) (44.58 mg kg^{-1}) soil while at the harvesting stage calcium silicate @ 4 g kg^{-1} soil + borax @ 0.5 g kg^{-1} (T_6) soil was superior (38.50 mg kg^{-1}). The silicon applied as soil application of calcium silicate would have prevailed in soil as monosilicic acid (H_4SiO_4) and enhanced soil silicon availability as reported by Sing *et al.*, 2006 and Chaudhari *et al.*, 2015).

The iron content in straw and grain were found to decrease with treatments receiving silicon while its uptake in plant alone was significantly increased. Application of calcium silicate @ 4 g kg^{-1} soil + borax @ 0.5 g kg^{-1} soil (T_6) resulted in significantly lower content of iron in both straw (333.3 mg kg^{-1}) and grain (119.6 mg kg^{-1}) (Table 3). The HCl extractable iron in the soil was also low for the above treatments due to the favourable effect of silicon in improving the oxidation power of rice roots thereby reducing iron toxicity in the soil. This might have resulted in reduced absorption of iron and this coupled with the dilution effect attributed to high dry matter production would have contributed to the reduced content of iron in straw and grain. However the total uptake of iron (2.99 g pot^{-1}) by the plant was significantly higher in the treatment receiving potassium silicate @ 0.5 % spray + borax 0.5 % spray thrice (T_8) (Table 3). This can be attributed to the higher dry matter production associated with this treatment. Similar results reported by Qiang *et al.*, 2012.

The application of potassium silicate @ 0.5 % spray + borax 0.5 % spray thrice (T_8) resulted in significantly lower content of Mn in grain (237.4 mg kg^{-1}) and straw (123.8 mg kg^{-1}) (Table 4). This may be due to dilution effect. The increased dry matter production in straw and grain might have resulted in

Table 2. Silicon content in soil at different stages of rice

Treatments	Silicon (mg kg^{-1})		
	Maximum tillering stage	Flowering stage	Harvesting stage
T_1	25.00	25.25	23.91
T_2	26.08	44.58	37.66
T_3	27.50	35.25	32.83
T_4	26.08	27.08	25.66
T_5	26.41	27.83	26.16
T_6	27.50	43.75	38.50
T_7	26.25	43.00	36.25
T_8	26.08	32.08	27.83
T_9	25.91	33.33	29.91
CD (P<0.05)	NS	5.03	5.82

Table 3. Effect of silicon iron content in straw, grain and total uptake by plant

Treatments	Fe content (mg kg^{-1})		Total uptake (g pot^{-1})
	Straw	Grain	
T_1	431.6	216.0	1.90
T_2	390.0	128.3	2.70
T_3	396.0	127.6	2.56
T_4	422.6	194.3	2.68
T_5	424.6	215.3	2.74
T_6	333.3	119.6	2.70
T_7	339.3	148.3	2.49
T_8	336.0	124.0	2.99
T_9	342.0	157.3	2.27
CD (P<0.05)	8.4	25.1	0.07

Table 4. Effect of silicon on the manganese content in straw, grain and total uptake by plant

Treatments	Mn content (mg kg^{-1})		Total uptake (g pot^{-1})
	Straw	Grain	
T_1	365.0	139.3	1.61
T_2	326.6	131.6	2.27
T_3	314.6	131.3	2.03
T_4	359.2	135.9	2.27
T_5	326.6	132.6	2.10
T_6	293.3	125.6	2.38
T_7	227.3	126.0	1.67
T_8	237.4	123.8	2.11
T_9	306.6	129.3	2.03
CD (P<0.05)	14.3	10.6	0.11

Table 5. Effect of silicon on the silicon content in straw, grain and total uptake by plant

Treatments	Si content (%)		Total uptake (g pot^{-1})
	Straw	Grain	
T_1	2.80	1.23	1.65
T_2	5.18	3.61	5.51
T_3	5.20	3.20	4.93
T_4	3.20	1.36	2.68
T_5	3.11	1.45	2.72
T_6	4.05	2.88	5.07
T_7	4.13	2.53	4.45
T_8	5.35	3.68	7.26
T_9	5.18	3.25	5.09
CD (P<0.05)	0.63	0.61	0.62

decreased content of Mn, as reported by Marschner, 1995. There was significantly higher uptake (2.38 g pot^{-1}) of Mn associated with the treatment receiving calcium silicate @ 4 g kg^{-1} soil + borax @ 0.5 g kg^{-1} soil (T_6) (Table 4). The available Mn content of soil is the lowest in these treatments which would have helped in reducing Mn toxicity in rice. This would have resulted in better adsorption of all nutrients including Mn by the plant which has reflected in the higher uptake of Mn by the plant.

The silicon nutrition of rice evaluated in terms of concentration and uptake was naturally influenced by silicon fertilization as calcium silicate (soil application) and potassium silicate (foliar spray). With respect to content and uptake of silicon, application of potassium silicate @ 0.5 % spray + borax 0.5% spray thrice (T_8) was significantly superior to other treatments. Foliar application of potassium silicate @ 0.5% proved to be superior to soil application of calcium silicate. However it should be noted that with respect to available silicon in soil, soil application of calcium silicate was superior to foliar application of potassium silicate (Table 5). Hence, it can be presumed that the foliar application of potassium silicate (0.5%) would have resulted in better absorption and translocation of silicon compared to soil application of calcium silicate which would has reflected in the significantly higher content and uptake of Si in plant (Singh *et al*., 2006).

Application of potassium silicate @ 0.5 % spray + borax 0.5 % spray thrice (T_8) recorded maximum plant height (131.6 cm) and number of productive tillers $plant^{-1}$ (23.33). The thousand grain weight of 27.16 g, grain yield of 68.30 g pot^{-1} and straw yield of 88.79 g pot^{-1} were obtained in the treatment (T_8) receiving potassium silicate @ 0.5 % spray + borax 0.5 % spray 3 rounds (Table 6). The tune of increase in grain yield

Table 6. Effect of silicon on yield and yield attributes of rice

Treatments	Plant height (cm)	Number of productive tillers $plant^{-1}$	Thousand grain weight (g)	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
T1	91.6	14.66	23.00	33.96	44.15
T2	110.0	18.33	25.53	53.30	69.29
T3	107.3	17.00	25.70	49.63	64.52
T4	115.0	16.33	25.80	48.63	63.22
T5	105.0	19.00	25.10	50.96	66.25
T6	120.0	21.33	26.03	62.30	80.99
T7	101.6	19.33	24.80	56.30	73.19
T8	131.6	23.33	27.16	68.30	88.79
T9	106.6	17.00	24.86	49.46	64.30
CD (P<0.05)	18.6	4.53	1.01	0.88	1.15

in the superior treatment was 34.34 g pot^{-1}. This can be attributed to the significant increase in available nutrients and positive influence on the availability and uptake of macro and micronutrients except Fe and Mn, as reported by Gholami and Falah, 2013; Ahmad *et al*., 2013.

It may be concluded that application of potassium silicate @ 0.5 % spray + borax 0.5 % spray thrice at 15 days interval significantly improved the available nutrients in soil, the content and uptake of silicon by the plant and maximum plant height, number of productive tillers plant^{-1}, thousand grain weight, grain yield and straw yield of rice. It was also effective in reducing the toxicity of Fe, Mn and Al in the paddy soil.

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