



P-ISSN: 2349-8528

E-ISSN: 2321-4902

IJCS 2017; 5(6): 166-173

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Received: 23-09-2017

Accepted: 25-10-2017

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Periodical status of plant available silicon as influenced by silicon extractants and levels of silicon in alkaline soils

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Abstract

An incubation study was conducted by using calcium silicate as a source of silicon in alkaline soils of order Inceptisols and Vertisols. The purpose of study was to know the periodical status of plant available silicon (PAS) as influenced by silicon extractants and levels of silicon in alkaline soils. The experiment was laid out in factorial completely randomized design having seventy treatment combinations replicated thrice. The main treatments were ten silicon extractants and sub treatments were levels of silicon. The periodical status of PAS in Inceptisols and Vertisols showed bell shaped curve throughout incubation study. The PAS status increased from 0 to 40 day and then decreased from 60 to 100 day. The maximum PAS was recorded at 40 day. The silicon extractant 0.1 M Citric acid (1:50) and application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS status in Inceptisols and Vertisols throughout incubation study.

Keywords: plant available silicon, periodical status, silicon extractants, calcium silicate, alkaline soils

Introduction

Silicon (Si) is the second most abundant element in the earth's crust, with soils containing approximately 32 percent Si by weight (Lindsay, 1979) [14]. Its content in soils varies greatly ranging from less than 1 to 45% by dry weight (Sommer *et al.*, 2006) [22] mainly as quartz and crystalline silicates, their contribution to the plant available silicon (PAS) pool in soil is very little due to their poor solubility. Most Si is present in the soil as insoluble oxides or silicates. The soil water, or the "soil solution," contains silicon, mainly as silicic acid, [Si(OH)₄], at 0.1-0.6 mM-concentrations on the order of those of potassium, calcium and other major plant nutrients and well in excess of those of phosphate. The plant absorbs Si from the solution in the form of mono silicic acid (H₄SiO₄) which has no electric charge and is not very much mobile in plant (Yoshida, 1975; Savant *et al.*, 1997) [26,20].

The concentration of silicon in soil solutions is between that for amorphous silica and quartz. The solubility of pure silica in water is independent of pH, but in the soil, dissolution decreased with increasing pH up to pH 8-9 due to changes in adsorption and then rapidly increases due to the formation of silicate ions. The dissolution kinetics of soil silicon is very slow (Lindsay, 1979) [14]. Silicic acid is also dissolved in soil solution with some part of the silicic acid adsorbed to soil minerals, particularly oxides and hydroxides of iron and aluminium (Hansen *et al.*, 1994) [7]. Nagabovanalli *et al.* (2014) [15] conducted an incubation study by using acidic and alkali soils in a plastic pot with different levels (0, 150, 300 and 600 kg ha⁻¹) of diatomite under field capacity and submerged conditions. The soil samples were periodically analyzed on 7, 15, 30, 60, 90 and 120 days after incubation (DAI) with a special emphasis on plant available silicon (PAS). Increase in PAS was observed at 15 DAI in acidic and alkaline soil with the increasing levels of diatomite, whereas the highest was observed at 30 DAI in both types of soil. Irrespective of application rates of diatomite, there was a decrease in PAS at 90 DAI and thereafter increased at 120 DAI in both soil types and higher than control.

Several extractants are being employed in different countries for determination of extractable soil silicon. Acquaye and Tinsley (1965) [1] used 0.1 M Citric acid as an extractant in estimation of plant available silicon in soils and this extracts specifically adsorbed silicon apart from water soluble silicon. Nayar *et al.* (1977) [16] compared *N* Sodium acetate buffer (pH 4.0) with three other chemical extractants (Distilled water, 0.2 N HCl and 0.025 M Citric acid)

and it was found that extracting power of different extractants for Si as: 0.2 N HCl > 0.025 M Citric acid > N Sodium acetate buffer (pH 4.0) > Distilled water. The different methods have been used worldwide to determine the amount of Si available for plant growth. The quantity of Si varies depending on the extracting solution used to solubilize the soil Si. In general, the most successful extractants are acid rather than neutral solutions, and dissolution is further increased by chelating agents (due to decreased Si sorption resulting from the lower concentration of Al and Fe in solution). Other factors such as the method of equilibration, soil: solution ratio, temperature, and pH of extractant solution are also important. Once in solution, Si (OH)₄ can be measured by the silicomolybdate blue colour method (Iler, 1979) [8]. Rodrigues *et al.* (2003) [19] collected 137 mineral soil samples from 31 countries to extract Si and reported that sodium acetate buffer extracted the greatest amounts of Si (0 to 509 mg kg⁻¹), followed by acetic acid (1 to 239 mg kg⁻¹) and calcium chloride (3 to 109 mg kg⁻¹). Acetic acid and sodium acetate buffer soil test Si values were fairly well correlated (r=0.77) and both methods performed well across a wide range of soils. Results with calcium chloride were less well correlated with acetic acid (r=0.73) and were poorly related to sodium acetate buffer (r=0.57). When considering only the subset of soils testing at or below the critical value, the correlation between acetic acid and sodium acetate buffer extractions was improved (r=0.84). Wang *et al.* (2004) reported that the plant available silicon as extracted by seven extractants follows the order as Mehlich III > 0.5 M Citric acid > 0.1 M HCl > 0.5 M Acetic acid > 1 M Sodium acetate buffer pH 4.0 > 0.5 M Ammonium acetate buffer pH 4.8 > Deionized water. Plant available silicon as extracted by seven extractants was well correlated among 0.5 M Citric acid, 0.1 M HCl, 0.5 M Acetic acid, 1 M Sodium acetate buffer pH 4.0 and 0.5 M Ammonium acetate buffer pH 4.8 (r² = 0.611, P < 0.001). Deionized water and Mehlich III showed poor correlation with other extractants (r² = 0.430). The highest extraction potential of plant available silicon was showed by H₂SO₄ and citric acid. However, distilled water extraction method recorded least plant available silicon (Daniela *et al.*, 2006) [3].

The dissolution of plant available silicon from different silicon sources like calcium silicate and slag silicate fertilizer in acidic soils is well documented in the literature. However, the behaviour of calcium silicate in alkaline soils is not well understood. Therefore an incubation study was conducted to know the periodical status of plant available silicon as influenced by silicon extractants and levels of silicon in alkaline soils.

Materials and Methods

An incubation study was conducted in the Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India. The alkaline soil samples from order Inceptisols and Vertisols were collected for incubation study. The representative soil samples were air dried and passed through 2 mm sieve. The experimental soil was clay in textural class, low in available nitrogen, medium in available phosphorus and very high in available potassium. Plastic bowls were filled with 2 kg soil samples from order Inceptisols and Vertisols separately; than mixed thoroughly with the calculated amount of different levels of silicon. Calcium silicate was used as a source of silicon. The chemical compositions of calcium silicate are given in Table 1. The experiment was laid out in factorial completely randomized design having seventy treatment combinations replicated thrice.

The main treatments were ten silicon extractants viz. 0.5 M Acetic acid (1:2.5), 0.5 M Acetic acid (1:10), 0.1M Citric acid (1:50), N NaOAc-HOAc pH 4.0 (1:10), 0.5 M NH₄OAc pH 4.8 (1:10), 0.01M CaCl₂ (1:10), Distilled water (1:10), Tris buffer pH 7.0 (1:10), 0.19 M Na₂CO₃ (1:20) and 0.5 M NaHCO₃ pH 8.5 (1:20). Whereas sub treatments were levels of silicon viz. T₁: Absolute control, T₂: General recommended dose of fertilizers (GRDF) (100:50:50 kg ha⁻¹ N:P₂O₅:K₂O + 5 t ha⁻¹ FYM), T₃: GRDF + Si @ 25 kg ha⁻¹, T₄: GRDF + Si @ 50 kg ha⁻¹, T₅: GRDF + Si @ 100 kg ha⁻¹, T₆: GRDF + Si @ 150 kg ha⁻¹ and T₇: GRDF + Si @ 200 kg ha⁻¹. The soil moisture in the plastic bowls was maintained at field capacity. Soil samples were collected and analyzed after 20 days interval (0, 20, 40, 60, 80 and 100 day) for plant available silicon (PAS).

Table 1: Chemical composition of calcium silicate

S. No	Parameters	Values
1	pH (1:10)	8.0
2	EC (1:10) (dS m ⁻¹)	0.98
3	Si (%)	36
4	N (%)	Trace
5	P (%)	0.09
6	K (%)	0.06
7	Ca (%)	9.40
8	Mg (%)	3.10
9	Fe (%)	0.08
10	Mn (%)	0.02
11	Zn (%)	0.002
12	Cu (%)	0.009

Extraction of plant available silicon

The plant available silicon from soil samples of incubation study was extracted by using ten silicon extractants as outlined by researchers (Table 2).

Table 2: Silicon extractants used for evaluating the plant available silicon

Ex. No.	Extractants	Soil/ Ex. ratio	Shaking period	Reference
E ₁	0.5 M Acetic acid	1:2.5	Overnight resting and then continuous shaking for 2 hr.	Snyder (2001) [5-13-21]
E ₂	0.5 M Acetic acid	1:10	Continuous shaking for 1hr.	Korndorfer <i>et al.</i> (1999) [11]
E ₃	0.1 M Citric acid	1:50	Shaking for 2 hr., resting for overnight and then shaking for 1 hr.	Acquaye and Tinsley (1965) [1]
E ₄	N NaOAc-HOAc (pH 4.0)	1:10	Occasional shaking for 5 hr.	Imaizumi and Yoshida (1958) [9]
E ₅	0.5 M NH ₄ OAc (pH 4.8)	1:10	Continuous shaking for 1hr.	Fox <i>et al.</i> (1967) [6]
E ₆	0.01 M CaCl ₂	1:10	Continuous shaking for 1hr.	Korndorfer <i>et al.</i> (1999) [11]
E ₇	Distilled water	1:10	Continuous shaking for 1hr.	Korndorfer

				<i>et al.</i> (1999) ^[11]
E ₈	Tris buffer (pH 7.0)	1:10	Shaking for 2 hr., resting for overnight and then shaking for 1 hr.	Filho <i>et al.</i> (2001) ^[5]
E ₉	0.19 M Na ₂ CO ₃	1:20	Shaking for 30 min.	Xu <i>et al.</i> (2001) ^[25]
E ₁₀	0.5 M NaHCO ₃ (pH 8.5)	1:20	Shaking for 5 hr.	Xu <i>et al.</i> (2001) ^[25]

Estimation of plant available silicon

The silicon in the extracting solution was determined by transferring 0.25 mL of filtrate into a plastic centrifuge tube and then adding 10.50 mL of distilled water, plus 0.25 mL of 1:1 hydrochloric acid (HCl), and 0.50 mL of 10% ammonium molybdate [(NH₄)₆Mo₇O₂₄] solution (pH 7- 8). After 5 minutes, 0.50 mL of 20% tartaric acid solution was added and after two minutes, 0.50 mL of the reducing agent amino naphthol n-sulphonic acid (ANSA) was added. After five minutes, but not later than 30 minutes following addition of the reducing agent, absorbance was measured at 630 nm using spectrophotometer. Simultaneously, Si standards (0.2, 0.4, 0.8 and 1.0 mg L⁻¹) were prepared in the same matrix and measured using spectrophotometer (Korndorfer *et al.*, 2001)^[13].

Statistical Analysis

Soil analysis data generated from present experiment was statistically analyzed by methods suggested by Panse and Sukhatme (1985)^[18].

Results and Discussion

Plant available silicon (PAS) status in Inceptisols

The data on effect of silicon extractants, levels of silicon and their interactions on PAS status in Inceptisols soil samples under incubation study are presented in Table 3.

PAS status at 0 day

The PAS was significantly influenced by silicon extractants. However, results were non-significant in case of levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (372.69 ppm) over all the silicon extractants.

PAS status at 20 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (454.45 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (221.00 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (512.12 ppm) over all the interactions.

PAS status at 40 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (472.53 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (232.94 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (524.17 ppm) over all the interactions.

PAS status at 60 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (430.36 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (212.43 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (479.99 ppm) over all the interactions.

PAS status at 80 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (388.18 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (189.43 ppm) over all the levels of silicon. However, it was at par with T₆ (183.63 ppm). The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 100 kg ha⁻¹ (E₃T₅) recorded significantly highest PAS (419.74 ppm) over all the interactions. However, it was at par with E₃T₆ and E₃T₇ (409.70 and 407.69 ppm, respectively).

PAS status at 100 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (383.88 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (175.25 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (403.67 ppm) over all the interactions. However, it was at par with E₃T₅ and E₃T₆ (393.63 and 395.64 ppm, respectively).

Table 3: Effect of silicon extractants, levels of silicon and their interactions on PAS status in Inceptisols under incubation study

	Plant Available Silicon (ppm)					
	0 day	20 day	40 day	60 day	80 day	100 day
A. Silicon extractants (E)						
E ₁ : 0.5 M Acetic acid (1:2.5)	337.31	367.22	371.56	363.34	356.17	345.55
E ₂ : 0.5 M Acetic acid (1:10)	110.49	152.67	166.35	147.90	132.01	116.75
E ₃ : 0.1 M Citric acid (1:50)	372.69	454.45	472.53	430.36	388.18	383.88
E ₄ : N NaOAc-HOAc pH 4.0 (1:10)	183.31	218.95	234.15	222.42	205.77	190.42
E ₅ : 0.5M NH ₄ OAc pH 4.8 (1:10)	292.05	335.83	357.79	336.94	315.73	298.12
E ₆ : 0.01 M CaCl ₂ (1:10)	54.64	96.19	106.16	88.18	76.47	64.41
E ₇ : Distilled water (1:10)	16.34	28.50	29.86	25.56	21.57	18.51
E ₈ : Tris buffer pH 7.0 (1:10)	49.57	80.54	85.27	75.50	66.99	59.03
E ₉ : 0.19 M Na ₂ CO ₃ (1:20)	32.33	84.82	92.63	82.91	64.48	51.62
E ₁₀ : 0.5 M NaHCO ₃ pH 8.5 (1:20)	38.00	92.22	114.18	94.03	77.97	65.20

SE (m) \pm	1.899	1.646	1.886	2.316	2.661	1.728
CD @ 5%	5.335	4.625	5.298	6.507	7.476	4.854
B. Levels of silicon (T)						
T ₁ : Absolute control	150.48	161.94	170.70	158.69	148.78	141.33
T ₂ : GRDF	147.93	167.06	178.50	166.70	152.59	146.58
T ₃ : GRDF + Si @ 25 kg ha ⁻¹	145.74	178.68	192.03	179.14	166.49	156.97
T ₄ : GRDF + Si @ 50 kg ha ⁻¹	149.11	190.24	203.14	186.47	170.25	159.65
T ₅ : GRDF + Si @ 100 kg ha ⁻¹	150.70	203.60	216.56	198.19	182.57	167.05
T ₆ : GRDF + Si @ 150 kg ha ⁻¹	146.69	215.45	227.46	205.36	183.63	168.62
T ₇ : GRDF + Si @ 200 kg ha ⁻¹	150.04	221.00	232.94	212.43	189.43	175.25
SE (m) \pm	1.589	1.377	1.578	1.938	2.226	1.445
CD @ 5%	NS	3.869	4.433	5.444	6.255	4.061
C. Interactions (E x T)						
E ₁ T ₁	344.14	333.57	334.76	329.52	324.89	322.32
E ₁ T ₂	326.46	339.60	344.04	326.47	320.61	314.03
E ₁ T ₃	331.01	351.15	355.10	350.66	343.05	336.34
E ₁ T ₄	343.75	365.17	370.71	365.96	363.20	344.34
E ₁ T ₅	355.40	382.35	388.55	379.00	371.89	359.55
E ₁ T ₆	327.65	396.38	401.12	393.41	382.95	364.48
E ₁ T ₇	332.78	402.30	406.65	398.35	386.60	377.81
E ₂ T ₁	111.78	127.98	139.04	128.37	119.68	103.49
E ₂ T ₂	110.20	130.35	142.20	139.43	120.08	106.25
E ₂ T ₃	108.62	141.80	152.47	139.43	128.37	118.50
E ₂ T ₄	107.83	154.44	168.27	150.49	131.93	119.29
E ₂ T ₅	110.60	164.71	179.33	156.42	143.20	124.42
E ₂ T ₆	112.18	175.19	189.60	160.76	141.80	122.84
E ₂ T ₇	112.18	174.19	193.55	160.37	139.04	122.45
E ₃ T ₁	383.59	401.66	417.73	387.60	355.47	357.48
E ₃ T ₂	383.59	413.72	429.78	395.64	351.45	373.55
E ₃ T ₃	355.47	427.77	457.90	417.73	379.57	379.57
E ₃ T ₄	367.52	453.88	477.98	425.78	393.63	383.59
E ₃ T ₅	371.54	473.96	494.05	451.87	419.74	393.63
E ₃ T ₆	367.52	498.06	506.10	453.88	409.70	395.64
E ₃ T ₇	379.57	512.12	524.17	479.99	407.69	403.67
E ₄ T ₁	187.72	194.30	205.01	192.25	185.66	172.48
E ₄ T ₂	173.31	192.66	204.60	199.66	181.95	172.08
E ₄ T ₃	183.19	205.83	220.24	218.59	205.01	193.48
E ₄ T ₄	188.13	213.65	232.18	222.71	205.83	198.01
E ₄ T ₅	181.13	228.88	242.26	223.53	207.89	192.25
E ₄ T ₆	181.95	245.35	263.46	244.94	222.71	200.48
E ₄ T ₇	187.72	252.00	271.29	255.23	231.36	204.18
E ₅ T ₁	293.10	306.05	316.41	300.87	289.21	277.56
E ₅ T ₂	290.51	303.03	320.73	305.62	295.26	281.88
E ₅ T ₃	284.03	327.63	350.51	337.56	316.41	295.26
E ₅ T ₄	289.21	332.38	357.85	341.01	310.37	294.39
E ₅ T ₅	302.60	348.79	377.27	351.37	332.81	311.23
E ₅ T ₆	287.49	363.03	385.48	353.53	325.04	304.91
E ₅ T ₇	297.42	369.94	396.27	368.64	341.01	321.59
E ₆ T ₁	50.95	65.14	70.95	60.63	50.95	43.86
E ₆ T ₂	58.05	79.33	89.65	83.85	73.53	60.63
E ₆ T ₃	54.82	87.72	99.33	78.04	76.11	65.79
E ₆ T ₄	55.47	101.26	113.52	99.97	80.60	69.01
E ₆ T ₅	55.47	107.07	118.10	95.46	82.56	70.30
E ₆ T ₆	55.47	116.10	126.42	99.97	84.49	69.66
E ₆ T ₇	52.24	116.74	125.13	99.33	87.07	71.59
E ₇ T ₁	15.21	21.47	21.97	18.03	16.34	14.08
E ₇ T ₂	16.90	24.22	22.53	19.72	18.03	17.46
E ₇ T ₃	16.34	25.91	27.60	23.66	19.72	18.03
E ₇ T ₄	15.77	27.60	29.29	25.91	21.97	18.59
E ₇ T ₅	16.34	30.98	33.80	28.50	24.22	20.28
E ₇ T ₆	17.46	33.24	36.62	32.67	26.48	21.41
E ₇ T ₇	16.34	36.05	37.18	30.42	24.22	19.72
E ₈ T ₁	45.23	60.68	62.34	52.96	51.30	45.23
E ₈ T ₂	50.75	66.20	71.71	62.34	56.82	52.96
E ₈ T ₃	47.44	71.71	78.33	70.06	63.44	55.72
E ₈ T ₄	52.96	78.34	80.54	65.65	56.27	54.06
E ₈ T ₅	50.20	88.26	97.64	89.37	78.33	65.65
E ₈ T ₆	52.40	95.99	103.16	90.47	76.13	65.65
E ₈ T ₇	47.99	102.61	103.16	97.64	86.61	73.92

E ₉ T ₁	34.07	53.53	60.83	54.75	45.02	38.93
E ₉ T ₂	32.85	59.62	68.03	62.05	46.23	36.50
E ₉ T ₃	34.07	68.13	77.87	74.22	63.27	46.23
E ₉ T ₄	29.20	83.95	86.38	76.65	59.62	48.67
E ₉ T ₅	31.63	99.77	110.72	99.77	77.87	62.05
E ₉ T ₆	30.42	111.94	120.45	105.85	73.00	60.83
E ₉ T ₇	34.07	116.80	124.10	107.07	86.38	68.13
E ₁₀ T ₁	38.99	55.04	77.97	61.92	49.31	37.84
E ₁₀ T ₂	36.69	61.92	91.73	72.24	61.92	50.45
E ₁₀ T ₃	42.43	79.12	100.91	81.41	69.95	60.77
E ₁₀ T ₄	41.28	91.73	114.67	90.59	79.12	66.51
E ₁₀ T ₅	32.11	111.23	123.84	106.64	87.15	71.09
E ₁₀ T ₆	34.40	119.25	142.19	118.11	94.03	80.27
E ₁₀ T ₇	40.13	127.28	147.92	127.28	104.35	89.44
SE (m) ±	5.024	4.355	4.989	6.128	7.040	4.571
CD @ 5%	NS	12.24	14.02	17.22	19.78	12.84

Plant available silicon (PAS) status in Vertisols

The data on effect of silicon extractants, levels of silicon and their interactions on PAS status in Vertisols soil samples under incubation study are presented in Table 4.

PAS status at 0 day

The PAS was significantly influenced by silicon extractants. However, results were non-significant in case of levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (387.32 ppm) over all the silicon extractants.

PAS status at 20 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (482.00 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (231.66 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (530.20 ppm) over all the interactions.

PAS status at 40 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (509.83 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (246.97 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (554.30 ppm) over all the interactions. However, it was at par with E₃T₆ (544.26 ppm).

PAS status at 60 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (483.43 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (232.03 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (528.19 ppm) over all the interactions.

PAS status at 80 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (440.69 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (212.18 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (492.04 ppm) over all the interactions.

PAS status at 100 day

The PAS was significantly influenced by silicon extractants, levels of silicon and their interactions. The silicon extractant 0.1 M Citric acid (1:50) recorded significantly highest PAS (412.57 ppm) over all the silicon extractants. The application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (196.26 ppm) over all the levels of silicon. The interaction effect of 0.1 M Citric acid (1:50) with GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS (453.88 ppm) over all the interactions.

Table 4: Effect of silicon extractants, levels of silicon and their interactions on PAS status in Vertisols under incubation study

	Plant Available Silicon (ppm)					
	0 day	20 day	40 day	60 day	80 day	100 day
A. Silicon extractants (E)						
E ₁ : 0.5 M Acetic acid (1:2.5)	349.48	377.54	384.45	379.43	373.06	367.42
E ₂ : 0.5 M Acetic acid (1:10)	117.32	157.66	176.00	164.26	141.18	131.70
E ₃ : 0.1 M Citric acid (1:50)	387.32	482.00	509.83	483.43	440.69	412.57
E ₄ : N NaOAc-HOAc pH 4.0 (1:10)	184.96	234.12	245.88	230.36	219.89	205.19
E ₅ : 0.5 M NH ₄ OAc pH 4.8 (1:10)	295.38	356.19	365.93	351.62	331.64	320.42
E ₆ : 0.01 M CaCl ₂ (1:10)	62.01	101.63	113.61	100.25	86.34	75.93
E ₇ : Distilled water (1:10)	18.51	30.50	35.09	30.74	26.24	23.74
E ₈ : Tris buffer pH 7.0 (1:10)	58.95	86.61	95.83	85.51	77.71	71.24
E ₉ : 0.19 M Na ₂ CO ₃ (1:20)	42.24	96.81	111.41	93.68	73.35	59.27
E ₁₀ : 0.5 M NaHCO ₃ pH 8.5 (1:20)	47.01	117.12	132.52	115.32	95.34	80.59

SE (m) \pm	1.608	1.462	1.351	1.552	1.336	1.309
CD @ 5%	4.518	4.107	3.795	4.360	3.753	3.679
B. Levels of silicon (T)						
T ₁ : Absolute control	155.19	169.30	181.61	172.04	158.36	151.13
T ₂ : GRDF	157.79	181.71	194.02	181.50	169.02	160.78
T ₃ : GRDF + Si @ 25 kg ha ⁻¹	155.98	196.58	208.83	196.43	179.44	169.04
T ₄ : GRDF + Si @ 50 kg ha ⁻¹	156.64	208.27	219.63	206.12	188.07	175.05
T ₅ : GRDF + Si @ 100 kg ha ⁻¹	156.93	216.22	229.25	213.40	194.75	181.59
T ₆ : GRDF + Si @ 150 kg ha ⁻¹	154.56	224.39	239.09	222.72	203.98	189.80
T ₇ : GRDF + Si @ 200 kg ha ⁻¹	157.14	231.66	246.97	232.03	212.18	196.26
SE (m) \pm	1.345	1.223	1.130	1.298	1.118	1.095
CD @ 5%	NS	3.436	3.175	3.648	3.140	3.078
C. Interactions (E x T)						
E ₁ T ₁	350.17	353.92	358.96	354.71	351.06	346.12
E ₁ T ₂	349.18	354.91	361.33	357.48	353.82	350.17
E ₁ T ₃	349.58	359.65	365.87	361.03	357.67	352.93
E ₁ T ₄	348.39	366.26	371.40	367.35	361.03	356.39
E ₁ T ₅	346.12	382.26	391.64	382.26	374.56	367.55
E ₁ T ₆	351.06	409.12	419.49	415.05	404.48	396.78
E ₁ T ₇	351.85	416.63	422.45	418.11	408.83	402.01
E ₂ T ₁	118.50	133.91	143.78	134.30	106.65	103.49
E ₂ T ₂	123.24	138.25	150.10	137.86	120.48	120.87
E ₂ T ₃	112.97	145.76	160.77	152.08	132.72	123.24
E ₂ T ₄	116.13	155.63	174.59	163.93	143.39	129.96
E ₂ T ₅	116.53	167.48	188.81	174.59	152.08	138.65
E ₂ T ₆	114.55	176.57	201.85	188.02	161.95	147.73
E ₂ T ₇	119.29	186.05	212.12	199.08	171.04	158.00
E ₃ T ₁	383.59	397.65	435.81	417.73	381.58	371.54
E ₃ T ₂	387.61	433.80	461.92	437.82	405.68	379.58
E ₃ T ₃	387.61	486.02	508.11	488.03	435.81	403.68
E ₃ T ₄	391.63	504.09	530.20	496.06	443.84	411.71
E ₃ T ₅	385.60	510.12	534.22	506.10	455.89	427.78
E ₃ T ₆	385.60	512.13	544.26	510.12	469.95	439.83
E ₃ T ₇	389.62	530.20	554.30	528.19	492.04	453.88
E ₄ T ₁	181.55	201.31	212.42	198.84	187.72	180.72
E ₄ T ₂	186.90	210.36	219.01	203.78	198.01	188.54
E ₄ T ₃	187.31	219.42	229.71	219.83	211.60	200.89
E ₄ T ₄	186.90	235.06	248.65	232.18	220.24	209.13
E ₄ T ₅	186.07	251.53	261.82	240.41	227.65	214.89
E ₄ T ₆	179.49	257.70	271.70	254.41	239.59	219.01
E ₄ T ₇	186.49	263.47	277.88	263.06	254.41	223.12
E ₅ T ₁	291.81	313.82	319.87	309.07	298.71	291.81
E ₅ T ₂	296.56	328.93	335.84	322.89	308.64	302.60
E ₅ T ₃	298.28	347.49	356.13	341.45	320.30	312.53
E ₅ T ₄	293.53	367.78	372.10	360.44	336.70	323.32
E ₅ T ₅	294.83	375.55	380.73	363.90	344.47	330.66
E ₅ T ₆	297.85	378.57	393.68	375.98	352.67	340.15
E ₅ T ₇	294.83	381.16	403.18	387.64	360.01	341.88
E ₆ T ₁	61.92	65.79	74.82	65.79	58.05	52.25
E ₆ T ₂	62.57	82.56	97.40	80.63	71.60	67.08
E ₆ T ₃	59.34	95.46	110.30	96.11	80.63	72.89
E ₆ T ₄	65.79	104.49	119.97	108.36	92.24	81.92
E ₆ T ₅	63.21	114.81	124.49	112.88	95.46	81.92
E ₆ T ₆	58.05	121.26	130.94	116.75	100.62	85.79
E ₆ T ₇	63.21	127.07	137.39	121.26	105.78	89.66
E ₇ T ₁	18.59	21.97	25.35	20.84	17.46	15.77
E ₇ T ₂	17.46	26.48	29.86	26.48	22.53	19.15
E ₇ T ₃	18.59	29.86	32.67	28.73	24.22	23.10
E ₇ T ₄	18.59	30.42	34.93	30.98	27.60	23.66
E ₇ T ₅	20.28	31.55	35.49	33.80	28.73	25.91
E ₇ T ₆	18.59	36.05	40.56	35.49	30.98	27.04
E ₇ T ₇	17.46	37.18	46.76	38.87	32.11	31.55
E ₈ T ₁	57.37	64.55	74.48	68.41	61.24	57.93
E ₈ T ₂	60.13	72.27	81.10	73.92	69.51	64.55
E ₈ T ₃	60.13	81.10	91.58	81.65	73.92	69.51
E ₈ T ₄	60.68	88.27	95.99	86.61	79.44	72.27
E ₈ T ₅	62.34	91.03	103.16	88.27	80.54	73.37
E ₈ T ₆	55.17	100.40	109.23	95.99	87.72	78.34
E ₈ T ₇	56.82	108.68	115.30	103.71	91.58	82.75

E ₉ T ₁	41.37	63.27	75.43	68.13	52.32	38.93
E ₉ T ₂	43.80	76.65	91.25	76.65	59.62	51.10
E ₉ T ₃	38.93	86.38	105.85	87.60	66.92	55.97
E ₉ T ₄	38.93	103.42	114.37	94.90	74.22	59.62
E ₉ T ₅	45.02	108.28	126.53	102.20	81.52	65.70
E ₉ T ₆	46.23	116.80	128.97	105.85	86.38	68.13
E ₉ T ₇	41.37	122.88	137.48	120.45	92.47	75.43
E ₁₀ T ₁	47.01	76.83	95.17	82.56	68.80	52.75
E ₁₀ T ₂	50.45	92.88	112.37	97.47	80.27	64.21
E ₁₀ T ₃	47.01	114.67	127.28	107.79	90.59	75.68
E ₁₀ T ₄	45.87	127.28	134.16	120.40	102.05	82.56
E ₁₀ T ₅	49.31	129.57	145.63	129.57	106.64	89.44
E ₁₀ T ₆	38.99	135.31	150.21	129.57	105.49	95.17
E ₁₀ T ₇	50.45	143.33	162.83	139.89	113.52	104.35
SE (m) ±	4.254	3.867	3.574	4.106	3.534	3.464
CD @ 5%	NS	10.87	10.04	11.54	9.930	9.733

The PAS status in Inceptisols under incubation study as extracted by ten silicon extractants follows the order viz. 0.1 M Citric acid (1:50) > 0.5 M Acetic acid (1:2.5) > 0.5 M NH₄OAc pH 4.8 (1:10) > N NaOAc-HOAc pH 4.0 (1:10) > 0.5 M Acetic acid (1:10) > 0.01 M CaCl₂ (1:10) > 0.5 M NaHCO₃ pH 8.5 (1:20) > Tris buffer pH 7.0 (1:10) > 0.19 M Na₂CO₃ (1:20) > Distilled water (1:10). However, PAS status in case of Vertisols follows the order viz. 0.1 M Citric acid (1:50) > 0.5 M Acetic acid (1:2.5) > 0.5 M NH₄OAc pH 4.8 (1:10) > N NaOAc-HOAc pH 4.0 (1:10) > 0.5 M Acetic acid (1:10) > 0.5 M NaHCO₃ pH 8.5 (1:20) > 0.01 M CaCl₂ (1:10) > 0.19 M Na₂CO₃ (1:20) > Tris buffer pH 7.0 (1:10) > Distilled water (1:10).

The PAS status in Inceptisols as well as Vertisols under incubation study showed bell shaped curve. The PAS status increased from 0 to 40 day. The maximum PAS was recorded at 40 day and then PAS status decreased from 60 to 100 day. However, PAS status of soil enhanced over initial values due to application of calcium silicate as a source of silicon. Among ten silicon extractants, 0.1 M Citric acid (1:50) recorded highest PAS in both the alkaline soil samples. This might be due to higher soil: extractant ratio, longer contact time of soil with extractant, continuous shaking and acidic nature of extractant. The application of GRDF along with Si @ 200 kg ha⁻¹ was also responsible to enhance PAS content in both the soils.

There was increase in PAS content over period of incubation in Inceptisols as well as Vertisols. This might be due to dissolution of silicon from calcium silicate as well as native silicon from soil. The dissolution kinetics of soil silicon was influenced not only by nature of Si polymorphs but also by a myriad of soil factors such as organic matter, redox potential, metallic ions, phyllosilicates, sesquioxides, surface area, surface coating and overall soil solution dynamic (Drees *et al.*, 1989) [4]. The dissolution of Si from a slag silicate fertilizer into aqueous solution increases with increased pH and calcium concentrations in the solution (Kato and Owa, 1997) [10]. The particle size and surface area of applied silicon minerals also influenced the dissolution rate of silicon in soils. Slightly higher soil pH promotes the transformation of polysilicic acid (insoluble) acid into monosilicic acid (soluble) and played a dominant role in silicon availability (Korndorfer *et al.*, 2005) [12].

The maximum PAS was recorded at 40 day and then PAS status decreased from 60 to 100 day in Inceptisols as well as Vertisols. The silicon concentration in a soil is controlled by the dissolution of the siliceous materials and by the sorption reactions between soluble silica and reactive soil materials, particularly the iron and aluminium oxides and hydroxides,

other anions and soil pH also influence the reactions (Obihara and Russell, 1972) [17]. Silicon adsorption capacity differs between soils and associated with the amount of active aluminium, iron and manganese hydroxides which functions as Si adsorbents (Ando *et al.*, 2002) [2]. These results are in conformity with the findings of Suhei *et al.* (2013) [23] who reported that the effects of slag silicate fertilizer on Si supply in solution were affected by Si dissolution from the applied slag silicate fertilizer and the Si adsorption capacity of the soil. When slag silicate fertilizer was applied to paddy soil, Si dissolves from the slag silicate fertilizer in soil solution, and part of the dissolved Si was adsorbed onto the soil solid phase. A part of the adsorbed Si in the soil solid phase can then be desorbed and redissolved into soil solution. Similar results were also reported by Nagabovanalli *et al.* (2014) [15].

Conclusion

The periodical dissolution and release of silicon was found to vary in ten silicon extractants as well as levels of silicon in alkaline soils of order Inceptisols and Vertisols. The silicon extractant 0.1 M Citric acid (1:50) and application of GRDF + Si @ 200 kg ha⁻¹ recorded significantly highest PAS status in Inceptisols and Vertisols throughout incubation study. The PAS status in both the soils showed bell shaped curve and maximum PAS was recorded at 40 day. However plant available silicon status of alkaline soils enhanced over initial due to application of calcium silicate as a source of silicon.

References

1. Acquaye D, Tinsley J. Soluble silica in soils. In: Hallworth EG, Crawford DV. (eds.) Experimental Pedology. Proceeding of the Eleventh Easter School in Agricultural Science, University of Nottingham, Butterworth's, London, 1965, 126-148.
2. Ando T, Fujii H, Yokoyama K, Ando H, Mayumi H. Categorization of soil type with reference to behaviour of silicon in soil. In Proceedings of the 2nd Silicon in Agriculture Conference. Psuruoka, Japan, 2002, 247-248.
3. Daniela S, Loredana S, Daniela JC, Ludger H, Michael S. Review of methodologies for extracting plant available and amorphous Si from soils and aquatic sediments. Biogeochemistry. 2006; 80:89-108.
4. Drees LR, Wilding LP, Smeck NE, Sankayi AL. Silica in soils: quartz and disordered silica polymorphs. In: Dixon JB, Weed SB. (eds.) Minerals in Soil Environments, Soil Science Society of America Book Series, Madison, WI, USA. 1989; 1:913-974.
5. Filho BMP, Snyder GH, Elliot CL, Datnoff LE. Evaluation of soil test procedures for determining rice

- available silicon. *Commun. Soil Sci. Plant Anal.* 2001; 32:1779-1792.
6. Fox RL, Silva JA, Younge OR, Plunkett DL, Sherman GD. Soil and plant silicate response by sugarcane. *Soil Sci. Soc. Am. Proc.* 1967; 6:775-779.
 7. Hansen HCB, Ranben Lange B, Rauland R, Kand Borggard OK. Monosilicate adsorption by ferrihydrite and goethite at pH 3-6. *Soil Sci.* 1994; 158:40-46.
 8. Iler RK. *The Chemistry of Silica (Solubility, polymerization, colloid and surface properties, and biochemistry)*. John Wiley and Sons, USA, 1979, 621.
 9. Imaizumi K, Yoshida S. Edapological studies on silicon supplying power of paddy soils. *Bull. Nat. Inst. Agric. Sci. Japan.* 1958; 8:261-304.
 10. Kato N, Owa N. Dissolution of slag fertilizers in a paddy soil and Si uptake by rice plant. *Soil Sci. Plant Nutr.* 1997; 43:329-341.
 11. Korndorfer GH, Coelho MN, Snyder GH, Mizutani CT. An evaluation of soil extractants for silicon availability in upland rice. *J. Plant Nutr.* 1999; 23:101-106.
 12. Korndorfer GH, Nolla A, Ramos LA. Available silicon in tropical soils and crop yield. In *Proceedings of the 3rd Silicon in Agriculture Conference*, Uberlandia, Brazil, 2005, 72-81.
 13. Korndorfer GH, Snyder GH, Ulloa M, Powell G, Datnoff LE. Calibration of soil and plant silicon analysis for rice production. *J. Plant Nutr.* 2001; 24(7):1071-1084.
 14. Lindsay WL. *Chemical equilibria in soils*. John Wiley and Sons, New York, USA, 1979, 449.
 15. Nagabovanalli BP, Anitha MS, Sandhya K. Behaviour of different levels and grades of Diatomite as silicon source in acidic and alkaline soils. In *Proceedings of the 6th International Conference on Silicon in Agriculture*, Stockholm, Sweden, 2014, 132.
 16. Nayar PK, Misra AK, Patnaik S. Evaluation of silica supplying power of soils for growing rice. *Plant and Soil.* 1977; 47:487-494.
 17. Obihara CH, Russell EW. Specific adsorption of silicate and phosphate by soils. *J. Soil Sci.* 1972; 23:105-117.
 18. Panse VG, Sukhatme PV. *Statistical method of Agricultural Workers*, ICAR, New Delhi, 1985, 143-147.
 19. Rodrigues LL, Daroub SH, Rice RW, Snyder GH. Comparison of three soil test methods for estimating plant available silicon. *Commun. Soil Sci. Plant Anal.* 2003; 34:2059-2071.
 20. Savant NK, Snyder GH, Datnoff LE. Silicon management and sustainable rice production. *Adv. Agron.* 1997; 58:151-199.
 21. Snyder GH. Methods for silicon analysis in plants, soils and fertilizers. In: Datnoff LE, Snyder GH, Korndorfer GH. (eds.) *Silicon in Agriculture*, Elsevier Science B.V., Amsterdam, The Netherlands, 2001, 185-207.
 22. Sommer MD, Fuzyakov, Breuer J. Silicon pools and fluxes in soils and landscapes: A review. *J. Plant Nutr. Soil Sci.* 2006; 169:310-329.
 23. Suhei MS, Ken IK, Yuka S, HO A. Effect of slag silicate fertilizer on dissolved silicon in soil solution based on the chemical properties of Gleysols. *Soil Sci. Plant Nutr.* 2013; 21:1-7.
 24. Wang JJ, Dodla SK, Henderson RE. Soil silicon extractability with seven selected extractants in relation to colorimetric and ICP determination. *Soil Sci.* 2004; 169:861-870.
 25. Xu GH, Zhan XH, Li CH, Bao SD, Liu XB, Chu TD *et al.* Assessing methods of available silicon in calcareous soils. *Commun. Soil Sci. Plant Anal.* 2001; 32:787-801.
 26. Yoshida S. *The physiology of silicon in rice*. Tech. Bull. No. 25. Food and Fertilizer Technical Centre, Taipei, Taiwan, 1975, 27.