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Effect of silicon application along with chemical fertilizers on nutrient uptake and nutrient availability for rice plants

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Abstract
The pot culture experiment was conducted at Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, India, to study the effect of silicon application along with chemical fertilizers on nutrient uptake and nutrient availability for rice plants. The soil samples from order Inceptisols and Vertisols were collected; 10 kg soil was filled in each plastic pot for study. The experiment was laid out in factorial completely randomized design having fourteen treatment combinations replicated thrice with rice as a test crop. The main treatments were soil types Inceptisols and Vertisols; sub treatments were levels of silicon with T_1: Absolute control, T_2: General recommended dose of fertilizers (GRDF) (100:50:50 kg ha^{-1} N:P_2O_5:K_2O + 5 t ha^{-1} FYM), T_3: GRDF + Si @ 25 kg ha^{-1}, T_4: GRDF + Si @ 50 kg ha^{-1}, T_5: GRDF + Si @ 100 kg ha^{-1}, T_6: GRDF + Si @ 150 kg ha^{-1}, T_7: GRDF + Si @ 200 kg ha^{-1}. The soil samples from Vertisols and application of GRDF + Si @ 200 kg ha^{-1} showed significantly highest grain yield, straw yield, nutrient uptake (N, P, K and Si) also micronutrient uptake (Fe, Mn, Zn and Cu) over Inceptisols and other levels of silicon, respectively. The application of silicon along with chemical fertilizers enhanced the yield potential as well as residual soil fertility status at harvest of rice plants.

Keywords: silicon, chemical fertilizers, nutrient uptake, nutrient availability, rice plants

Introduction
Silicon is absorbed as monosilicic acid [$Si(OH)_4$] by rice plants from soil in large amounts that are several fold higher than those of other essential macronutrients (IFA, 1992) [6]. For example, the uptake of Si is about 108% greater in comparison to nitrogen. In general, a rice crop producing a grain yield of about 5,000 kg ha^{-1} is estimated to remove about 230 to 470 kg elemental Si ha^{-1} from soil depending mainly on soil and plant factors (Amarasiri and Perera, 1975) [2]. Silicon is the only element known that does not damage plants with excess accumulation. Silicon (Si) is second most abundant element (27.72%) in the earth crust after oxygen (46.60%). Although soluble silicic acid occurs in the range of 0.1-0.6 Mm, most of the silicon is present in the soil as insoluble oxides or silicates. Rice is a high silicon accumulator plant and this element has been demonstrated to be necessary for healthy growth and stable production. Silicon plays a significant role in imparting both biotic and abiotic stress resistance and enhances grain productivity. For this reason, Si has been recognized as an agronomically essential element in Japan, and silicate fertilizers have since then been applied to paddy soils (Ma *et al*., 2001) [11]. In recent years, Si has been regarded as a quasi-essential element (Epstein, 1999) [5]. Although silicon has not been recognized as an essential element for plant growth, the beneficial effects of silicon have been observed in a wide variety of plant species. The depletion of plant available Si in soils under intensive rice cultivation system could also be a possible soil related factor for declining yields (Savant *et al*., 1997) [23]. The extensive cultivation of rice in some regions of Asia and Southeast Asian countries has led to depletion of available silicon and warrants the application of silicate fertilizers for achieving sustainable rice yields. For any mineral to be useful as a silicon fertilizer, it must have a relatively high content of silicon, provides sufficient water soluble silicon to meet the needs of the plant. It should be cost effective and have a physical nature that facilitates storage as well as its application. Also it should not contain substances that will contaminate the soil. The use of silica fertilizers in the form of either soluble silicates or of calcium silicate slag is still very restricted. An adequate supply of silica is essential, if grasses and cereals are to give a good

yield. Hence the present investigation was undertaken to explore the effect of silicon application along with chemical fertilizers on nutrient uptake and nutrient availability for rice plants.

Materials and Methods

The pot culture experiment was conducted to study the effect of silicon application along with chemical fertilizers on nutrient uptake and nutrient availability for rice plants at Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, India. The soil samples from order Inceptisols (*Vertic Haplustept*) and Vertisols (*Typic Haplustert*) were collected for study. The details of physical and chemical properties of soils are given in table 1. The plastic pots of 15 kg capacity were taken and filled with 10 kg soil. The rice plants (*Cv*. Indrayani) were used as a test crop. The experiment was laid out in factorial completely randomized design having fourteen treatment combinations replicated thrice. The main treatments were soil types Inceptisols and Vertisols; sub treatments were levels of silicon (Si). The treatment details were T_1: Absolute control, T_2: General recommended dose of fertilizers (GRDF) (100:50:50 kg ha^{-1} N:P_2O_5:K_2O + 5 t ha^{-1} FYM), T_3: GRDF + Si @ 25 kg ha^{-1}, T_4: GRDF + Si @ 50 kg ha^{-1}, T_5: GRDF + Si @ 100 kg ha^{-1}, T_6: GRDF + Si @ 150 kg ha^{-1}, T_7: GRDF + Si @ 200 kg ha^{-1}. The above treatment doses were converted into grams based on 10 kg soil in each pot and doubled before application. The calcium silicate was used as a source of silicon and mixed in soil one month before sowing. Two rice seedlings in each pot were maintained for growth and yield observations. The plant available silicon (PAS) from soil samples was extracted and estimated as per procedures given by Snyder (2001) [11] and Korndorfer *et al.* (2001) [9], respectively. The digestion of rice plant samples as well as estimation of silicon was done as per procedure given by Nayar *et al.* (1975) [15]. The data generated from present experiment was statistically analyzed as per the methods suggested by Panse and Sukhatme (1985) [16].

Table 1: Initial physical and chemical properties of soil

S. No	Parameters	Values	
		Inceptisols	Vertisols
1	Particle size distribution		
	Coarse sand (%)	4.38	3.63
	Fine sand (%)	12.40	13.09
	Silt (%)	27.10	26.58
	Clay (%)	56.12	56.70
	Textural class	Clay	Clay
2	Bulk density (Mg m^{-3})	1.32	1.39
3	Organic carbon (g kg^{-1})	5.5	5.3
4	Calcium carbonate (g kg^{-1})	70.4	61.3
5	pH (1:2.5)	8.28	8.31
6	EC (1:2.5) (dS m^{-1})	0.32	0.34
7	Available N (mg kg^{-1})	121.2	123.0
8	Available P (mg kg^{-1})	11.0	13.7
9	Available K (mg kg^{-1})	225.7	257.8
10	Available Si (mg kg^{-1})	336.12	346.15
11	Available S (mg kg^{-1})	19.1	20.3
12	DTPA-Fe (mg kg^{-1})	9.24	9.87
13	DTPA-Mn (mg kg^{-1})	11.57	12.14
14	DTPA-Zn (mg kg^{-1})	1.18	1.24
15	DTPA-Cu (mg kg^{-1})	2.56	3.08

Results and discussion

Rice plants yield under pot culture

Grain

There was a significant influence of soil types and levels of silicon on grain yield. However, results were non-significant in case of their interactions (Table 2). Vertisols showed significantly highest grain yield (36.20 g pot^{-1}) over the Inceptisols (33.75 g pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest grain yield (43.15 g pot^{-1}) over all the levels of silicon. However, it was at par with GRDF + Si @ 150 kg ha^{-1} (41.28 g pot^{-1}). This might be due to application of silicon, as it enhanced the sturdiness in plant and helps to grow erect without lodging. The erectness exposed more plant parts to sunlight and enhanced the photosynthetic activity. These promote the growth and development of crop, as well as reduce the incidence of pest and disease. The crop grows vigorously and utilized the nutrient and moisture from Vertisols, which are turned into the economic yield of rice. Similar findings were also reported by Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Straw

There was a significant influence of soil types and levels of silicon on straw yield. However, results were non-significant in case of their interactions (Table 2). Vertisols showed significantly highest straw yield (39.42 g pot^{-1}) over the Inceptisols (37.60 g pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest straw yield (46.54 g pot^{-1}) over all the levels of silicon. However, it was at par with GRDF + Si @ 150 kg ha^{-1} (45.00 g pot^{-1}). The accumulation of silicon in plant parts reduces its lodging and enhanced resistance against biotic and abiotic stress. The application of silicon enhanced photosynthetic activity, water and nutrient use efficiency, which ultimately results into better vegetative growth. The higher straw yield was mainly associated with increased plant height and number of tillers hill^{-1}. These results are in conformity with the findings of Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Table 2: Effect of soil types, levels of silicon and their interactions on yield of rice plants under pot culture

	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
A. Soil types (S)		
S_1: Inceptisols	33.75	37.60
S_2: Vertisols	36.20	39.42
SE (m) $\pm$	0.414	0.433
CD at 5%	1.198	1.253
B. Levels of silicon (T)		
T_1: Absolute control	22.71	25.88
T_2: GRDF	30.06	33.49
T_3: GRDF + Si @ 25 kg ha^{-1}	32.65	36.63
T_4: GRDF + Si @ 50 kg ha^{-1}	36.11	39.64
T_5: GRDF + Si @ 100 kg ha^{-1}	38.90	42.40
T_6: GRDF + Si @ 150 kg ha^{-1}	41.28	45.00
T_7: GRDF + Si @ 200 kg ha^{-1}	43.15	46.54
SE (m) $\pm$	0.774	0.809
CD at 5%	2.242	2.344
C. Interactions (S x T)		
CD at 5%	NS	NS

Nutrient uptake by rice plants under pot culture

Nitrogen uptake

The nitrogen uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 3). Vertisols showed significantly highest nitrogen uptake (1142 mg pot^{-1}) over the Inceptisols (994 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest nitrogen uptake (1478 mg pot^{-1}) over all the levels of silicon. The application of silicon along with other nutrients significantly increased nitrogen uptake by rice plants. The silicon has synergistic effect with nitrogen hence, there was enhanced the nitrogen uptake. The nitrogen use efficiency increased with increase in silicon concentration, as the silicon fertilized plants gain maximum benefits of the ample nitrogen available (Rani and Narayanan, 1994). Similar results were also noticed by Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Phosphorus uptake

The phosphorus uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 3). Vertisols recorded significantly highest phosphorus uptake (394 mg pot^{-1}) over the Inceptisols (318 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest phosphorus uptake (471 mg pot^{-1}) over all the levels of silicon. There was significant increase in phosphorus uptake by rice plants with increased levels of silicon. This might be due to decreased phosphorus retention capacity of soil and increased solubility of phosphorus. The silicon enhanced the solubility of phosphorus by displacing it from ligand exchange sites. This ultimately leads to increased efficiency of phosphatic fertilizer. The applied silicon exerts a solvent action on phosphorus fertilizers and rendered the phosphorus available to plant. These findings are in concomitance with Epstein (1999) [5], Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Potassium uptake

The potassium uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 3). Vertisols showed significantly highest potassium uptake (962 mg pot^{-1}) over the Inceptisols (910 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest potassium uptake (1243 mg pot^{-1}) over all the levels of silicon. The application chemical fertilizers in combination with silicon levels significantly increased potassium uptake by rice plants. The positive response of higher silicon application towards uptake of potassium can be linked to silicification process of cell walls. Increased in the potassium uptake possibly might be due to stimulating effect of silicon on activation of H^+-ATPase in the membrane. Similar results were also noticed by Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Silicon uptake

The silicon uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 3). Vertisols showed significantly highest silicon uptake (2251 mg pot^{-1}) over the Inceptisols (1941 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest silicon uptake (2923 mg pot^{-1}) over all the levels of silicon. The higher silicon uptake was associated with increased levels of silicon. This might be due to increase in root growth and available form of silicon in soil. The addition of silicate material to soil and increased in silicon availability might have been the reason for higher silicon uptake. The application of silicon leads to improvement in crop stand, enhanced photosynthesis and resistance against biotic stress. This are the certain other factors might have responsible for higher silicon uptake by rice plants. These results are in conformity with the findings of Talashilkar *et al.* (2000) [29], Singh *et al*. (2006) [27], Wader *et al*. (2013) [31] and Patil (2013) [17].

Table 3: Effect of soil types, levels of silicon and their interactions on nutrient uptake by rice plants under pot culture

	Nutrient uptake (mg pot^{-1})			
	N	P	K	Si
A. Soil types (S)				
S_1: Inceptisols	994	318	910	1941
S_2: Vertisols	1142	394	962	2251
SE (m) ±	19.14	5.133	11.47	21.22
CD at 5%	55.44	14.87	33.24	61.46
B. Levels of silicon (T)				
T_1: Absolute control	636	215	572	1074
T_2: GRDF	866	288	769	1534
T_3: GRDF + Si @ 25 kg ha^{-1}	946	319	844	1820
T_4: GRDF + Si @ 50 kg ha^{-1}	1043	358	930	2150
T_5: GRDF + Si @ 100 kg ha^{-1}	1202	402	1046	2454
T_6: GRDF + Si @ 150 kg ha^{-1}	1304	440	1149	2717
T_7: GRDF + Si @ 200 kg ha^{-1}	1478	471	1243	2923
SE (m) ±	35.80	9.602	21.47	39.69
CD at 5%	103.7	27.82	62.18	115.0
C. Interactions (S x T)				
CD at 5%	NS	NS	NS	NS

Iron uptake

The iron uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 4). Vertisols showed significantly highest iron uptake (26.22 mg pot^{-1}) over the Inceptisols (22.76 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest iron uptake (31.75 mg pot^{-1}) over all the levels of silicon. There was significant increase in the iron uptake with increased levels of silicon by rice plants. This might be due to healthy crop growth and higher yield as influenced by application of silicon. These results are in conformity with the results of Epstein (1999) [5], Khoshgoftarmanesh *et al.* (2012) [8] and Wader (2012) [32].

Manganese uptake

The manganese uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 4). Vertisols showed significantly highest manganese uptake (10.09 mg pot^{-1}) over the Inceptisols (9.22 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest manganese uptake (13.32 mg pot^{-1}) over all the levels of silicon. The application of silicon significantly increase manganese uptake might be attributed to higher biological yield. The presence of silicon in nutrient solutions has also been reported to affect the absorption and translocation of several micronutrients (Epstein, 1999) [5]. These findings are in agreement with the reports of Verma and Minhas (1989), Khoshgoftarmanesh *et al.* (2012) [8] and Wader (2012) [32].

Zinc uptake

The zinc uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 4). Vertisols showed significantly highest zinc uptake (7.76 mg pot^{-1}) over the Inceptisols (6.02 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest zinc uptake (10.02 mg pot^{-1}) over all the levels of silicon. The increased zinc uptake might be attributed to the role of silicon in increasing dry matter production of rice plants. Similar results were also reported by Shi *et al.* (1996) [25], Singh *et al*. (2006) [27], Khoshgoftarmanesh *et al.* (2012) [8] and Wader (2012) [32].

Copper uptake

The copper uptake was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 4). Vertisols showed significantly highest copper uptake (1.55 mg pot^{-1}) over the Inceptisols (1.46 mg pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest copper uptake (2.02 mg pot^{-1}) over all the levels of silicon. There was significant increase in the copper uptake with application of silicon was noticed. This might be due to higher biological yield of rice plants. Similar findings had also reported by Wader (2012) [32].

Table 4: Effect of soil types, levels of silicon and their interactions on micronutrient uptake by rice plants under pot culture

	Micronutrient uptake (mg pot^{-1})			
	Fe	**Mn**	**Zn**	**Cu**
A. Soil types (S)				
S_1: Inceptisols	22.76	9.22	6.02	1.46
S_2: Vertisols	26.22	10.09	7.76	1.55
SE (m) $\pm$	0.267	0.146	0.098	0.020
CD at 5%	0.774	0.424	0.285	0.058
B. Levels of silicon (T)				
T_1: Absolute control	14.79	5.11	3.29	0.85
T_2: GRDF	20.01	7.28	4.81	1.18
T_3: GRDF + Si @ 25 kg ha^{-1}	22.42	8.54	5.89	1.36
T_4: GRDF + Si @ 50 kg ha^{-1}	25.17	9.77	7.02	1.54
T_5: GRDF + Si @ 100 kg ha^{-1}	27.51	11.28	8.08	1.73
T_6: GRDF + Si @ 150 kg ha^{-1}	29.75	12.29	9.13	1.87
T_7: GRDF + Si @ 200 kg ha^{-1}	31.75	13.32	10.02	2.02
SE (m) $\pm$	0.500	0.274	0.184	0.037
CD at 5%	1.447	0.793	0.533	0.108
C. Interactions (S x T)				
CD at 5%	NS	NS	NS	NS

Soil fertility status at harvest of rice plants under pot culture

Soil pH (1:2.5)

The soil pH was significantly influenced by levels of silicon. However, results were non-significant in case of soil types and their interactions (Table 5). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly lowest soil pH (8.09) over all the levels of silicon. There was significant decrease in soil pH with application of silicon at harvest of rice plants. This might be due to profuse root growth and tillering leads to production of significant amount of CO_2 due to root respiration. This CO_2 gets accumulated and converts into mild acid. The active root growth contributes in release of organic acids tended to reduce pH of soil. Also the electrochemical changes that take place under moist condition of rice pots might have contributed in reduction of soil pH at harvest. These results are in conformity with the findings of Ponnamperuma (1966) [18], Kato and Owa (1990) [17] and Sahrawat (2005) [22].

Electrical conductivity

The electrical conductivity of soil was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 5). Vertisols showed significantly higher soil EC (0.48 dS m^{-1}) over the Inceptisols (0.44 dS m^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly higher soil EC (0.52 dS m^{-1}) over all the levels of silicon. However, it was at par with T_4, T_5 and T_6 (0.49, 0.50 and 0.51 dS m^{-1}, respectively). The application of silicon showed slight increase in electrical conductivity of soil at harvest of rice plants. This might be due to increase in solubility of salts present in the soil as well as soluble salts contributed from calcium silicate under moist condition. There by increased the ionic concentration of the soil solution. Similar findings were also reported by Selvakumari *et al.* (2000) [24] and Sahrawat and Narteh (2002) [21].

Available nitrogen

The available nitrogen in soil was significantly influenced by levels of silicon. However, results were non-significant in case of soil types and their interactions (Table 5). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest available nitrogen (118.7 mg kg^{-1}) over all the levels of silicon. However, it was at par with GRDF + Si @ 150 kg ha^{-1} (115.7 mg kg^{-1}). There was decrease in available nitrogen content in soil at harvest over initial available nitrogen status of soil. This might be due to efficient utilization of nitrogen and higher biological yield of rice plants. The available nitrogen content was significantly increased with levels of silicon at harvest of rice plants. This might be due to synergistic effect of silicon with nitrogen and reduction in leaching losses of nitrogen with application of silicon. Similar observations were also reported by Selvakumari *et al.* (2000) [24] and Das *et al*. (2013) [3].

Available phosphorus

The available phosphorus in soil was significantly influenced by levels of silicon. However, results were non-significant in case of soil types and their interactions (Table 5). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest available phosphorus (13.5 mg kg^{-1}) over all the levels of silicon. However, it was at par with GRDF + Si @ 150 kg ha^{-1} (12.8 mg kg^{-1}). There was significant increase in available phosphorus in soil with levels of silicon at harvest of rice plants. This might be due to silicon application that decreases the phosphorus retention capacity of soil. Thus increases the water soluble phosphorus in soil leading to increase in efficiency of phosphatic fertilizers. The silicon in solution renders phosphorus available to plants reversing its fixation as silicon itself competes for phosphorus fixation sites in the soil. These findings are near to that of Mandal *et al.* (2004) [12], Matichenkov and Bocharnikova (2010) [13] and Das *et al*. (2013) [3].

Available potassium

The available potassium in soil was significantly influenced by levels of silicon. However, results were non-significant in case of soil types and their interactions (Table 5). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest available potassium (230.8 mg kg^{-1}) over all the levels of silicon. However, it was at par with T_5 and T_6 (220.8 and 222.5 mg kg^{-1}, respectively). There was significant increase in available potassium in soil with levels of silicon at harvest of rice plants. This might be due to positive interaction of silicon with potassium and reduction in its leaching. Mohanthy *et al.* (1982) [14] noticed that exchangeable potassium displaced from cation exchange sites into the soil solution due to competition for exchange sites from Fe and Mn might have increased the solution potassium concentration. This result agrees with reports of Selvakumari *et al.* (2000) [24], Rautaray *et al.* (2003) [20], Matichenkov and Bocharnikova (2010) [13] and Das *et al*. (2013) [3].

Available silicon

The soil available silicon as extracted by 0.5 M acetic acid (1:2.5) was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 5). Inceptisols showed significantly highest available silicon (337.44 mg kg^{-1}) over the Vertisols (336.29 mg kg^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest available silicon (344.74 mg kg^{-1}) over all the levels of silicon. With the levels of silicon fertilization, there was significant increase in the plant available silicon content at harvest of rice plants. Vertisols showed reduction in the silicon content at harvest. This might be due to uptake of silicon by rice plants and very slow dissolution kinetics of soil silicon (Lindsay, 1979). However, Inceptisols recorded significantly increase in silicon content at harvest. This might be due to less uptake of silicon by rice plants and higher desilisification process in Inceptisols. Similar trend was also reported by Dhamapurkar *et al*. (2011) [29], Wader (2012) [32], Patil (2013) [17] and Arekar (2014) [1].

Table 5: Effect of soil types, levels of silicon and their interactions on soil fertility status at harvest of rice plants under pot culture

	pH (1:2.5)	EC (dS m^{-1})	N	P	K	Si
			(mg kg^{-1})			
A. Soil types (S)						
S_1: Inceptisols	8.19	0.44	107.0	11.3	214.5	337.44
S_2: Vertisols	8.19	0.48	107.3	11.6	212.1	336.29
SE (m) $\pm$	0.004	0.006	0.712	0.116	2.252	0.152
CD at 5%	NS	0.017	NS	NS	NS	0.439
B. Levels of silicon (T)						
T_1: Absolute control	8.30	0.34	94.7	9.2	185.0	329.78
T_2: GRDF	8.26	0.41	100.8	10.1	205.8	331.80
T_3: GRDF + Si @ 25 kg ha^{-1}	8.23	0.46	102.9	10.8	213.3	334.37
T_4: GRDF + Si @ 50 kg ha^{-1}	8.18	0.49	107.5	11.4	215.0	336.84
T_5: GRDF + Si @ 100 kg ha^{-1}	8.15	0.50	109.9	12.3	220.8	339.21
T_6: GRDF + Si @ 150 kg ha^{-1}	8.13	0.51	115.7	12.8	222.5	341.33
T_7: GRDF + Si @ 200 kg ha^{-1}	8.09	0.52	118.7	13.5	230.8	344.74
SE (m) $\pm$	0.008	0.011	1.332	0.217	4.214	0.284
CD at 5%	0.024	0.032	3.858	0.628	12.21	0.822
C. Interactions (S x T)						
CD at 5%	NS	NS	NS	NS	NS	NS

Available Micronutrients (DTPA extractable Fe, Mn, Zn and Cu)

DTPA-Fe

The DTPA-Fe content in soil was significantly influenced by soil types, levels of silicon and their interactions (Table 6). Inceptisols showed significantly highest DTPA-Fe (9.30 mg kg^{-1}) over the Vertisols (8.28 mg kg^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Fe (9.48 mg kg^{-1}) over all the levels of silicon. However, it was at par with T_5 and T_6 (9.24 and 9.37 mg kg^{-1}, respectively). The interaction effect of Inceptisols with GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Fe (9.72 mg kg^{-1}) over all the interactions. However, it was at par with S_1T_3, S_1T_4, S_1T_5, S_1T_6 and S_2T_7 (9.19, 9.31, 9.46, 9.64 and 9.24 mg kg^{-1}, respectively). There was slight increase in the DTPA-Fe content in soil at harvest of rice plants due to application of silicon. These findings are in concomitance with the finding of Sikka and Kansal (1995) [26] and Das *et al*. (2013) [3].

DTPA-Mn

The DTPA-Mn content in soil was significantly influenced by soil types, levels of silicon and their interactions (Table 6). Inceptisols showed significantly highest DTPA-Mn (10.58 mg kg^{-1}) over the Vertisols (10.31 mg kg^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Mn (11.10 mg kg^{-1}) over all the levels of silicon. However, it was at par with treatment T_6 (10.93 mg kg^{-1}). The interaction effect of Vertisols with GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Mn (11.23 mg kg^{-1}) over all the interactions. However, it was at par with S_1T_7 and S_2T_6 (10.97 and 11.03 mg kg^{-1}, respectively). There was decrease in the DTPA-Mn content in soil at harvest of rice plants. This might be due to efficient utilization of Mn by rice plants. The DTPA-Mn content in soil increased significantly with levels of silicon. Similar results were also noticed by Das *et al*. (2013) [3].

DTPA-Zn

The DTPA-Zn content in soil was significantly influenced by soil types, and levels of silicon and their interactions (Table 6). Inceptisols showed significantly highest DTPA-Zn (1.07 mg kg^{-1}) but at par with Vertisols (0.86 mg kg^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Zn (1.17 mg kg^{-1}) over all the levels of silicon. However, it was at par with treatment T_5 and T_6 (1.13 and 1.15 mg kg^{-1}, respectively). The interaction effect of Inceptisols and Vertisols with GRDF + Si @ 200 kg ha^{-1} (S_1T_7 and S_2T_7) recorded significantly highest DTPA-Mn (1.17 mg kg^{-1}) over all the interactions. However, it was at par with S_1T_5, S_1T_6, S_2T_4, S_2T_5, and S_2T_6 (1.12, 1.15, 1.12, 1.14 and 1.15 mg kg^{-1}, respectively). Due to uptake of Zn by crop there was slight reduction in DTPA-Zn content in soil at harvest of rice plants. The application of silicon significantly increased DTPA-Zn content in soil at harvest. These findings are similar to Das *et al*. (2013) [3].

DTPA-Cu

The DTPA-Cu content in soil was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interactions (Table 6). Vertisols showed significantly highest DTPA-Cu (2.43 mg kg^{-1}) over the Inceptisols (2.35 mg kg^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest DTPA-Cu (2.57 mg kg^{-1}) over all the levels of silicon. However, it was at par with treatment T_6 (2.51 mg kg^{-1}). There was slight reduction in the DTPA-Cu content in soil at harvest of rice plants. This might be due to uptake of Cu by rice plants. The application of silicon significantly increased DTPA-Cu content in soil at harvest of rice plants. These results are in conformity with the findings of Das *et al*. (2013) [3].

Table 6: Effect of soil types, levels of silicon and their interactions on DTPA extractable micronutrients at harvest of rice plants under pot culture

	Soil nutrient (mg kg^{-1})			
	Fe	**Mn**	**Zn**	**Cu**
A. Soil types (S)				
S_1: Inceptisols	9.30	10.58	1.07	2.35
S_2: Vertisols	8.28	10.31	1.05	2.43
SE (m) $\pm$	0.070	0.035	0.007	0.011
CD at 5%	0.202	0.102	0.020	0.032
B. Levels of silicon (T)				
T_1: Absolute control	7.41	9.10	0.84	2.21
T_2: GRDF	8.31	10.08	0.96	2.28
T_3: GRDF + Si @ 25 kg ha^{-1}	8.77	10.45	1.05	2.33
T_4: GRDF + Si @ 50 kg ha^{-1}	8.95	10.65	1.10	2.40
T_5: GRDF + Si @ 100 kg ha^{-1}	9.24	10.81	1.13	2.46
T_6: GRDF + Si @ 150 kg ha^{-1}	9.37	10.93	1.15	2.51
T_7: GRDF + Si @ 200 kg ha^{-1}	9.48	11.10	1.17	2.57
SE (m) $\pm$	0.131	0.066	0.013	0.021
CD at 5%	0.378	0.190	0.037	0.061
C. Interactions (S x T)				
S_1T_1	8.66	9.94	0.94	2.16
S_1T_2	9.10	10.29	1.00	2.25
S_1T_3	9.19	10.57	1.04	2.30
S_1T_4	9.31	10.67	1.07	2.35
S_1T_5	9.46	10.78	1.12	2.42
S_1T_6	9.64	10.83	1.15	2.47
S_1T_7	9.72	10.97	1.17	2.53
S_2T_1	6.16	8.27	0.75	2.26
S_2T_2	7.52	9.86	0.93	2.31
S_2T_3	8.36	10.34	1.07	2.36
S_2T_4	8.58	10.62	1.12	2.45
S_2T_5	9.03	10.85	1.14	2.50
S_2T_6	9.09	11.03	1.15	2.55
S_2T_7	9.24	11.23	1.17	2.61
SE (m) $\pm$	0.185	0.093	0.018	0.030
CD at 5%	0.535	0.269	0.052	NS

Conclusion

The application of silicon (200 kg ha^{-1}) along with general recommended dose of fertilizers (100:50:50 kg ha^{-1} $N:P_2O_5:K_2O$ + 5 t ha^{-1} FYM) to rice plants resulted in the significant increase in yield, nutrient uptake and nutrient availability. The present study demonstrates the importance of silicon in maximizing the yield potential of rice as well as improvement in soil fertility status at harvest of rice plants.

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