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Effect of Different Sources of Silicon on the Growth, Yield and Si Uptake in Aerobic Rice

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to study the different sources of silicon (Si) on plant growth and yield. The experiment was laid in randomized complete design (RCBD) with four treatments and four replications. The experiment results revealed that There was an increase in plant height and the number of tillers plant^{-1} with the application of different sources of Si over RDF (T_1). At harvest RHB @ 4 t ha^{-1} recorded significantly higher plant height (106.05±1.23 cm) and the number of tillers hill^{-1} (15.25±2.75). Yield attributes like number of panicles hill^{-1} (13.23±0.49), Panicle length 23.43±0.29 cm), test weight (23.55±0.05 g), straw (7.15±0.59 t ha^{-1}), grain (3.60±0.16 t ha^{-1}) and total biomass yield (10. 75±1.01 t ha^{-1}) was recorded in treatment receiving SA @ 4 mL L^{-1} (T3). Whereas, higher Si content and uptake in both straw and grain was significantly higher in the recorded in the with the application of the RHB @ 4 t ha^{-1}. Thus, combined application of external Si sources and along with recommended dose of fertilizers found to increase the growth, yield and Si uptake in aerobic rice.

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Keywords: Silicon; rice; diatomaceous earth; silicic acid; rice husk biochar.

1. INTRODUCTION

In Karnataka, rice is grown in an area of 1.19 mha with an annual production of 3011 kg ha^{-1} [1]. Rice cultivation is the most water consuming system and utilizes about 60% of total available irrigation water. Aerobic rice system in a new term given by International Rice Research Institute (IRRI) for drought-tolerant, input-responsive, lodging-resistant and weed-competitive rice varieties grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil, which is responsive to nutrient supply, can be rainfed or irrigated and tolerates (occasional) flooding [2]. Maximization of aerobic rice yield could be achieved by the balanced use of fertilizers particularly major nutrients *viz*., nitrogen (N), phosphorus (P) and potassium (K) in optimum quantity. However, various abiotic and biotic factors are the main challenges and threats to aerobic rice production. Inclusion of the silicon (Si) fertilizers along with the recommended dose of fertilizers (RDF) will not only increase the production and productivity of aerobic rice [3-4] but also resistance to abiotic and biotic stress [5]. Hence, a field experiment was conducted with three different sources of Si to evaluate its effect on yield and uptake.

Rice is a typical Si accumulator plant that accumulates up to 10% Si their aboveground biomass more than the major nutrients [6]. Most of the traditional rice fields are deficient in plant-available Si (PASi) [7]. Although various Si fertilizers have been reported for the higher growth and yield in crops such as diatomaceous earth [7], silicic acid [8], $CaSiO_3$ [4] and rice husk biochar [9].

However, the comparative study of different sources of Si on aerobic rice is lacking. In this context, a comparative study of these Si sources on the growth, yield and Si uptake in aerobic rice was taken.

2. MATERIALS AND METHODS

A field experiment was conducted at C- Block, ZARS, V. C. Farm, Mandya during *Summer*, 2018. The latitude, longitude and altitude of Mandya is 19° N, 76°E, 695 m above MSL respectively. The soil of experimental soil is neutral in reaction with sandy loam in texture. Acetic acid and calcium chloride extractable silicon were medium in range. Available nitrogen and potassium content of the soil is medium in range whereas available phosphorus is very high. Secondary and micronutrient is higher than the critical limit (Table 1).

The experiment was carried out following randomized complete block design (RCBD) with four treatments and four replications. The source of Si used in this study was concentrated soluble silicic acid (SA), diatomaceous earth (DE) and rice husk biochar (RHB). The composition of DE and RHB is presented in Table 2 and concentrated soluble silicic acid (SA), obtained from ReXil Agro BV, Chennai, India, which contains 2 per cent Si as soluble H_4SiO_4 (Table 3). The entire dose of P and K were applied as per the treatments and N was applied in two split doses. The entire dose of DE and RHB was applied as basal before sowing whereas the SA was sprayed at 15 days of interval.

Treatment details:

T_1: RDF alone
T_2: T_1+ DE @ 300 kg ha^{-1},
T_3: T_1 + SA @ 4 mL L^{-1} and
T_4: T_1 + RHB @ 4 t ha^{-1}

Note: RDF- Recommended Dose of Fertilizers
DE- Diatomaceous earth
SA – Silicic Acid
RHB – Rice Husk Biochar

Five plants were randomly labelled and recorded for plant height and number of tillers at 30, 60, 90 DAT and at harvest. The height was measured from the base of the fully opened leaf or tip of the panicle, whichever is the longest. Mean of the height and tillers recorded from five plants were reported. The SPAD value and photosynthetic characteristics were measured with a SPAD-502 chlorophyll meter (Minolta, Osaka, Japan). The upper third of the rice flag leaves was used to measure the SPAD value at 60 and 90 DAS. Grains and straw yield from the corresponding net plot was sundried and the weight of grain and straw per net plot was computed and then expressed as ton per hectare.

Grain and straw samples were collected from the field after the harvest of the crop and washed with deionised water and were dried in an oven at 70 ℃, powdered and analysed for Si content (Ma and Takahashi, 2002). The Si uptake by the crop was computed using Si content and expressed as kg ha^{-1} using the following formula.

$$\text{Si uptake (kg ha}^{-1}) = (\text{Si content (\%) x biomass (kg ha}^{-1})/100$$

Data obtained were analysed using one way ANOVA at a 5 per cent level of significance as per the procedure outlined by [10]. Pearson's correlation and regression analysis was computed using MS-excel and SPSS 20.0.

Table 1. Physico-chemical properties of soil of V. C. Farm, Mandya

Parameter		Content
pH (1:2.5 water)		7.1
EC (dSm^{-1}) (1:2.5 water)		0.22
Organic carbon (g kg^{-1})		11.70
Particle size distribution (%)	Sand	76.54
	Silt	6.56
	Clay	16.90
Textural class		Sandy loam
0.01M $CaCl_2$ – Si (mg kg^{-1})		41.98
0.5M Acetic acid – Si (mg kg^{-1})		73.82
Available N (kg ha^{-1})		340.48
Available P_2O_5 (kg ha^{-1})		230.31
Available K_2O (kg ha^{-1})		348.09
Exch.Ca (c mol (p$^+$) kg^{-1})		4.75
Exch. Mg (c mol (p$^+$) kg^{-1})		2.25
Micronutrients (mg kg^{-1})		
Zn		3.18
Mn		20.40
Fe		89.52
Cu		3.75

Table 2. Composition of diatomaceous earth (DE) and rice husk biochar (RHB)

Properties	DE	RHB
pH (1:2.5 water)	9.21	7.39
EC (dSm^{-1}) (1:2.5 water)	0.72	1.62
Cation exchange capacity (c mol (p$^+$) kg^{-1})	52.00	38.63
Nutrient		
N	0.03	0.78
P	0.02	0.24
K	0.40	0.96
Si	30.00	31.00
Ca	2.70	0.36
Mg	3.25	0.31
S	0.17	0.05
Al_2O_3	15.30	n.d
Mg kg^{-1}		
Fe	2.00	0.08
Mn	0.02	0.055
B	6.00	8.36
Zn	19.00	63.00
Cu	20.00	31.00
Mo	0.10	n.d
Se	1.30	n.d
Cd	0.50	n.d

DE – Diatomite; RHB – Rice hush biochars n.d – not determined

Table 3. Composition and pH of foliar silicic acid material

Composition	Content (%)
Si as soluble H_4SiO_4 (%)	2.0
K as KCl (%)	1.2
B as H_3BO_3 (%)	0.8
HCl (%)	1.0
Demiwater (%)	47.00
PEG^{*}_{400} (%)	48.00
pH	
pH of raw material	0.88
pH of 4 ml L^{-1} solution	6.00

**PEG- Poly ethylene glycol*

3. RESULTS AND DISCUSSION

3.1 Plant Height and Number of Tillers Hill^{-1}

There was a significant ($p < 0.05$) improvement was observed on plant height with the application of DE @ 300 kg ha^{-1} (T_2), SA @ 4 mL L^{-1} (T_3) and RHB @ 4 t ha^{-1} (T_4) over RDF alone (T_1) at 30, 60, 90 DAS and at harvest (Table 4). Application of RHB @ 4 t ha^{-1} (11.66±0.55 cm) recorded significantly ($p<0.05$) higher plant height at 30 DAS whereas, DE @ 300 kg ha^{-1} (10.82±0.74 cm) showed on par results with the application of RHB @ 4 t ha^{-1} and SA @ 4 mL L^{-1} (10.04±0.13 cm) which was on par with the RDF (T_1) (9.18±0.51 cm). However, the effect of plant height at 60 and 90 DAS was recorded statistically similar among treatment receiving DE @ 300 kg ha^{-1}, SA @ 4 mL L^{-1} and RHB @ 4 t ha^{-1}. Treatment receiving RHB @ 4 t ha^{-1} (106.05±1.23 cm) and DE @ 300 kg ha^{-1} (104.80±3.68 cm) recorded significantly similar results whereas, SA @ 4 mL L^{-1} (101.75±2.68) was recorded statistically, on par with the RDF (T_1). The data presented in the Table 5 showed that treatments receiving external sources of silica *i.e.,* DE @ 300 kg ha^{-1} (T_2), SA @ 4 mL L^{-1}(T_3) and RHB @ 4 t ha^{-1} (T_4) were recorded significantly ($p<0.05$) higher number of tillers at 60, 90 DAS and at harvest over the RDF (T_1). At 60 DAS application of DE @ 300 kg ha^{-1} (T_2), SA @ 4 mL L^{-1}(T_3) and RHB @ 4 t ha^{-1} (T_4) recorded statistically similar results (8.10±0.42, 8.15±0.97 and 8.20±0.63, respectively). At 90 DAS highest no of tillers was recorded in treatment receiving SA @ 4 mL L^{-1} (11.70±1.45) and the remaining treatments were on par with each other. However, application of DE @ 300 kg ha^{-1} (T_2), and RHB @ 4 t ha^{-1} (T_4) recorded significantly ($p<0.05$) higher no of tillers (14.00±2.18 and 15.25±2.75, respectively) at harvest.

There was no definite trend in the increase of plant height and number of tillers with the application of different sources of silicon. There was an increase in the plant height and number of tillers per plant with the application of silicon sources over RDF (T_1). This can be attributed to a sufficient supply of nutrients and the beneficial effect of silicon released from the different silicon sources and thereby improvements in the nutrient use efficiency by crop. Rice husk biochar might have had a higher advantage due to its substantially higher amount of Si content (Table 2).

Si application makes the leaves and stems more erect, thus reducing self-shading and increasing photosynthesis rate, which contributes to an increase in plant height [11]. The beneficial effect of Si on the rice plant height and number of tillers are well known which has been reported by several others like Malav et al. [12], Swe et al. [13] and Cuong et al. [14] in rice [12-14]. Absorbed silicon is located in the leaf area in rice and this decreased the cuticle transpiration and decreases plant elongation [15]. Silicon improved plant height, inter-node length and fresh weight in rice [16]. A similar review was presented by Mauad et al. [17] and Singh et al. [18] for rice crops and reported an increase in the number of tillers due to the application of silicon [17-18].

3.2 SPAD Values

The addition of different sources of silicon caused a significant increase in SPAD values over RDF (T_1) in 60 and 90 DAS (Table 5). Application of SA @ 4 mL L^{-1} (50.8±5.41) recorded significantly ($p<0.05$) higher SPAD value at 60 DAS whereas, RHB @ 4 t ha^{-1} (45.1±4.85) showed on par results with the application of DE @ 300 kg ha^{-1} (47.0±6.57). At 90 DAS, SA @ 4 mL L^{-1} (42.8±1.10) recorded significantly higher SPAD value followed by RHB

@ 4 t ha^{-1} (40.7±2.31). Application of DE @ 300 kg ha^{-1} (36.7±2.37) recorded on par with the RDF (T_1) (38.5±2.33). Sivaranjani et al., [19] reported increase in SPAD reading with the application of silicic acid [19]. Simiarly song et al. [20], Haddad et al. [21] and Yogendra et al. [4] Increase in SPAD value and chlorophyll content by silicon fertilizers application over RDF (T_1) [4,20-21]. Rani and Narayanan [22] reported that higher SPAD value with the application of Si along with the N could be due to higher photosynthetic activity, better utilization of light and translocation of assimilated product to sink [22].

3.3 Yield Attributes

The yield attributes were increased with the application of different sources of Si along with the RDF (Table 6). The yield attributes like number of panicles per hill, panicle length, test weight, straw, grain and total biomass yield were recorded lower in the treatment receiving RDF alone (T_1). RHB @ 4 t ha^{-1} (14.23±0.49) recorded number of panicles per hill, whereas, higher panicle length (23.82±0.39 cm) and test weight (23.55±0.05 g) were in treatment receiving SA @ 4 mL L^{-1} (T_3).

The straw yield was recorded significantly ($p<0.05$) higher with the application of SA @ 4 mL L^{-1} (7.15±0.59 t ha^{-1}) whereas DE @ 300 kg ha^{-1} (6.60±0.61 t ha^{-1}), and RHB @ 4 t ha^{-1} (6.45±0.19 t ha^{-1}) are on par with each other but significantly ($p<0.05$) higher compared to RDF (5.90±0.58 t ha^{-1}). The total biomass yield followed the same trend as the straw yield. Application of Si sources recorded an empirical increase in the grain yield but statistically on par with the RDF (T_1) (Table 6).

The increase in the crop growth and yield attributes due to the external supply of Si in the present study are in agreement with several other workers. Accumulation of Si in the rice plant reduces the transpiration rate, thus increasing water use efficiency by the crop and improving the dry matter production [23]. The Si deposited on the leaf surface forms a protective barrier against invasion of pests and diseases as well as prevention of water losses through transpiration, imparting drought resistance [24]. Application of foliar silicic acid increased soybean yield by providing Si directly to the foliage [8]. These cumulative effects of Si on rice might have contributed to enhanced rice yield in the study. The beneficial effects of Si application *viz*., reducing mutual shading by improving leaf erectness, decreasing susceptibility to lodging, decreased incidence of abiotic and biotic stresses, improving structural support and biomass [25] and improving nutrient uptake [26]. Chen et al. [27] stated that silicon application increased grain yield by an increase in spikelet number, filled spikelet percentage and 1000-seed weight [27]. Gong et al. [28] reported foliar application of nano-silica fertilisers increased the grain yield over RDF (T_1) [28]. Agostinho et al. [29] reported a higher yield in rice receiving foliar Si over slag [29]. The beneficial effects of applied Si in rice had been reported in India [12,18,30], Thailand [31] and Korea [32].

3.4 Si Content and Uptake

The data pertaining to Si content and uptake as influenced by different sources of Si were presented in Table 7. Si content of rice straw (4.26±0.11%) was significantly higher in treatment with RHB @ 4 t ha^{-1}(T_4). DE @ 300 kg ha^{-1} (3.31±0.51%) and SA @ 4 mL L^{-1} (2.92±0.31%) recorded empirically higher value but was statistically on par with the treatment receiving RDF (T_1) (2.64±0.26%). Significantly higher Si uptake (275.06±34.07 kg ha^{-1}) was recorded in RHB @ 4 t ha^{-1}. Si uptake in DE @ 300 kg ha^{-1} (218.74±52.97 kg ha^{-1}) was statistically on par with SA @ 4 mL L^{-1} (208.30±16.84 kg ha^{-1}). Lower Si uptake (154.49±13.65 kg ha^{-1}) was recorded in RDF(T_1). Application of external sources of silicon recorded a numerical increase in the nutrient content and their uptake by the rice grain but was found to be non-significant. The total Si uptake by rice grain was also increased with the application of silicon sources over RDF *viz.,* RHB @ 4 t ha^{-1} (315.05±40.02%) and recorded higher Si content followed by DE @ 300 kg ha^{-1} (259.17±53.38%) and SA @ 4 mL L^{-1} (247.50±25.47%). A positive response of grain and straw Si content and uptake to Si fertilizer was observed. Similar results were reported by Sandhya et al. (2018) and Shwetakumari et al. (2020) [7-8]. The deficiency or sufficiency of Si in the soil is primarily determined by the rate of its replenishment in soil solution and its uptake during plant growth. Rice removes large quantities of Si (approximately 500 kg Si ha^{-1} yr^{-1}) more than essential nutrients (N, P and K), therefore, continuous cropping without external supplementation of Si can lead to reduced plant available Si in the soil [33].

Table 4. Effect of different sources of Si on plant height of aerobic rice at different interval

Treatments	Plant height (cm)			
	30DAS	60 DAS	90 DAS	At harvest
T_1: RDF alone	9.18±0.50 (C)	39.28±1.38(B)	54.50±2.74(B)	95.80±3.25(B)
T_2:T_1 + DE @ 300 kg ha^{-1}	10.82±0.74(AB)	43.63±0.68(A)	62.15±3.10(A)	104.80±3.68(A)
T_3: T_1 + SA @ 4 mL L^{-1}	10.04±0.13(BC)	43.88±1.88(A)	61.25±2.93(A)	101.75±2.68(AB)
T_4: T_1 + RHB@ 4 t ha^{-1}	11.66±0.55(A)	44.15±1.04(A)	62.05±2.61(A)	106.05±1.23(A)
S.Em±	0.26	0.66	1.43	1.43
C. D. @ 5%	0.83	2.11	4.57	4.57

±Values indicated standard deviation
Mean value having same alphabets do not differ significantly at p≤0.05

Table 5. Effect of different sources of Si on number of tillers per hill and SPAD value of aerobic rice at different interval

Treatments	No. of tillers $hill^{-1}$			SPAD value	
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS
T_1: RDF alone	5.95±0.70(B)	8.80±0.5(B)	10.50±1.00(B)	41.4±1.76(A)	35.98±1.72C)
T_2:T_1 + DE @ 300 kg ha^{-1}	8.10±0.42(A)	10.80±1.23(AB)	14.00±2.18(A)	45.4±4.51(A)	38.5±2.33(BC)
T_3: T_1 + SA @ 4 mL L^{-1}	8.15±0.97(A)	11.70±1.45(A)	13.75±2.14(AB)	50.8±5.41(A)	42.8±1.10(A)
T_4: T_1 + RHB@ 4 t ha^{-1}	8.20±0.63(A)	10.30±0.70(AB)	14.25±2.75(A)	47.8±4.59(A)	40.7±2.31(AB)
S.Em±	0.35	0.52	0.89	3.72	1.36
C. D. @ 5%	1.12	1.66	2.85		

±Values indicated standard deviation
Mean value having same alphabets do not differ significantly at p≤0.05

Table 6. Effect of different sources of Si on yield parameters in aerobic rice

Treatments	Number of panicles $hill^{-1}$	Panicle length (cm)	Test wt. (g)	Straw (t ha^{-1})	Grain (t ha^{-1})	Total biomass (t ha^{-1})
T_1: RDF alone	8.43±0.50 (B)	22.81±0.85(B)	21.98±0.01(B)	5.90±0.58(B)	3.28±0.13(A)	9.18±1.23(A)
T_2:T_1 + DE @ 300 kg ha^{-1}	13.32±0.58(A)	23.43±0.29(A)	23.18±0.03(A)	6.60±0.61(AB)	3.50±0.18(A)	10.10±1.26(AB)
T_3: T_1 + SA @ 4 mL L^{-1}	12.43±1.00(AB)	23.82±0.39(A)	23.55±0.05(A)	7.15±0.59(A)	3.60±0.16(A)	10. 75±1.01(A)
T_4: T_1 + RHB@ 4 t ha^{-1}	13.23±0.49(A)	23.24±0.47(A)	22.93±0.05(A)	6.45±0.19(AB)	3.55±0.21(A)	10.00±1.65(B)
S.Em±	0.89	0.52	0.28	0.27	0.09	0.90
C. D. @ 5%	12.11	1.60	0.28	0.83	NS	NS

±Values indicated standard deviation
Mean value having same alphabets do not differ significantly at p≤0.05

Table 7. Effect of different sources of Si on Si content (%) and uptake (kg ha^{-1}) in straw and grain at harvest in aerobic rice

Treatments	Silicon (%)		Si uptake (kg ha^{-1})		
	Straw	Grain	Straw	Grain	Total
T_1: RDF alone	2.64±0.26(B)	1.06±0.17(A)	154.49±13.65(B)	35.20±10.63(A)	189.74±19.16(C)
T_2:T_1 + DE @ 300 kg ha^{-1}	3.31±0.51(B)	1.14±0.13(A)	218.74±52.97(AB)	40.52±9.77(A)	259.17±53.38(AB)
T_3: T_1 + SA @ 4 mL L^{-1}	2.92±0.31(B)	1.08±0.10(A)	208.30±16.84(AB)	39.01±9.10(A)	247.50±25.47(B)
T_4: T_1 + RHB@ 4 t ha^{-1}	4.26±0.11(A)	1.15±0.11(A)	275.06±34.07(A)	40.17±7.93(A)	315.05±40.02(A)
S.Em±	0.23	0.09	23.55	24.30	17.69
C. D. @ 5%	0.52	NS	51.87	NS	56.95

±Values indicates standard deviation

Mean value having same alphabets do not differ significantly at p≤0.05.

4. CONCLUSION

This may be concluded from the results that the application of different sources of Si along with the RDF increased plant growth parameters and yield over RDF (T_1). The higher plant height (106.05±1.23 cm) and the number of tillers per plant (15.25±2.75) were recorded in the RHB @ 4 t ha^{-1}. Higher straw (7.15±0.59 t ha^{-1}) and grain yield (3.60±0.16 t ha^{-1}) were recorded with the application of SA @ 4 mL L^{-1} (T_3). Whereas, the Si content (straw: 4.26±0.11% and grain:1.15±0.11%) and uptake (Straw: 275.06±34.07 kg ha^{-1}, grain: 40.17±7.93 kg ha^{-1} and total: 315.05±40.02 kg ha^{-1}) in straw and grain was recorded in the RHB @ 4 t ha^{-1} (T_4). Application of DE, SA and RHB as Si sources increased the straw and grain yield over RDF. This improvement in growth, yield and Si uptake of rice with the addition of Si reduces abiotic and biotic stress. Therefore, external Si supplementation in aerobic rice can be effectively used for sustainable rice production. Further research is needed to find out the optimum levels of Si, N, P and K fertilizers for other locations with a different package of practices and rice varieties.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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