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EVALUATION OF SUITABLE EXTRACTANT FOR SOIL AVAILABLE SILICON IN INCEPTISOLS AND VERTISOLS

A. A. Patil *et al.*,

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A. A. PATIL*, A. G. DURGUDE AND A.L. PHARANDE
Department of Soil Science and Agricultural Chemistry,
Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar - 413 722, Maharashtra, INDIA
e-mail: atishpatil53@gmail.com

ABSTRACT

The pot culture experiment was conducted in wire house at Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri, during *kharif* 2013. The purpose of this study was to evaluate suitable silicon extractant for Inceptisols and Vertisols. Ten extractants were tested to evaluate a suitable method by correlating the extractable soil Si with nutrient uptake and yield of upland paddy under pot culture. Among the methods studied the suitable extractant for available silicon in Inceptisols and Vertisols are 0.1 M Citric acid (1:50) and 0.5 M NH_4OAc pH 4.8 (1:10) respectively. In Inceptisols the available silicon as extracted by 0.1 M Citric acid (1:50) recorded positively highest and significant correlation with grain yield (r=0.973), grain Si uptake (r=0.986), straw yield (r=0.968) and straw Si uptake (r=0.982). Whereas, in Vertisols the available silicon as extracted by 0.5 M NH_4OAc pH 4.8 (1:10) showed positively highest and significant correlation with grain yield (r=0.954), grain Si uptake (r=0.979), straw yield (r=0.950) and straw Si uptake (r=0.987). Hence, 0.1 M Citric acid (1:50) in Inceptisols and 0.5 M NH_4OAc pH 4.8 (1:10) in Vertisols can be considered as the most suitable extractant for routine analysis of soil available silicon.

***Corresponding author**

INTRODUCTION

Rice occupies a pivotal place in India's national food and livelihood security. Total area under rice in India is 39.47 million hectares with annual production of 87.10 million tonnes and productivity was 2.20 tonnes ha^{-1} (Anonymous, 2013). Rice is a silicon accumulating plant. No other crop requires as much Si as rice. Silica is required for healthy and productive/protective development of the rice plant (Yoshida, 1975). Silicon absorbed by rice from the soil in large amounts that are several fold greater than those of other macronutrients. It is estimated that a rice crop producing a total grain yield of about 5 tonnes ha^{-1} will normally remove 230 to 470 kg Si ha^{-1} (500-1000 SiO_2 kg ha^{-1}) from soil (Amarasiri and Perera, 1975). For this reason, Si has been recognized as an agronomically essential element in Japan and silicate fertilizers have been applied to paddy soils (Ma *et al.*, 2001).

Silicon is recognized as a beneficial plant nutrient. It is the second most abundant element (27.72%) after oxygen available in the earth crust. Its content in soils varies greatly ranging from less than 1 to 45 % by dry weight (Sommer *et al.*, 2006). The extensive cultivation of paddy in some regions of Asia and Southeast Asian countries has led to depletion of available silicon (Savant *et al.*, 1997) and warrants the application of silicate fertilizers for achieving sustainable rice yields. As yield responses of rice to Si application are related to available Si in soils and the Si content of rice plants, there is a need for evaluation of simple and rapid extractant for determination of available soil Si based on the crop response and its uptake. Several extractants are being employed in different countries for determination of extractable soil Si based on the crop response and its uptake mostly for lowland acidic type of soils. There is a need for evaluation of simple and rapid extractants for determination of extractable soil Si for upland alkaline type of soils.

Acquaye and Tinsley (1965) 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) 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 acetate buffer > water. Silicon extracted by citric acid showed better correlation with the Si uptake by rice plants. Filho *et al.* (2001) reported that the Si extracted with 0.5 M acetic acid appeared most suitable for evaluating Si availability, followed by extraction with citric acid at 1%. These methods provided the best correlations with rice straw and panicle Si percentage (r^2 = 0.899, r^2 = 0.768 and r^2 = 0.839, r^2 = 0.774, respectively). These methods, being rapid and effective in extracting Si in comparison to other methods, appears to be the most suitable for routine soil testing for Si in the Everglades Agricultural Area in South Florida. 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 acidic. In this context, the present investigation was undertaken to find suitability of extractant for available silicon and its response to upland paddy grown on Inceptisols and Vertisols under pot culture.

MATERIALS AND METHODS

Experimental site, soil and treatments

The pot culture experiment was conducted in wire house at Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri, during *kharif* 2013. The upland paddy (*Cv.* Indrayani) was used as a test crop to evaluate suitable extractant for available silicon in Inceptisols and Vertisols. Plastic pots having 15 kg capacity were taken and filled with 10 kg soil. The details of initial soil properties are presented in the Table 1. Initially 5 paddy seeds per pot were sown. After 15 days only 2 seedlings per pot were maintain for biometric observations. The experiment was laid out in Factorial Completely Randomized Design (FCRD) having 14 treatment combinations with three replications. The calcium silicate was used as a source of silicon and applied one month before sowing. The treatment details were T_1: Absolute control, T_2: General Recommended Dose of Fertilizers *i.e.* GRDF (0.446:0.223:0.223 g $N:P_2O_5:K_2O$ kg^{-10} soil + 22.32 g FYM kg^{-10} soil), T_3: GRDF + 0.111 g Si kg^{-10} soil, T_4: GRDF + 0.223 g Si kg^{-10} soil, T_5: GRDF + 0.446 g Si kg^{-10} soil, T_6: GRDF + 0.669 g Si kg^{-10} soil, T_7: GRDF + 0.892 g Si kg^{-10} soil.

Grain and Straw yield

The grain and straw yield were recorded at harvest. The harvesting of paddy was done by cutting the stem close to ground and stored in paper bags separately from each pot for threshing. The grain yield was recorded and expressed in g pot^{-1} at 14 percent moisture level. The straw yield was obtained by weighing the sun dried straw which remained after removal of grains and expressed in g pot^{-1}.

Silicon uptake

The silicon uptake by paddy in each pot was determined by rapid microdetermination method of Nayar *et al.* (1975).

Soil available silicon

The available silicon from soil samples was extracted by using ten extractants as outlined by researchers. The ten extractants were E_1: 0.5 M Acetic acid, soil to extractant ratio (1:2.5) Snyder (2001), E_2: 0.5 M Acetic acid (1:10) Korndorfer *et al.* (1999), E_3: 0.1 M Citric acid (1:50) Acquaye and Tinsley (1965), E_4: *N* NaOAc-HOAc pH 4.0 (1:10) Imaizumi and Yoshida (1958), E_5: 0.5 M NH_4OAc pH 4.8 (1:10) Fox *et al.* (1967), E_6: 0.01 M $CaCl_2$ (1:10) Korndorfer et *al.* (1999), E_7: Distilled water (1:10) Korndorfer *et al.* (1999), E_8: Tris buffer pH 7.0 (1:10) Filho *et al.* (2001), E_9: 0.19 M Na_2CO_3 (1:20) Xu *et al.* (2001) and E_{10}: 0.5 M $NaHCO_3$ pH 8.5 (1:20) Xu *et al.* (2001).

Statistical analysis

The soil analysis and yield data generated from pot culture experiment was statistically analyzed by methods suggested by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Crop yield

The grain and straw yield was significantly influenced by soil types and levels of silicon. However, results were found to be non-significant in case of their interactions (Table 2). The soil type Vertisols showed significantly highest grain yield (36.20 g pot^{-1}) over the Inceptisols (33.75 g pot^{-1}). The application of GRDF + Si @ 200 kg ha^{-1} (T_7) recorded significantly highest grain yield (43.15 g pot^{-1}) over all the levels of silicon. However, it was at par with T_6 (41.28 g pot^{-1}). Similar trend was also noticed in case of straw yield. The soil type Vertisols showed significantly highest straw yield (39.42 g pot^{-1}) over the Inceptisols (37.60 g pot^{-1}). The application of GRDF + Si @

Table 1: Initial soil properties of pot culture experiment

Sr.No.	Parameters	Values Inceptisols	 Vertisols
1.	Particle size distribution		
	Coarse sand (%)	4.38	3.63
	Fine sand (%)	12.40	13.09
	Silt (%)	27.10	26.58
	Clay (%)	56.12	56.70
	Textural class	Clayey	Clayey
2.	Bulk density (Mg m^{-3})	1.32	1.39
3.	Organic carbon (%)	0.55	0.53
4.	Calcium carbonate (%)	7.04	6.13
5.	pH (1:2.5)	8.28	8.31
6.	EC (1:2.5) (dS m^{-1})	0.32	0.34
7.	Available N (mg kg^{-1})	121.20	123.00
8.	Available P (mg kg^{-1})	11.00	13.78
9.	Available K (mg kg^{-1})	225.71	257.86
10.	Available Si (mg kg^{-1}) as extracted by ten extractants		
E_1	0.5 M Acetic acid (1:2.5)	336.12	346.15
E_2	0.5 M Acetic acid (1:10)	108.17	116.13
E_3	0.1M Citric acid (1:50)	380.44	383.88
E_4	*N* NaOAc-HOAc pH 4.0 (1:10)	182.07	185.60
E_5	0.5 M NH_4OAc pH 4.8 (1:10)	295.63	304.33
E_6	0.01M $CaCl_2$ (1:10)	63.58	64.41
E_7	Distilled water (1:10)	21.49	22.21
E_8	Tris buffer pH 7.0 (1:10)	54.62	56.51
E_9	0.19 M Na_2CO_3 (1:20)	47.45	50.06
E_{10}	0.5 M $NaHCO_3$ pH 8.5 (1:20)	48.65	53.07

Table 2: Effect of soil types, levels of silicon and their interactions on yield and Si uptake by upland paddy under pot culture

A. Soil types (S)	Grain yield(g pot^{-1})	Grain Si uptake(mg pot^{-1})	Straw yield(g pot^{-1})	Straw Si uptake(mg pot^{-1})
S_1: Inceptisols	33.75	439.66	37.60	1501.36
S_2: Vertisols	36.20	488.39	39.42	1762.54
SE (m) +	0.414	7.05	0.433	14.83
CD at 5%	1.198	20.42	1.253	42.96
B. Levels of silicon (T)				
T_1: Absolute control	22.71	240.90	25.88	832.88
T_2: GRDF	30.06	342.09	33.49	1191.64
T_3: GRDF + Si @ 25 kg ha^{-1}	32.65	398.55	36.63	1421.09
T_4: GRDF + Si @ 50 kg ha^{-1}	36.11	472.65	39.64	1677.74
T_5: GRDF + Si @ 100 kg ha^{-1}	38.90	540.71	42.40	1913.48
T_6: GRDF + Si @ 150 kg ha^{-1}	41.28	595.38	45.00	2121.55
T_7: GRDF + Si @ 200 kg ha^{-1}	43.15	657.91	46.54	2265.29
SE (m) ±	0.774	13.19	0.809	27.74
CD at 5%	2.242	38.20	2.344	80.37
C. Interactions (S × T)	NS	NS	NS	NS

Table 3: Effect of soil types, levels of silicon and their interactions on soil available silicon as extracted by silicon extractants at harvest of upland paddy under pot culture

	Soil available silicon (mg kg^{-1})									
	E_1 0.5 M Acetic acid (1:2.5)	E_2 0.5 M Acetic acid (1:10)	E_3 0.1 M Citric acid (1:50)	E_4 *N* NaOAc-HOAcpH 4.0 (1:10)	E_5 0.5 M NH_4OAc pH 4.8 (1:10)	E_6 0.01 M $CaCl_2$ (1:10)	E_7 Distilled water (1:10)	E_8 Tris buffer pH 7.0 (1:10)	E_9 0.19 M Na_2CO_3 (1:20)	E_{10} 0.5 M $NaHCO_3$ pH 8.5 (1:20)
A. Soil types (S)										
S_1: Inceptisols	337.44	95.42	381.30	173.66	301.61	81.92	30.58	67.46	62.75	73.88
S_2: Vertisols	336.29	85.21	388.47	168.72	293.29	77.68	29.21	58.00	45.02	61.76
SE (m) +	0.152	1.693	3.520	1.040	1.076	1.327	0.418	1.023	0.886	1.683
CD at 5%	0.439	4.905	NS	3.014	3.117	3.845	1.211	2.964	2.567	4.874
B. Levels of silicon (T)										
T_1:Absolute control	329.78	70.31	295.23	144.70	264.18	57.41	19.72	47.17	35.89	41.85
T_2:GRDF	331.80	73.47	321.33	151.70	276.70	62.24	19.44	46.34	38.33	49.88
T_3:GRDF + Si @ 25 kg ha^{-1}	334.37	84.33	353.47	160.55	290.08	71.60	26.76	56.27	48.06	61.92
T_4:GRDF + Si @ 50 kg ha^{-1}	336.84	85.12	390.62	169.40	298.71	79.66	32.11	63.44	57.18	68.80
T_5:GRDF + Si @ 100 kg ha^{-1}	339.21	98.36	418.74	181.13	308.86	88.69	35.21	69.79	62.66	78.55
T_6:GRDF + Si @ 150 kg ha^{-1}	341.33	106.06	444.85	190.60	317.49	96.75	37.18	74.48	64.48	81.99
T_7:GRDF + Si @ 200 kg ha^{-1}	344.74	114.55	469.95	200.28	326.12	102.23	38.87	81.65	70.57	91.73
SE (m) ±	0.284	3.168	6.585	1.946	2.013	2.483	0.782	1.914	1.658	3.148
CD at 5%	0.822	9.177	19.08	5.639	5.832	7.193	2.266	5.544	4.803	9.119
C. Interactions (S × T)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

200 kg ha^{-1} (T_7) recorded significantly highest straw yield (46.54 g pot^{-1}) over all the levels of silicon. However, it was at par with T_6 (45.00 g pot^{-1}). There was significant increase in the grain and straw yield with increased levels of silicon. This might be due to role of silicon in improvement of photosynthetic activity, water and nutrient use efficiency. That ultimately results into better vegetative growth, increased plant height and number of tillers per hill. The accumulation of silicon in plant parts reduces its lodging and enhanced resistance against biotic and abiotic stress. These results are in conformity with the findings of Singh *et al.* (2006) and Chaudhari *et al.* (2015). The combined use of burnt rice husk ash along with inorganic fertilizers resulted in increased rice yield in comparison to use of inorganic fertilizers alone (Ganaie *et al.,* 2015). Among the four levels of silicon (0, 100, 200 and 300 ppm), 200 mg Si kg^{-1} soil significantly augmented grain and straw yield of rice variety Gurjari on *Typic Ustochrept* soil of Gujarat (Malav *et al.,* 2015).

Silicon uptake by grain and straw

The grain and straw silicon uptake was significantly influenced by soil types and levels of silicon. However, results were found to be non-significant in case of their interactions (Table 2). The soil type Vertisols showed significantly highest grain and straw silicon uptake (488.39 and 1762.54 mg pot^{-1}, respectively) over the Inceptisols (439.66 and 1501.36 mg pot^{-1}, respectively). The application of GRDF + Si @ 200 kg ha^{-1} (T_7) recorded significantly highest grain and straw silicon uptake (657.91 and 2265.29 mg pot^{-1}, respectively) over all the levels of silicon. The higher silicon uptake was associated with increased levels of silicon. This might be due to increase in root growth and available form of silicon in soil. The addition of silicate material to soil and increased in silicon availability might have been the reason for higher silicon uptake. Similar results were also reported by Singh *et al.* (2006) and Prakash *et al.* (2011). The Si uptake by rice grain and straw was

Table 4: Correlation coefficient of silicon extractants with yield and Si uptake by upland paddy grown on Inceptisols and Vertisols under pot culture

Silicon extractants	Inceptisols				Vertisols			
	Grain yield	Grain Si uptake	Straw yield	Straw Si uptake	Grain yield	Grain Si uptake	Straw yield	Straw Si uptake
E_1 : 0.5 M Acetic acid (1:2.5)	0.913	0.953	0.909	0.961	0.944	0.917	0.939	0.984
E_2 : 0.5 M Acetic acid (1:10)	0.914	0.956	0.914	0.948	0.758	0.793	0.745	0.820
E_2 : 0.1 M Citric acid (1:50)	0.973	0.986	0.968	0.982	0.930	0.963	0.924	0.965
E_4 : *N* NaOAc-HOAc pH 4.0 (1:10)	0.916	0.956	0.910	0.963	0.907	0.950	0.897	0.961
E_5 : 0.5 M NH_4OAc pH 4.8 (1:10)	0.933	0.951	0.928	0.968	0.954	0.979	0.950	0.987
E_6 : 0.01 M $CaCl_2$ (1:10)	0.908	0.950	0.900	0.956	0.852	0.906	0.841	0.920
E_7 : Distilled water (1:10)	0.934	0.946	0.929	0.951	0.913	0.942	0.906	0.946
E_8 : Tris buffer pH 7.0 (1:10)	0.905	0.946	0.899	0.951	0.849	0.898	0.853	0.901
E_9 : 0.19 M Na_2CO_3 (1:20)	0.905	0.923	0.901	0.939	0.867	0.919	0.857	0.935
E_{10} : 0.5 M $NaHCO_3$ pH 8.5 (1:20)	0.800	0.816	0.792	0.853	0.911	0.936	0.914	0.941

(Note: All the values are significant at 1 per cent)

significantly affected by Si levels (0, 100, 200 and 300 ppm), in low (<25 mg Si kg^{-1}) and medium (25-50 mg Si kg^{-1}) soil categories as compared to high (>50 mg Si kg^{-1}) category soils. Highest Si uptake by grain (2.71 g pot^{-1}) and straw (23.35 g pot^{-1}) was recorded by 200 mg Si kg^{-1} soil in low category soils. The Si uptake by grain and straw was significantly increased at different levels of Si in all categories of soils over control (Malav *et al.,* 2015).

Soil available silicon at harvest

The determination of silicon from soil at harvest of upland paddy under pot culture was carried out with ten different silicon extractants (Table 3). These silicon extractants were categorized as acidic, neutral and alkaline in reaction. The available silicon as extracted by various extractants irrespective of the soils used for the pot study was in the order of 0.1 M Citric acid (1:50) > 0.5 M Acetic acid (1:2.5) > 0.5 M NH_4OAc pH 4.8 (1:10) > *N* NaOAc-HOAc pH 4.0 (1:10) > 0.5 M Acetic acid (1:10) > 0.01 M $CaCl_2$ (1:10) > 0.5 M $NaHCO_3$ pH 8.5 (1:20) > Tris buffer pH 7.0 (1:10) > 0.19 M Na_2CO_3 (1:20) > Distilled water (1:10). The same trend of silicon availability by various extractants was also observed in the GRDF + Si @ 200 kg ha^{-1} (T_7). There was great variation in silicon content of soil at harvest as extracted by different silicon extractants. This variation might be due to different pH of extractants, soil: extractant ratio, shaking period, dissolution of soluble, exchangeable and adsorbed silicon present in the soil. Due to these factors there was variation in silicon content in soil at harvest of upland paddy under pot culture study. Hence 0.1 M Citric acid (1:50) extracts more silicon (469.95 mg kg^{-1}) whereas, Distilled water (1:10) extracts less silicon (38.87 mg kg^{-1}) at application of highest level of silicon (T_7: GRDF + Si @ 200 kg ha^{-1}). In general, the lower pH, higher soil: extractant ratio and longer contact between soil: extractant reported higher silicon extraction power. There was significant increase in the silicon content at harvest due to application of silicon. The soil type Vertisols showed reduction in the silicon content at harvest. This might be due to uptake of silicon by crop and very slow dissolution kinetics of soil silicon as reported by (Lindsay, 1979). However, Inceptisols recorded significantly increase in silicon content at harvest. This might be due to less uptake of silicon by crop and higher desilisification process in Inceptisols. Similar trend of results were also reported by many others using different silicon extractants like Dhamapurkar *et al.* (2011) used 0.025 M Citric acid; whereas, Patil (2013) used 0.5 M Ammonium acetate pH 4.8 as an silicon extractant for determination of available silicon. Different extractants reported different capabilities to extract silicic acid. Hence Sulphuric acid and Citric acid reported greater extraction potential, whereas, distilled water noted least potential to extract silicic acid (Sauer *et al.,* 2006).

Correlation coefficient

The results revealed that the amount of soil available silicon as extracted by ten silicon extractants correlated positively and significantly with yield and silicon uptake by upland paddy grown on Inceptisols and Vertisols under pot culture (Table 4). In Inceptisols the available silicon as extracted by 0.1 M Citric acid (1:50) recorded positively highest and significant correlation with grain yield (r=0.973), grain Si uptake (r=0.986), straw yield (r=0.968) and straw Si uptake (r=0.982). Whereas, in Vertisols the available silicon as extracted by 0.5 M NH_4OAc pH 4.8 (1:10) showed positively highest and significant correlation with grain yield (r=0.954), grain Si uptake (r=0.979), straw yield (r=0.950) and straw Si uptake (r=0.987). However, number of extractants can be successfully used to estimate soil silicon. The choice of extractant will often be based on its ease of adoption for a particular laboratory and its suitability for specific soil characteristics, which will in turn be reflected in its ability to correlate with yield and uptake of silicon. These results resembled to the findings reported by Acquaye and Tinsley (1965), Korndorfer *et al.* (1999) and Filho *et al.* (2001).

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