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Effect of silicon fertilization on yield attributing factors, yield and economics of rice cultivation

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Abstract
A Field experiment was conducted at a farmer's field in Kerala during *Kharif* 2016 to study the effect of various silicon sources on yield attributing factors, yield and economics of rice cultivation. Experiment was laid out in randomised block design replicated thrice with different sources of silicon as soil and foliar application. Rice variety Uma was used as the test crop. Silicon nutrition enhanced yield and yield attributing factors of rice grown in iron toxic laterite soils of Kerala. Among the treatments, recommended dose of NPK kg ha^{-1} + fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}, has shown the better results with respect to most of the yield attributing factors, yield and economics of rice cultivation.

Keywords: silicon, laterite soils, rice, yield, B: C ratio

Introduction
Rice (*Oryza sativa* L.) is the important staple food crop of Kerala. In Kerala, rice is cultivated in 1.98 l ha with the production of 5.62 l t and an average productivity of 2874 kg ha^{-1} in 2014-2015 (Maneesh and Deepa, 2016) [10]. For the last few decades, the rice farming sector in Kerala is facing a multitude of problems, which has led to drastic decline in area and production. The key reasons for this decline are non-availability and high cost of labour at the peak period of work and low profit coupled with multiple soils related constraints. Among these, the main problem yet to be addressed in detail is soil related constraints. About 60 percent of the Kerala soils being lateritic in nature, 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. This creates soil stress and the yields of rice crop grown in these soils are reduced, far below the yield potentials.

Silicon (Si) is the second most abundant element in soil. Si is assimilated by plant roots as monosilicic acid (H_4SiO_4) (Epstein, 1999) [4]. Rice is a high silicon accumulating plant which contains Si at levels up to 10% in dry matter weight. Si is a beneficial element for plant growth and is agronomically essential for improving and sustaining rice productivity. Si plays beneficial roles in rice plants such as photosynthesis enhancement and lodging resistance. (Savant *et al.*, 1997) [14]. Besides rice yield increase, Si has many fold advantages of increasing nutrient availability (N, P, K, Ca, Mg and Zn) and minimizing biotic and abiotic stress in plants. Silicon has been long recognized as a key nutrient to increase and stabilize rice yields in Japan (Savant *et al.*, 1997) [14]. Hence the application of Si to soil or plant is practically useful in laterite derived paddy soils. Ahmad *et al*. (2013) [1] reported that application of Si fertilizers enhanced the growth parameters, increased yield, yield attributes and quality of rice crop. With this background, the present study on the silicon nutrition on yield attributing factors, yield and economics of rice was carried out.

Materials and Methods
A field experiment was conducted at a farmer's field in Kerala, with the application of various silicon sources to rice crop in laterite derived paddy soils, to study its effect on yield attributing factors, yield and economics. The experiment was laid out in randomized block design replicated thrice with the test crop of rice variety Uma. There were 7 treatments *viz.* 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%.

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 soil of the experimental site was acidic in nature (pH 4.50), high in OC (1.01%) and sandy clay loam in nature. Yield attributing factors are recorded from the five tagged plants from each plot and averaged. Grain and straw yield were recorded from the net plot area and expressed in t ha^{-1}. The cost of inputs, labour charges and prevailing market rates of farm produce were taken into consideration for working out gross and net returns per hectare. The benefit cost ratio was worked out for various treatments by dividing the gross returns by cost of cultivation. The data obtained from field investigation was subjected to statistical analysis using analysis of variance (ANOVA) as applied to Randomized Block Design. After statistical analysis CD values were worked out and data was interpreted.

Results and Discussion

Effect of silicon nutrition on yield attributes

The results of the statistical analysis of the data with respect to yield attributing factors are given in Table 1. The results indicated that higher number of productive tillers m^{-2} was noticed in those treatments, where rice husk ash was included as one of the silicon source. The treatment T_6 produced higher number of productive tillers (467) and it was on a par with T_7 (460), and T_5 (450). The increase in the number of productive tillers might be attributed to the higher silicon uptake and dry matter production in rice in these treatments. Other yield parameters like number of filled grains panicle^{-1} and sterility percentage also followed a similar trend as that of number of productive tillers m^{-2}. However, with respect to thousand grain weight, the treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 125 kg ha^{-1} + foliar application of potassium silicate at maximum tillering stage @ 0.5%) was found to be significantly superior to all other treatments, which might be due to the highest quantity of silicon (200 kg) applied in this treatment. The better expression of yield attributes could be due to adequate silicon availability, which increased the number of panicles, the number of grains panicle^{-1}.

Silicon has a positive effect on the number of spikelets on secondary branches of panicles and the ripening of grains (Seo and Ota, 1983). After transplanting, silicon application increased the number of panicles (IRRI, 1965) [6]. According to Prakash (2002) [12] application of rice husk ash @ 2 to 4 t ha^{-1} increased rice yields to an extent of 15-20 per cent. In the present study also, the treatments receiving rice husk ash *i.e*, T_5, T_6 and T_7 exhibited significantly higher yield attributes. The favorable effect of silicon nutrition on yield attributes of rice were reported earlier (Sunikumar, 2000; Gholami and Falah, 2013; Ahmad *et al.*, 2013 and Bhaskaran, 2014) [5, 1, 3].

Table 1: Effect of silicon nutrition on productive tillers, panicle weight, thousand grain weight, filled grains per panicle and sterility percentage

Treatments	Productive tillers m^{-2}	Panicle weight (g panicle^{-1})	Number of filled grains pancicle^{-1}	Sterility percentage	Thousand grain weight (g)
T_1	440	3.03	117.89	13.73	23.15
T_2	411	3.01	115.32	13.85	23.01
T_3	435	2.99	112.22	13.26	23.16
T_4	438	3.23	118.69	13.53	23.07
T_5	450	3.30	119.60	12.77	23.18
T_6	467	3.43	128.92	12.33	24.36
T_7	460	3.41	123.12	12.68	23.29
S E m±	11.8	0.152	4.360	0.298	0.349
CD (0.05)	25.848	0.337	9.502	0.651	0.762

Effect of Silicon nutrition on Yield and Harvest Index

The results of the statistical analysis of the data with respect to yield and harvest index are given in Table 2. The highest grain yield of 6.14 t ha^{-1} was recorded in T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) and it was significantly superior to all the other treatments. The better realization of grain yield in this treatment could be due to the fact that maximum quantity of silicon (200 kg ha^{-1}) was applied in this treatment compared to 100 kg in T_1, 83.75 kg in T_2, 76.08 kg in T_3, 59.83 in T_4, 150 in T_5 and 126.08 in T_7. The higher quantity of silicon supplied in T_6 enhanced the yield attributes like number of productive tillers m^{-2}, thousand grain weight, number of filled grains panicle^{-1} and reduced sterility percentage which inturn resulted in higher yield in T_6. Sunilkumar (2000) [16] reported that translocation of photosynthates from straw to ear head, increased the thousand grain weight and yield by the application of silicon. Moreover the application of silicon might have improved light receiving posture of rice plants, thereby enhancing photosynthetic rate and yield.

Table 2: Effect of silicon nutrition on grain yield, straw yield and harvest index

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
T_1	5.73	8.73	0.39
T_2	5.58	8.57	0.38
T_3	5.73	8.75	0.39
T_4	5.72	8.57	0.39
T_5	5.78	8.75	0.39
T_6	6.14	8.77	0.41
T_7	5.99	8.77	0.40
S E m±	0.057	0.063	0.000
CD (0.05)	0.128	0.143	0.010

The favorable effect of silicon nutrition on the grain yield of rice in the iron toxic laterite soils of the experimental field, could be due to the increase in the oxidizing power of the roots by silicon which converts ferrous ion into ferric ion thereby preventing large scale uptake of Fe reducing its toxicity, as reported by Ma and Takahashi (2002) [9]. Ahmad *et al.* (2013) [1] reported that foliar application of 1% silicon solution produced the highest paddy yield (4.88 t ha^{-1}). However the three rates of applications (0.25, 0.5 and 1%) were statistically similar and differed from control. Corroboratory results on the favourable effect of silicon nutrition on grain yield of rice were reported by, Sunilkumar (2000) [16], Murali *et al.* (2007) [11], Rao *et al.* (2017) [13] and Bhaskaran (2014) [3].

Silicate slag application at the rate of 1.5 to 2.0 t ha^{-1} is now mostly used in degraded paddy fields and peaty paddy fields in Japan (Kono, 1969) [8]. Synder *et al.* (1986) [17] showed that silicon application increased rice yields on Histosols mainly due to the supply of plant available silicon. Increased rice yields have been reported due to recycling of silicon in rice hulls and straw in the Philippines (IRRI, 1966) [6]. This explains why higher yield in the range of 5.58 to 6.14 t ha^{-1} could be realized in the iron toxic laterite soils of experimental site compared to 4.5 t ha^{-1} in the surrounding farmers' field. According to Savant *et al.* (1997) [14] intensive cropping (two or more crops per year) resulted in rapid depletion of all nutrients, including that of silicon. The short fallow periods between two successive crops in a year may not be sufficient for replenishing plant available silicon (PAS) in soil when the dissolution rate of soil silicon is very slow and, addition of large amount of NPK fertilizers alone could gradually reduce their effectiveness.

With respect to straw yield, T_6 and T_7 resulted in the highest value of 8.77 t ha^{-1} and these treatments were on a par with T_5, T_3 and T_1. A similar trend as that of yield was observed in the case of harvest index also. The treatment T_6 produced the highest harvest index of 0.41 and it was on a par with T_7. Rice hull is not harmful to the soil but is slightly beneficial as a fertilizer (IRRI, 1966) [6]. Agarie *et al.* (1992) [2], also stated that the maintenance of photosynthetic activity due to silicon nutrition could be one of the reasons for the increased yield in rice.

Effect of silicon nutrition on economics of rice cultivation

The results of the statistical analysis of the data with respect to economics of rice cultivation are given in Table 3.

Table 3: Effect of silicon nutrition on gross income, net income and B: C ratio

Treatments	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C ratio
T_1	155030	62963	1.68
T_2	151270	59315	1.64
T_3	155185	57574	1.54
T_4	154335	56837	1.58
T_5	156235	64218	1.69
T_6	164470	72503	1.78
T_7	161075	63514	1.65
S E m±	1420.2	1420.2	0.000
CD (0.05)	3094.713	3094.713	0.033

Silicon application significantly influenced the economics of rice cultivation. The treatment T_6 (fine silica @ 50 kg ha^{-1} + rice husk ash @ 250 kg ha^{-1}) resulted in significant increase in the gross income, net income and B:C ratio. This might be due to the increased grain and straw yield in these treatments. The gross income, net income and B:C ratio of T_6 were ₹ 164470 ha^{-1}, ₹ 72503 ha^{-1} and 1.78 respectively. The combination of fine silica (50 kg ha^{-1}) and rice husk ash (250 kg ha^{-1}) can be considered as most suitable silicon sources for iron toxic laterite soils as they are cheap, readily availability, with high content of available silicon (Marafon and Endres, 2013). Yadav *et al.* (2017) [13] reported that there was an increase in net income, gross income and B:C ratio w with silicon application, which was due to the increase in the straw yield and grain yield with increased silicon uptake by rice. Similar results were reported by Jawahar and Vaiyapuri (2012), Sunilkumar (2000) [16] and Bhasakaran (2014).

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