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Full Length Research Paper

A study of the correlations between Si analyzed extract and Si management agenda of rice cultivars

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A pot experiment was conducted in 2012 in the greenhouse of the Anand Agricultural University Anand Gujarat, India. Treatments were arranged in a factorial completely randomized complete design with silicon factor at four levels (0, 100, 200 and 300 ppm) with three replicates. Indian improved and high - yielding variety Gurajari was used. The Si application up to 200 mg kg-1 soil significantly increased grain and straw yields of rice over the control under low (< 25 mg Si kg-1 soil) and medium (25 - 50 mg Si kg-1 soil) category soils, while it was up to 100 mg Si kg -1 soil in high category soils. The soil, grain and straw samples were analyzed for their Si, P, K, S and Na content at harvest. The Si content in grain ranged from 1.77 to 2.69% in untreated plots, whereas in treating plots, it ranged from 1.85 to 3.40%. The average value of Si content in straw was 7.78, 7.46 and 7.82% in low, medium and high category soils, respectively.

Key words: Silicon, yield, mineral composition, content, rice.

INTRODUCTION

Silicon (Si) is the second most abundant element in the earth's crust and soil. It has been considered to be quasi-essential element for plant growth (Epstein and Bloom, 2005). Rice is a known silicon accumulator (Takahashi et al., 1990) and the plant is benefiting from Si nutrition (Singh et al., 2005). Consequently, there is a definite need to consider Si as an essential minor element to increase sustained rice productivity (Sudhakar et al., 2006).

Rice is the staple food of about half of the world's population. It is cultivated in an area of 158 m ha^{-1} with the production level of 472 million tons and productivity of 4.32 t ha^{-1}. Globally, 23% of the total calorie (35% in Asia and 31% in India) and 16% of the total protein comes from rice. Hence, 2004 AD is the "International Year of Rice" had a slogan as "Rice is Life". Rice cultivation possesses a formidable place from the beginning of Indian agriculture and it has always played a significant role in our food and civilization. In India, rice is grown in an area 44 million ha with the production level of 105.92 million tons and average productivity of 2393 kg ha^{-l} during 2011-2012. The rice occupies an area of over 44 million hectares and in Gujarat, total area under rice cultivation was 8.36 lakh ha with total production of 17.9 lakh million tons and productivity of 2141 kg ha^{-1} during 2011-2012.

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Silicon is a beneficial element for plant growth, especially for grasses, ferns, and horsetails. Most research on plant silicon has focused on the role of plant silicon as a beneficial element against herbivore and pest stress, as well as on its protective role against abiotic stressors including salinity and heavy metal pollution (Fauteux et al., 2005; Epstein, 2009). Recent studies revealed that in grasses, silicon uptake affects nutrient stoichiometry, cellulose, and phenol content in aboveground plant parts (Schaller et al., 2012a, b). However, little is currently known whether silicon uptake by plants affects mineralization or sequestration rates of litter through impacts on hardly degradable compounds and nutrient stoichiometry.

The species accumulates high amounts of silica in the shoots (as amorphous silica deposits or phytoliths) (Schaller et al., 2012b, 2013). In this study, *Pleurotus australis* was grown under both Si-rich and Si-poor conditions, resulting in plants differing in nutrient stoichiometry and very low in phenol and cellulose content. We tested whether macro or micro nutrient release/fixation of the leaf litter differed significantly between both sets of litter during aquatic litter decomposition. Furthermore, it was tested whether silicon availability during plant growth affects the decomposition process itself. It was the authors' hypothesis that higher availability of silicon to plants could increase the decomposition process due to an alteration of litter quality. In addition, we tested how invertebrate shredders, which have a key function in decomposition, affected the decomposition dynamics of the used litter. Our hypothesis is that the decay rate increases by the activity of the invertebrates.

Furthermore, the invertebrates may be deterred of feeding on leaf litter by the high amount of phytoliths in treatment Si, as described for folivores, for which high density of phytoliths in the food results in enhanced mandible wear (Massey and Hartley, 2009). Inverter at feeding neutralizes the effect of different litter quality on mass loss during microbial litter decomposition. The interaction of litter silica content and invertebrate feeding may be explained as follows: The faster decay of litter with invertebrate feeding is commonly known. Higher silica content may result in more biofilm on the litter, which is preferred by the invertebrates (see above). In contrast, the high amount of phytoliths in treatment Si+ may result in lower feeding activity (see above). Overall, litter decay was fastest in the presence of invertebrates.

In soil, most of the Si is held in the crystalline structure of sand, silt and clay particles. Upon weathering of soil silicate minerals, released Si into soil solution is taken up by plants in the form of silicic acid (H_4SiO_4) (Faure, 1991). There is a need to identify the nature and magnitude of the Si status of different rice eco-systems and thereby developing suitable Si management agenda for obtaining or sustaining rice yield potentials of improved rice cultivars. Most of them apply an anion to replace adsorbed Si and have been tested by determining the correlations between Si analyzed in the extract and crop yield. Not all of them were intended to extract the complete amount of plant available Si.

MATERIALS AND METHODS

To know the available silicon status in different rice growing *goradu* soils, 60 surface soil samples were collected from the rice fields of Anand and Kheda districts. These soil samples were analyzed for available Si using NaOAc buffer extracts (Korndorfer et al., 1999) and categorized into low (< 25 mg kg^{-1}), medium (25 to 50 mg kg^{-1}) and high (>50 mg kg^{-1}) (Table 1).

Available silicon was extracted using NaOAc (pH- 4.0) extracts and silicon in the extracting solution was determined spectrophotometerically as suggested by Imaizumi and Yoshida (1958). The Si concentration of the digested plant samples was determined by spectrophotometric method given by (Ma and Tamai, 2002).

Available phosphorus, potassium and Sulphur was analyzed as per the standard procedures advised by Jackson (1973) and Williams and Steinberg (1959), respectively.

RESULTS AND DISCUSSION

Available silicon status

The textural class of soils under study was sandy clay loam to clay loam with average clay content of more than 30.0%. The CEC ranged from 15.0 to 23.0 c mol (p+) kg^{-1} soil. The soils of rice fields were neutral to alkaline in reaction, soluble salts (EC) were low to high, the organic carbon status was low and available P_2O_5 status was low to high category and available K_2O status was in medium to high category, while available S status was in low to medium (10 to 20 mg kg^{-1}) category (Table 2).

The NaOAc extractable available silicon content in rice soils of Anand district ranged from 30.58 to 78.73 mg kg^{-1} with a mean value of 47.74 mg kg^{-1}, while in soils of Kheda district, it ranged from 18.38 to 44.06 mg kg^{-1} with a mean value of 28.78 mg kg^{-1} (Table 3). An overall available Si status in both the districts ranged from 18.38 to 78.73 mg kg^{-1} with a mean of 41.42 mg kg^{-1}. This could be attributed to the depletion of available Si due to continuous rice cultivation, low solubility and/or slow dissolution kinetics of soil Si (Lindsay, 1979; Drees et al., 1989), high uptake of Si by rice crop to the extent of 250 kg ha^{-1} for producing grain yield of 5 t ha^{-1} (Savant et al., 1997), limited attempts by farmers to recycle Si through crop residues and/or lack of balanced fertilization (Savant et al., 1997). The variation among different soils in the available Si could be mainly attributed to the differences in cultivation practices followed, cropping system, organic carbon content of the soil, soil reaction, rainfall, materials, topography of the land, soil type and type and nature of the crop residues incorporated etc.

The results are in agreement with those of Nayar et al. (1982). They revealed that the available Si extracted by

Table 1. Initial soil properties of the bulk samples used in pot house study.

S/N	Soils (S)	pH (1:2.5)	EC (dSm^{-1}) (1:2.5)	OC ($g\ kg^{-1}$)	Av. P_2O_5 ($Kg\ ha^{-1}$)	Av. K_2O ($Kg\ ha^{-1}$)	Av. S (ppm)	Av. Si (ppm)
Low category								
1	S1	7.52	0.20	3.8	50.9	461	10.0	18.4
2	S2	7.53	0.53	3.8	70.6	514	13.9	18.3
3	S3	8.14	0.33	4.6	19.3	421	7.20	19.0
Medium category								
4	S4	7.71	0.18	3.5	19.6	371	16.3	44.7
5	S5	7.74	0.31	3.4	42.4	253	10.0	44.7
6	S6	8.00	0.32	2.7	34.1	325	15.8	44.7
High category								
7	S7	8.09	0.24	2.2	18.5	245	16.4	58.8
8	S8	7.25	0.34	3.3	65.7	341	14.5	58.8
9	S9	7.57	0.19	1.4	39.1	490	21.8	58.8

Estimation of silicon in soil and plant.

Table 2. Soil chemical properties of rice soils of middle Gujarat.

Variables	pH (1:2.5)	EC (dSm^{-1})	Org. C (%)	Av. P_2O_5 ($Kg\ ha^{-1}$)	Av. K_2O ($Kg\ ha^{-1}$)	Av. S ($mg\ kg^{-1}$)
Anand District (40 samples)						
Range	7.25-8.15	0.17 - 0.89	0.14-0.56	14.0-91.6	171-570	6.2-23.0
Mean	7.77	0.33	0.36	44.9	350	16.5
Kheda District (20 samples)						
Range	7.35-8.94	0.20-1.06	0.14-0.52	4.7-89.0	189-730	6.2-19.5
Mean	8.00	0.48	0.35	43.6	426	11.3
Overall (60 samples)						
Range	7.25-8.94	0.17-1.06	0.14-0.56	4.72-91.6	171-730	6.2-23.0
Mean	7.8	0.38	0.36	44.5	376	14.8

different extracts in soils of Kerala ranged from 8 to 435 mg kg^{-1}. Similarly, the available Si in soils of Coimbtore (Tamilnadu) ranged from 29 to 80 mg kg^{-1} (Subramanian and Gopalaswamy, 1991). Nayar et al. (1977) reported that the available Si extracted by NaOAc ranged from 8 to 278 mg kg^{-1} in soils of Orissa. Gontijo (2000) observed that soil Si values decreased with increased content of the sand in the soil. A soil having high percentage of sand tends to show low Si contents due to their poor capacity to supply Si to plants.

Response to Si application by rice

The results given in Table 4 indicated that the application of Si at all levels significantly increased the grain and straw yields over control in all categories of soils under study. Among the different soils studied, low and medium category soils have responded to the applied Si up to 200 mg kg^{-1} soil in achieving higher grain and straw yields over the control. Whereas, soils under the high category have recorded higher grain and straw yields with the application of 100 mg kg^{-1} soil and then showed a declining trend.

The rice growing under soils having low to medium available Si status responded to Si levels to a greater extent than the soils having higher levels of available Si. The maximum yield obtained due to the supplement of varied levels of Si in different soils ranged from 10.70 to 16. 84 g pot^{-1} and yield increase ranged from 1.84 to 8.81 g pot^{-1}. This variation may be attributed to differences in native available Si and response to the added Si fertilizer.

Table 3. Available Si and cation status in rice soils of middle Gujarat.

	Av. Si ($mg\ kg^{-1}$)	Exch. Ca ($me\ 100\ g\ soil^{-1}$)	Exch. Mg ($me\ 100\ g\ soil^{-1}$)	Av. Fe ($mg\ kg^{-1}$)	Av. Zn ($mg\ kg^{-1}$)
Anand District (40 samples)					
Range	30.58-78.73	24.0-122.0	58.8-304.0	10.5-77.7	0.44-5.2
Mean	47.74	55.0	103.0	34.6	1.7
Kheda District (20 samples)					
Range	18.38-44.06	12.0-198.0	55.2-178	19.0- 87.8	0.56-4.7
Mean	28.78	67.0	107.2	44.8	1.8
Overall (60 samples)					
Range	18.38-78.73	12.0-198.0	55.2-303.0	10.5-87.8	0.44-5.2
Mean	41.42	58.9	104.1	38.0	1.7

Table 4. Effect of Si rates in rice grain and straw yield in different soils.

Category	Soils (S)	Si levels ($mg\ kg^{-1}$ soil)							
		Grain Yield ($g\ pot^{-1}$)				Straw Yield ($g\ pot^{-1}$)			
		Si_0	Si_{100}	Si_{200}	Si_{300}	Si_0	Si_{100}	Si_{200}	Si_{300}
Low	S_1	8.03	14.13	16.84	12.38	20.48	23.37	27.30	25.77
	S_2	7.80	14.18	16.49	13.81	22.87	25.03	28.13	23.97
	S_3	10.03	14.50	15.86	13.83	18.93	23.10	26.07	24.57
	Mean	8.62	14.27	16.40	13.34	20.76	23.84	27.17	24.77
Medium	S_4	8.45	9.87	14.86	13.40	20.39	21.52	24.81	22.43
	S_5	8.23	11.27	12.90	10.65	20.79	22.83	23.72	23.74
	S_6	8.00	10.30	11.93	9.90	21.64	23.10	26.03	24.23
	Mean	8.22	10.48	13.23	11.32	20.94	22.48	24.86	23.47
High	S_7	8.10	11.33	8.83	7.83	17.40	18.90	18.97	16.73
	S_8	8.86	10.70	9.22	9.05	18.68	23.09	19.93	19.37
	S_9	6.53	11.80	10.83	7.77	17.31	24.49	19.90	18.33
	Mean	7.83	11.28	9.63	8.22	17.80	22.16	19.60	18.14
C.D. Soils				0.80				1.09	
Silicon				0.54				0.73	
S × Si				1.61				2.18	
C.V. %				8.93				6.05	

Similar results were also observed by Korndorfer et al. (2001) in soils of Florida. Increase in rice yield under flooded condition was noticed with Si fertilization in Sri Lanka (Takijima et al., 1970), Thailand (Takahashi et al., 1990), India (Singh et al., 2006) and Florida (Datnoff et al., 1992). Snyder et al. (1986) showed that application of calcium silicate increased the rice yields in histosols mainly due to the supply of available Si and not due to supply of other nutrients. The effect of Si on reducing diseases unquestionably contributed to increase yields, but Si has also been shown to increase yield in the absence of disease (Datnoff et al., 1992).

Effect of Si fertilization on silicon and nutrient content in rice

Nutrient content

The results presented in Table 5 revealed that Si content in grain was significantly increased under medium and high categories of soils as compared to low category soils. The highest Si content in grain (2.74%) was recorded in soils having high status of available Si, that is, high category soils. The Si content in grain ranged from 1.77 to 2.69% in untreated plots, whereas in treating

Table 5. Effect of Si application of silicon content in rice grain and straw in different soils of middle Gujarat.

Category	Soils (S)	Grain and straw Si content (%) — Si levels (mg kg^{-1} soil) — Si_0 Grain	Si_0 Straw	Si_{100} Grain	Si_{100} Straw	Si_{200} Grain	Si_{200} Straw	Si_{300} Grain	Si_{300} Straw	Mean (Soil) Grain	Mean (Soil) Straw
Low	S_1	1.77	6.53	1.85	7.73	2.01	7.12	2.18	8.06	1.95	7.36
	S_2	1.89	7.43	2.76	8.03	2.74	8.29	3.01	8.14	2.60	7.98
	S_3	2.28	6.93	3.00	7.74	2.50	8.37	2.32	9.00	2.52	8.01
	Mean	1.98	6.97	2.54	7.84	2.42	7.93	2.50	8.40	2.36	7.78
Medium	S_4	2.30	6.47	3.24	7.13	2.61	7.47	2.46	8.50	2.65	7.39
	S_5	2.13	5.35	2.76	6.78	2.37	8.84	2.77	8.73	2.51	7.43
	S_6	2.23	6.02	2.69	7.66	2.77	7.93	2.90	8.66	2.65	7.57
	Mean	2.22	5.94	2.90	7.19	2.58	8.08	2.71	8.63	2.60	7.46
High	S_7	2.66	6.83	2.92	7.33	3.36	7.68	3.03	8.54	2.99	7.60
	S_8	2.69	7.13	2.92	8.67	3.40	8.62	3.35	8.90	3.09	8.33
	S_9	1.90	6.67	2.31	7.10	2.12	8.13	2.25	8.25	2.14	7.54
	Mean	2.42	6.88	2.71	7.70	2.96	8.14	2.88	8.56	2.74	7.82
Overall	Range	1.77-2.69	5.35-7.43	1.85-3.24	6.78-8.67	2.01-3.40	7.12-8.84	2.18-3.35	8.06-9.00		
	Mean (Si)	2.21	6.60	2.72	7.58	2.65	8.05	2.70	8.53		

	Grain S. Em. ±	Grain C.D. at 5%	Straw S. Em. ±	Straw C.D. at 5%
Soils (S)	0.12	0.33	0.11	0.30
Silicon (Si)	0.08	0.22	0.02	NS
S x Si	0.24	NS	0.06	0.17
C.V. %	15.87		14.44	

	S. Em. ± Grain	S. Em. ± Straw	C.D. at 5% Grain	C.D. at 5% Straw
Soil category	0.07	0.02	0.19	NS
Si within soil category	0.136	0.04	NS	0.10
Si (Low)	0.24	0.01	NS	NS
Si (Medium)	0.24	0.01	NS	0.04
Si (High)	0.24	0.02	NS	NS

plots, it ranged from 1.85 to 3.40%. The highest value of Si content in grain was observed at Si_{100} level at 2.54 and 2.90% under low and medium category soils, respectively, but further increment in Si levels, it decreased in both categories. Also, the effect of Si application significantly increased Si content in grain at all the levels over control (Si_0). The average value of Si content in straw was 7.78, 7.46 and 7.82% in low, medium and high category soils, respectively. The significant critical difference in Si content of straw due to different Si levels was observed only under medium category soils. The Si content in straw was significantly increased at Si_{100}, Si_{200} and Si_{300} levels over control (5.94%). Nayar et al. (1982)

Table 6. Effect of Si application of phosphorus content in rice grain and straw in different soils of middle Gujarat.

Category	Soils (S)	Grain and straw Phosphorus content (%) – Si levels (mg kg^{-1} soil) – Si_0		Si_{100}		Si_{200}		Si_{300}		Mean (Soil)	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Low	S_1	0.48	0.13	0.49	0.13	0.53	0.14	0.57	0.12	0.52	0.13
	S_2	0.38	0.13	0.40	0.14	0.37	0.12	0.37	0.14	0.38	0.13
	S_3	0.39	0.20	0.42	0.21	0.43	0.23	0.38	0.22	0.41	0.21
	Mean	0.42	0.15	0.44	0.16	0.44	0.16	0.44	0.16	0.43	0.16
Medium	S_4	0.35	0.15	0.35	0.20	0.37	0.15	0.32	0.22	0.35	0.18
	S_5	0.52	0.21	0.56	0.23	0.52	0.22	0.53	0.20	0.53	0.22
	S_6	0.39	0.19	0.38	0.18	0.40	0.17	0.36	0.18	0.38	0.18
	Mean	0.42	0.18	0.43	0.21	0.43	0.18	0.41	0.20	0.42	0.19
High	S_7	0.36	0.18	0.39	0.17	0.37	0.19	0.36	0.16	0.37	0.17
	S_8	0.57	0.21	0.47	0.20	0.50	0.22	0.49	0.20	0.51	0.21
	S_9	0.45	0.24	0.45	0.20	0.45	0.20	0.44	0.21	0.45	0.22
	Mean	0.46	0.21	0.44	0.19	0.44	0.20	0.43	0.19	0.44	0.20
Overall	Range	0.35-0.57	0.13-0.24	0.35-0.56	0.13-0.23	0.37-0.53	0.12-0.23	0.32-0.57	0.12-0.22		
	Mean (Si)	0.43	0.18	0.43	0.19	0.44	0.18	0.43	0.18		

	Grain S. Em. ±	Grain C.D. at 5%	Straw S. Em. ±	Straw C.D.at 5%
Soils (S)	0.004	0.01	0.003	0.010
Silicon (Si)	0.003	0.01	0.002	NS
S x Si	0.009	0.02	0.007	0.02
C.V. %	3.55		6.53	

	S. Em. ± Grain	S. Em. ± Straw	C.D. at 5% Grain	C.D. at 5% Straw
Soil category	0.003	0.002	0.01	0.01
Si within soil category	0.009	0.004	0.02	0.01
Si (Low)	0.009	0.01	0.02	0.02
Si (Medium)	0.009	0.01	0.02	0.02
Si (High)	0.005	0.01	0.01	0.02

whole plant increased with the progress of growth and was also during vegetative growth and high after flowering stage. The silica absorption was slow during the initial growth stages, but increased with the onset of the reproductive growth period after flowering.

Several researchers also observed that the SiO_2 content of straw ranged from 4.4 to 19.6% with an average of 11.0% (Imaizumi and Yoshida, 1958), 7.5 to 9.0% (Wu and Lian, 1965). Nayar et al. (1977) had indicated that the SiO_2 content in harvested straw and grain was 7.13 and 2.67%, respectively.

Similar results were also reported by Takahashi et al. (1990) in soils of Sri Lanka, Singh et al. (2006) in soils of India and Snyder et al. (1986) and Korndorfer et al. (2001) in some soils of Florida.

The nutrients viz., P, K, S and Na content in grain and straw differed significantly by Si levels among soil categories (Tables 6 to 9). The highest P and K content reported that the silica content of

Table 7. Effect of Si application of phosphorus content in rice grain and straw in different soils of middle Gujarat.

Category	Soils (S)	Grain and straw Potassium content (%)									
		Si levels (mg kg^{-1} soil)								Mean (Soil)	
		Si_0		Si_{100}		Si_{200}		Si_{300}			
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Low	S_1	0.57	1.05	0.54	1.02	0.55	0.93	0.59	1.17	0.56	1.04
	S_2	0.87	1.31	0.90	1.07	0.88	0.93	0.90	1.39	0.89	1.17
	S_3	0.55	0.85	0.65	1.04	0.65	1.12	0.72	1.19	0.64	1.05
	Mean	0.66	1.07	0.70	1.04	0.69	0.99	0.74	1.25	0.70	1.09
Medium	S_4	0.79	1.16	0.78	1.12	0.80	1.25	0.78	1.39	0.78	1.23
	S_5	0.48	1.31	0.49	1.59	0.50	1.60	0.56	1.60	0.51	1.52
	S_6	0.78	0.99	0.87	1.07	0.85	0.97	0.76	1.04	0.81	1.01
	Mean	0.68	1.15	0.71	1.26	0.72	1.27	0.70	1.34	0.70	1.25
High	S_7	0.62	1.08	0.76	1.09	0.83	1.27	0.80	1.13	0.75	1.14
	S_8	0.86	0.96	0.92	0.93	0.87	0.90	0.96	0.96	0.90	0.93
	S_9	1.11	1.33	1.09	1.39	0.97	1.36	1.14	1.32	1.08	1.35
	Mean	0.86	1.12	0.92	1.13	0.89	1.17	0.97	1.14	0.91	1.14
Overall	Range	0.48-1.11	0.85-1.33	0.49-1.09	0.93-1.59	0.50-0.97	0.93-1.60	0.56-1.14	0.96-1.60		
	Mean (Si)	0.74	1.11	0.78	1.14	0.76	1.14		1.24		

	Grain		Straw	
	S. Em. ±	C.D. at 5%	S. Em. ±	C.D. at 5%
Soils (S)	0.006	0.02	0.012	0.03
Silicon (Si)	0.004	0.01	0.008	0.02
S x Si	0.012	0.03	0.024	0.07
C.V. %	2.66		3.55	

	S. Em. ±		C.D. at 5%	
	Grain	Straw	Grain	Straw
Soil category	0.003	0.007	0.01	0.02
Si within soil category	0.007	0.014	0.02	0.04
Si (Low)	0.012	0.024	0.03	0.07
Si (Medium)	0.012	0.024	0.03	0.07
Si (High)	0.012	0.024	0.03	0.07

the silicon.

The interaction effect of soil and Si levels was significant for P, K, S and Na contents of rice grain and straw. Similar results were also reported by Okuda and Takahashi (1962b) who stated that added silicon increased the translocation rate of absorbed phosphorous to the grain, especially at the phosphorus deficient level. This effect might have resulted from the action of silicon, in which the increasing amount of silicon decreased the iron content of rice plant. Si controls the chemical and biological properties of soil with the following benefits: Silicon reduced leaching of phosphorous (P) and potassium (K) (Sadgrove, 2006), reduced Aluminium (Al), Iron (Fe), Manganese (Mn) and

Table 8. Effect of Si application of sulfur content of rice grain and straw in different soils of middle Gujarat.

Category	Soils (S)	Grain and straw Sulphur content (%)									
		Si levels (mg kg^{-1} soil)								Mean (Soil)	
		Si_0		Si_{100}		Si_{200}		Si_{300}			
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Low	S_1	0.81	0.89	0.86	0.86	0.72	0.86	0.81	0.87	0.80	0.87
	S_2	0.72	0.74	0.82	0.73	0.83	0.67	0.85	0.93	0.80	0.77
	S_3	0.65	0.96	0.76	0.86	0.65	0.91	0.85	0.86	0.73	0.90
	Mean	0.73	0.86	0.81	0.82	0.73	0.81	0.83	0.88	0.78	0.84
Medium	S_4	0.65	0.76	0.63	0.78	0.63	0.87	0.69	0.73	0.65	0.79
	S_5	0.81	0.82	0.82	0.78	0.85	0.78	0.86	0.87	0.83	0.81
	S_6	0.80	0.43	0.87	0.44	0.81	0.54	0.85	0.47	0.83	0.47
	Mean	0.75	0.67	0.77	0.67	0.76	0.73	0.80	0.69	0.77	0.69
High	S_7	0.84	0.77	0.85	0.75	0.74	0.72	0.84	0.75	0.82	0.75
	S_8	0.88	0.72	0.82	0.85	0.87	0.78	0.84	0.77	0.85	0.78
	S_9	0.63	0.82	0.64	0.79	0.67	0.89	0.57	0.92	0.62	0.86
	Mean	0.78	0.77	0.77	0.80	0.76	0.80	0.75	0.82	0.77	0.80
Overall	Range	0.63-0.88	0.43-0.96	0.63-0.87	0.44-0.86	0.63-0.87	0.54-0.91	0.57-0.86	0.47-0.93		
	Mean (Si)	0.75	0.77	0.78	0.76	0.75	0.78	0.79	0.80		

	Grain		Straw	
	S. Em. ±	C.D. at 5%	S. Em. ±	C.D. at 5%
Soils (S)	0.007	0.02	0.010	0.03
Silicon (Si)	0.00	0.01	0.007	0.02
S x Si	0.01	0.04	0.020	0.06
C.V. %	3.02		4.52	

	S. Em. ±		C.D. at 5%	
	Grain	Straw	Grain	Straw
Soil category	0.004	0.006	NS	0.02
Si within soil category	0.01	0.012	0.02	0.03
Si (Low)	0.01	0.020	0.04	0.06
Si (Medium)	0.01	0.020	0.04	0.06
Si (High)	0.01	0.020	0.04	0.06

heavy metal mobility (Matichenkov and Calvert, 2002), improved microbial activity (Matichenkov and Calvert, 2002), increased stability of soil organic matter, improved soil texture (Sadgrove, 2006), improved water holding capacity (Sadgrove, 2006), increased stability against soil erosion (Sadgrove, 2006), and increased cationic exchange capacity (CEC) (Camberato, 2001).

Form of Si in soil present SiO_2 and as various silicates minerals and form of Si in soil solution present silicic acid [Si (OH) 4]. Islam and Saha (1969) inferred that the application of silicon

Table 9. Effect of Si application of Sodium content of rice grain and straw in different soils of middle Gujarat.

Category	Soils (S)	Grain and straw Sodium content (%)									
		Si levels (mg kg^{-1} soil)								Mean (Soil)	
		Si_0		Si_{100}		Si_{200}		Si_{300}			
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Low	S_1	0.26	0.31	0.27	0.29	0.29	0.31	0.27	0.32	0.27	0.31
	S_2	0.34	0.34	0.32	0.32	0.33	0.37	0.34	0.37	0.33	0.35
	S_3	0.42	0.22	0.44	0.22	0.44	0.21	0.44	0.23	0.43	0.22
	Mean	0.34	0.29	0.34	0.27	0.35	0.30	0.35	0.31	0.35	0.29
Medium	S_4	0.34	0.36	0.36	0.34	0.33	0.38	0.31	0.38	0.34	0.36
	S_5	0.40	0.23	0.35	0.24	0.34	0.29	0.33	0.27	0.36	0.26
	S_6	0.46	0.24	0.47	0.22	0.47	0.27	0.45	0.22	0.46	0.24
	Mean	0.40	0.28	0.39	0.27	0.38	0.31	0.36	0.29	0.38	0.29
High	S_7	0.37	0.32	0.32	0.37	0.34	0.35	0.34	0.36	0.34	0.35
	S_8	0.23	0.21	0.26	0.18	0.20	0.22	0.24	0.18	0.23	0.20
	S_9	0.34	0.37	0.36	0.34	0.36	0.35	0.34	0.34	0.35	0.35
	Mean	0.31	0.30	0.31	0.30	0.30	0.31	0.31	0.29	0.31	0.30
Overall	Range	0.23-0.46	0.21-0.37	0.26-0.47	0.18-0.37	0.20-0.47	0.21-0.38	0.24-0.44	0.18-0.38		
	Mean (Si)	0.35	0.29	0.35	0.28	0.34	0.31	0.34	0.29		

	Grain		Straw	
	S. Em. ±	C.D. at 5%	S. Em. ±	C.D. at 5%
Soils (S)	0.003	0.01	0.005	0.01
Silicon	0.002	0.01	0.003	0.01
(Si) S x Si	0.007	0.02	0.009	0.03
C.V. %	3.50		5.61	

	S. Em. ±		C.D. at 5%	
	Grain	Straw	Grain	Straw
Soil category	0.002	0.003	0.01	0.01
Si within soil category	0.004	0.005	0.01	0.02
Si (Low)	0.007	0.009	NS	NS
Si (Medium)	0.007	0.009	0.02	0.03
Si (High)	0.007	0.009	0.02	0.03

generally decreased the potassium content of rice plants.

Conclusion

Among the different soils studied, low and medium category soils have responded to the applied Si up to 200 mg kg^{-1} soil in achieving higher grain and straw yields over the control. Whereas, soils under the high category have recorded higher grain and straw yields with the application of 100 mg kg^{-1} soil and then showed a declining trend. The application of Si at different rates recorded 1.85 to 3.40% Si content in the grain, whereas, it ranged from 1.77 to 2.69% under control. The highest Si content in grain (2.74%) was recorded in high category soils. The average value of Si content in straw was 7.78, 7.46 and 7.82% in low, medium and high category soils, respectively.

Conflict of Interest

The authors have not declared any conflict of interest.

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