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Soil Silicon Status and Integrated Use of Silicate Sourcesand Silicate Solubilizing Bacterial Culturein Sugarcane

Phonde D.B.[1,2] **and Kaushik Banerjee**[3]

Abstract: *The study was undertaken to assess silicon availability in sugarcane soils, its requirement, uptake and management with Si sources and silicate solubilizing bacterial culture for sustainable sugarcane productivity.The highest extraction pool of plant available Si from soil was by 0.5M acetic acid followed by 0.5M ammonium acetate and least by 0.01M calcium chloride. The available Si content in soil increased with pH, clay%, and cation exchange capacity. Phosphate availability was more in higher PA-Si containing soils. In the fields,leaf Si, cane and sugar yield showed positive strong correlation with 0.5M acetic acid extractable PA-Si indicating more suitable extractant to measure plant available silicon. Response examined to the levels andsources of Si and silicate solublizing bacterial culture (SSB)revealed significant increase in cane yieldwithSi @ 400 kg ha*$^{-1}$ *(142.8 t ha*$^{-1}$*) and found cost effective. Thermal power station fly ash, pond ash and bagasse ash which were equally beneficial as calcium silicate.Bagasse ash from sugar mills followed by calcium silicate in conjunction with consortia ofSSB culture@ 5.0 lit ha*$^{-1}$*showedsignificantrole inincreasing soil available Si, sheath moisture, Si uptake, cane yield, sugar yield and found cost effective.*

Keywords: *Sugarcane, plant available silicon, physico-chemical properties, cane and sugar yield.*

INTRODUCTION

The recent stagnation of cane and sugar yields in India has been largely associated with the loss of productive capacity of sugarcane-growing soils under long-term monoculture. Despite the improvement in production technologies, declining soil fertility continues to be a significant problem for long-term sustainability of the sugar industry. Sugar industry development has intensified the monoculture system, with a concurrent increase in the use of major nutrient elements. Over the period, deficiencies of sulfur, zinc, iron, boron have been identified as nutrient factors affecting cane yield in sugarcane growing states. However, silicon (Si) is a nutrient that is not normally considered to be essential for sustained sugarcane production and getsactively accumulatedin sugarcane, suggesting both physiological and morphological roles in growth. A 12 month crop can accumulate 380 kg/ha Si in the above ground tissues, compared to 180 kg/ha K, 140 kg/ha N and 20 kg/ha P (Samuels, 1969). Although it can grow normally with small amounts of Si, its ability to absorb large quantities suggests that Si may be necessary, or at least beneficial, for optimal growth. Therefore, Si is recognized as an agronomically essential element for sustainable sugarcane production (Savant *et. al.*, 1999). There is association of adequate levels of plant tissue Si with increased resistance to disease and insect and improved root growth and structural strength (Epstein, 1994; Epstein, 1999). Silicon increases longevity of active roots, functional leaves and photosynthetic efficiency. Plants assimilate silicon as monosilicicacid, and its deposition in epidermal cells reduces the transpiration under water stress conditions. Monosilicic acid reacts with heavy metals in soil forming slightly soluble heavy metal complexes, which alleviates toxic effects. Silicon increases phosphate availability in soil, increases CEC and microbial activity in soil. It has an important

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[1] Sr. Scientist, Vasantdada Sugar Institute, Pune, Maharashtra, India. *E-mail : db.phonde@vsisugar.org.in*

[2] Department of AGPM, Shivaji University Kolhapur, Maharashtra, India

[3] Principal Scientist, ICAR-National Research Centre for Grapes, Manjari Farm, Pune, Maharashtra, India

role to promote good crop growth and yield of sugarcane (Ayres,1966). Silicon is a major constituent of soils present in the solid phase of soils as alumino-silicate clay minerals and crystalline minerals and amorphous forms. Soil incubation studies showed significant solubility of native soil Si due to the treatment of silicate solubilizing microbial culture (Balasubramaniam *et al* 2011). Hence, the current study was undertaken with the objectives to assess the plant available soil silicon,verify suitable extractant and impactof levels and sources of Siand silicate solubilizing bacterial culture in sugarcane.

MATERIALS AND METHODS

Soil Sampling and Analysis

Composite surface (0 – 22.5 cm depth) soil samples were collected from 74 representative sites before planting of sugarcane which has long been under sugarcane cultivation from South, Central, Marathwada and Vidhrbha regions of Maharashtra, India. The soil samples were air dried and sieved through 2 mm mesh prior to analysis. Plant available Si was extracted using three extractants *i.e.* 0.5 M ammonium acetate (pH 4.8), 0.5 M acetic acid and 0.01M calcium chloride. The silicon was estimated using molybdenum blue colorimetric method (Fox *et al* 1967). Soil samples were analyzed for their texture, pH, electrical conductivity, organic carbon, available N, P and K, exchangeable cations and cation exchange capacity(CEC) using standard methods of AOAC (1975) and outlined by Jackson (1973).

Monitoring of Fields and Correlations

A set of 33 fields from different sites of sugar mills wherefrom soil samples were collected were monitored up to harvest for the record of leaf Si contents, cane yields and juice quality. The composite leaf samples (4th) at 120 days after planting were collected and analyzed for Si content by blue silcomolybdous procedure following autoclave digestion method (Elliott and Snyder, 1991). The juice quality analysis for brix, pol and purity was carried outby the method soutlined by Spencer and Meade (1955) and cane yield data of each monitored plot was collected at harvest. Correlation studies were carried out using statistical packages for Social Sciences SPSS software.

Field Experiments

Levels and sources of silicon

The field experiments were conducted to examine the response of sugarcane (var.Co86032) to the levels of silicon in inceptisols at Vasantdada Sugar Institute (VSI), Pune. The silicon was applied @ 0, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 kg ha^{-1} as a basal dose before planting of setts through calcium silicate. Application of FYM @ 20t ha^{-1} and recommended dose of (250 kg ha^{-1}N, 115 kg ha^{-1} P_2O_5 and 115 Kg ha^{-1} K_2O) fertilizers was common for all the treatments. The treatments were replicated thrice in randomized block design.

Sources of silicones

In succession of the experiment, the best level of silicon @ 400 kg ha^{-1} was examined with silicon containing sources viz. thermal power station fly ash (20% reactive Si), bagasse ash (28% Si) and calcium silicate (24% Si) in randomized block design.

Sources of Silicon and Silicate solubilizing bacterial culture

An experiment was conducted to study the effect of sources of Si along with silicate solubilizing bacterial (SSB) culture on sugarcane.The experiment was conducted in split plot design with consortia of microbial culture containing bacterial strains of silicate solubilizing ability developed at VSI, Pune at four levels (0, 2.5, 3.75 and 5.0lit. ha^{-1}) and two sources of Si (Bagasse ash and calcium silicate) were used with three replications. The recommended 250:115:115 NPK and FYM @ 20 t ha^{-1} were uniformly applied to all the treatments.

Field observations and laboratory analysis

The soil chemical analysis was done by methods of AOAC (1975). The field observations of growth and yield attributing factors were taken by standard methods. Sheath moisture was estimated gravimetrically at 120 days after planting. Whole plant samples were analyzed for Si content (Elliott and Snyder, 1991) and their uptake was calculated. Cane juice quality was determined by using methods of Spencer and Meade (1955).

RESULTS AND DISCUSSION

Plant available Si in relation to soil properties

The plant available silicon status in sugarcane growing soils of Maharashtra State (India) following

0.5M ammonium acetate extractant was ranged from 31.42 to 465.76 mg kg^{-1} with mean content of 194.19 mg kg^{-1} while it was 66.76 to 590.19 with the mean of 359.71 mg kg^{-1} using 0.5M acetic acid. The 0.01M calcium carbonate extractable Si ranged from 12.65 to 134.40 mg kg^{-1} with the mean content of 63.63 mg kg^{-1}. Extraction pool of PA-Si was found maximum by 0.5M acetic acid followed by 0.5M ammonium acetate and least by 0.01M calcium chloride. The PA-Si contents extracted by these three extractants were found positively correlated to each other. Jim jain Wang (2004) also showed similar results and reported that different extractants have characteristics of pools of Si supplying capacity of the soil.

Plant available soil Si extracted by both 0.5M NH_4OAc and 0.5M CH_3COOH (Table1)increased with increased values of clay content and decreased with sand content. Inspite of high SiO_2 content in the composition of sand, it has low release potential due to great leaching and prevention of Si accumulation could be the reason for low reserves of PA-Si in sandy soils (Meyer, 2001).Significant positive correlation between soil pH and PA-Si indicated increase in PA-Si with increased pH of soil. Positive significant correlation between PA-Si and available phosphate indicated high reserves of PA-Si which increases P availability in soil. It is reported that Si-rich substances adsorb mobile P and keep in plant available form (Matichenkov and Bocharnikova, 1999).Significant positive correlation (Table1) between PA-Si and CEC indicates good reserves of plant available silicon in high CEC soils.It has been reported (Berthelsen *et al*, 2002) that the basic cations are stripped out from the exchange complex due to high rainfall resulting in soil acidification and the dissolution of alumino-silicate clay minerals takes place. Thus plant available silicon was found higher in alkaline soils containing high base saturation and CEC.

Influence of Native Soil PA-Si on leaf Si and Cane Yield

Of the fields surveyed a set of 33 fields were monitored to record the Si content in initial soil samples, leaf, and cane yield. The correlation between PA-Si extracted by 0.5M ammonium acetate and 0.5M acetic acid with leaf Si content (fig. 1) was significantly positive while, 0.01M $CaCl_2$-Si showed in significant relationship. The significant positive influence on cane yield was also observed with increased levels of plant available Si in soil. The strong correlation obtained between 0.5M acetic acid PA-Si and leaf tissue Si and cane yield suggest that 0.5M acetic acid is a more suitable extractant for plant available Si from the soils. Korndorfer *et al* (1999) also similarlyconcluded that 0.5M acetic acid is the best extractantto estimate the available Si in soil.

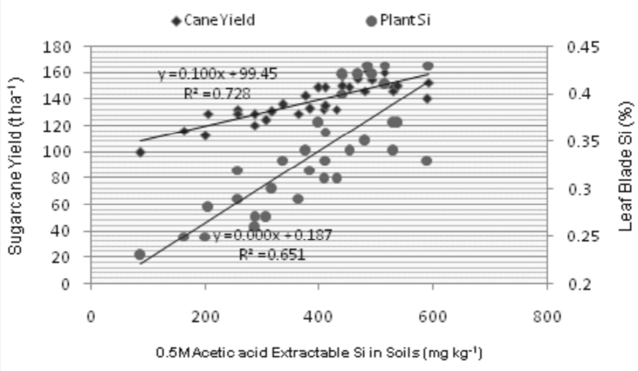

Figure 1. Sugarcane leaf Si and Cane Yield influeced by PA - Si in Soil

Effect of Levels of Si in Sugarcane

The field experiment with levels of Si applied through calcium silicate (fig. 2) showed that the cane yields were increased in all the levels of Si over the control. The significant increase in cane yield (142.8 t ha^{-1}) was recorded at 400 kg ha^{-1} Si level over the control plot (124.5 t ha^{-1}). The cane yields beyond 400 kg ha^{-1}Si level were increased but differences were not significant except the cane yield (158.9 t ha^{-1}) at 1000 kg ha^{-1} Si level. However, the application rate@ 1000

Table 1
Correlation coefficient (*r*) between plant available silicon and soil properties

PA–Si extractants	*Soil Texture*			*pH*	*Organic Carbon*	*Avail. N*	*Avail. P*	*Avail. K*	*CEC*
	Sand	*Silt*	*Clay*						
0.5M NH4OAc Si	–.257	–0.230	0.369**	.666**	0.111	–0.203	.265*	0.215	.399**
0.5M CH_3COOH Si	–.600**	–0.223	0.721**	.515**	0.055	–0.12	.435**	0.096	.515**
0.01M $CaCl_2$ Si	–.102	–0.10	–0.111	.332**	.390**	0.15	.266*	.258*	.485**

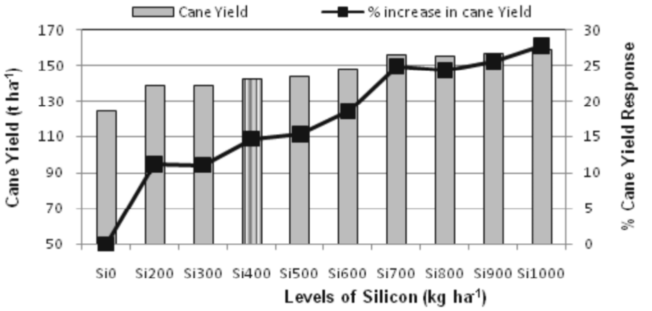

Figure 2: Cane Yield Response to Levels of Silicon

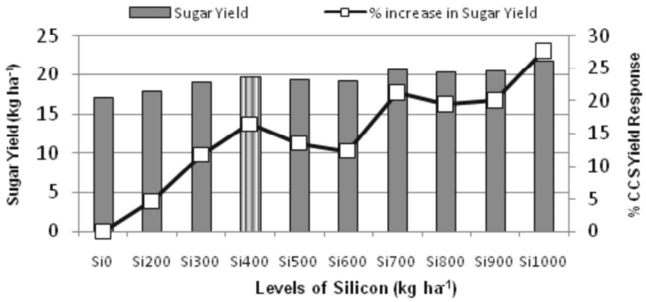

Figure 3: Sugar Yield Response to Levels of Silicon

kg ha^{-1} was not found cost effective.The CCS yield (fig.3) was also found significant at 400 kg ha^{-1} Si level and on par at all the increased levels of Si. It indicated that silicon @ 400 kg ha^{-1} through calcium silicate was optimum and increased cane yield by 14.70 and sugar yield 16.47%. Talashilkar *et al* (2001) also reported significant increase in plant growth, sugarcane and CCS yield due to the calcium silicate slag @ 6 t ha^{-1} on vertisol and inceptisol. In Brazil, De Camargo *et al* (2011) also concluded that silicon rates of 0, 185, 370 and 555 kg ha^{-1}Si through Ca Mg silicate increased Si availability and Si uptake in sugarcane with residual effect, even if high initial contents were presented in tropical soils.

Effect of Sources of Si in Sugarcane

To examine the effect of different locally available sources of silicon at 400 kg ha^{-1} level on sugarcane variety Co86032 was studied in inceptisol. The results revealed that the cane yield (Table 2) significantly increased due to silicon application @ 400 kg ha^{-1} through bagasse ash, fly ash, pond ash and calcium silicate over control. However, Pond ash found to be superior over bagasse ash and on par with fly ash and calcium silicate in relation to milliable canes and cane yield. Foliar application of 2.5% potassium silicate alone also found to be effective for increasing cane yield. The sucrose content in juice was not affected due to silicon while sugar yield significantly increased mainly due to increased cane yield. Bagasse ash from sugar mill, fly ash and pond ash from thermal power station were found equally beneficial as calcium silicate. Similar results were also reported by Pan *et al*(1979), Khanand Qasim, (2008).

Silicon nutrition and insect pest incidence

The incidence of pests and diseases was also recorded in the silicon applied plots (Table 3 & 4). The early shoot borer incidence at 45 days after planting in silicon applied plots was recorded in the range of 8.92 to 11.33% while it was 16.86% in control. The internode borer intensity was recorded minimum 0.71 and 0.72 %, in pond ash and calcium silicate applied plots respectively, whereas intensity was 3.88 in control plot. It indicated that Silicon has controlled the borer damage in sugarcane. Silicon deposited in the epidermal tissue may have functions of support and protection from pests (Takahashi, 1996). Mayer and Keeping (2000) also reported 24% reductions in borer damage and 20% in borer mass with calcium silicate in artificially infested sugarcane trial.

Disease incidence

The natural incidence of sugarcane diseases was recorded (Table 4) every 2 months during the crop

Table 2
Sugarcane growth, Cane and CCS Yield influenced by different Sources of silicon

Sources of Silicon	*Milliable cane Height (cm)*	*Plant population (000′ ha^{-1})*	*Cane Yield (t ha^{-1})*	*Sucrose content (%)*	*CCS Yield (t ha^{-1})*	*Benefit cost Ratio*
Control	210.54	87.48	89.20	20.53	13.26	2.92
Bagasse Ash	218.49	90.59	98.90	20.36	14.55	3.22
Fly Ash	212.73	96.13	106.06	20.59	15.79	3.38
Pond Ash	213.16	98.70	111.79	20.41	16.44	3.56
Calcium Silicate	210.49	94.44	106.65	21.07	16.20	3.19
2.5% K_2SiO_3 Spray	212.40	92.63	102.07	21.03	15.58	3.26
S.E. ±C.D. at 5%	4.78NS	2.297.05	3.19.7	0.23NS	0.541.68	0.100.30

Table 3
Natural incidence of early shoot borer and internode borer in experimental plot

Sources of Silicon	Percent incidence of Early shoot borer at 45 DAP	Internode Borer Incidence at harvest		
		% incidence	% intensity	Index
Control	16.86	40	3.88	1.94
Bagasse Ash	8.92	20	1.24	0.24
Fly Ash	11.33	20	2.66	0.53
Pond Ash	9.38	10	0.71	0.14
Calcium Silicate	11.29	10	0.72	0.14
2.5% K_2SiO_3 Spray	8.94	30	1.92	0.63
SE±	3.4	7.34	0.67	0.39
CD at 5%	N.S.	N.S.	2.07	1.22

period. A major fungal diseases of sugarcane, whip smut, pokkah boeng and rust were not observed so far in all the treatments, where asgrassy shoot disease caused by Mycoplasmaand viral disease like mosaic were noticed.Improved resistance to pathogenic fungal attack has been reported due to Si accumulation in cell walls that may act as a mechanical barrier (Raid *et al.,* 1992, Mayer and Keeping, 2001).

Effect of Si sources and Silicate Solubilizing Bacterial (SSB) culture

Among the Si sources fly ash and pond ash from thermal power station have limitations in agriculture use due to its heavy metal contents. Considering the possibilities of soil contaminations in long term, the successive experiment was carried out excluding fly ash and pond ash. The calcium silicate is not easily available in market and is costly input at present. The bagasse ash is available in sugar mills and is cheaper than other sources. The sources calcium silicate and bagasse ash were further studied for their effect in conjunction with silicate solublizing microbial culture (SSB) developed at VSI.

Both calcium silicate and bagasse ash showed (Table 5) significant influenceon cane and CCS yield. The soil application of consortia of SSB culture @ 5.0 lit.ha^{-1} gave significant cane and sugar yield and found on par with the rates of 2.5 and 3.75 lit.ha^{-1}. The interaction effect of bagasse ash and SSB culture @ 5.0 lit ha^{-1} gave the highest cane yield and sugar yield compared to calcium silicate and SSB culture.The increased plant available Si in soil, sheath moisture content and Si uptake in the treatments of Si sources and SSB culture might havecontributed to cane yield. Du YH et al (2011) reported that major silicate fertilizers used widely in the world have disadvantages of their low solubility, suggesting that compound bio-fertilizer could dissolve silicate in soil significantly. Vijayapriya and Muthukkaruppan (2010) also reported bacterial isolate *Bacillus mucilaginosus* to have efficient ability of silicate solubilization. Vasanthi*et al.* (2012) studied the bacterium *Bacillus sp* isolated from sugarcane field and confirmed Mg, Ca, Si and Znsolubilization potential.

CONCLUSION

The extraction pool of plant available silicon was maximum by 0.5M CH_3COOH followed by 0.5M NH_4OAc and least by 0.01M $CaCl_2$ in sugarcane growing soils. The available Si content in soil increased with the pH, clay%, exchangeable cations and cation exchange capacity of the soil. Phosphate availability was found more in higher PA-Si containing soils. Application of bagasse ash (400 kg Si ha^{-1}) followed by calcium silicate along with silicate solubilizing bacterial culture @ 5.0 lit ha^{-1}significantly influenced available Si in soil, Si uptake, growth, cane and sugar yield of sugarcane.

Table 4
Natural incidence of sugarcane diseases in experimental plot

	Diseases Recorded								
	Whip Smut		Grassy Shoot		PokkahBoeng		Rust		Mosaic
Sources of Silicon	% DI	DR	% DI	DR	% DI	DR	% DI	DR	DI
Control	0.0	A	0.0	A	0.0	A	0.0	A	P (m)
Bagasse Ash	0.0	A	2.90	P	0.0	A	0.0	A	P (m)
Fly Ash	0.0	A	0.0	A	0.0	A	0.0	A	P (m)
Pond Ash	0.0	A	2.77	P	0.0	A	0.0	A	P (m)
Calcium Silicate	0.0	A	0.0	A	0.0	A	0.0	A	P (m)
2.5% K_2SiO_3 Spray	0.0	A	3.33	P	0.0	A	0.0	A	P (m)

Where, A: Absent, P- Present, P (m): Present in mild stage , % DI – Mean % disease incidence

Table 5
Effect of Si Sources and Silicate solubilizing bacterial (SSB) culture on PA–Si in soil, Si uptake, cane and sugar yield.

Treatments	*Plant available Si (mg kg^{-1})*						
	At Earthing up	*At harvest*	*Sheath moisture at 120 DAP (%)*	*Si Uptake (kgha^{-1})*	*Cane Yield (t ha^{-1})*	*CCS Yield (t ha^{-1})*	*C : B ratio*
Main Treatments: Sources of Si							
S_1 Control	207.05	199.97	81.12	560.33	118.96	17.37	3.35
S_2Ca – silicate	307.14	276.00	82.59	755.54	125.57	18.55	2.74
S_3 Bagasse ash	306.95	273.61	82.91	829.51	141.33	20.36	3.82
SE ± CD at 5%	3.209.86	2.658.15	0.130.38	14.0455.00	1.564.79	0.200.63	0.0330.10
Sub Treatments: Silicate Solubilizing bacterial culture (lit. ha^{-1})							
M_1 Control	266.47	245.73	81.44	663.21	125.11	18.17	3.23
M_2 SSB @ 2.5 lit.	276.38	247.06	82.14	687.70	129.57	18.94	3.32
M_3 SSB @ 3.75 lit.	269.93	248.33	82.33	722.92	129.37	18.96	3.32
M_4SSB @ 5.0 lit.	282.08	258.32	82.93	786.68	130.45	18.99	3.34
SE ± CD at 5%	4.707.68	2.978.41	0.150.45	13.4339.81	1.173.32	0.210.60	0.030.08
Interaction effects: Sources of Si X Silicate solubilizing bacterial culture							
S_1: Without Si source							
M_1Control	194.91	189.25	80.04	447.86	114.74	17.04	3.25
M_2 SSB @ 2.5 lit.	206.98	196.65	80.77	505.01	123.61	18.16	3.45
M_3 SSB @ 3.75 lit.	208.91	201.33	81.56	565.67	118.54	17.61	3.34
M_4SSB @ 5.0 lit.	217.41	212.66	82.11	722.75	118.96	16.7	3.35
S_2: Calcium silicate							
M_1Control	300.88	272.24	82.15	727.43	122.23	17.66	2.68
M_2 SSB @ 2.5 lit.	312.91	274.02	82.57	733.72	125.07	18.60	2.72
M_3 SSB @ 3.75 lit.	294.52	267.84	82.57	771.12	126.95	18.83	2.77
M_4SSB @ 5.0 lit.	320.25	289.89	83.07	789.91	128.06	19.11	2.78
S_3: Bagasse Ash							
M_1Control	303.61	275.7	82.13	814.33	138.36	19.8	3.75
M_2 SSB @ 2.5 lit.	309.25	270.51	83.07	824.35	140.03	20.05	3.78
M_3 SSB @ 3.75 lit.	306.36	275.83	82.84	831.97	142.63	20.44	3.85
M_4SSB @ 5.0 lit.	308.59	272.41	83.60	847.38	144.33	21.17	3.90
SE ±	5.19	5.19	0.27	24.57	2.03	0.37	0.05
CD at 5%	NS	NS	NS	80.45	5.75	1.05	NS

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