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Economic potential of silicon sources for sustainable rice production

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Abstract
The application of silicon through various sources has been in practice as a major component of integrated nutrient management for sustainable rice production. The beneficial effects of silicon fertilization on rice production has been described and quantified in numerous literature citations. The present investigation was carried out at Division of Soil Science and Agricultural Chemistry, College of Agriculture Kolhapur, India, to study the economic potential of silicon sources for sustainable rice production. The rice husk ash (RHA) and bagasse ash (BA) were used as source of silicon. The experiment was carried out in randomized block design consist of four levels of silicon (Si) *viz.* 0, 250, 500 and 750 kg Si ha^{-1} which were supplied through rice husk ash and bagasse ash. The plant height (cm), number of tillers hill^{-1}, thousand grains weight (g) and dry matter hill^{-1} (g) of rice increased significantly due to application of silicon. The application of silicon through bagasse ash @ 250 kg ha^{-1} was found optimum for increase in the grain yield (49.66 q ha^{-1}) and straw yield (53.84 q ha^{-1}) of rice. The nitrogen, phosphorus, potassium and silicon uptake of rice increased significantly due to application of silicon through rice husk ash and bagasse ash. The highest benefit-cost ratio (1.52) was recorded with application of silicon @ 250 kg ha^{-1} through bagasse ash.

Keywords: economic potential, silicon, rice husk ash, bagasse ash, rice, yield

Introduction
Rice cultivation is the principal activity and source of income for about 100 million households in Asia and Africa. Rice is the principal food crop grown right from historic days. This unique grain helps to sustain two-thirds of the world's population. About four-fifths of the world's rice is produced by small-scale farmers and is consumed locally. Rice is the staple food for more than 50% of the population in Asia and South Asia alone, the figure is around 70% (Bishwajit *et al*., 2013) [3]. Silicon application has been in practice as a component of balanced integrated nutrient management for sustained rice productivity. Rice is a known silicon accumulator and it was estimated that a rice crop giving 5 tonnes ha^{-1} grain yields removed on an average 230-270 kg Si ha^{-1} from soil (Nayar *et al.*, 1982) [7]. The total area under rice cultivation in India is 42.75 million hectares with annual production of 105.24 million tonnes and productivity of 2462 kg ha^{-1}. In Maharashtra state rice is cultivated over an area of 1.56 million hectares with an annual production of about 3.06 million tonnes and productivity of 1963 kg ha^{-1} (Anonymous, 2014) [2]. Rice is having the ability to absorb and accumulate silicon metabolically while many upland crop plants seem to lack such ability. A rice crop producing 5 t ha^{-1} grain yields in a lateritic soil of India has been found to remove 468 kg Si ha^{-1} (Sahu, 1990) [11]. Rice and sugarcane are best example of silicon accumulating crops. The crop residues like rice husk ash and bagasse ash are used as silicon source. The rice husk ash is already being used in rice nurseries and main fields in different parts of southern India. Likewise bagasse ash which is one of the organic wastes obtained from sugar industries may be used as silicon source. Due to higher cost, the use of silicon fertilizers either in the form of soluble silicates or calcium silicate slags is still very restricted in Indian agriculture. The easily available rice husk ash and bagasse ash may prove to be the cheapest silicon source for rice cultivation. The present study was undertaken to investigate the economic potential of silicon sources for sustainable rice production.

Materials and Methods
Experimental location, soil and treatments
The field experiment was conducted with test crop rice (*Cv*. Indrayani) on soil order Inceptisol at Agronomy Farm, College of Agriculture Kolhapur, India during *Kharif* season of 2012. The initial soil properties are presented in table 1. The statistical design was randomized block design with four replications.

The treatments consisted of four levels of silicon (Si) *viz.*, 0, 250, 500 and 750 kg Si ha^{-1} which were supplied through rice husk ash (RHA) and bagasse ash (BA). The treatment details are given in table 2.

Table 1: Initial chemical properties of experimental soil

Parameter	Value
pH (1:2.5)	7.50
EC (dS m^{-1})	0.20
Organic carbon (%)	0.80
Available nitrogen (kg ha^{-1})	272.00
Available phosphorous (kg ha^{-1})	20.82
Available potassium (kg ha^{-1})	212.41
Available silica (kg ha^{-1})	210.56
DTPA extractable micronutrient	
Fe (ppm)	4.62
Mn (ppm)	1.46
Zn (ppm)	1.62
Cu (ppm)	1.48

Table 2: Treatment details with sources and levels of silicon

Treatments	Source of silicon	Silicon content (%)	Levels (kg ha^{-1})	Quantity of source applied (kg ha^{-1})
T_1 (Control)	Control	-	-	-
T_2 (RHA @ 250)	Rice husk ash	34.2	250	731
T_3 (RHA @ 500)	-	-	500	1462
T_4 (RHA @ 750)	-	-	750	2193
T_5 (BA @ 250)	Bagasse ash	27.9	250	896
T_6 (BA @ 500)	-	-	500	1792
T_7 (BA @ 750)	-	-	750	2688

(Note: RHA-Rice husk ash and BA-Bagasse ash)

Extraction and estimation of silicon

The plant available silicon (PAS) from soil samples was extracted and estimated as per methods given by Fox *et al.* (1967) [4] and Korndorfer *et al.* (2001), respectively. The digestion of rice plant samples and estimation of silicon from them was done as per procedure given by Nayar *et al.* (1975) [6].

Statistical analysis

The experimental data were analyzed statistically by applying the technique of analysis of variance and significance was tested by variance ratio *i.e.* F value at 5 per cent level of significance as described by Panse and Sukhatme (1967) [8]. The standard error of mean (SE) and critical difference (CD) was worked out to evaluate differences between treatment means.

Gross monetary returns, cost of cultivation, net monetary returns and B:C ratio

On the basis of result obtained from the field experiment, the economics of various treatments was worked out. The gross monetary returns per hectare were calculated on the basis of grain and straw yield from each respective treatment. The prevailing market price for grain and straw yield were considered. The cost of cultivation of crop under individual treatment was worked out by taking into account the cost of all inputs. The net monetary returns were worked out by subtracting cost of cultivation from gross monetary of individual treatment and the benefit-cost (B:C) ratio was worked out by dividing gross monetary returns ha^{-1} with cost of cultivation ha^{-1}.

Results and Discussion

Effect of silicon on growth and yield of rice

The growth and yield attributes *viz.*, plant height (cm), number of tillers $hill^{-1}$, thousand grains weight (g) and dry matter $hill^{-1}$ (g) of rice were increased significantly due to silicon application through different sources (Table 3). The results revealed that the application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) recorded significantly highest plant height (76.82 cm) but it was at par with T_4, T_5 and T_6. The application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) recorded significantly highest number of tillers $hill^{-1}$ (12.35), but it was at par with all other treatments except control (T_1). The thousand grains weight was significantly increased with application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (22.60 g). However, it was at par with all treatments except T_1 and T_2. The dry matter $hill^{-1}$ at harvest was significantly increased with application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (24.68 g), but it was at par with application of silicon @ 500 kg ha^{-1} through bagasse ash (T_6). The grain and straw yield of rice was increased significantly with silicon application. The application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) recorded significantly highest grain yield (49.82 q ha^{-1}) and straw yield (54.20 q ha^{-1}). However, it was at par with all the treatments (up to lowest dose of silicon @ 250 kg ha^{-1} through rice husk ash and bagasse ash) except control (T_1). The increase in grain and straw yield might be attributed to increased rate of photosynthesis due to leaf erectness, reduction in percent spikelet sterility, increased number of productive tillers and reduction of incidence of insect pests and diseases. The crop grows vigorously and utilized the nutrient and moisture from soil which are turn into the economic yield of rice (Patil *et al.*, 2017) [9]. These results are in confirmative with those reported by Wader *et al.* (2013) [14], Aarekar (2014) [1] and Patil *et al.* (2015) [10].

Table 3: Effect of silicon sources and levels of silicon on growth and yield of rice

Treatments	Plant height (cm)	No. of tillers $hill^{-1}$	1000 grains wt. (g)	Dry matter $hill^{-1}$ (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
T_1 (Control)	68.14	10.96	20.50	22.01	41.21	46.25
T_2 (RHA @ 250)	73.12	11.82	21.21	23.68	47.43	51.50
T_3 (RHA @ 500)	73.24	12.27	22.15	23.52	48.66	52.50
T_4 (RHA @ 750)	75.23	12.30	22.50	23.59	49.12	53.60
T_5 (BA @ 250)	75.39	11.86	22.20	23.91	49.66	53.84
T_6 (BA @ 500)	75.84	12.23	22.47	24.53	49.56	53.60
T_7 (BA @ 750)	76.82	12.35	22.60	24.68	49.82	54.20
S.E. $\pm$	0.90	0.32	0.40	0.25	1.42	1.68
C.D. (P=0.05)	2.60	0.98	1.28	0.75	4.23	5.04

Effect of silicon on uptake of nitrogen, phosphorus and potassium

The nutrient uptake at harvest by rice increased significantly due to the application of silicon through sources *viz.*, rice husk ash and bagasse ash (Table 4). The significantly highest uptake of nitrogen was recorded in application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (83.75 kg ha^{-1}) and it was at par with treatment T_6. The uptake of phosphorus at harvest by rice increased significantly due to silicon application. The significantly highest total uptake of phosphorus was found with application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (20.83 kg ha^{-1}) and it was at par with treatment T_6. The highest uptake of potassium at harvest by rice was found in application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (83.49 kg ha^{-1}), however it was at par with other treatments except control (T_1). The better crop stand, probable root growth, synergistic effect of silicon and favourable physical environment created on account of addition of rice husk ash and bagasse ash to the soil would have facilitated better absorption of nutrients by rice. The increase in uptake of nitrogen, phosphorus and potassium due to application of silicon were reported by Singh *et al.* (2006) [13], Wader *et al*. (2013) [14] and Aarekar (2014) [1].

Silicon uptake of rice

The silicon uptake at harvest by rice increased significantly with levels of silicon (Table 4). The highest uptake of silicon at harvest was recorded in application of silicon @ 750 kg ha^{-1} through bagasse ash (T_7) (262.40 kg ha^{-1}) and it was at par with application of silicon @ 500 kg ha^{-1} through bagasse ash (T_6) (251.20 kg ha^{-1}). The increase in uptake of silicon might be due to increase availability of silicon with supply of silicon through both the sources of silicon and its luxury consumption. The similar findings were also reported by Singh *et al*. (2006) [13], Wader *et al*. (2013) [14], Aarekar (2014) [1] and Patil *et al.* (2015) [10].

Table 4: Effect of silicon sources and levels of silicon on nutrient uptake of rice

Treatments	Nutrient uptake (kg ha^{-1})			
	N	P	K	Si
T_1 (Control)	60.53	13.20	68.80	179.42
T_2 (RHA @ 250)	73.10	16.55	77.68	198.74
T_3 (RHA @ 500)	76.54	18.48	81.97	210.38
T_4 (RHA @ 750)	78.97	19.29	82.77	224.00
T_5 (BA @ 250)	78.33	18.10	83.29	227.62
T_6 (BA @ 500)	81.34	19.77	83.46	251.20
T_7 (BA @ 750)	83.75	20.83	83.49	262.40
S.E. ±	1.46	0.43	2.3	3.86
C.D. (P=0.05)	4.34	1.28	6.9	11.48

Effect of sources and levels of silicon on economics of rice

The data in respect of gross monetary returns, cost of cultivation, net monetary returns and benefit-cost (B: C) ratio are presented in table 5. The significantly highest gross monetary returns were obtained in treatment T_7 (36.44 thousand Rs. ha^{-1}) however, it was at par with treatments T_6, T_5, and T_4. The cost of rice cultivation was significantly highest in treatment T_4 (24.10 thousand Rs. ha^{-1}) however, it was at par with all other treatments except control (T_1). The net monetary returns obtained from rice cultivation were found to increase with sources and levels of silicon application. The significantly highest net monetary returns was observed in the treatment T_5 (12.47 thousand Rs. ha^{-1}) but it was at par with other treatments except T_1 (control), T_2 and T_3. The significantly highest B:C ratio (1.52) was recorded in treatment T_5 (BA @ 250 kg ha^{-1}). Hence considering availability and benefit-cost ratio, the bagasse ash @ 250 kg ha^{-1} may prove as a good source of silicon for increasing the growth, yield and nutrient uptake of rice. Similar benefits of silicon application to rice were reported by Singh *et al.* (2005) [12] and Wader (2012) [15].

Table 5: Economics of rice as influenced by sources and levels of silicon application

Treatments	Gross monetary returns ('000' Rs. ha^{-1})	Cost of cultivation ('000' Rs. ha^{-1})	Net monetary returns ('000' Rs. ha^{-1})	B:C ratio
T_1 (Control)	30.49	21.72	8.77	1.40
T_2 (RHA @ 250)	34.63	23.20	11.43	1.49
T_3 (RHA @ 500)	35.21	23.98	11.23	1.46
T_4 (RHA @ 750)	35.74	24.10	11.64	1.48
T_5 (BA @ 250)	36.03	23.56	12.47	1.52
T_6 (BA @ 500)	36.06	23.90	12.16	1.50
T_7 (BA @ 750)	36.44	24.00	12.44	1.51
S.E. ±	0.30	0.34	0.33	-
C.D. (P=0.05)	0.89	1.01	0.98	-

Conclusion

The application of bagasse ash as a source of silicon @ 250 kg ha^{-1} was found beneficial and optimum for increase in the growth, yield and nutrient uptake of rice. The present study proves the importance of silicon in enhancing the yield potential as well as economics of rice.

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