International Journal of Chemical Studies 2018; 6(2): 807-812

International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(2): 807-812
© 2018 IJCS
Received: 06-01-2018
Accepted: 09-02-2018

DTPA: Extractable Fe, Mn, Zn and Cu status of loamy sand after harvest of rice as influenced by different levels of silicon and nitrogen application

JK Malav, VP Ramani, Alok Gora, JK Patel, RP Pavaya, BB Patel and IM Patel

JK Malav
Dept. of Agricultural Chemistry & Soil Science, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

VP Ramani
Micronutrient Research Project (ICAR), Anand Agricultural University, Anand, Gujarat, India

Alok Gora
Dept. of Agricultural Engineering, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

JK Patel
Dept. of Agricultural Chemistry & Soil Science, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

RP Pavaya
Dept. of Agricultural Chemistry & Soil Science, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

BB Patel
Dept. of Agricultural Chemistry & Soil Science, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

IM Patel
Cental Instrumentation laboratories, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

Correspondence
JK Malav
Dept. of Agricultural Chemistry & Soil Science, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar, Gujarat, India

Abstract

A field experiment was conducted at Anand Agricultural University, Anand, India, to investigate the available micronutrients (Fe, Mn, Zn & Cu) status of loamy sand after harvest of rice as influenced by different levels of silicon and nitrogen application. The research was designed as randomized block design (Factorial) having three replications and 4.4m x 2.7m net plot size was maintained. 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. Results revealed that sole application of nitrogen at 125 kg ha^{-1} and Si at 600 kg ha^{-1} produced the maximum 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. A glance at data pertaining to influence of N application on available Fe, Mn and Zn at harvest showed significant increase over control. The available Zn content in soil was increased due to individual application of N (100 kg ha^{-1}) as well as Si (600 kg ha^{-1}) in the soil. The combined effect of N and Si on micronutrient contents after harvest of the crop was observed under 600 kg Si ha^{-1} in conjunction with either 100 or 125 kg N ha^{-1}.

Keywords: Silicon, nitrogen, yield, micronutrients

Introduction

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) [5]. 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) [25]. Information on the importance of Si in Indian rice farming system is limited (Prakash, 2002) [28]. 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 to rice from tillering to elongation stage increases the number of grains panicle^{-1} and the percentage of ripening (Korndorfer *et al.* 2001) [13]. Silicon has been reported to raise the optimal level of nitrogen in rice.

Low Si content was reported to be associated with geologically old soils (Foy, 1992) [6]. Moreover, it is common to find depletion of plant-available Si in soils where rice is cultivated for a long time (Savant *et al.* 1997) [31]. In some countries, such as Japan, the practice of Si fertilization is already common in rice fields. Silicon is commonly applied to soil as slags from iron (Fe), ferronickel, and manganese (Mn) ore smelters (IRRI, 1978) [9]. Slags are abundant and an inexpensive Si source, but require application at high rates (Haynes *et al.*, 2013) [7]. The foliar application of Si-containing solution was proposed as an alternative Si fertilization method. A number of research findings have demonstrated the positive effect of foliarly applied Si in suppressing a foliar plant diseases in different crops, such as rice, wheat (Triticum aestivum), grape (Vitis vinifera), cucumber (Cucumis sativus), zucchini (Cucurbita pepo), and muskmelon (Cucumis melo). The suppressive effects are attributed to the deposition of dried Si solution affecting pathogen infection via ions, or a change in pH on the leaf surface (Rodrigues *et al.*, 2015) [30]. On the other hand, there are other reports suggesting that the Si plant content increased by foliar application of Si.

These are interesting findings, especially since no functional Si transporter genes have been reported for leaves to date. 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.

Si 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 plant, 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) [24] 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 rules are surprisingly diverse. Therefore, the study deals with available Fe, Mn, Zn & Cu status of loamy sand after harvest of rice as influenced by different levels of silicon and nitrogen application.

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 Agriculture Research Station, Anand Agricultural University, Jabugam, Gujarat. Geographically, Jabugam is situated at $22^0$17’37.70” north latitude, $73^0$46’41.02” 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 were 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 5.0m×3.6m 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 illustrates that the application of nitrogen had significant effect on grain yield of rice. The treatment 125 kg N ha^{-1} gave significantly higher grain yield over the control. The increase in yield as a result of nitrogen application could be due to 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) [19], Dehal and Mishra (1994) [4]. Sudhakar *et al.* (2006) [36] 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) [23]. Singh *et al.* (2002) [34] 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 illustrates 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}) yields per plot was recorded due to silicon application at 600 kg ha^{-1}; while lowest grain (5693 kg ha^{-1}) and straw (7319) yields 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.* 1989). The results are in line with the findings of Savant *et al.* (1997) [31]. Chen *et al.* (2011) [3] stated that 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) [17] reported that grain yield increased by silicon application. The interaction effect between N and Si on grain and straw yields of rice was not 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 micronutrients (Fe, Mn, Zn and Cu) 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 the 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 Iron (mg kg^{-1})

A glance at data pertaining to influence of N application on available Fe at harvest, given in Table 3 indicate that application of N resulted in significant increase available Fe content in soil at harvest, over the control during both individual years as well as on a pooled basis. The treatment 100 kg N ha^{-1} gave a significantly highest available Fe content (1.49 and 1.51 mg kg^{-1}) during first year and pooled basis. But in case of second year, it was found maximum value (1.55 mg kg^{-1}) with the application of 125 kg N ha^{-1}. The data on available Fe at harvest were presented in Table 3. The results pertaining to available Fe content revealed that there was significant influence by different treatments over control (1.92, 2.06 and 1.99 mg kg^{-1}) during both individual years as well as on a pooled basis. The treatment 600 kg Si ha^{-1} gave significantly the lowest Fe content at harvest (1.11, 1.03 and 1.07 mg kg^{-1}) compared to other treatments which received lower levels of silicon doses during both the years as well as on a pooled basis. Silicon substances for reducing the Fe toxicities were very effective (Baylis *et al.* 1994) [1]. It is possible to postulate five different mechanisms of Fe toxicity reduction by Si-rich compounds. Firstly, monosilicic acid can increase soil pH (Lindsay, 1979) [15]. Secondly, monosilicic acid can be adsorbed on Fe hydroxides, impairing their mobility (Panov *et al.* 1982) [26]. Thirdly, soluble monosilicic acid can form slightly soluble substances with ions of Al (Horigushi, 1988) [8]. Another possibility for Fe toxicity reduction by Si-rich compounds can be strong adsorption of mobile Fe on silicon surfaces (Shulthess *et al.* 1996) [33]. Fifthly, mobile silicon compounds can increase plant tolerance to Fe (Rahman *et al.* 1998) [29]. All of these mechanisms may work simultaneously, with certain ones prevailing under various soil conditions.

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 showed that interaction effect between N and Si application on Fe content at harvest was found significant. Among all treatment combinations, the lowest available Fe content (0.57 mg kg^{-1}) was observed under combined application of 125 kg N ha^{-1} and 600 kg Si ha^{-1} on a pooled basis. The results are in conformity with the findings of Matichenkov (2007) [22], Epstein, (1999) [5]; Matichenkov *et al.* (1999) [21]; Savant *et al.* (1997) [31]; Baylis *et al.* (1994) [1]; Lindsay (1979) [15]; Panov *et al.* (1982) [26] and Shulthess *et al.* (1996) [33].

Available Manganese (mg kg^{-1})

From the perusal of the data, presented in Table 3 observed that available Mn content at harvest was significantly influenced by the application of N. The lowest available Mn at harvest (18.59, 16.53 and 17.56 mg kg^{-1}) was observed under control during both the years as well as on a pooled basis. The maximum available Mn content at harvest (22.88, 20.19 and 21.54 mg kg^{-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} gave significantly higher available Mn content at harvest over the control during both individual years as well as on a pooled basis, respectively. However, it was at par with 75 and 100 kg N ha^{-1} during both individual years as well as on a pooled basis, respectively. A perusal of data pertaining to influence of Si application on available Mn content at harvest, given in Table 3 indicate that application of silicon resulted in significant decrease in Mn content at harvest, over the control during both individual years as well as on a pooled basis. The treatment 600 kg Si ha^{-1} gave significantly the lowest available Mn content at harvest (19.04, 16.74 and 17.89) compared to other treatments which received lower levels of silicon doses during both the years as well as on a pooled basis. Interaction between Si and Mn occurs in solution, probably by the formation of Mn-Si complexes, a non-toxic form. However, monosilicic acid concentration in the soil initiated decomposition of secondary minerals that control numerous soil properties (Karmin, 1986 [11]; Marsan and Torrent, 1989) [20]. A second negative effect of reduced monosilicic acid concentration in the soil is decreased Mn concentration; thereafter it leads to plant disease and pest resistance (Epstein, 1999 [5]; Matichenkov *et al.* 1999 [21]; Savant *et al.* 1997) [31].

Perusal of data in Table 4 illustrate that interaction effect between N and Si application on available Mn content at harvest of crop was found significant. Among all treatment combinations, the lowest available Mn content at harvest of crop (16.31 mg kg^{-1}) was observed under combined application of 100 kg N ha^{-1} and 600 kg Si ha^{-1} on a pooled basis. However, monosilicic acid concentration in the soil initiated decomposition of secondary minerals that control numerous soil properties (Karmin, 1986 [11]; Marsan and Torrent, 1989) [20]. A second negative effect of reduced monosilicic acid concentration in the soil is decreased Mn concentration; thereafter it leads to plant disease and pest resistance (Epstein, 1999 [5]; Matichenkov *et al.* 1999 [21]; Savant *et al.* 1997) [31].

Available Zinc (mg kg^{-1})

From the perusal of the data, presented in Table 3 observed that available Zn content at harvested was significantly influenced by the application of N under the rice crop. The significantly maximum available Zn content at harvest (2.84 and 2.74 mg kg^{-1}) was recorded due to application of 100 kg N ha^{-1} during first year and pooled. But in case of second year, it was maximum tune (2.71 mg kg^{-1}) recorded with the application of 125 kg N ha^{-1}. These results confirm the earlier findings of Schindler *et al.* (1976); Lindsay, (1979) [15]; Epstein, (1999) [5]; Matichenkov *et al.* (1999) [21] and Savant *et al.* (1997) [31]. Data in Table 3 illustrated that application of silicon had a significant effect on available Zn content at harvest during both individual years and pooled as well. The highest available Zn content at harvest (2.81, 2.77 and 2.79 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, respectively. The treatment 600 kg Si ha^{-1} gave significantly higher available Zn content at harvest over the control and 200 kg Si ha^{-1} during both individual years as well as on a pooled basis. However, it was at par with 200 and 400 kg Si ha^{-1} during first year only. The greatest improvement was to the value of 17, 29 and 23 per cent during both individual years as well as on a pooled basis respectively, over control. In soil solution monosilicic acids are able to combine with Zn in soluble complex compounds (Schindler *et al.* 1976) and poorly soluble as Zn silicate (Lindsay, 1979) [15]. Low concentration of monosilicic acids in the solution leads to formation of complexes of a Zn with a silicic acid anion. As the result of this reaction, the content of Zn increases the concentration of monosilicic acids in the solution slightly increases (Bocharnikova *et al.* 1995) [2]. The interaction effect between N and Si on Zn content in soil after harvest of the crop was found not significant in all cases.

Available Copper (mg kg^{-1})

The data revealed that the individual effect of N and Si and also their interaction found to be non-significant for Cu content in soil after harvest of rice during both individual years as well as on a pooled basis (Table 4).

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 & Asija (1956)
2	Available Si (kg ha^{-1})	190.8	185.0	NaOAc (pH- 4) Colorimetric method	Korndorfer *et al.* (1999)
3	Available Fe (mg kg^{-1})	1.14	1.04	AAS (0.005 M DTPA, pH 7.3)	Lindsay and Norvell (1978) [14]
4	Available Mn (mg kg^{-1})	23.3	21.6		
5	Available Zn (mg kg^{-1})	1.64	1.45		
6	Available Cu (mg kg^{-1})	1.74	1.62		

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 Fe, Mn, Zn and Cu contents after harvest of rice under low land conditions (pooled 2 years)

Treatments		**Fe (mg kg^{-1})**			**Mn (mg kg^{-1})**			**Zn (mg kg^{-1})**			**Cu (mg kg^{-1})**		
		2014	**2015**	**Pooled**	**2014**	**2015**	**Pooled**	**2014**	**2015**	**Pooled**	**2014**	**2015**	**Pooled**
Nitrogen levels (kg ha^{-1})													
N 0		1.26	1.15	1.20	18.59	16.53	17.56	2.42	2.24	2.33	2.00	2.63	2.31
N 75		1.41	1.40	1.41	21.89	19.50	20.70	2.55	2.31	2.43	2.08	2.66	2.37
N 100		1.49	1.53	1.51	21.84	18.43	20.13	2.84	2.64	2.74	2.03	2.68	2.35
N 125		1.43	1.55	1.49	22.88	20.19	21.54	2.65	2.71	2.68	2.08	2.52	2.30
N	S. Em ±	0.05	0.04	0.03	0.63	0.52	0.41	0.10	0.06	0.06	0.07	0.07	0.05
	CD (0.05)	0.15	0.12	0.09	1.82	1.51	1.16	0.28	0.18	0.16	NS	NS	NS
Y x N	S. Em ±	0.05	0.05	0.05	0.58	0.58	0.58	0.08	0.08	0.08	0.07	0.07	0.07
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Silicon levels (kg ha^{-1})													
Si 0		1.92	2.06	1.99	24.12	20.96	22.54	2.40	2.14	2.27	2.02	2.54	2.28
Si 200		1.27	1.30	1.29	21.81	19.00	20.40	2.68	2.44	2.56	2.09	2.59	2.34
Si 400		1.29	1.25	1.27	20.22	17.96	19.09	2.57	2.54	2.56	2.02	2.65	2.33
Si 600		1.11	1.03	1.07	19.04	16.74	17.89	2.81	2.77	2.79	2.05	2.72	2.38
Si	S. Em ±	0.05	0.04	0.03	0.63	0.52	0.41	0.10	0.06	0.06	0.07	0.07	0.05
	CD (0.05)	0.15	0.12	0.09	1.82	1.51	1.16	0.28	0.18	0.16	NS	NS	NS
Y x Si	S. Em ±	0.05	0.05	0.05	0.58	0.58	0.58	0.08	0.08	0.08	0.07	0.07	0.07
	CD (0.05)	-	-	NS	-	-	NS	-	-	NS	-	-	NS
Interactions													
N X Si		Sig	Sig	Sig	Sig	NS	Sig	NS	NS	NS	NS	NS	NS
Y X N X Si		-	-	NS	-	-	NS	-	-	NS	-	-	NS
CV %		12.6	11.3	12.0	10.2	9.7	10.0	13.0	8.7	11.2	11.3	9.9	10.5

Table 4: Interaction effect of N x Si on Fe and Mn contents after harvest of rice (pooled 2 years)

Treatments	**Nitrogen levels (kg ha^{-1})**							
Silicon levels (kg ha^{-1})	**Fe (mg kg^{-1})**				**Mn (mg kg^{-1})**			
	N_0	N_{75}	N_{100}	N_{125}	N_0	N_{75}	N_{100}	N_{125}
Si_0	1.79	1.75	2.10	2.31	18.92	23.84	21.78	25.62
Si_{200}	1.04	1.00	1.70	1.41	17.45	19.65	23.04	21.47
Si_{400}	1.06	1.34	1.01	1.67	17.35	20.20	19.41	19.40
Si_{600}	0.92	1.55	1.24	0.57	16.51	19.10	16.31	19.65
	S. Em ±		CD (0.05)				CV %	
Fe	0.07		0.19				12.0	
Mn	0.82		2.31				10.0	
Cu								

References

1. Baylis A, Gragopoulou G, Davidson K, Birchall JD. Effects of silicon on the toxicity of aluminum to soybean. Communication in Soil Science and Plant Analysis. 1994; 25:537-546.
2. Bocharnikova EA, Matichenkov VV, Pinsky DL. The influence of soluble silica acids on behavior of heavy metals in soil and natural waters: Pollution in Large Cities. In Proceedings of the World-Wide Symposium, Venice-Padova, Italy, 1995, 43-50.
3. Chen JX, Tu NM, Yi ZX, Zhu HL. Effect of Silicon Fertilizer on Nitrogen Utilization Efficiency of Super Early Rice. Cereal Crop Research. 2011.
4. Dehal P, Mishra G. Interaction of spacing and nitrogen in rice. *Oryza*, 1994; 1(2):149-150.
5. Epstein E Silicon. Annual Review of Plant Physiology and Plant Molecular Biology, 1999; 50:641-644.
6. Foy CD. Soil chemical factors limiting plant root growth. Advances Soil Science. 1992; 19:97–149.
7. Haynes RJ, Belyaeva ON, Kingston G. Evaluation of industrial wastes as sources of fertilizer silicon using chemical extractions and plant uptake. Journal of Plant Nutrition Soil Science. 2013; 176:238–248.
8. Horigushi T. Mechanism of manganese toxicity and tolerance of plant: Effect of silicon on alleviation of manganese toxicity of rice plants. Soil Science and Plant Nutrition. 1988; 34:65-68.
9. International Rice Research Institute (IRRI). Annual Report 1977; IRRI: Los Banos, Laguna, Philippines.
10. Jackson ML. Soil chemical analysis. Prentice Hall of India Pvt. Ltd. New Delhi. 1973.
11. Karmin Z. Formation of ferrihydrite by inhibition of grun rust structures in the presence of silicon. Soil Science Society of America Journal. 1986; 50(1):247-254.
12. Korndorfer GH, Coelho MN, Snyder GH, Mizutani CT. An evaluation of soil extractants for silicon availability in upland rice. Journal of Plant Nutrition. 1999; 23:101-106.
13. Korndorfer GH, Snyder GH, Ulloa M, Datnoff LE. Calibration of soil and plant silicon for rice production. Journal of Plant Nutrition. 2001; 24:1071-1084.
14. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal. 1978; 42:421-428.
15. Lindsay WL. Chemical equilibrium in soils. John Wiley & Sons, New York. 1979, 449.

16. Ma JF, Nishimura K, Takahashi E. Effect of silicon on the growth of rice plant at different growth stages. Soil Science Plant Nutrition. 1989; 35:347-356.
17. Ma JF, Takahashi E. Effect of silicate on phosphate availability of rice in a P deficient soil. Plant Soil. 1990; 133:151-155.
18. Ma JF, Tamai K, Yamaji N, Mitani N, Konishi S, Katsuhara M, *et al.* A silicon transporter in rice. Nature. 2006; 440:688-691.
19. Mahajan KK, Tripathi BR. Effect of increasing levels of different Urea based fertilizers on yield and nitrogen nutrition of rice in an alfisal. Oryza. 1992; 29(2):101-106.
20. Marsan FA, Torrent J. Fragipan bonding by silica and iron oxides in a soil from northwestern Italy. Soil Science Society of America Journal. 1989; 53(4):1140-1145.
21. Matichenkov VV, Calvert DV, Snyder GH. Silicon fertilizers for citrus in Florida. Proceedings of the Florida State Horticultural Society. 1999; 112:5-8.
22. Matichenkov VV. Soil gradation on the plant-available Si. Agrochemistry. 2007; 7:47-58.
23. Mauad M, Crusciol CAC, Grassi Filho H, Correa JC. Nitrogen and silicon fertilization of upland rice. Scientia Agricola. 2003; 60:761-765.
24. Muir S, Khoo C, McCabe. Some effects of silicon in mixes on growth and protection of plants against fungal diseases. In L.E. Datnoff, G.H. Snyder and G.H. Komdorfer, (eds.) - Silicon in Agriculture. Elsevier Science B.V, Amsterdam., 2001.
25. Munir M, Carlos ACC, Hello GF, Juliano CC. Nitrogen and silicon fertilization of upland rice. Scientia Agricola. 2003; 60:1-10.
26. Panov NP, Goncharova NA, Rodionova LP. The role of amorphous silicic acid in solonetz soil processes. Vestnik Agricultural Science. 1982; 11:18.
27. Piper CS. Soil and Plant Analysis. Hans Publishers, Bombay. 1966, 137-153.
28. Prakash NB. Status and utilization of silicon in Indian rice farming. In Proceedings 1111 of Second Silicon in Agriculture. 2002.
29. Rahman M, Kawamura K, Koyama H, Hata T. Varietal differences in the growth of rice plants in response to Aluminium and silicon. Soil Science and Plant Nutrition. 1998; 44:423-431.
30. Rodrigues FÁ, Datnoff LE. Silicon and Plant Diseases, 1st ed.; Springer: Berlin/Heidelberg, Germany, 2015, 67–100.
31. Savant NK, Datnoff LE, Snyder GH. Depletion of plant available silicon in soils: a possible cause of declining rice yields. Communication in Soil Science and Plant Analysis. 1997; 28:1245-1252.
32. Savant NK, Snyder GH, Datnoff LE. Silicon management and sustainable rice production. Adv. Agron. 1997; 58:151–199.
33. Shulthess CP, Tokunda Y. Metal and pH effect is on adsorption of poly (vinyl alcohol) by silicon oxide. Soil Science Society of America Journal. 1996; 60:92. Netherlands, 374.
34. Singh K, Singh Y, Singh CS, Singh R, Singh KK, Singh AK. Silicon nutrition in paddy. Fertilizer news. 2002; 50(2):41-48.
35. Subbaiah BV, Asija GL. A rapid procedure for the determination of available nitrogen-in soils. Current Science. 1956; 25:259-260.
36. Sudhakar PC, Singh JP, Yogeshwar S, Raghavendra S. Effects of graded levels and silicon sources on crop yield, uptake and nutrient use efficiency in rice. Indian Journal of Agronomy. 2006; 51(3):186-188.
37. Walkley A, Black CA. Estimation of organic carbon by chromic acid titration method. Soil Science. 1934; 37: 29-38.