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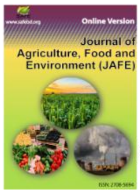

Original Article

Yield and NPK Uptake of Rice as Influenced by Si Fertilization under Ambient and Elevated Temperature

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A B S T R A C T

Application of silicon (Si) influences the stress resistance, and thereby could boost up the growth and yield of rice. An experiment was conducted to investigate the effect of Si fertilization on rice cv. Binadhan-8 at ambient and elevated temperature during *Boro* season of Bangladesh. Significant differences were observed in the studied parameters: plant height, SPAD reading, yield and concentration of NPK in grain and straw of rice. At ambient temperature (AMT) condition, plant height, SPAD reading, grain and straw yield were also the highest in case of 10 g pot^{-1} Si application. Moreover, the highest NPK contents in grain and straw were observed in the application of Si @ 10 g pot^{-1}, whereas the lowest NPK contents were mostly recorded in control (0 g Si pot^{-1}). The increased rate of Si contributed to the NPK absorption in grain, yield attributes and yield of rice up to 10g pot^{-1} Si application. On the other hand, yield contributing characters, grain yield and NPK uptake were showed a similar response to Si application at elevated temperature (ELT). But, the yield contributing characters as well as grain yield at ELT showed less performance in comparison to AMT. Therefore, the application of Si could be recommended to optimize the yield attributes, yield and NPK uptake of rice.

Introduction

Rice (*Oryza sativa* L.) is a staple food as well as the principal source of carbohydrate for the majority of the 1.7 billion population of South Asia including Bangladesh (Mohanty, 2014). Currently, Bangladesh is producing 50 million tons of paddy from 11 million hectares of rice field (Mohanty, 2014). Now, Bangladesh is the world's fourth-biggest rice producing country and achieving self-sufficiency in rice production (BBS, 2017). Land use intensification for high rice production without appropriate nutrient management practices causes depletion of residual soil nutrients, which is strongly related to yield decline. But the introduction of high yielding varieties in cropping patterns along with the optimization of nutrients can boost up the average yield and overall crop performances. A hypothesis postulated that a diminution in the effective N supply from the soil although total soil N remains unaffected causes a substantial decline in yield (Cassman *et al.*, 1995). Beside essential plant nutrients, long term intensive crop cultivation also drains the availability of soil Si (Meena *et al.*, 2014). However, another possibility that lack of availability or depletion of plant-available Si, could be one of the possible limiting factors amongst others contributing to declining crop yields.

Si has been shown essential for maximizing growth and yield of different crop species including rice (Ma and Yamaji, 2015). Its absorption brings several benefits, especially for rice, such as the increase of cell wall thickness below the cuticle, imparting mechanical resistance to the penetration of fungi, decrease in transpiration and improvement of the leaf angle, making leaves more erect, thus reducing self-shading, especially under high nitrogen rates (Rodrigues and Dantoff, 2005). Increased level of Si in rice plant is associated with decreasing grain discoloration at harvest. Si has been reported to reduce shattering of the grains in rice and to increase the number and weight of grains. Although Si is not considered as an essential plant nutrient but it is proved that Si is a fundamental element for rice farming (IRRI, 1965; Ma *et al*., 1989; Yoshida, 1981; Ma *et al*., 2001). The deposition of Si varies greatly among different organs of the rice plant like hull, leaf, culm and grain and it is considered to be the most Si-accumulating species (Akter *et al*., 2017). For instance, Si is available @ 0·5 g kg^{-1} in polished rice, 50 g kg^{-1} in rice bran, 130 g kg^{-1} in rice straw, 230 g kg^{-1} in rice hulls and 350 g kg^{-1} in the base of the rice grain (Currie and Perry, 2007). Availability of Si in soil and its increase uptake influence plant defense mechanism and enhance root system, which demands absorption of high amount of plant nutrients (Savant *et al*., 1996; Singh *et al*., 2005; Jawahar and Vaiyapuri, 2013). The application of Si in rice can substantially influence the growth and yield of rice. Moreover, foliar silicon application has a biostimulative effect and the satisfactory plant performances are observed in high temperature conditions (Artyszak, 2018). Hence, Si management is essential for increasing and sustaining rice productivity to tackle the challenge of ensuring the food security of Bangladesh. In Bangladesh, a limited research program was carried out about silicon application on growth and yield performances and the uptake of N, P and K in grain and straw of rice. Therefore, the present study was undertaken to investigate the suitable Si level for maximizing the grain and straw yield of rice and finally the uptake of nitrogen (N), phosphorus (P), and potassium (K) in grain and straw at (AMT) and at (ELT) conditions.

Materials and Methods

Experiment site and plant materials

The experiment was conducted at the greenhouse of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh during January - June 2012 to observe the effect of Si on the NPK uptake, growth and yield of rice. The geographical position of experiment site was 90°25' E and 24°74' N. The plants were grown in 24 cm × 30 cm size plastic pot containing 10 kg air dry soil, collected from rhizosphere of rice field. The soil was silty loam with low organic matter content (1.64%) and slightly acidic in nature (pH 6.5). The N (0.08%), P (7.0 mg kg^{-1}) and K (0.12 meq%) contents were low. S (10mg kg^{-1}), Zn (0.09 mg kg^{-1}), B (0.07 mg kg^{-1}) contents are also low but Ca (5.16 meq%) and Mg (2.94 meq%) contents are sufficient. Binadhan-8, a high yielding rice variety which is recommended for cultivation in both the *Boro* and *Aman* seasons in Bangladesh used in the experiment.

Treatment and design

The experiment consists of six levels of Si viz. 0 (Si_0), 5 (Si_5), 7.5 ($Si_{7.5}$), 10 (Si_{10}), 12.5 ($Si_{12.5}$) and 15 (Si_{15}) g pot^{-1} soil. The treatments were assigned in two different temperature conditions: AMT condition (outside of greenhouse) and ELT condition (inside greenhouse). During the experimentation, the average maximum temperature prevailed in the greenhouse condition was 37ºC to 39ºC, and outside the greenhouse it was below 35ºC. Treatments were assigned in completely randomized design with four replications.

Crop husbandry

Before transplanting rice seedling, each pot soil was fertilized with urea, triple super phosphate (TSP) and muriate of potash (MoP) at the rate of 12 g (N), 6 g (P_2O_5) and 6 g (K_2O) on high yield goal basis. The full amounts of TSP, MoP were applied as a basal dose and urea was applied in three splits. Calcium silicate (CaSiO3) was supplied as a source of Si (24% Si). Calcium silicate and all other fertilizers were applied before transplanting. Sprouted seeds were sown in a plastic tray and 20-day old two seedlings pot^{-1} were transplanted. Intercultural operations *e.g.,* gap filling, weeding, irrigation, and drainage was done as per requirement. The experiment was terminated at plant maturity, when the plants were ripen and started to die.

Recording data and statistical analysis

The data on plant height, tillers $plant^{-1}$, grains $spanicle^{-1}$, panicle length, 1000-grain weight, grain & straw yield and concentration of NPK in grain & straw were measured from each pot at final harvest. A chlorophyll meter (SPAD-502, Minolta Camera Co. Ltd, Osaka, Japan) was used to record the SPAD value from rice plant. A new fully expanded leaves that adjacent to a similar leaf about to emerge was selected for recording SPAD values. The mean of five readings per plant was taken in between 7:00 and 9:00 am to lessen the potential effects of light intensity on chloroplast movement. The analysis of N, P, and K in plant samples were done by micro-Kjeldahl digestion, spectrophotometer and flame photometer, respectively. Analysis of variance was done with the help of computer package MSTAT-C (Russel, 1986). The mean differences among the treatments were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984) and LSD test at 0.05 level of probability.

Results and Discussion

Effect of Si on plant height and SPAD reading of rice

Plant height was significantly influenced by the different levels of Si (Table 1). At ambient temperature, the highest plant height (91.67 cm) was attained in Si_{10} followed by Si_{15} (90.33 cm) and the lowest plant height (85.67 cm) was observed in Si_0 (control). On the other hand, for elevated temperature, the highest plant (99.33 cm) was attained in treatment $Si_{10,}$ and the lowest plant height (86.00 cm) was observed in treatment Si_0. These mean that nitrogen (N), phosphorus (P), potassium (K) fertilizers together with 10 g Si pot^{-1} showed the highest plant height compared to control. These findings are supported with the results of Tamai and Ma (2008), who also revealed that the increased plant height of rice resulted from the increased Si application as the deposition of Si in the cell wall can make the leaves and stems more erect and increase the culms. Besides this, Si application in rice significantly influenced the SPAD reading (Table 1). The highest SPAD reading (47.07 and 45.80) were observed in the treatment $Si_{10,}$ and the lowest SPAD reading (41.03 and 38.30) was observed in the control condition under both growing conditions. The previous work of Ali *et al.* (2014) also agrees with our findings who also obtained maximum SPAD reading value with increased Si application which ultimately contributed to higher grain yield of rice. At the same time the positive effect of Si might be attributed to increases in SPAD values under two different growing conditions. As the SPAD value gave the best indicator of photosynthetic activity in cereals, the increased chlorophyll content is also correlated with increased grain yield (Rahman *et al*., 2014).

Table 1. Effect of different levels of Si on plant height and SPAD readings at ambient and elevated temperature.

Level of Si	Plant height (cm)		SPAD reading	
	AMT	ELT	AMT	ELT
Si_0	85.67c	86.00b	41.03c	38.30c
Si_5	87.33bc	95.67a	42.67bc	40.87bc
$Si_{7.5}$	87.67bc	97.33a	43.20bc	43.90ab
Si_{10}	91.67a	99.33a	47.07a	45.80a
$Si_{12.5}$	88.33bc	96.33a	42.00bc	43.53ab
Si_{15}	90.33ab	95.43a	43.90b	40.00bc
$LSD_{0.05}$	3.18	4.06	2.54	3.73
SE(±)	0.885	1.90	0.853	1.15
CV%	8.02	7.40	5.30	4.99

Figures having common letter (s) in a column do not differ significantly; SE (±) = Standard error of means.

Effect of Si on yield attributes and yield grain and straw

Data revealed that Si application significantly contributed to the different yield contributing characters and yield of rice (Table 2). The highest number of effective tillers hill^{-1} (18.33) was obtained inSi_{10}, and the lowest number (14.33) was recorded in S_0which was statically similar to all other levels of Si application. Similarly, the highest number of effective tillers hill^{-1} (15.33) was obtained in the treatment Si_{10} whereas the lowest number (12.33) was recorded in treatment Si_0. Interestingly, the number of tillers was much less in elevated temperature compared to ambient temperature. Both the ambient and elevated temperature condition, the highest number of effective panicles hill^{-1} (17.00) and (14.00) was obtained in the treatment Si_{10} whereas the lowest number of effective panicles hill^{-1} (11.67) and (12.00) were recorded in treatment Si_0, respectively. The findings are in agreement with Cuong *et al*., (2017) who stated that the beneficial role of Si fertilizer in an increasing number of tillers hill^{-1}.

Table 2. Yield and yield contributing attributes of rice as influenced by different levels of Si application at ambient and elevated temperature.

Level of Si	Number of Tillers hill^{-1}		Number of Panicles hill^{-1}		Panicle length (cm)		Number of grains panicle^{-1}		1000-grain weight (g)		Grain yield (g pot^{-1})		Straw yield (g pot^{-1})	
	AMT	ELT	AMT	ELT	AMT	ELT	AMT	ELT	AMT	ELT	AMT	ELT	AMT	ELT
Si_0	14.33b	12.33d	11.67d	12.00e	21.17b	20.83b	87.67d	33.33c	23.37c	20.99b	26.21e	18.28c	38.44e	25.19d
Si_5	15.33b	13.33bc	12.67cd	13.33bc	22.67a	21.33b	93.67c	55.67ab	24.49bc	21.89ab	35.67d	19.12c	42.67d	27.86c
$Si_{7.5}$	15.67b	14.00ab	14.33b	13.67ab	22.83a	21.33b	117.00a	56.33ab	25.29ab	22.45a	39.47c	21.30b	45.88c	29.04b
Si_{10}	18.33a	15.33a	17.00a	14.00a	23.17a	24.50a	119.0a	58.00a	26.07a	22.53a	46.50a	25.40a	48.21a	31.15a
$Si_{12.5}$	14.67b	12.67cd	12.33cd	12.67d	22.33ab	21.00b	107.0b	35.33c	24.09bc	21.25b	42.95b	20.58b	47.46b	30.42b
Si_{15}	14.33b	13.00cd	13.33bc	12.00cd	21.33b	21.33b	93.67c	52.00b	24.33bc	21.02b	35.69d	18.36c	47.22b	29.86b
$LSD_{0.05}$	1.69	0.679	1.21	0.424	1.19	0.993	4.20	4.60	1.16	0.842	1.92	0.823	1.944	1.026
SE(±)	0.618	0.315	0.782	0.294	0.336	0.563	5.41	4.54	0.387	0.286	.872	0.817	0.645	0.624
CV%	6.16	6.64	5.02	7.70	3.01	3.57	9.29	5.34	3.19	3.68	4.87	6.44	8.26	7.57

Figures having common letter(s) in a column do not differ significantly; SE(±) = Standard error of means.

The highest panicle length was observed in Si_{10} whereas the lowest panicle length was observed in Si_0 at both ambient and elevated temperature conditions. The results are in line with the findings of Abro *et al*. (2009), where they reported that Si significantly increased the length of rice panicle. The number of grains per panicle was substantially increased by the exogenous application of Si. The highest number of grains panicle^{-1} (119.0) and (58.00) was found in Si_{10} and the lowest number of grains panicle^{-1} (87.67) and (33.33) was recorded in $Si_{0,}$ under AMT and ELT, respectively. The notable information is that the filled grain in case of ELT condition greatly fall down which might be due to less absorption of Si in high temperature resulted in poor resistance to abiotic and biotic stress, and less plant growth. Our findings were also exhibited similar trends like the findings of Lavinsky *et al*. (2016) who revealed Si as a key player to enhance the number of grains in rice. It might be because of the availability of Si at the reproductive stage might have more assimilation of carbohydrates in panicles which resulted in more number of grains panicle^{-1} in rice.

The highest 1000-grain weight (26.07 g) and (22.53 g) were observed in the application of Si @ 10 g pot^{-1} whereas the lowest 1000-grain weight (23.37 g) and (20.99 g) were observed in control under both growing environments. Dallagnol *et al*. (2014), reported, a substantial increase in the weight of 1000-grain weight when Si level was increased. The highest grain yield (46.43 g pot^{-1} and 23.43 g pot^{-1}) was produced by Si_{10}. On the contrary, the lowest grain yield (26.21 g pot^{-1} at AMT and 18.28 g pot^{-1} at ELT) was found in Si_0. The findings were in agreement with Lavinsky *et al*. (2016) and Pati *et al*. (2016), who stated that Si positively affected yield-related traits of rice.

Like grain yield, the straw yield of Binadhan-8 responded significantly to the application of different silicon levels. The highest straw yield of 48.21 g pot^{-1} was obtained from$Si_{10}$and the lowest straw yield of 38.44 g pot^{-1} was found in Si_0 under AMT. On the contrary, the straw yield of rice varied from 25.19 g to 31.15 g pot^{-1} under ELT condition where the highest straw yield (31.15 g pot^{-1}) was obtained from treatment Si_{10} and the lowest straw yield (25.19 g pot^{-1}) obtained from Si_0. These results are supported by the findings of Cuong *et al*. (2017) who obtained straw yields was significantly affected by Si application.

Effect of Si on nutrient contents of grain and straw of rice

The N content in grain and straw of rice was significantly influenced by the different treatments of Si (Table 3). In AMT, the highest N content (1.67%) in grain was observed in Si_{10}whereas the lowest (0.920%) was observed in $Si_{12.5}$ treatment. On the other hand, the highest N content (1.67%) in straw was observed in Si_{10} and the lowest N content (0.440 %) was observed in the Si_0 treatment. In case of ELT, the highest N content in grain (1.66%) was observed in the treatment Si_{10}whereas the lowest N content in grain (0.800%) was observed in the treatment Si_0 treatment. For straw maximum N content (0.55%) was observed in the treatment Si_{10} and the lowest N content in (0.42%) was observed in $Si_{12.5}$.

The P content in grain and straw of Binadhan-8 was influenced significantly by the different Si levels at both AMT and ELT condition (Table 3). The highest P content (0.26%) in grain was observed in Si_{10} at both temperature conditions, whereas the lowest P content (0.19% and 0.17%)were observed in Si_{15} and Si_0 treatment in AMT and ELT conditions, respectively. Similarly, the treatment Si_{10}offered the highest P content (0.260% and 0.155%) in the grain of rice at AMT and ELT conditions, respectively. On the other hand, control and $Si_{12.5}$treatment produced the lowest P content (0.107% and 0.105%) in the straw at AMT and ELT conditions, respectively.

Table 3. N, P and K contents in grain and straw of rice as influenced by different levels of Si under ambient and elevated temperature.

	Level of Si	%N		%P		%K	
		Grain	Straw	Grain	Straw	Grain	Straw
AMT (°C)	Si_0	0.970b	0.440c	0.210ab	0.1070a	0.180b	1.370b
	Si_5	1.100b	0.550a	0.250ab	0.150b	0.240ab	1.520a
	$Si_{7.5}$	1.120b	0.530a	0.230ab	0.127b	0.230ab	1.460ab
	Si_{10}	1.670a	0.560a	0.260a	0.170b	0.290a	1.540a
	$Si_{12.5}$	0.920b	0.500ab	0.200ab	0.123b	0.240ab	1.210c
	Si_{15}	1.170b	0.460bc	0.190b	0.120b	0.240ab	1.380b
	$LSD_{0.05}$	0.238	0.0562	0.0562	0.0795	0.0562	0.0974
	SE(±)	0.110	0.021	0.011	0.164	0.014	0.050
	Sign. level	0.01	0.01	0.01	0.01	0.05	0.01
	CV%	11.73	5.41	10.50	14.54	14.12	4.10
ELT (°C)	Si_0	0.800c	0.430b	0.170b	0.115	0.1430b	1.100a
	Si_5	1.140b	0.540a	0.220ab	0.119	0.119b	1.130a
	$Si_{7.5}$	1.070b	0.510a	0.240a	0.153	0.2160a	0.940c
	Si_{10}	1.660a	0.550a	0.260a	0.155	0.239a	1.140a
	$Si_{12.5}$	1.050b	0.420b	0.230ab	0.105	0.226a	1.060ab
	Si_{15}	1.090b	0.430b	0.200ab	0.115	0.214a	1.010bc
	$LSD_{0.05}$	0.125	0.0562	0.0562	0.056	0.0562	0.0795
	SE(±)	0.116	0.026	0.012	0.009	0.020	0.031
	Sign. level	0.01	0.01	0.05	ns	0.01	0.01
	CV%	6.04	6.53	13.89	19.47	20.05	4.69

Figures having common letter (s) in a column do not differ significantly; SE (±) = Standard error of means.

Different doses of Si significantly influenced the potassium content in grain and straw of rice under AMT and ELT conditions (Table 3). The highest K content in the grain (0.290% and 0.239%) and straw (1.540% and 1.140%) were as found in the treatment Si_{10} at the both temperature conditions, respectively. On the contrary, the lowest K content (0.180 % and 0.119%) in grain were obtained from $Si_0$and Si_5 treatment under AMT and ELT conditions, respectively whereas the minimum K content(1.21% and 0.94%) in straw were observed from $Si_{12.5}$ and $Si_{7.5}$ under AMT and ELT, respectively. The findings of the present study were in close agreement with the observations of Savant *et al*. (1996) and Singh *et al*. (2005). They reported that, increased absorption of Si enhanced the essential nutrients uptake, root growth, cell division and development of rice.

Conclusion

Results of the present study revealed that the application of Si had a positive significant effect on the plant height, SPAD value, yield attributes and yield of rice along with the accumulation of N, P and K. Therefore, it may be recommended to apply Si along with N, P, K fertilizer for increasing rice productivity. The study warrant the field experiment in different locations to optimize the rate of Si application in rice. However, since Si application has been swelling fast for ensuring a good harvest across the world, impacts of Si should be studied in multi-locations along with different settings to ensure judicious use of Si in the crop field and before reaching any precise conclusion.

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