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Effect of soil types and silicon fertilization on growth and yield of upland paddy

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Abstract
Field experiment was conducted at Post Graduate Research Farm, Mahatma Phule Krishi Vidyapeeth Rahuri India, to study the effect of soil types and silicon fertilization on growth and yield of upland paddy. The field experiment was laid out in split plot design having fourteen treatment combinations replicated thrice. The main treatments were soil types Inceptisols and Vertisols; sub treatments were levels of silicon, T_1: Absolute control, T_2: 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} and T_7: GRDF + Si @ 200 kg ha^{-1}. The results revealed that soil type Vertisols showed significantly highest growth, yield attributes, grain (3701 kg ha^{-1}) and straw (4213 kg ha^{-1}) yield of upland paddy over Inceptisols. Application of general recommended dose of fertilizers (GRDF) along with Si @ 200 kg ha^{-1} recorded significantly highest growth, yield attributes, grain (4185 kg ha^{-1}) and straw (4763 kg ha^{-1}) yield of upland paddy over other levels of silicon.

Keywords: Soil types, silicon fertilization, growth, yield, upland paddy

Introduction
Rice is the inimitable crop. It is the dominant crop of India and staple food of the people. India is one of the world's largest producers of rice accounting for 20% of all world rice production. Rice occupies a pivotal place in India’s national food and livelihood security. Total area under rice in India is 42.75 million hectares with annual production of 105.24 million tonnes and productivity of 2462 kg ha^{-1}. In Maharashtra state of India the rice is cultivated over an area of 1.56 million hectares with an annual production of about 3.06 million tonnes and productivity of 1963 kg ha^{-1} (Anonymous, 2014) [2]. Rice is a silicon accumulating plant. No other crop requires as much silicon as rice. Silica is required for healthy and productive development of the rice plant (Yoshida, 1975) [17]. Silicon content of monocots is higher than that of dicots. Silicon absorbed by rice from the soil in large amounts that are several fold greater than those of other macronutrients. It is estimated that a rice crop producing a total grain yield of about 5 tonnes ha^{-1} will normally remove 230 to 470 kg Si ha^{-1} (500-1000 SiO_2 kg ha^{-1}) from soil (Amarasiri and Perera, 1975) [1]. 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 been applied to paddy soils (Ma *et al*., 2001) [8]. In recent years, Si has been regarded as a quasi-essential element (Epstein, 2005) [3]. Several studies suggested that Si enhances disease resistance in plants, imparts turgidity to the cell walls and has a putative role in mitigating the metal toxicities. It is also suggested that Si plays a crucial role in preventing or minimizing the lodging in the cereal crops, a matter of great importance in terms of agricultural productivity. Application of nitrogenous fertilizers is an important practice for increasing rice yield. However, when applied in excess it may limit yield because of lodging, promote shading and susceptibility to insects and diseases. These effects could be minimized by the use of Si (Ma *et al*., 2002) [9]. Silicon has been reported to raise the optimum level of nitrogen in rice. Adequate supply of Si to rice from tillering to elongation (reproductive) stage increases the number of panicles, the number of grains $panicle^{-1}$ and the percentage of ripening. The adequate Si nutrition can also improve the light receiving posture of rice plants, thereby stimulating photosynthate production in rice plants (Savant *et al*., 1997) [14]. In this context the present study was undertaken to study the effect of soil types and silicon fertilization on growth and yield of upland paddy.

Materials and Methods
Experimental location, soil and treatments
The field experiment was conducted at Post Graduate Research Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, India. The location of the experimental farm is situated in between 19^0 47' to 19^0 57' North latitude and between 74^0 18' - 74^0 19' East longitude. The elevation is 540 m above mean sea level. The representative soil samples from respective plots were collected from field before sowing and after harvest of upland paddy. The collected soil samples were air dried under shade, pounded in wooden pestle and mortar, sieved through 2 mm sieve and utilized for analysis of soil properties. The details of initial soil properties are presented in table 1. The field experiment was laid out in split plot design having fourteen treatment combinations replicated thrice. The main treatment were soil types Inceptisols and Vertisols; sub treatments were levels of silicon, T_1: Absolute control, T_2: 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} and T_7: GRDF + Si @ 200 kg ha^{-1}. The necessary observations of growth parameters *viz*. plant height (cm), number of tillers $hill^{-1}$, panicle length (cm); yield parameters *viz*. panicle weight (g), number of grains $panicle^{-1}$, 1000 grain weight (g) and crop yield *viz*. grain and straw yield were recorded from each treatment.

Statistical analysis
Soil analysis and yield data generated from present experiment was statistically analyzed by methods suggested by Panse and Sukhatme (1985) [10].

Table 1: Initial soil properties of field experiment

Parameters	Values	
	Inceptisols	Vertisols
pH (1:2.5)	8.28	8.30
EC (1:2.5) (dS m^{-1})	0.30	0.36
Available N (kg ha^{-1})	261.6	264.7
Available P (kg ha^{-1})	15.8	17.0
Available K (kg ha^{-1})	510.4	588.8
Available Si (kg ha^{-1})	759	776
DTPA-Fe (mg kg^{-1})	9.19	10.04
DTPA-Mn (mg kg^{-1})	12.01	12.36
DTPA-Zn (mg kg^{-1})	1.22	1.26
DTPA-Cu (mg kg^{-1})	2.89	3.23

Results and discussion
Plant growth characters
Plant height
The plant height was significantly influenced by soil types and levels of silicon (Table 2). Vertisols showed significantly highest plant height (73 cm) over the Inceptisols (70.81 cm). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest plant height (76.50 cm) over all the levels of silicon. However, it was at par with the application of GRDF + Si @ 150 kg ha^{-1} (75.67 cm). However, interaction effect of soil types and levels of silicon was non-significant. There was significant increase in plant height might owe to supply of nutrients from Vertisols and beneficial effects of added silicon. The increase in cell division, elongation, expansion and deposition of silicon at cellular level make the plant leaves more erect. Plant tissue analysis has revealed the optimum amount of silicon is necessary for cell development and differentiation (Liang *et al*., 2005) [7]. Similar findings were also reported by Patil *et al*. (2017) [11].

Number of tillers $hill^{-1}$
The numbers of tillers $hill^{-1}$ were significantly influenced by soil types and levels of silicon (Table 2). Vertisols recorded significantly higher tillers $hill^{-1}$ (10.52) over the Inceptisols (10). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest numbers of tillers $hill^{-1}$ (11.50) over all the levels of silicon. However, it was at par with application of GRDF + Si @ 50, 100 and 150 kg ha^{-1} (11.17, 10.83 and 11.17, respectively). The interaction effect of soil types and levels of silicon was non-significant. Tillering is the production of expanding auxiliary bud which is clearly associated with nutritional condition of the mother clump. Tillers receive carbohydrate and nutrients from the mother clump during early growth period and this was improved by silicon application (Liang *et al*., 1994). Silicon also has synergistic effects with nitrogen, phosphorus and potassium. These results corroborate those obtained by Jawahar *et al*. (2015) [4] and Patil *et al*. (2017) [11].

Panicle Length
The panicle length was significantly influenced by soil types, levels of silicon and their interactions (Table 2). Vertisols recorded significantly highest panicle length (17.96 cm) over the Inceptisols (16.85 cm). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest panicle length (18.59 cm) over all the levels of silicon. However, it was at par with the application of GRDF + Si @ 150 kg ha^{-1} (18.46 cm). The interaction effect of Vertisols with GRDF + Si @ 200 kg ha^{-1} recorded significantly highest panicle length (19.09 cm) over all the interactions. However, it was at par with Vertisols with GRDF + Si @ 100 and 150 kg ha^{-1} (18.70 and 18.87 cm, respectively). The panicle length was significantly increased with increased levels of silicon. The increase in panicle length might be due to deposition of silica at cellular level and on the tissues causing its erectness. Singh *et al*. (2007) [16] studied effect of recycling Si carriers through rice straw compost at different times of Si application on rice productivity in rice-wheat cropping systems. Rice straw compost at 50% + 50% calcium silicate gave the highest number of panicle length (20.57 cm). Shashidhar *et al*. (2008) [15] reported that the application of calcium silicate at 2 t ha^{-1} was found to be effective in increasing plant height, number of tillers $hill^{-1}$ and panicle length over the control, that resulted in 25-30% higher grain yield. Similar findings were also reported by Patil *et al*. (2017) [11].

Table 2: Effect of soil types, levels of silicon and their interactions on growth parameter of upland paddy

	Plant height(cm)	No. of tillers hill^{-1}	Panicle Length (cm)
A. Soil types (S)			
S_1: Inceptisols	70.81	10.00	16.85
S_2: Vertisols	73.00	10.52	17.96
SE (m) $\pm$	0.089	0.034	0.026
CD at 5%	0.542	0.205	0.158
B. Levels of silicon (T)			
T_1: Absolute control	63.50	8.00	15.83
T_2: GRDF	69.67	9.00	16.76
T_3: GRDF + Si @ 25 kg ha^{-1}	71.00	10.17	16.82
T_4: GRDF + Si @ 50 kg ha^{-1}	72.50	11.17	17.26
T_5: GRDF + Si @ 100 kg ha^{-1}	74.50	10.83	18.11
T_6: GRDF + Si @ 150 kg ha^{-1}	75.67	11.17	18.46
T_7: GRDF + Si @ 200 kg ha^{-1}	76.50	11.50	18.59
SE (m) $\pm$	0.397	0.276	0.098
CD at 5%	1.158	0.805	0.287
C. Interactions (S x T)			
S_1T_1	62.33	7.67	15.21
S_1T_2	68.33	9.33	16.32
S_1T_3	69.00	9.67	16.37
S_1T_4	71.33	10.67	16.37
S_1T_5	73.67	11.00	17.52
S_1T_6	74.67	10.67	18.05
S_1T_7	76.33	11.00	18.09
S_2T_1	64.67	8.33	16.45
S_2T_2	71.00	8.67	17.20
S_2T_3	73.00	10.67	17.28
S_2T_4	73.67	11.67	18.14
S_2T_5	75.33	10.67	18.70
S_2T_6	76.67	11.67	18.87
S_2T_7	76.67	12.00	19.09
SE (m) $\pm$	0.561	0.390	0.139
CD_1 at 5%	NS	NS	0.406
SE (m) $\pm$	0.527	0.363	0.131
CD_2 at 5%	NS	NS	0.399

Plant yield attributing characters

Panicle weight

The panicle formation is directly related with number of productive tillers that ultimately resulted in production of higher number of panicles. The panicle weight was significantly influenced by soil types, levels of silicon and their interactions (Table 3). Vertisols showed significantly highest panicle weight (2.19 g) over the Inceptisols (1.99 g). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest panicle weight (2.45 g) over all the levels of silicon. The interaction effect of Vertisols with GRDF + Si @ 200 kg ha^{-1} recorded significantly highest panicle weight (2.51 g) over all the interactions. However, it was at par with Vertisols with GRDF + Si @ 150 kg ha^{-1} (2.46 g). The panicle weight was increased might be due to role of silicon in photosynthetic activity and better assimilation of carbohydrates in panicle. The increase in panicle weight due to application of silicon was also reported by Singh *et al*. (2007) and Patil *et al*. (2017) [11].

Number of grains panicle^{-1}

The numbers of grains panicle^{-1} were significantly influenced by levels of silicon. However, results were non-significant in case of soil types and their interactions (Table 3). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest numbers of grains panicle^{-1} (139.63) over all the levels of silicon. The availability of nutrients to the crop at later growth stages due to silicon resulted in more numbers of grains panicle^{-1}. Similar results were also reported by Singh *et al*. (2007) [16], Jawahar *et al*. (2015) [4] and Patil *et al*. (2017) [11].

Thousand grain weight

The thousand grain weight 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 thousand grain weight (18.10 g) over the Inceptisols (17.72 g). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest thousand grain weight (18.81 g) over all the levels of silicon. However, it was at par with the application of GRDF + Si @ 150 kg ha^{-1} (18.67 g). There was significant increase in the thousand grain weight with increased levels of silicon. This might be attributed to better crop stand and enhanced photosynthesis. That resulted into the availability and translocation of nutrients as well as photosynthates from source to sink. These results are in conformity with the findings of Jawahar *et al*. (2015) and Patil *et al*. (2017) [11].

Table 3: Effect of soil types, levels of silicon and their interactions on yield parameter of upland paddy

	Panicle Weight (g)	No. of grains panicle^{-1}	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
A. Soil types (S)					
S_1: Inceptisols	1.99	122.21	17.72	3547	3946
S_2: Vertisols	2.19	124.99	18.10	3701	4213
SE (m) $\pm$	0.001	0.825	0.029	10.4	22.4
CD at 5%	0.008	NS	0.173	63.4	136.5
B. Levels of silicon (T)					
T_1: Absolute control	1.73	103.82	16.36	2321	2636
T_2: GRDF	1.85	111.72	17.24	3469	3895
T_3: GRDF + Si @ 25 kg ha^{-1}	1.88	114.38	17.63	3653	4082
T_4: GRDF + Si @ 50 kg ha^{-1}	2.10	126.83	18.40	3739	4222
T_5: GRDF + Si @ 100 kg ha^{-1}	2.28	132.87	18.25	3927	4433
T_6: GRDF + Si @ 150 kg ha^{-1}	2.35	135.95	18.67	4073	4527
T_7: GRDF + Si @ 200 kg ha^{-1}	2.45	139.63	18.81	4185	4763
SE (m) $\pm$	0.014	1.023	0.099	34.8	28.6
CD at 5%	0.041	2.987	0.289	101.6	83.4
C. Interactions (S x T)					
S_1T_1	1.69	100.97	16.13	2278	2542
S_1T_2	1.76	110.33	17.13	3346	3790
S_1T_3	1.78	115.07	17.47	3533	3961
S_1T_4	1.94	125.93	18.29	3664	4110
S_1T_5	2.12	131.00	17.94	3827	4201
S_1T_6	2.23	135.07	18.45	4035	4340
S_1T_7	2.40	137.13	18.62	4145	4679
S_2T_1	1.78	106.67	16.59	2364	2729
S_2T_2	1.94	113.10	17.34	3592	4001
S_2T_3	1.97	113.70	17.79	3773	4204
S_2T_4	2.26	127.73	18.50	3814	4334
S_2T_5	2.43	134.73	18.56	4027	4666
S_2T_6	2.46	136.83	18.89	4110	4714
S_2T_7	2.51	142.13	19.00	4225	4847
SE (m) $\pm$	0.020	1.447	0.140	49.2	40.4
CD_1 at 5%	0.058	NS	NS	NS	118.0
SE (m) $\pm$	0.019	1.573	0.133	46.8	43.6
CD_2 at 5%	0.054	NS	NS	NS	163.9

Crop yield

Grain yield

The grain yield of upland paddy was significantly influenced by soil types and levels of silicon. However, results were non-significant in case of their interaction (Table 3). Vertisols showed significantly highest grain yield (3701 kg ha^{-1}) over the Inceptisols (3547 kg ha^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest grain yield (4185 kg ha^{-1}) over all the levels of silicon. There was significant increase in the grain yield of upland paddy grown on Vertisols. This might be due to high nutrient status and water holding capacity of Vertisols. The adequate silicon supply might have improved the crop stand by making leaves more erect. That enhanced the photosynthetic activity and enabled plant to accumulate sufficient photosynthates. Rani *et al.* (1997) reported that the increase in grain yield might be due to more efficient use of solar radiation, moisture and nutrients since silicon makes the rice plant more erect. The accumulation of silicon in plant reduced its lodging as well as pest and disease incidence. These together coupled with efficient translocation of photosynthates towards sink. That ultimately resulted in more panicles and more number of filled grains with increased test weight. The effect of Si on reducing disease unquestionably contributes to increased yields (Korndorfer *et al*., 2001) [5, 8]. These results resembled to the findings reported by Singh *et al*. (2007) [16], Jawahar *et al*. (2015) [4] and Patil *et al*. (2018) [12].

Straw Yield

The straw yield of upland paddy was significantly influenced by soil types, levels of silicon and their interactions (Table 3). Vertisols showed significantly highest straw yield (4213 kg ha^{-1}) over the Inceptisols (3946 kg ha^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} recorded significantly highest straw yield (4763 kg ha^{-1}) over all the levels of silicon. The interaction effect of Vertisols with GRDF + Si @ 200 kg ha^{-1} recorded significantly highest straw yield (4847 kg ha^{-1}) over all the interactions. The higher straw yield mainly attributed to increased plant height and number of tillers hill^{-1}. The application of silicon might have enhanced the leaf erectness which facilitated better penetration of sunlight. The application of silicon to soil and its accumulation in plant enhanced resistance against biotic and abiotic stress. Hence, the proper crop stand, availability of water and nutrients leads to enhance photosynthetic activity of crop. That enabled crop to accumulated sufficient photosynthates with increased dry matter production. This might be the reason for increase in the straw yield of upland paddy with application of GRDF + Si @ 200 kg ha^{-1} on Vertisols. This was in agreement with the findings of Singh *et al*. (2007) [16], Jawahar *et al*. (2015) [4] and Patil *et al*. (2018) [12].

Conclusion

The application of general recommended dose of fertilizers along with Si @ 200 kg ha^{-1} recorded significantly highest growth and yield of upland paddy grown on Vertisols. The result generated from the study showed that silicon could be a source of plant nutrient and enhanced nutrient status of soil at harvest of crop. Hence silicon could be used on Vertisols for upland paddy production.

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