



Effect of silicate solubilizing bacteria and fly ash on silicon uptake and yield of rice under lowland ecosystem

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Abstract: A field experiment was conducted in sandy loam soils of eastern farm, Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu, India to study the effect of silicon on yield and uptake of rice (var. BPT 5204) during *Kharif* season of 2010-11 by taking the treatment combinations based on graded levels of Fly Ash (FA), Silicate Solubilizing Bacteria (SSB) and Farm Yard Manure (FYM) at fixed fertilizer schedule. The experimental soil (0-15 cm) had pH 7.22; organic C 1.4 %; available Si 66.0 mg kg⁻¹; available N 266.0 kg ha⁻¹; available P 14.42 kg ha⁻¹ and available K 107.50 kg ha⁻¹. The results of graded levels of FA show that all the growth and yield attributes were significantly influenced by silicon uptake. The mean silicon uptake at panicle initiation, straw and grain at harvest varied from 53.8 - 98.7, 105.5 - 197.2 and 21.4- 62.3 kg ha⁻¹ respectively, in rice. Number of filled grains per panicle and grain yield displayed conspicuous relationships with content of Si in grains. The highest mean grain yield of 3622 kg ha⁻¹ was recorded by the addition of SSB+FYM followed by FYM (3530 kg ha⁻¹), SSB (3310 kg ha⁻¹) and control (3240 kg ha⁻¹). The combined application of 25 t ha⁻¹ FA with SSB+FYM was recorded the highest grain yield of 3710 kg ha⁻¹ which was 16.3 per cent more over yield of control. The results further show that 25 t ha⁻¹ FA and SSB+FYM have been proved to be superior treatments for best management of silicon in coastal loamy sand soils under irrigated rice ecosystem.

Keywords: Farm yard manure, Fly ash, Silicon and rice, Silicate solubilizing bacteria

INTRODUCTION

Although silicon (Si) is not considered an essential element for higher plants, it has been proven to be beneficial for the healthy growth and development of many plant species, particularly tropical graminaceous plants such as rice (Liang *et al.*, 2007). Total Si removed by rice grown in an Inceptisol varied from 205–611 kg Si ha⁻¹ (Narayanawamy 2009). Although Si fertilization is not a standard practice in India, the beneficial role for the application of Si in increasing the yield of rice was evident through several studies. Thermal power stations using pulverized coal as fuel and generating large quantities of ash as a by-product. The annual generation of fly ash is projected to exceed 185 million tonne per annum by 2014-15 in India (MOEFCC,2014). This cumbersome volume of fly ash occupies large area of land and possesses threat to environment. Hence, there is an urgent and imperative need to adapt technologies for gainful utilization and safe management of fly ash on sustainable basis. As the fly ash contains high amount of silicon, it was programmed to investigate the effect of fly ash with silicate solubilizing bacteria, farm yard manure on yield and uptake of rice.

MATERIALS AND METHODS

A field experiment was conducted in a field No. N1, eastern farm of Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu for rice (in *Kharif*), replicated thrice in a split plot design. The BPT 5204 for rice was taken as a test crop. The field was divided into four main plots and each main plot into five sub plots carrying the following treatments. The main plot treatments were M₁: Control; M₂: SSB @ 2 kg ha⁻¹; M₃: Farm Yard Manure @ 12.5 t ha⁻¹ and M₄: SSB + FYM and sub plots were graded levels of fly ash @ 0,25,50,75 and 100 t ha⁻¹. The initial physico-chemical properties of soil were analysed and characterization of fly ash was carried out for experimentation are mentioned in Table.1. The available Si (N NaOAc (pH 4.0) extractable Si) of experimental soil was low (66.0 mg Kg⁻¹). The fixed NPK recommendation made uniformly to all the plots based on soil test value with Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) module. The major yield limiting attributes *viz.*, number tillers per hill, number of productive tillers per hill and number of filled grains per panicles were recorded. Drymatter production at panicle initiation, straw and

grain yield were quantified. The samples from panicle initiation, grain and straw at harvest were collected and oven dried at 65°C for 72 hours and powdered in Wiley mill. These samples were analysed for content of Si colorimetrically after digestion with tri acid and dissolved with sodium carbonate (Nayar *et al.*, 1975). All the data were subjected to statistical analysis and relevant data for correlation following the standard procedures. Silicon uptake was calculated as following Nutrient uptake (kg ha^{-1}) = Nutrient content (%) \times Dry matter yield (kg ha^{-1}) / 100

RESULTS AND DISCUSSION

Yield attributes vs. yield: The tiller number per hill varied from 29.6 to 38.3. Among the imposed treatments SSB + FYM registered the highest number of tillers per hill (37.1) followed by FYM (34.8), SSB (33.8) and Control (32.3) (Table 2). The number of tillers per hill was positively correlated with straw yield ($r=0.47$) (Table 5). Among different levels, 50 t ha^{-1} of fly ash resulted higher number of tillers (38.34) followed by 75 t ha^{-1} (37.5) and 100 t ha^{-1} (35.3). The number of tillers produced by the addition of fly ash @ 100 t ha^{-1} with SSB and FYM was statistically at par with application of fly ash @ 50 t ha^{-1} with FYM which might be due to polymerization of excessively released silicic acid from fly ash on addition of SSB and FYM (Zhang *et al.*, 2008). Fly ash @ 50 t ha^{-1} with SSB and FYM based treatment recorded the highest tiller number (44.8) where as in terms of number of productive tillers FA @ 25 t ha^{-1} with SSB and FYM performed

Table 1. Initial characterization of experimental soil and schedule of activities of field experiments.

Particulars	Fly Ash	Field No. N1
Physical properties		
Bulk density (Mg m^{-3})	1.27	1.42
Particle density (Mg m^{-3})	1.99	2.19
Total porosity (%)	42.0	35.1
Maximum water holding capacity (%)	33.0	30.2
Water in air dry fly ash (%)	1.32	NA
Mechanical Composition Sand (%)	24.15	71.38
Silt (%)	62.25	10.41
Clay (%)	6.25	16.84
Soil Texture	sil	ls
Physicochemical properties		
pH _{1:2.5}	9.10	7.2
EC _{1:2.5} (dSm^{-1})	0.50	0.26
Cation Exchange Capacity (c mole(p^+)/ kg^{-1})	2.1	15.7
Organic Carbon (g kg^{-1})	0.11	1.4
Available Nitrogen	NA	266.0
(Alkaline permanganate N) (kg ha^{-1})		
Available Phosphorus (Olsen's P) (kg ha^{-1})	NA	33.0
Available Potassium ($\text{NH}_4\text{OAc K}$) (kg ha^{-1})	36.5*	107.50
Available Silicon (NaOAc pH4.0 Si) (mg kg^{-1})	215.	66.0

ls- loamy sand; sil-silty loam* in ppm; NA- Not Applicable

well. The present findings also supported the results obtained by Das *et al.*, (2013).

The trend of changes in the number of productive tillers per hill was almost similar to that of number of tillers per hill. The productive tillers increased significantly with an increase in levels of fly ash (Table 2). The recorded values did not show any particular trend with progress of crop growth, but mostly the productive tillers increased in all the main plot, sub plot and combinations. Among the different treatments, application of SSB+FYM recorded the highest productive tillers (21.6) followed by FYM alone (20.3), SSB (19.3) and control (18.8). Application of fly ash @ 25 t ha^{-1} with SSB+FYM showed its superiority in terms of productive tiller number (23.6) which might be due to initial deficit in supply of nutrients by slower mineralization of fly ash. The results were corroborated with the investigation of Zhang *et al.*, (2008).

The number of filled grains varied from 130.0 to 157.3 irrespective of treatments and progress of crop growth. SSB+FYM based treatments were comparable and superior to other treatments (157.3) followed by FYM (145.1) and SSB (139.8). Similar results were observed by Nwugo and Huerta (2008) which explained increased photosynthetic rate and translocation of carbohydrates by Si and adequate K supply for the development of reproductive organ and filling of storage tissues with photosynthetic products. The number of filled grains positively and significantly correlated with grain yield ($r = 0.85^{**}$) (Table 5).

Yield and Si uptake: An increase in grain yield from applied fly ash ranged from 3294-3710 kg ha^{-1} (Table 3) depending on the treatment as compared to control, no fly ash application (3104 kg ha^{-1}). The largest mean grain yield of 3622 kg ha^{-1} was recorded by the addition of SSB+FYM followed by FYM (3530 kg ha^{-1}), SSB (3310 kg ha^{-1}) and control (3240 kg ha^{-1}) (Table 3). The treatment received 25 t ha^{-1} fly ash with SSB+FYM recorded the highest grain yield (3710 kg ha^{-1}) which might be due to effective utilization of Si and K released from the applied fly ash in soil. The increased grain yield was in good agreement with the findings of Chandramani *et al.*, (2009).

The straw yield was varied from 3223 to 4997 kg ha^{-1} irrespective of treatments and progress of crop growth. Significant and positive correlation was observed in between applied doses of fly ash and dry matter produced at different growth stages of rice. Among main plot treatments, SSB + FYM registered higher straw yield (4410 kg ha^{-1}) followed by FYM (4023 kg ha^{-1}). Among the levels of fly ash, application of fly ash @ 25 t ha^{-1} recorded 4337 kg ha^{-1} of straw yield which was higher among the different levels of fly ash applied. Application of fly ash @ 25 t ha^{-1} of fly ash along with SSB+FYM showed its superiority over rest of the treatments (4997 kg ha^{-1}) (Table 3). The increase in yield of 8.35 per cent was reported by the application of fly ash alone. Increase in yield of 12.4

Table 2. Effect of graded levels of fly ash with /without SSB and FYM on number of tillers, productive tillers and filled grains.

Treatments	Number of Tillers hill ⁻¹					Number of Productive Tillers hill ⁻¹					Number of filled Grains per panicle							
	Levels of fly ash (t ha ⁻¹)					Levels of fly ash (t ha ⁻¹)					Levels of fly ash (t ha ⁻¹)							
	0	25	50	75	100	Mean	0	25	50	75	100	Mean	0	25	50	75	100	Mean
Control	29.6	30.2	33.5	34.7	33.8	32.3	18.2	19.6	19.1	18.7	18.5	18.8	113	141	134	132	130	130.0
SSB	29.8	31.7	36.6	36.3	34.4	33.8	18.5	20.8	20.2	19.2	18.04	19.3	125	152	146	141	136	139.8
FYM	30.2	31.7	38.3	39.3	34.7	34.8	19.06	21.9	20.8	20.09	19.4	20.3	136	156	152	143	138	145.1
SSB + FYM	30.5	32.5	44.8	39.6	38.3	37.1	20.09	23.6	22.5	21.1	20.8	21.6	141	178	169	155	144	157.3
Mean	30.05	31.6	38.34	37.5	35.3	34.5	18.9	21.4	20.6	19.77	19.18	20.0	128.75	156.5	150.25	142.75	137.12	143.05
		SED			CD(0.05)		SED			CD(0.05)			SED				CD(0.05)	
Factor (F)	0.073				0.23		0.034			0.110			3.181				10.125	
Level (L)	0.071				0.15		0.053			0.114			3.538				7.501	
F at L	0.15				0.35		0.10			0.23			7.084				16.53	
L at F	0.14				0.30		0.11			0.22			7.07				15.0	

Values are mean of three replications

Table 3. Effect of graded levels of fly ash with /without SSB and FYM on dry matter production (DMP) and yield (kg ha⁻¹) of rice.

Treatments	DMP at Panicle initiation (kg ha ⁻¹)					Straw (kg ha ⁻¹)					Grain (kg ha ⁻¹)							
	Levels of fly ash (t ha ⁻¹)					Levels of fly ash (t ha ⁻¹)					Levels of fly ash (t ha ⁻¹)							
	0	25	50	75	100	Mean	0	25	50	75	100	Mean	0	25	50	75	100	Mean
Control	2223	2938	2666	2495	2389	2502	3223	3523	3587	3510	3460	3460	3104	3294	3265	3265	3257	3240
SSB	2574	2984	2882	2848	2737	2805	3306	4036	3843	3651	3536	3674	3163	3380	3315	33150	3290	3310
FYM	2729	3210	3178	3124	2955	3040	3472	4792	4356	3780	3715	4023	3358	3620	3612	3563	3497	3530
SSB + FYM	2992	3710	3363	3240	3152	3291	3731	4997	4804	4356	4164	4410	3440	3710	3688	3654	3620	3622
Mean	2630	3160	3022	2926	2810	2810	3433	4337	4150	3824	3718	3266	3500	3482	3450	3416		
	SED				CD(0.05)		SED			CD(0.05)		SED			CD(0.05)			
Factor (F)	0.12				0.37		0.143			0.45		6.3			0.20			
Level (L)	0.09				0.21		0.07			0.14		1.6			0.034			
F at L	0.21				0.52		0.19			0.52		6.9			0.21			
L at F	0.19				0.42		0.14			0.29		3.3			0.07			

Values are mean of three replications

Table 4. Effect of graded levels of fly ash with /without SSB and FYM on silicon uptake* (kg ha^{-1}) of rice.

Treatments	At Panicle initiation										At Harvest										
	Levels of fly ash (t ha^{-1})					Mean	Levels of fly ash (t ha^{-1})					Mean	Levels of fly ash (t ha^{-1})					Mean			
	0	25	50	75	100		0	25	50	75	100		0	25	50	75	100				
Control	28.6	46.4	48.0	46.1	45.8	43.0	80.2	121.6	129.8	128.6	131.3	118.3	131.3	131.3	131.3	118.3	18.1	17.7	19.5	20.0	17.0
SSB	35.8	58.2	59.6	61.4	64.0	56.0	110.0	162.8	151.4	145.7	166.7	147.3	166.7	166.7	166.7	147.3	21.5	25.4	25.4	23.5	22.0
FYM	41.5	64.0	69.4	75.4	74.0	65.0	131.0	182.3	164.4	166.8	159.0	160.7	166.8	159.0	160.7	160.7	27.6	28.1	34.5	29.0	27.0
SSB + FYM	55.6	79.3	76.3	82.7	85.5	76.0	153.6	203.6	187.1	192.0	202.2	195.2	192.0	202.2	195.2	195.2	32.7	35.1	35.1	38.7	31.7
Mean	40.3	62.0	63.4	66.4	67.3	60	118.7	177.1	158.2	158.3	164.8	155.4	164.8	164.8	155.4	155.4	25.0	26.6	28.6	27.8	24.4
Factor (F)	1.0				3.1			2.1			6.5						0.54			1.73	
Level (L)	0.4				0.9			1.0			2.0						0.56			1.18	
F at L	1.2				3.4			2.6			7.3						1.14			2.70	
L at F	0.8				1.7			1.8			4.0						0.12			2.40	

Values are mean of three replications

and 22.1 per cent registered which might be due to low Si status and effective utilization of Si released from the applied fly ash in soil. Similar results were observed in findings of Das *et al.*, (2013). Among levels of fly ash, application of 25 t ha^{-1} of fly ash recorded maximum straw yield as explained in earlier findings of Karmakar *et al.*, (2010).

The results suggested that the highest Si uptake was observed in straw (149.5 kg ha^{-1}) followed by plant at panicle initiation (76.28 kg ha^{-1}) and grain (39.42 kg ha^{-1}). In grain, the uptake of Si ranged from 21.4 to 62.3 kg ha^{-1} . Among the different main treatments, SSB + FYM recorded the highest mean uptake of 49.4 kg ha^{-1} followed by FYM (42.8 kg ha^{-1}), SSB (34.6 kg ha^{-1}). Application of fly ash @ 100 t ha^{-1} with SSB + FYM registered the highest grain uptake of 62.3 kg ha^{-1} . However, it was statistically at par with application of fly ash @ 25 t ha^{-1} along with SSB + FYM. The trend of changes in straw Si uptake was similar to grain. Among the different main treatments the highest mean Si uptake of 178.6 kg ha^{-1} was registered by the addition of SSB + FYM followed by FYM (157.5 kg ha^{-1}), SSB (140.3 kg ha^{-1}) and control (121.6 kg ha^{-1}) (Table 5). Among the graded levels of fly ash, the highest mean uptake of 164.6 kg ha^{-1} was recorded by the addition of 25 t ha^{-1} of fly ash. Though the application of 50 t ha^{-1} recorded the highest straw uptake which was statistically at par with 25 t ha^{-1} with SSB and FYM (197.2 kg ha^{-1}). It is suggested that rice straw should contain 34 g kg^{-1} of Si for optimum yield production (Richard *et al.*, 2013). Simple correlation matrix (Table 5) indicated that silicon uptake has been found to be significantly correlated with grain yield and yield attributes of rice. It is vivid that the uptake was due to increased dry matter production and content of Si. It was accelerated with advancement of growth stages. The uptake of Si in straw was greater than grain in contrast to the rest of the nutrients.

Conclusion

It was concluded that in sandy loam soil, the growth and yield attributes viz., plant height, number of tillers and numbers of filled grains were increased by the addition of 25 t ha^{-1} fly ash with SSB+FYM. The highest yield of grain and straw was recorded by the addition of 25 t ha^{-1} fly ash with SSB+FYM. The increase in graded levels of fly ash significantly increased Si content in straw and grain. The maximum Si content was observed by application of fly ash @ 100 t ha^{-1} with SSB + FYM. The uptake of Si was accelerated with advancement of growth stages. The application of fly ash @ 25 t ha^{-1} with SSB + FYM registered maximum uptake of Si. Similar to the content of Si in straw, the uptake of Si in straw was also greater than grain. From the experiment application of 25 t ha^{-1} fly ash with SSB+FYM proved to be superior treatment in improving yield attributes and yield in rice. It can be taken up as the best alternative

Table 5. Simple correlation matrix showing the relationship of silicon uptake at different growth stages of rice with grain yield

Parameter	No. of productive tillers	Number of filled grains	Si at PIS	Si at straw HS	Si at grain HS	Grain yield
No. of productive tillers	1					
Number of filled grains	0.92**	1				
Si uptake at PI	0.69*	0.74**	1			
Si at straw	0.79*	0.84**	0.94**	1		
Si at grain	0.69*	0.72*	0.96**	0.89**	1	
Grain yield	0.87**	0.85**	0.89*	0.90**	0.87**	1

* Significant at the 0.05 probability level and ** significant at the 0.01 probability level.

for the effective replenishment of silicon in intensively rice growing soils.

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