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Effect of various silicon sources on nutrient uptake by rice and available nutrient status in soil

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Abstract
Silicon nutrition is gaining importance in agriculture owing to its positive effects in rice production. A field experiment was carried out at the farmer's field in Kerala during *Kharif*, 2016 to evaluate different silicon sources on nutrient uptake by rice and available nutrient status of soil after the harvest. Field was laid out in randomised block design with seven treatments and replicated three times. Different silicon sources viz., potassium silicate, fine silica, rock dust, rice husk ash were involved in the treatments and fertilizer application was done according to the recommended dose of fertilizers as per Kerala Agricultural University, Package of Practice. Silicon nutrition have shown significant influence on the total nutrient uptake by the crop and available soil nutrient status of soil after the harvest. Among the treatments, fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}, has shown the better results with respect to nutrient uptake by the crop and available nutrient status of the soil after the harvest.

Keywords: silicon, rice, nutrient uptake, nutrient status

Introduction

Rice is the main staple food crop of Kerala. The rice farming sector of Kerala is facing an extreme decline in area and production due to numerous soil related constraints like Iron and Aluminium toxicity and high acidity of the soils of the state (Maneesh *et al.*, 2016) [15]. Majority of Kerala soils are lateritic in nature (low in Organic carbon, N and K, very low in Ca and Mg) which need separate management package. The foremost reasons behind the low productivity of rice in laterite soils of Kerala mainly in lowland situations is due to the low nutrient status of the soil coupled with the iron and aluminium toxicities (GOK, 2016) [6].

Silicon (Si) is one of the abundant element in the earth's crust with nearly 29 percent mean content. Silicon is known to have several beneficial effects on crop growth, especially for Poaceae crops like Rice (Devanur, 2015; Rao, 2017) [3, 19]. The potential of silicon in enhancing/improving rice yield has been demonstrated in numerous studies especially under biotic and abiotic stress conditions (diseases, insect pests, drought, salinity, heavy metals) (Epstein, 2001) [4]. Silicon is known to reduce the concentration of toxic elements like Fe, Al, other heavy metals in laterite derived paddy soils and also improve soil physical properties and available nutrient status in soil (Devanur, 2015) [3]. Rice being a high Si demanding crop, increasing rice yield per unit area is relatively associated with Silicon depletion, which is a matter of concern. In general farmers export silicon from field by removing straw residues with the harvest and the exogenous application of silicon in rice is overlooked. Therefore, a continued supply of Silicon would be required predominantly for the healthy and productive development of plant during all growth stages (Savant *et al.*, 1997; Epstein, 2001) [20, 4]. With this background the present investigation was undertaken with an objective to assess the effect of silicon nutrition in rice on total nutrient uptake by the crop and available nutrient status of soil after the harvest.

Materials and Methods

The field experiment was conducted at a farmer's field in Kerala, during *Kharif* 2016. The soil of the experimental site was sandy clay loam, acidic in nature (pH 4.50), high in OC (1.01%) and safe EC (0.10 dS m^{-1}). The initial nutrient status of the soil were N (550.5 kg ha^{-1}), P (16.86 kg ha^{-1}), K (196.90 kg ha^{-1}) and Si (45.02 kg ha^{-1}) respectively. The experiment was laid out in randomized block design with seven treatments and three replications with each plot size of 5 m x 4 m using Rice variety Uma, which was transplanted during first week of July with a spacing of 20 x 15 cm. All treatments were supplied with similar recommended dose of fertilizers i.e. Lime @ 150 kg ha^{-1} + farm yard manure @ 5 t ha^{-1} + NPK @ 90:45:120 kg ha^{-1} (KAU, 2016) The treatments are, T_1: Fine silica @ 100 kg ha^{-1}; T_2: Fine silica @ 75 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}; T_3 : Fine silica @ 75 kg ha^{-1}+ foliar application of K_2SiO_3 at maximum tillering stage @ 0.5%; T_4 : Fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of K_2SiO_3 at maximum tillering stage @ 0.5%; T_5: Fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}; T_6: Fine silica @ 50 kg ha^{-1} + rice husk ash @ 250kg $ha^{-1;}$ T_7: Fine silica @ 50 kg ha^{-1} + rice husk ash @ 125kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%**.** Silicon sources such as fine silica, rock dust, and rice husk ash were applied basally as per treatments at transplanting, and foliar application of potassium silicate @ 0.5 % at maximum tillering stage. Soil samples were analysed for available nutrient status before and after the harvest of the crop and expressed as kg $ha^{-1.}$. Plant samples were collected at harvest stage and analyzed for different nutrients *viz.,* N, P, K and Si. The total uptake of N, P, K and Si by the plant at harvest was calculated as the product of the respective nutrient content and plant dry weight and expressed as kg $ha^{-1.}$ The data obtained were subjected to statistical analysis and were tested at five per cent level of significance to interpret the treatment differences.

Results and Discussion

Effect of silicon on nutrient content in rice straw, grain and total nutrient uptake

The data with respect to N content in grain, straw and total N uptake are presented in Table 1. The silicon nutrition had no shown significant influence on N content in grain and straw, but total N uptake increased significantly by silicon nutrition. With respect to total N uptake, T_6 (Fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) was superior with the uptake of 189.74 kg ha^{-1}. The available N content of soil was also low for the above treatment after harvest compared to the initial soil N. This might naturally be due to enhanced absorption of N by the crop ultimately leading to higher N uptake by plant, resulting in low available N status in soils. Similar results have also been reported by Devanur (2015) [3] and Chanchareonsook *et al.,* (2002) [2].

The data with respect to P content in grain, straw and total P uptake are presented in Table 1. Phosphorus concentration in plant and uptake of P were positively influenced by silicon application. Treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) produced significantly higher content of P in grain and total P uptake, probably because this treatment received the highest quantity of silicon *i.e.* 200 kg ha^{-1}. The P content of straw was also found to be the highest in T_6 (0.07 %), followed by T_7 (0.06 %). The available P content in the soil after the experiment was also high in the above treatments. The monosilicic acid anions released from silicon sources might have replaced the phosphate anions released from Fe and Al phosphate, which might have resulted in higher P content and uptake by the plants. Increase in P uptake by the rice crop increased from 26 to 34% when P as single superphosphate was applied along with a silicate fertilizer (Savant *et al.* 1997 and Ma and Takahashi 1991) [20, 12]. Tavakkoli *et al.* (2011) [25] reported that overall beneficial effect of silicon may be attributed to a higher P: Mn ratio in the plant shoot due to the decreased Mn and Fe uptake, and thus indirectly improving P utilization within the rice plants. Addition of silicon fertilizers also increased the pH in acid soils which will release P from Fe-P and Al-P complexes (Suekisha *et al.,* 1963) [23]. Ma and Takahashi (1991) [12], noticed significant increase in shoot dry weight with increased application of P when silicon was applied suggesting silicon application raised the optimum P level in rice.

Table 1: Effect of silicon nutrition on the N and P content in grain, straw and total N and P uptake by plant

Treatments	N content (%)		Total N uptake (kg ha^{-1})	P content (%)		Total P uptake (kg ha^{-1})
	Grain	Straw		Grain	Straw	
T_1	1.46	0.97	166.73	0.15	0.04	12.08
T_2	1.45	1.01	164.49	0.14	0.03	10.39
T_3	1.45	0.95	166.02	0.14	0.04	11.52
T_4	1.42	1.03	169.30	0.15	0.05	12.86
T_5	1.51	0.97	175.25	0.16	0.06	14.49
T_6	1.55	1.04	189.74	0.18	0.07	17.19
T_7	1.56	0.99	181.36	0.17	0.06	15.44
S E m±	0.096	0.051	4.582	0.000	0.000	0.112
CD (0.05)	NS	NS	9.985	0.005	0.009	0.243

The data with respect to K content in grain, straw and total K uptake are presented in Table 2. The content of K in grain, straw and total uptake of K by rice crop increased with silicon application. Fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5 % spray (T_7) and fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6) were significantly superior with respect to K content in straw. However, T_7 was found to be the treatment with highest grain K and total K uptake. Soil application of silicon has synergistic interaction with applied K and also promotes the release of K from the exchange sites to the soil solution by the hydrogen ions produced during the oxidation of Fe and Al compounds (Savant *et al.,* 1997) [20]. Silicon application increased yield response to applied potassium in upland rice (Burbey *et al.,* 1988) [1]. Similar beneficial effect of silicon fertilizers on K content in plant and K uptake are reported by Singh and Singh (2005) [5], Liang (1999) [11] and Sunilkumar (2000) [24].

Table 2: Effect of silicon nutrition on the K and Si content in grain, straw and total K and Si uptake by plant

Treatments	K content (%)		Total K uptake (kg ha^{-1})	Si content (%)		Total Si uptake (kg ha^{-1})
	Grain	Straw		Grain	Straw	
T_1	0.40	0.95	105.81	0.76	3.20	322.78
T_2	0.36	0.93	99.82	0.61	2.8	273.89
T_3	0.39	0.97	107.25	0.68	3.11	311.19
T_4	0.37	0.95	104.84	0.59	2.9	282.27
T_5	0.50	0.96	113.10	0.85	3.21	330.11
T_6	0.56	1.06	127.38	0.92	3.29	345.14
T_7	0.86	1.09	147.07	0.96	3.37	352.93
S E m±	0.115	0.036	1.414	0.051	0.057	2.192
CD (0.05)	0.059	0.082	3.082	0.108	0.125	4.778

Silicon content in rice straw, grain and total uptake

The data with respect to Si content in grain, straw and total Si uptake are presented in Table 2. The silicon nutrition of rice evaluated in terms of concentration and uptake of silicon was influenced by silicon fertilization. With respect to silicon content in grain and straw, T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250kg ha^{-1}) were significantly superior to other treatments. Silicon supply in T_7 was less, but foliar application of potassium silicate helped to improve silicon uptake. However, with respect to available silicon in soil, T_6 was superior to T_7. According to Ma and Yamaji (2008) [13], the increase in plant available silicon in the soil was usually accompanied by increased silicon accumulation in the plant, which might have result in increased growth and productivity in several crops, especially rice. Silicon content of rice straw shows large variations from 1.7 to 9.3%. (Yoshida, 1978) [27] and is influenced by several factors such as soil, irrigation water quality, amount of fertilizers applied, rice cultivars and season (Ponnamperuma, 1984) [16]. The straw silica content of rice at harvest ranged from 4.8 to 13.5% in dry season and from 4.3 to 10.3%, in wet season (Devanur, 2015) [3]. Similar observations were also reported by Pawar and Hegde (1978) [17], Savant *et al.* (1997) [20].

Effect of silicon on available nutrient status of soil

The data on available nutrient (N, P, K and Si) content in soil are presented in Table 3. The available N content in the soil was not significantly influenced by the treatments. The treatments had not shown significant effect on available N in soil, but when compared to initial soil N status, there was a decline in soil N status in all the treatments. This decrease in available N in soil might be due to enhanced uptake of soil N, because silicon in soil has the ability to raise the optimum N rate, thus enhancing the productivity of existing lowland paddy fields. These results are in confirmation with the work done by Yoshida *et al.* (1969) [26], Ho *et al.* (1980) [8] and Chanchareonsook *et al.* (2002) [2].

The available P content in soil was significantly higher in the case of application of fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1} (T_6), followed by T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) and T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}). This increase in P might be due to the possibility of replacing the phosphate anion $[HPO_4]^{2-}$ from Al and Fe phosphates by monosilicic acid $[Si(OH)_3]^-$ of silicon sources. Guntzer *et al.* (2012) [7] observed that there was an increase in the response of applied phosphorus in rice, when applied along with silicon fertilizers. Similar results were also reported by Eneji *et al.* (2008) [5] and Ma and Takahashi (1991) [12].

The available potassium content in soil was significantly influenced by the silicon application. The highest available K was found in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}), which was followed by T_7 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%), T_1 (fine silica @ 100 kg ha^{-1}), T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}) and T_4 (fine silica @ 50 kg ha^{-1}+ rock dust @ 25 kg ha^{-1}+ foliar application of potassium silicate at maximum tillering stage @ 0.5%). The production of hydrogen ions during reduction of Fe and Al might have helped in the release of K from the exchange sites or from the fixed pool to the soil solution. Devanur (2015) [3] stated that beside yield enhancement in rice, silicon also has many fold advantages of increasing availability of major nutrients and also alleviating iron toxicity problems in soils. These results are confirmative with the findings of Burbey *et al.* (1988) [1], Liang (1999) [11] and Mali and Aery. (2008) [14].

Table 3: Effect of silicon nutrition on available nutrients (N, P, K and Si) in soil

Treatments	Available nutrients (kg ha^{-1})			
	N	P	K	Si
T_1	356.10	32.58	199.10	75.40
T_2	323.33	31.87	183.40	74.92
T_3	363.43	29.54	177.87	74.17
T_4	315.53	27.49	187.84	74.06
T_5	370.99	34.72	196.06	80.76
T_6	377.73	36.37	206.25	83.61
T_7	366.68	33.96	204.89	79.33
S E m±	19.971	1.567	8.675	1.547
CD (0.05)	NS	3.415	18.904	3.372

Silicon nutrition significantly influenced soil silicon status also. The soil silicon was found to be higher in all the treatments after harvest compared to the initial status, but the highest soil available silicon was found in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) followed by T_5 (fine silica @ 75 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1}). The silicon applied through various silicon sources, would have prevailed in soil as monosilicic acid (H_4SiO_4) due to its residual activity and enhanced soil silicon availability. These findings are in agreement with those reported by Singh *et al*. (2006) [6] and Korndorfer *et al*., (2001) [10]. Prasanta and Heinz (2009) [18] reported that changes in the pH of soils due to soil flooding significantly influence the solubility of Fe, P and Si in soil; so also plant available soil silicon increases due to increase in soil reaction. In the present study also, the increase in soil reaction compared to the initial value might have resulted in significantly higher silicon content in soil.

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