

Original Research Article

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Rice Yield and Available Nutrients Status of Loamy Sand Soil as Influenced by Different Levels of Silicon and Nitrogen

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ABSTRACT

A field trial was conducted during *kharif* seasons of 2014 and 2015 on loamy sand, at the Agriculture Research Station, Anand Agricultural University, Jabugam, Gujarat (India), to assess the available nutrient status after harvest of rice soil as influenced by different levels of silicon and nitrogen application under loamy sand. The experiment encompassed four levels of nitrogen *viz.*, 0, 75, 100 and 125 kg N ha⁻¹ from ammonium sulphate and four levels of silicon *viz.*, 0, 200, 400 and 600 kg Si ha⁻¹ from calcium silicate. The experiment was laid out in randomized block design (Factorial) with three replications. Results revealed that individual application of nitrogen @ 125 kg ha⁻¹ and Si @ 600 kg ha⁻¹ produced the highest grain and straw yields of rice. The salt content, pH and organic carbon content of soil remained almost unchanged due to N and/ or Si applications. The available N content in soil was found to increase with graded levels of N and Si application. Similarly, available Si content in soil was also increased due to Si as well as N application. Application of 600 kg Si ha⁻¹ significantly increased the P, K and S contents in soil after harvest of rice. The effect of N on available K₂O content in soil after harvest of the crop was significantly increased.

Keywords

Nutrients, Loamy sand soil, Silicon, Nitrogen

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Introduction

Silicon (Si) is one of the most abundant elements found in the earth's crust, but is mostly inert and only slightly soluble. Agriculture activity tends to remove large quantities of Si from the soil. Rice is known to absorb more Si than any other mineral nutrient

accumulates in the plant. Response to silicon fertilization has been documented in some areas of the world. The reason for this plant response or yield increase is not fully understood, but several mechanisms have been proposed. Plant growth studies indicate that rice yield responses to silicon may be associated with induced resistance to biotic

and abiotic stresses such as disease and pest resistance, Al, Mn and Fe toxicity alleviation, increased P availability, reduced lodging, improved leaf and stalk erectness, freeze resistance, and improvement in plant water economy. This review covers the relationship of silicon to rice crop production, including recommendations on how to manage silicon in soils and plants and silicon interactions with other elements in a best manner.

Rice is considered to be a Si accumulator plant and tends to actively accumulate Si to tissue concentrations of 5 per cent or higher (Epstein, 1999). Application of N fertilizers is an important practice for increasing rice yields. However, when applied in excess may limit, yield because of lodging, promote shading and susceptibility to insects and diseases. These effects could be minimized by the use of Si (Munir *et al.*, 2003). Information on the importance of Si in Indian rice farming system is limited (Prakash, 2002). Rice is prone to various stresses if the available soil silicon is low for absorption. Production of 5 t ha⁻¹ of grain yield of rice is estimated to remove about 230-470 kg elemental Si from soil, depending upon soil and plant factors. Absorption will be about 108 % more than the N content. Adequate supply of silicon of rice from tillering to elongation stage increases the number of grains panicle⁻¹ and the percentage of ripening (Korndorfer *et al.*, 2001). Silicon has been reported to raise the optimal level of nitrogen in rice.

Silicon plays an important role in balancing nutrient absorption (Ma *et al.*, 2006). Its absorption and transport, Si often interacts with other elements. In an agricultural context, those interactions in which Si interferes with absorption or partitioning of nutrients at concentrations high enough to be damaging to the plants, are particularly noteworthy. Toxicities of Al and other metal ions common in highly leached, acidic, and decalcified soils,

are often mitigated by Si, and experimental work with solution cultures has shown the same effect. Si may retard or minimize Na uptake by plants, thereby reducing the potential damage caused due to salinity. Silicon may enhance soil fertility, improve disease and pest resistance, increase photosynthesis, improve plant architecture, regulate transpiration, increase tolerance to the toxicity of the elements such as Fe and Mn, and reduce frost damage. Silicon promotes plant health (Muir *et al.*, 2001) and soil productivity. Both agronomists and horticulturists use Si; as a fertilizer for crop on certain soil and reported that its use increases yields and sometimes act as a quality-key factor in crop production. Silicon is involved in a great number of structural and dynamic aspects of plant life, and its roles are surprisingly diverse. Therefore, the paper deals with available nutrients status after harvest of rice soils in influenced by different levels of silicon and nitrogen application under loamy sand.

Materials and Methods

In order to achieve the pre-set objectives of the present investigation, a field experiment was conducted during the *Kharif* season for two years 2014 and 2015 at Agricultural Research Station, Anand Agricultural University, Jabugam, Gujarat. Geographically, Jabugam is situated at 22^o17'37.70" north latitude, 73^o46'41.02" east longitude with an elevation of 92 meters above mean sea level. The climate of Jabugam region is semi-arid and sub-tropical with hot summer and cold winter. In this region, generally monsoon commences in the month of June and retreats from the end of September. Most of the rainfall is received from south-west monsoon currents. July and August are the months of heavy showers. The total rainfall of the region is about 800-1000 mm. Average minimum and maximum temperature of both the year of

study was 19.6°C and 33.3°C, respectively. The soil was loamy sand, with a sand, fine sand, silt and clay composition of 49.85, 26.6, 10.0 and 12.1%, respectively.

To assess the fertility status of soil, representative composite soil samples from each net plot area was collected after harvesting of the crop. Soil samples were thoroughly mixed and air-dried. Soil was ground using wooden mortar and pestle and then passed through 2 mm plastic sieve to avoid metallic contamination. The processed soil samples were analyzed for soil physical and chemical properties by adopting standard methods given in Table 1.

The experiment was based on a Randomized Block Design with factorial concept encompassing three replications and sixteen combined treatments. The plot size was 5.0 m × 3.6 m and the total numbers of unit plots were 48 (16 × 3), GAR 13 (Gujarat Anand Rice 13) variety was used in this experiment. The entire dose of phosphorus as per recommendation was applied through single super phosphate. Four levels (0, 75, 100 and 125 kg ha⁻¹) of N were applied through ammonium sulphate in 3 equal splits (1/3 basal, 1/3 at active tillering stage and 1/3 at panicle initiation stage) and four levels (0, 200, 400 and 600 kg ha⁻¹) of Si were applied through calcium silicate at the time of sowing.

Results and Discussion

Grain and straw yield

Data in Table 2 illustrated that application of nitrogen had a significant effect on grain yield of rice. The lowest grain (5241 kg ha⁻¹) and straw (6961 kg ha⁻¹) yield was observed under control and maximum grain (6445 kg ha⁻¹) and straw (8658 kg ha⁻¹) yields was recorded due to application of 125 kg N ha⁻¹. The treatment 125 kg N ha⁻¹ gave a significantly higher grain

yield over the control. The increase in yield as a result of nitrogen application could be due to the marginal nitrogen content of soil, improvement in root development and vegetative growth as well. The improvement in yield attributing traits may be ascribed to the improved vegetative growth due to N fertilization, facilitating photosynthesis, thereby increasing translocation of organic food materials towards the reproductive organs; which enhanced the formation of panicles with fertile grains. The results are in conformity with those of Mahajan and Tripathi (1992), Dehal and Mishra (1994).

Sudhakar *et al.*, (2006) also observed 16.7 per cent increase in grain yield with application of N at 160 kg ha⁻¹ as compared to 80 kg N ha⁻¹. Above all, excess N also prolongs the vegetative growth at the cost of reproductive growth, thus, diminishing the production of carbohydrates (Mauad *et al.*, 2003). Singh *et al.*, (2002) reported that the grain yield increased significantly due to 120 kg N ha⁻¹ contributing in three times (transplanting time, tillering time and panicle initiation).

The results presented in Table 2 illustrate that the rice grain and straw yield was significantly influenced by silicon application. The significantly higher grain (6163 kg ha⁻¹) and straw (8536 kg ha⁻¹) yield per plot was recorded due to silicon application at 600 kg ha⁻¹; while the lowest grain (5693 kg ha⁻¹) and straw (7319 kg ha⁻¹) yield per plot was recorded under control. The treatment 600 kg Si ha⁻¹ gave significantly higher grain and straw yields over the control and 200 kg Si ha⁻¹; which was at par with 400 kg Si ha⁻¹. The increase in rice yield might be due to increased availability of silicon. The lower yield in the control compared to silicon fertilized plots, might be due to leaching and fixation loss of native silicon in submerged conditions which is inadequate in meeting the Si requirement by the crop for producing

higher grain yield. The increase in yield with Si application could be due to beneficial effects *viz.*, decreasing mutual shading by improving leaf erectness, decreasing susceptibility to lodging, decreasing the incidence of infections with root parasites and pathogens, leaf pathogens and preventing manganese and iron toxicity or both. Increased water use efficiency observed with the application of Si, probably might be due to prevention of excessive transpiration. During the reproductive stage, silicon is preferentially transported into the flag leaves, and interruption of silicon supply at this stage is detrimental for spikelet fertility (Ma *et al.*, 2006). The results are in line with the findings of Savant *et al.*, (1997). Chen *et al.*, (2011) stated that the silicon application increased grain yield by increase of spikelet number, filled spikelet percentage and 1000-seed weight. Mauod *et al.*, (2003) and Ma and Takahashi, (1990) reported that grain yield increased by silicon application. The interaction effect between N and Si on a grain and straw yields of rice was non-significant.

Effect of N and Si on chemical properties of soil after harvest of rice

At the harvest of the crop, some of the soil physico-chemical and chemical parameters *viz.*, pH, EC, OC, available N, P₂O₅, K₂O, S and Si were studied to observe the influence of different N and Si levels on the soil properties with rice crop. The results pertaining to the soil parameters are presented in Table 2 to 4.

pH, electrical conductivity and organic carbon

The data Table 2 revealed that individual effect of N and Si and also their interaction found to be non-significant for organic carbon, electrical conductivity (dS m⁻¹) and soil pH after harvest of rice during both individual years as well as on a pooled basis.

Available nitrogen (kg ha⁻¹)

The data presented in Table 3 indicated that varying levels of N significantly influenced the available nitrogen in soil after harvest of rice. The lowest available nitrogen content after harvest of crop (255, 231 and 243 kg ha⁻¹) was observed under control during both individual years as well as on a pooled basis. The maximum available nitrogen content (324, 308 and 316 kg ha⁻¹) was recorded due to application of 125 kg N ha⁻¹ during both individual years as well as on a pooled basis. The treatment 125 kg N ha⁻¹ registered significantly higher available nitrogen over the control and 75 kg N ha⁻¹ during both individual years as well as on a pooled basis. However, it was at par with 100 kg N ha⁻¹ during the first year only. The highest improvement over control was to the tune of 27, 34 and 30 per cent during both individual years as well as on a pooled basis, respectively. When compared to the initial status, there was 29 percent depletion in the control and 24 percent built up in available status at N₁₂₅ fertility level. It could also be observed that with increase in N levels, the nutrient contents also increased accordingly.

Data in Table 3 illustrated that application of silicon had a significant effect on available nitrogen in soil after harvest of crop during both individual years and as well as on a pooled basis. The lowest available nitrogen content in soil after harvest of rice crop (258, 237 and 248 kg ha⁻¹) was observed under control during both the years as well as on a pooled basis. The maximum available nitrogen content in soil (320, 309 and 315 kg ha⁻¹) was recorded due to application of 600 kg Si ha⁻¹ during both individual years as well as on a pooled basis. The treatment 600 kg Si ha⁻¹ gave significantly higher available nitrogen content in soil after harvest of crop over the control and 200 kg Si ha⁻¹ during both the years as well as on a pooled basis. However, it

was at par with 400 kg Si ha⁻¹ during first year only. The greatest improvement was to the tune of 24, 30 and 27 per cent during both individual years as well as on a pooled basis respectively, over control. When compared to the initial status, there was 26 percent depletion in the control and 23 percent built up in available status at Si₆₀₀ fertility level. It could also be observed that, with increase in N levels, the nutrient contents also increased accordingly. The improved nitrogen status in soil by the use of N and Si fertilization can be explained by high adsorption capacity of Si and increased microbial activity, which might have hastened the process of mineralization during crop growth period resulting in high accumulation of N in soil in the Si treated soil (Biel *et al.*, 2008).

The data on the interaction effect of N x Si (Table 4) revealed that significantly highest N content in soil after harvest of crop was observed due to combined effect of 125 kg N ha⁻¹ and 600 kg Si ha⁻¹ application (386 kg ha⁻¹) over rest of the combinations. The lowest N content in soil after harvest of crop was noticed in control plots (226 kg ha⁻¹). It could also be observed that, with increase in N levels, the nutrient contents also increased accordingly.

The improved nitrogen status in soil by the use of N and Si fertilization can be explained by high adsorption capacity of Si and increased microbial activity, which might have hastened the process of mineralization during crop growth period resulting in high accumulation of N in soil in the Si treated soil (Biel *et al.*, 2008). The improved nitrogen status in soil by the use of N fertilization can be explained by high adsorption capacity of N and increased microbial activity, which might have hastened the process of mineralization during crop growth period resulting in high accumulation of N in soil in the N treated soil (Biel *et al.*, 2008). Matichenkov *et al.*, 2000 reported

similar results in commercial fields of Mossman to Bundaberg. These results are in accordance with the findings of Snyder *et al.*, (1986) and Malidareh *et al.*, (2009).

Available silicon (kg ha⁻¹)

A perusal of data presented in Table 3 revealed that application of N increased the Si content in soil after harvest of rice crop during both individual years as well as on a pooled basis. The lowermost silicon content (199.6, 214.7 and 207.2 kg ha⁻¹) was observed under control during both the years as well as on a pooled basis. The maximum silicon content in soil after harvest of rice crop (241.0, 258.1 and 249.6 kg ha⁻¹) was recorded due to application of 125 kg N ha⁻¹ during both individual years as well as on a pooled basis, respectively. The treatment 125 kg N ha⁻¹ gave significantly higher Si content in soil after harvest of crop over the control and 75 kg N ha⁻¹ during both the years as well as on a pooled basis. However, it was at par with 100 kg N ha⁻¹ during both the years as well as pooled basis. The furthestmost improvement over control was to the assessment of 21, 20 and 20 per cent during both individual years as well as on a pooled basis, respectively.

There was an increase up to an extent of 26 per cent in available Si content of the soil when compared to the initial status even without its fertilization. This could be due to the reason that Si is released into the soil solution after flooding as well as with organic matter content of soil as reported earlier by Ponnampereuma (1972). The highest Si status by submerged may be due to reduction of silicon by hydrous oxide of Fe³⁺ sorbing occluded silicon and the action of carbon dioxide on aluminosilicates (Ponnampereuma 1972 and Nayar *et al.*, 1982). The application of N fertilizers showed greater accumulation of Si in soil. The results are in agreement with the findings of Inanaga *et al.*, (2002).

Table.1 Initial physico-chemical properties of the experimental soil

Sr. No.	Determination	2014	2015	Method	Reference
A Physical Properties					
1	Particle size distribution (g 100 g ⁻¹)			International pipette method	Piper (1966)
	Coarse Sand	49.85	49.80		
	Fine sand	26.6	26.70		
	Silt	10.0	10.0		
	Clay	13.55	13.50		
	Texture	Loamy sand	Loamy sand		
2	Bulk density (Mg m ⁻³)	1.38	1.26	Cylindrical core method	Jackson (1973)
3.	W.H.C. (g 100g ⁻¹ soil)	38.89	37.37	Brass Cup Method	Jackson (1973)
B Physico-Chemical Properties					
1	pH (1:2.5)	6.32	6.13	Potentiometry	Jackson (1973)
2	EC (1:2.5) dSm ⁻¹	0.43	0.38	Conductometry	Jackson (1973)
3	Organic carbon (g kg ⁻¹)	6.10	5.50	Modified Walkley and Black method	Walkley and Black (1934)
C Chemical Properties					
1	Available N (kg ha ⁻¹)	313	310	Alkaline KMnO ₄ method	Subbiah and Asija (1956)
2	Available P ₂ O ₅ (kg ha ⁻¹)	88	90	Olsen's method (0.5 M NaHCO ₃ , pH 8.5)	Olsen <i>et al.</i> , (1954)
3	Available K ₂ O (kg ha ⁻¹)	221	205	Neutral N NH ₄ OAc Flame photometry method	Jackson (1973)
4	Available S (mg kg ⁻¹)	3.53	3.98	Turbidimetric method (0.15 % CaCl ₂)	Williams and Steinbergs (1959)
5	Available Si (kg ha ⁻¹)	190.8	185.0	NaOAc (pH- 4) Colorimetric method	Korndorfer <i>et al.</i> , (1999)

Table.2 Effect of N and Si on yield, pH, EC and OC contents after harvest of rice under low land conditions (pooled 2 years)

Treatments		Yield (kg ha ⁻¹)			pH			EC (dSm ⁻¹)			OC (g kg ⁻¹)		
		2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Nitrogen levels (kg ha⁻¹)													
N 0		5316	5166	5241	6.82	6.75	6.79	0.24	0.27	0.25	3.48	3.65	3.57
N 75		5910	6171	6040	7.19	6.80	6.99	0.24	0.25	0.24	3.82	3.91	3.86
N 100		6023	6304	6163	6.68	7.02	6.85	0.22	0.25	0.23	3.94	4.10	4.02
N 125		6405	6486	6445	6.84	7.11	6.98	0.25	0.27	0.26	4.03	4.21	4.12
N	S. Em ±	113	109	78	0.17	0.20	0.13	0.01	0.01	0.01	0.16	0.17	0.12
	CD (0.05)	325	314	221	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y x N	S. Em ±	111	111	111	0.19	0.19	0.19	0.01	0.01	0.01	0.16	0.16	0.16
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Silicon levels (kg ha⁻¹)													
Si 0		5570	5816	5693	6.58	6.88	6.73	0.22	0.25	0.24	3.59	4.15	3.87
Si 200		5951	5936	5944	6.75	7.07	6.91	0.23	0.27	0.25	3.77	3.85	3.81
Si 400		6030	6151	6091	6.99	6.86	6.93	0.24	0.24	0.24	3.92	4.09	4.00
Si 600		6102	6224	6163	7.20	6.87	7.03	0.23	0.27	0.25	3.99	3.77	3.88
Si	S. Em ±	113	109	78	0.17	0.20	0.13	0.01	0.01	0.01	0.16	0.17	0.12
	CD (0.05)	325	314	221	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y x Si	S. Em ±	111	111	111	0.19	0.19	0.19	0.01	0.01	0.01	0.16	0.16	0.16
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Interactions													
N X Si		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y X N X Si		-	-	NS	-	-	NS	-	-	NS	-	-	NS
CV %		6.6	8.5	7.6	8.8	10.3	9.6	12.9	11.7	12.3	14.7	14.5	14.6

Table.3 Effect of nitrogen and silicon on N, P₂O₅, K₂O, Silicon and Sulphur contents after harvest of rice under low land conditions (pooled 2 years)

Treatments		Nitrogen (kg ha ⁻¹)			P ₂ O ₅ (kg ha ⁻¹)			K ₂ O (kg ha ⁻¹)			Silicon (kg ha ⁻¹)			Sulphur (mg kg ⁻¹)		
		2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Nitrogen levels (kg ha⁻¹)																
N 0		255	231	243	86.4	72.8	79.6	218	236	227	199.6	214.7	207.2	7.14	9.80	8.47
N 75		276	262	269	88.0	75.1	81.5	220	238	229	211.8	229.6	220.7	7.92	10.8	9.37
N 100		298	284	291	90.1	75.1	82.6	254	283	268	235.1	255.5	245.3	8.15	11.7	9.93
N 125		324	308	316	91.9	78.7	85.3	255	290	272	241.0	258.1	249.6	8.26	10.9	9.62
N	S. Em ±	10	8	6	2.11	2.13	1.50	8	7	5	4.7	6.3	3.9	0.27	0.31	0.21
	CD (0.05)	28	22	17	NS	NS	NS	23	20	15	13.5	18.3	11.1	0.79	0.88	0.58
Y x N	S. Em ±	9	9	9	2.12	2.12	2.12	7	7	7	5.6	5.6	5.6	0.29	0.29	0.29
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Silicon levels (kg ha⁻¹)																
Si 0		258	237	248	81.8	64.5	73.2	194	204	199	162.5	169.5	166.0	6.74	8.94	7.84
Si 200		280	260	270	85.0	68.6	76.8	234	256	245	231.4	250.3	240.8	7.52	10.4	8.98
Si 400		294	280	287	94.6	83.6	89.1	252	279	266	242.5	263.2	252.9	8.07	11.2	9.65
Si 600		320	309	315	95.1	84.8	89.9	267	308	288	251.1	275.0	263.0	9.14	12.7	10.9
Si	S. Em ±	10	8	6	2.11	2.13	1.50	8	7	5	4.7	6.3	3.9	0.27	0.31	0.21
	CD (0.05)	28	22	17	6.1	6.2	4.2	23	20	15	13.5	18.3	11.1	0.79	0.88	0.58
Y x Si	S. Em ±	9	9	9	2.12	2.12	2.12	7	7	7	5.6	5.6	5.6	0.29	0.29	0.29
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Interactions																
N X Si		NS	Sig	Sig	Sig	NS	Sig	NS	NS	Sig	Sig	Sig	Sig	NS	NS	NS
Y X N X Si		-	-	NS	-	-	NS	-	-	NS	-	-	NS	-	-	NS
CV %		11.6	9.7	10.8	8.2	9.8	8.9	11.6	9.3	10.4	7.3	9.2	8.4	12.1	9.8	10.8

Table.4 Interaction effect of N x Si on N, P₂O₅, K₂O and Silicon content after harvest of rice (pooled 2 years)

Treatments	Nitrogen levels (kg ha ⁻¹)															
Silicon levels (kg ha ⁻¹)	N ₀				N ₇₅				N ₁₀₀				N ₁₂₅			
	N	P ₂ O ₅	Si	K ₂ O	N	P ₂ O ₅	Si	K ₂ O	N	P ₂ O ₅	Si	K ₂ O	N	P ₂ O ₅	Si	K ₂ O
Si ₀	226	76.0	178.5	200	243	75.2	169.0	193	248	71.8	160.1	195	274	69.7	156.3	207
Si ₂₀₀	243	78.5	202.7	223	270	79.6	219.0	224	279	72.1	269.4	268	287	77.0	272.3	265
Si ₄₀₀	248	80.3	212.7	236	278	85.3	240.9	243	303	90.6	275.3	289	318	100.2	282.6	295
Si ₆₀₀	254	83.6	234.9	248	284	86.1	254.0	258	335	95.9	276.2	322	386	94.3	287.0	323
	S. Em ±				CD (0.05)				CV %							
N	12				35				10.8							
P ₂ O ₅	3.0				8.5				8.9							
K ₂ O	11				30				10.4							
Si	7.9				22.3				8.4							

At higher levels of N viz., 100 and 125 kg ha⁻¹, integration with Si could regulate the absorption and mobility of Si in the soil and maintains an optimum level of Si and hence on one side N fertilization increases the silicon content in soil (Shivay and Dinesh Kumar, 2009).

Available Si in soil at harvest was influenced significantly by different fertility levels. The data presented in Table 3 showed that effect of silicon on available silicon content was found significant during both the years as well as on a pooled basis. The lowest available silicon content (162.5, 169.5 and 166.0 kg ha⁻¹) was observed under control during both the years as well as on a pooled basis. The maximum available silicon content (251.1, 275.0 and 263.0 kg ha⁻¹) was recorded due to application of 600 kg Si ha⁻¹ during both individual years as well as on a pooled basis. The treatment 600 kg Si ha⁻¹ gave significantly higher available silicon content in soil after harvest of crop over the control and 200 kg Si ha⁻¹ during both the years as well as on a pooled basis. However, it was at par with 400 kg Si ha⁻¹ during both the years as well as on a pooled basis. The maximum enhancement over control was to the significance of 55, 62 and 58 per cent during both individual years as well as on a pooled basis, respectively. Silicon fertilizers are Si rich inorganic substance that increases the content of plant available Si compounds (Monosilicic acids) in the soil. This was attributed to the possibility of sorption and desorption of silicate fertilizers under lowland rice ecosystem. The increased available Si was anticipated because the added silicate material might have contributed for release of soluble Si. Under submerged conditions, monosilicic acid concentration was increase in the soil solution due to the application of silicate fertilizer and it leads to such a concentration of monosilicic acid in the soil solution to synthesis of poly silicic acids. As a

result, the concentration of monosilicic acids falls down due to the effect from silicate fertilizers. Hereafter, an increase in the dose of silicate fertilizers results increasing concentration of monosilicic acids, which is enough to promote both further synthesis of poly silicic acids and an increase in monosilicic acids concentration in the soil solution. Further, it leads to new soil Si status, characterized by a high concentration of both mono and poly silicic acids.

Data presented in Table 4 revealed that combination of highest N level *i.e.* 125 kg N ha⁻¹ with highest Si level @ 600 kg ha⁻¹ showed maximum significant Si content (287.0 kg ha⁻¹) in soil; being at par with N level (100 kg ha⁻¹) when coupled with 200, 400 and 600 kg Si ha⁻¹. The lowest Si content in soil after harvest was observed due to 125 kg N ha⁻¹ without Si (160.1 kg ha⁻¹). Application of N along with Si has recorded highest per cent Si in soil as mentioned above. Silicon fertilizers are Si rich inorganic substances that increase the content of plant available Si compounds (Monosilicic acids) in the soil. This was attributed to the possibility of sorption and desorption of silicate fertilizers under lowland rice ecosystem of the present study. The increased available Si was anticipated because of the added silicate material might have contributed for release of soluble Si. These results confirm the earlier findings of Epstein, (1999); Matichenkov *et al.*, (1999) and Savant *et al.*, (1997a).

Available P₂O₅ (kg ha⁻¹)

The effect of different levels of N on P₂O₅ content in soil after harvest of the rice crop was found non-significant during both the years as well as on a pooled basis (Table 3). Available P₂O₅ in soil at harvest was influenced significantly by different fertility levels. The data presented in Table 3 revealed that effect of silicon on available P₂O₅ was

found significant during both individual years as well as on a pooled basis. The lowest available P_2O_5 content (81.8, 64.5 and 73.2 kg ha^{-1}) was observed under control during both the years as well as on a pooled basis. The maximum available P_2O_5 content (95.1, 84.8 and 89.9 kg ha^{-1}) was recorded due to application of 600 kg Si ha^{-1} during both individual years as well as on a pooled basis. The treatment 600 kg Si ha^{-1} gave a significantly higher available P_2O_5 content in soil after harvest of crop over the control and 200 kg Si ha^{-1} during both the years as well as on a pooled basis. However, it was at par with 400 kg Si ha^{-1} during second year and pooled. The maximum enhancement was to the value of 16, 31 and 23 per cent during both individual years as well as on a pooled basis respectively, over control. The increased available P with Si application could be due to the release of absorbed P by anion exchange. Due to application Si compounds and their large surface area, they increase the soil adsorption capacity. These changes in soil optimize the phosphate fertilizer efficiency and due to this transformation of slightly soluble phosphate turn in to plant available forms and reduces the phosphate leaching from the arable horizon. Si fertilizes can also increase the quantity of mobile phosphate in the soil (Gladcova, 1982) and thermodynamic calculations showed that the reaction of displacing phosphate anion by silicate anion from slightly soluble phosphate of the corresponding silicate is possible (Matichenkov and Snyder, 1996).

The interaction effect between N and Si was found significant during both the years as well as on a pooled basis. Perusal of data in Table 4 illustrated that interaction effect between N and Si application on available P_2O_5 content in soil after harvest of crop was found significant. Among all treatment combinations, the highest available P_2O_5 content in soil (100.2 kg ha^{-1}) was observed

under combined application of 100 kg N ha^{-1} and 400 kg Si ha^{-1} on a pooled basis. Application of N along with Si has recorded highest per cent P_2O_5 in soil as mentioned above. The increase in the available P content of soil with the application of silicon could be due to utilization of native phosphorus with increasing levels of silicon which resulted in building up of higher soil P status. Si fertilizes can also increase the quantity of mobile phosphate in the soil (Gladcova, 1982) and thermodynamic calculations showed that the reaction of displacing phosphate anion by silicate anion from slightly soluble phosphate of the corresponding silicate is possible (Matichenkov and Snyder, 1996). The model and field experiments have completely confined this suggestion. First, an increase in concentration of monosilicic acids is observed in the soil solution, along with their adsorption on slightly soluble phosphate of calcium, Al, ferric and magnesium, phosphorus was absorbed by applied silicon rich substances. The data demonstrated that adsorbed P remained in a plant available form (Lindsay, 1979).

Available K_2O (kg ha^{-1})

The data presented in Table 3 indicated that effect of nitrogen on available K_2O content was found significant during both individual years as well as on a pooled basis. The results revealed that application of 125 kg N ha^{-1} gave the highest available K_2O content (255, 290 and 272 kg ha^{-1}) during both the years as well as on a pooled basis. The lowest available K_2O content (218, 236 and 227 kg ha^{-1}) was observed under control during both the years as well as on a pooled basis. When Si was not applied, increase in level of 0 to 125 kg ha^{-1} did not show any significant influence on available K status of the soil. At 0 to 100 kg ha^{-1} level of N, available K increased due to integration with Si at 0 to 600 kg ha^{-1} 227, 229, 268 and 272 kg ha^{-1} ,

respectively. These results confirm the earlier findings of Epstein, (1999); Matichenkov *et al.*, (1999) and Savant *et al.*, (1997a).

The data presented in Table 3 revealed that effect of silicon on available K_2O was found significant during both the years as well as on a pooled basis. The lowest available K_2O content (194, 204 and 199 $kg\ ha^{-1}$) was observed under control during both individual years as well as on a pooled basis. The maximum available K_2O content in soil after harvest of crop (267, 308 and 288 $kg\ ha^{-1}$) was recorded due to application of 600 $kg\ Si\ ha^{-1}$ during both individual years as well as on a pooled basis. The treatment 600 $kg\ Si\ ha^{-1}$ gave a significantly higher available K_2O content in soil after harvest of crop over the control and 200 $kg\ Si\ ha^{-1}$ during both the years as well as on a pooled basis. However, it was at par with 400 $kg\ Si\ ha^{-1}$ during the first year only. The maximum enhancement was to the significance of 38, 51 and 45 per cent during both individual years as well as on a pooled basis respectively, over control. Perusal of data in Table 4 illustrated that interaction effect between N and Si application on available K_2O content in soil after harvest of crop was found significant. Among all treatment combinations, the highest available K_2O content in soil (323 $kg\ ha^{-1}$) was observed under combined application of 125 $kg\ N\ ha^{-1}$ and 600 $kg\ Si\ ha^{-1}$ on a pooled basis. Application of N along with Si has recorded highest per cent K_2O in soil as mentioned above. The increase in available K_2O content of soil with application of silicon could be due to utilization of native K_2O with increasing levels of silicon which resulted in building up of higher soil K_2O status. The increased available K with Si application could be ascribed to the alterations in crystal structures of clay lattices which might have related in a reduction in K fixation thus releasing potassium. The increased available K with Si application

could be ascribed to the alterations in crystal structures of clay lattices which might have related in a reduction in K fixation thus releasing potassium. The results are in conformity with the findings of Matichenkov (2007); Epstein, (1999); Matichenkov *et al.*, (1999) and Savant *et al.*, (1997a).

Available sulphur ($mg\ kg^{-1}$)

The data presented in Table 3 indicated that varying levels of N significantly influenced the available sulphur in soil after harvest of rice. The maximum available S content in soil (11.72 and 9.93 $mg\ kg^{-1}$) was recorded due to application of 100 $kg\ N\ ha^{-1}$ during second years and pooled, but in case of first year it was maximum value (8.26 $mg\ kg^{-1}$) with the application of 125 $kg\ N\ ha^{-1}$. The treatment 100 $kg\ N\ ha^{-1}$ gave significantly higher available sulphur content in soil after harvest of crop over the control during second year as well as on a pooled basis. Application of Si significantly increased the available S content in soil Table 3 during both individual years as well as on a pooled basis. The maximum available S content in soil after harvest of crop (9.14, 12.72 and 10.93 $mg\ kg^{-1}$) was recorded due to application of 600 $kg\ Si\ ha^{-1}$ during both individual years as well as on a pooled basis. The treatment 600 $kg\ Si\ ha^{-1}$ gave a significantly higher available S content in soil after harvest of crop over the control, 200 and 400 $kg\ Si\ ha^{-1}$ during both the years as well as on a pooled basis. The maximum enhancement was to the significance of 36, 42 and 39 per cent during both individual years as well as on a pooled basis respectively, over control. Available sulphur in soil after harvest of crop was significantly increased by silicon fertilization. The calcareousness and high clay content also contribute to more adsorption of sulphur on exchangeable complexes and sulphates in soils are retained more than one mechanism. The low mobility of sulphur in soil and the soil conditions conducive for

adsorption might have resulted in residual availability of sulphur in soil after harvest of the crop. The results are in conformity with the findings of Epstein (1999); Matichenkov *et al.*, (1999) and Savant *et al.*, (1997a). The interaction effect of N × Si on sulphur content in soil after harvest of the crop was found non-significant during both the years as well as on a pooled basis.

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