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Research Article

Exogenous Silicon Application Improves Growth and Morpho-Physiological Properties of Rice

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ABSTRACT

Rice covers most of the arable land in coastal region of Bangladesh during wet season; where silicon (Si) application has been proposed to improve growth and morpho-physiological properties of rice. The purpose of the experiment was to evaluate the effect of Si on the growth, biomass yield and morpho-physiological properties of rice. The experiment was established at the net house of the Department of Soil Science of Patuakhali Science and Technology University, Bangladesh during wet season of 2021. The single factor completely randomized design was employed in the experiment having replicated thrice. There were eight treatments with different doses of silicon e.g. 0, 5, 10, 20, 50, 100, 200 and 400 mg Si kg^{-1} soil. The source of Si was calcium silicate and the test rice variety was BRRI dhan73. The tested parameters including plant height, tillers per hill, shoot dry weight, root dry weight, root volume, leaf area index, shoot Si content, root Si content, shoot Si uptake, root Si uptake, chlorophyll a, chlorophyll b, and total chlorophyll content enhanced progressively with increasing Si doses up to 100 mg Si kg^{-1} soil dose, beyond this level increasing Si doses had no significant improvement of the tested parameters. Si application significantly reduced leaf angle of rice which facilitate plants to be more erect and stronger. Based on the growth, biomass yield and Si uptake, 100 mg Si kg^{-1} soil was found as the optimum silicon dose to apply for growing rice.

Introduction

Rice, among the cereal crops, stands second position in relation to their coverage globally (IRRI, 2015). It is the staple food for approximately 168 million people of Bangladesh. Rice, paddy production of Bangladesh increased from 15.1 million tonnes in 1972 to 56.9 million tonnes in 2021 to feed its inhabitants (Knoema, 2023). Every year total rice growing area decreasing substantially due to rapid urbanization, consequently the rice production needs to increase another fold (BER, 2019). Besides this per area rice yield attained in a plateau, some cases diminishing due to nutritional imbalance in plant and soil, and many other soil and environmental factors. Nutrient mining by crops has been increased several folds due to recent increase in cropping intensity (Haque et al., 2022; 2023a; Haque and Hoque 2023), which signifies the importance of macronutrients along with micronutrients although their requirement is relatively low (Haque et al., 2003; 2015; 2018). Silicon (Si) is an important micronutrient which may help to break the yield stagnation and can facilitate another peak of rice yield at south East Asia (Singh et al., 2020; Rea et al., 2022).

Next after oxygen, Si is the most abundant naturally occurring mineral nutrient element in soil. Typically a soil contains around 28 % Si by its dry weight, although their availability is highly dependent on the nature and properties of soils (Schaller et al., 2021). Silicon has diversified effect on crops especially mitigating abiotic as well as biotic stresses (Vaculik et al., 2020; Sultana et al., 2021). In fact Si application in soil is reported to improve plant growth and yield in varying agricultural ecosystems (Akter et al., 2021; Das et al., 2021).

There is a synergistic effect of Si with other plant nutrients like nitrogen, phosphorus, potassium etc. as those use efficiency increases by Si supplementation in soil (Teixeira et al., 2022). Silicon application in soil considerably increases nitrogen content of crops (Minden et al., 2020). Silicon application improves the plant physiological activity, increase photosynthesis, and reduce transpiration rates, and regulate various metabolic processes in plant (Khan et al., 2021). Cell

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development and differentiation depends on the optimum supply of silicon in plants (Liang et al., 2005).

Coastal region of Bangladesh is characterized by heavy tidal water flooding during monsoon and salinity in varying degree during dry season (Haque et al. 2014; Sikder et al. 2016; Kumar et al. 2018; Haque 2018; 2020). Cyclone and storm surges are very common which frequently damaged the transplanted Aman rice crop. Due to water stagnation and cyclonic wind speed many of the rice varieties become lodging during reproductive and ripening stage and causes huge losses of crop yield. Silicon application is reported to increase thickness of cuticle (Jang et al. 2020) which gives plants more strength and prevent lodging of crops (Jinger et al. 2022). Silicon application in coastal soil may add benefit on improving plants morphological and physiological properties.

Although major nutrients including nitrogen, phosphorus, potassium etc. are being applied at optimum level, still the yield ceiling of crops especially in rice could not overcome, therefore other nutrients including micronutrients especially Si application need to be taken into consideration. In addition, there is no evidence of using Si in coastal region of Bangladesh. We hypothesize that Si application in soil will improve rice growth at coastal region of Bangladesh. The present experiment was therefore undertaken to explore the effects of different doses of Si application on growth, and morphological and physiological properties of rice under pot culture condition.

Materials and Methods

Site and soil description

The experiment was conducted at the net house of the Department of Soil Science of Patuakhali Science and Technology University (PSTU), Bangladesh during wet season 2021. The geographical location of the study site was 22.46465°N latitude and 90.38843°E longitude. The study soil was collected from PSTU nearby farmers' field. The farmers' field from where study soils were collected belongs to the Agro–ecological zone of AEZ–13. The soil was collected from 0 to 15 cm soil depth of the field. Ten sub-samples were collected from different spots of the soil volume. The sub samples were mixed thoroughly to make a composite sample. The soils were air-dried for one week and then ground and passed through a 2 mm sieve. The processed soil sample was then stored in a container. The physical and chemical analysis of soil sample was done following methods described by Page et al. (1982).

Texturally the soil was silt loam having 117, 754 and 128 g kg^{-1} sand, silt and clay, respectively. The soil had pH (water) of 5.5, electrical conductivity 1.63 dS m^{-1}, organic carbon 13.0 g kg^{-1}, total nitrogen 1.1 g kg^{-1}, Bray and Kurtz phosphorus 2.7 mg kg^{-1}, exchangeable potassium 0.28 cmol kg^{-1}, available sulphur 17.4 mg kg^{-1} and Si content 29.1%. The soil series was Ramgoti.

Crop and crop variety

The crop under study was rice and the variety was BRRI dhan73 which was developed by Bangladesh Rice Research Institute (BRRI), Gazipur for cultivation in the coastal region of Bangladesh.

Design and treatments

The layout of the experiment was prepared following completely randomized design. There were eight treatments consisting 0, 5, 10, 20, 50, 100, 200 and 400 mg Si kg^{-1} soil in the experiment. All the treatments were replicated thrice.

Pot preparation and fertilizer application

The collected study soils were spread on the floor of the net house for drying. When the soils were adequately dried, they were grounded using a wooden hammer. Twenty four plastic buckets each of 10 liter size were taken. Five kilogram dried and ground soil was taken in each plastic buckets. The nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) were applied in the soil at a rate of 120, 20, 100 and 16 mg kg^{-1} soil, respectively. Urea, triple super phosphate, muriate of potash and gypsum were the sources of N, P, K and S, respectively. The P, K and S fertilizers were properly mixed with soil before seed sowing. Nitrogen was applied at 7, 30 and 60 days after seed sowing. The source of Si was calcium silicate ($CaSiO_3$). Silicon fertilizers were applied during pot preparation according to the treatments and layout. In the experiment say 5 mg Si kg^{-1} soil treatment received 25 mg Si for 5 kg soil.

Seed sowing and intercultural operations

Initially ten sprouted seeds were sown per pot on 26 August 2021, after 7 days when crops were well established the extra seedlings were uprooted and kept two healthy seedlings per pot. Irrigation was done using distilled water whenever necessary. Spraying was done using a mini hand sprayer to control insects.

Harvesting and data recording

At maximum vegetative stage crops were harvested by cutting plants at ground level. Roots were removed from the soil, washed and cleaned using excess water. Both root and shoot samples were sun dried and weight of sample was expressed as sundry basis. For performing chemical analysis the root and shoot samples was oven dried at 62°C and grinded to pass through 20 mesh sieve.

To measure the leaf angle, a mother tiller was separated from the hill. The separated tiller was fixed using a scotch tape on a white board. The angles between the culm (stem) and tip of fully expanded top third leaf was marked on the white board to determine the angle of leaf (Yoshida et al. 1976). Root volume was measured by immersing the roots in water within a graduated cylinder; the water volume increase was the measurement of root volume.

To determine silica (SiO_2) content one gram of root and shoot samples were weighed into a digestion tube. Digestion of the plant samples was done using a mixture of three inorganic acids (nitric acid-HNO_3: perchloric acid-$HClO_4$: sulphuric acid-H_2SO_4= 5:2:1). The silica content in the digested sample was measured following method outlined by Yoshida et al. (1976). The silica content data were then converted to elemental silicon (Si) using their molecular weight values. The shoot and root Si uptake was estimated from root and shoot yield and their respective Si content data. Before harvesting, the third fully expanded leaf was collected and analysed for chlorophyll content following method described by Coombs et al. (1985).

Data analysis

The recorded data on various crop characters were statistically analyzed using computer based software "Statistical Tool for Agricultural Research (STAR)". The mean separation was done using Least Significant Difference test at the 95% confidence level.

Results and Discussion

Plant height

Different doses of Si significantly influenced the plant height of rice (Table 1). All the treatments increased plant height over control (T_1). Plant height varied from 91.2 to 100.0 cm over the treatments. The control treatment had the lowest plant height (91.2 cm). The highest plant height was found in 100 mg Si kg^{-1} soil treatment. However, the 20 to 400 mg Si kg^{-1} soil treatments had statistically similar plant height. The enhanced plant height with Si at higher levels may be attributed to leaf erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of plant and higher production of carbohydrates (Prakash et al. 2011; Lakshmi et al. 2020). The progressively increased level of Si addition in soil enhances the elongation rate of stem which finally contributed to higher plant height of rice (Deshmukh et al. 2015).

Tillers per hill

Silicon application in soil significantly improved the number of effective tillers per hill (Table 1). Results showed that 200 mg Si kg^{-1} soil produced the highest number of tillers per hill (10.0). The lowest number of tillers per hill of 6.3 was found in T_1 (control) and the second lowest result of 6.7 was found from 5 mg Si kg^{-1} soil. Increased doses of Si progressively improved the tiller production of rice and at 200 mg Si kg^{-1} soil treatment it reaches in peak (Table 1). Some other reports also described that soil application of Si increased the shoot weight of rice, productive tillers, filled grains per panicle, thousand grain weight and grain yield of rice (Dorairaj et al. 2020; Elshayb et al. 2021). The increased tillering was due to production of expanding auxiliary buds which clearly depend upon the nutritional condition of mother tiller because Si improves the nutritional condition of mother tiller (Singh et al. 2020).

Table 1. Effects of different doses of Si on growth and yield parameters of rice (cv. BRRI dhan73)

Treatment	Plant height (cm)	Number of tiller per hill	Shoot dry weight (g pot^{-1})	Root dry weight (g pot^{-1})	Root volume (cc)
T_1: 0 mg Si kg^{-1} soil	91.2 b	6.3 c	8.08 c	1.15 b	5.45 c
T_2: 5 mg Si kg^{-1} soil	92.3 b	6.7 c	8.47 c	1.30 b	5.58 c
T_3: 10 mg Si kg^{-1} soil	92.9 b	7.0 bc	9.41 bc	1.28 b	6.42 c
T_4: 20 mg Si kg^{-1} soil	97.0 ab	7.7 abc	10.23 bc	1.40 b	7.42 bc
T_5: 50 mg Si kg^{-1} soil	99.7 a	8.7 abc	13.11 ab	2.04 a	10.33 ab
T_6: 100 mg Si kg^{-1} soil	100.0 a	9.7 ab	15.50 a	2.24 a	13.00 a
T_7: 200 mg Si kg^{-1} soil	98.6 ab	10.0 a	16.18 a	2.31 a	12.08 a
T_8: 400 mg Si kg^{-1} soil	97.7 ab	9.0 abc	16.82 a	2.55 a	12.58 a
Significance level	**	**	***	***	***
CV (%)	2.92	12.05	10.77	11.13	13.66

Means with the same letter are not significantly different. CV: Coefficient of variation
- Significant at 1% level, *-Significant at 0.1% level

Shoot dry weight

There was a significant effect of Si application on shoot dry weight of rice. With increasing the doses of silicon, the shoot dry weight of BRRI dhan73 was raised progressively (Table 1). Application of 400 mg Si kg^{-1} soil produced the highest shoot dry weight (16.82 g pot^{-1}). Although 400 mg Si kg^{-1} soil treatment recorded the highest shoot dry weight, but it was statistically similar with 100 (15.50 g pot^{-1}) and 200 mg Si kg^{-1} soil (16.18 g pot^{-1}) treatments. In our experiment lowest shoot dry weight was obtained in 0 mg Si kg^{-1} soil treatment which was statistically at par with 5 mg Si kg^{-1} and 10 mg Si kg^{-1} soil treatments. The adequate supply of Si contributed to obtain stronger and larger plants with bigger leaf size, which enhances photosynthesis that finally resulted in higher biomass yield of rice (Jinger et al., 2022). The shoot dry weight data were fitted to the quadratic polynomial curve against different rates of Si (Figure 1). The curve parameters indicated that the shoot dry weight increasing trend best fitted to the quadratic polynomial curve (R^2 = 0.939). The curve shows that up to a certain level increasing Si dose linearly increase the shoot dry weight but after that level it was declined or remains in a plateau. This type of relation was also reported by some other studies on grain yield of rice (Cassola et al. 2021; Haque et al. 2023b) and maize (Haque et al. 2023c).

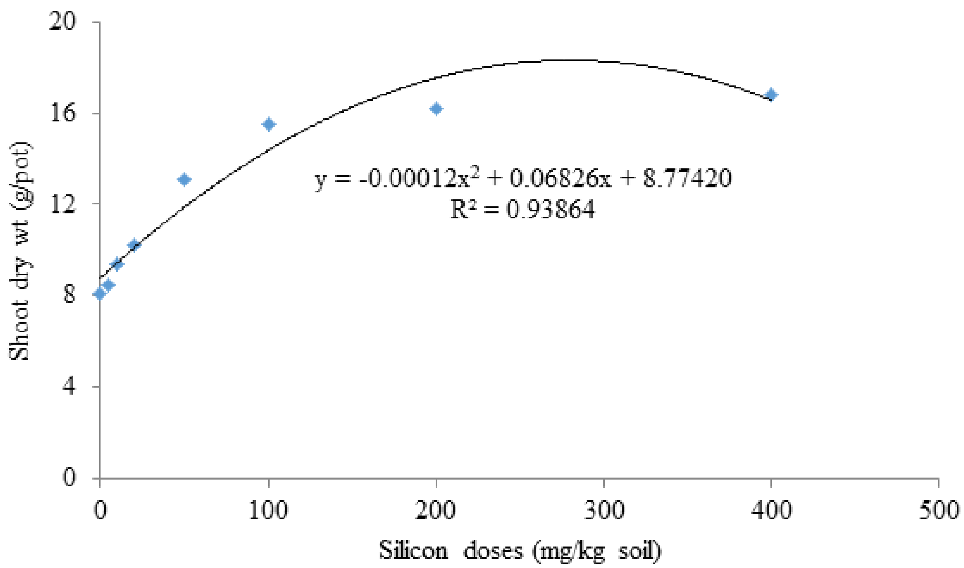

Figure 1. Trend of increasing shoot dry weight under different increasing doses of Si in rice

Root weight and volume

The root dry weight was also significantly improved by Si application on soil (Table 1). Application of 400 mg Si kg^{-1} soil produced maximum root dry weight at harvest (2.55 g pot^{-1}). Although 400 mg Si kg^{-1} soil treatment gave the highest root dry weight but it was statistically similar with 200 mg Si kg^{-1} soil (2.31 g pot^{-1}), 100 mg Si kg^{-1} soil (2.24 g pot^{-1}) and 50 mg Si kg^{-1} soil (2.04 g pot^{-1}) treatment. The lowest root dry weight was obtained in 0 mg Si kg^{-1} soil which was not significantly lower than 5, 10 and 20 mg Si kg^{-1} soil treatments. The results indicated that lower dose of Si could not create a positive impact on root production; rather it needs a higher dose to achieve a significant impact.

The root volume was remarkably affected by different doses of silicon (Table 1). Application of 100 mg Si kg^{-1} soil produced the highest root volume of 13.0 cc pot^{-1}, however, it was statistically similar with 200 mg Si kg^{-1} soil treatment (12.08 cc pot^{-1}) and 400 mg Si kg^{-1} soil treatment (12.58 cc pot^{-1}). The lowest root volume was found in 0 mg Si kg^{-1} soil which was statistically similar with 5 and 10 mg Si kg^{-1} soil treatments. In agreement with the present study, Sharma et al. (2021) reported that Si supplementation along with recommended dose of fertilizer potentially enhanced the root characteristics (root length and root volume) of rice. Silicon application in soil improves root proliferation, therefore increases nutrient and water uptake (Luyckx et al. 2017). Further Si application contributed to improve in lateral root architecture, and enhance root length and diameter in rice (Kim et al. 2014).

Leaf angle

Fully expanded top 1st and 2nd leaves of each tiller were used to measure leaf angle. Different doses of Si significantly influenced the both 1st and 2nd leaf angle of rice (Table 2). Silicon fertilizer reduced the leaf angle, therefore it improve the plant morphology. Application of 0 mg Si kg^{-1} soil produced the highest leaf angle of rice (30.7°). By increasing the Si dose 1st leaf angle was reduced gradually and therefore lowest leaf angle was found in 400 mg Si kg^{-1} (12.7°). Regarding 2nd leaf, the control treatment had the highest leaf angle of 46.7°. Similar to 1st leaf, the leaf angle in 2nd leaf gradually decreased with the increase of the dose of Si application. The lowest leaf angle was found in 400 mg Si kg^{-1} soil treatment (29.7°). Lower leaf angle indicates more erectness of the leaf which ultimately improves photosynthetic capacity of leaf by reducing self-shading of leaves (Sume et al. 2023).

Table 2. Effects of different rates of Si on leaf angle and leaf area index of rice (cv. BRRI dhan73)

Treatment	1st leaf angle (°)	2nd leaf angle (°)	Leaf area index
T_1: 0 mg Si kg^{-1} soil	30.7 a	46.7 a	2.30 b
T_2: 5 mg Si kg^{-1} soil	24.7 ab	42.7 ab	2.35 ab
T_3: 10 mg Si kg^{-1} soil	25.7 ab	41.7 ab	2.38 ab
T_4: 20 mg Si kg^{-1} soil	20.0 bc	41.0 ab	2.52 ab
T_5: 50 mg Si kg^{-1} soil	18.7 bc	37.0 abc	3.05 ab
T_6: 100 mg Si kg^{-1} soil	20.3 b	36.0 bc	3.25 a
T_7: 200 mg Si kg^{-1} soil	18.3 bc	30.7 c	2.53 ab
T_8: 400 mg Si kg^{-1} soil	12.7 c	29.7 c	3.25 a
Significance level	***	***	**
CV (%)	12.19	9.01	12.44

Means with the same letter are not significantly different. CV: Coefficient of variation
- Significant at 1% level, *-Significant at 0.1% level

Leaf area index

The leaf area index was significantly affected by different doses of Si (Table 2). Leaf area index varied from 2.30 to 3.25. The highest leaf area index was found in 100 mg Si kg^{-1} soil treatment. The lowest leaf area index of 2.30 was found in control treatment. Higher leaf area index in Si receiving treatments may be due to higher uptake of Si from soil (Soumya et al, 2020).

Silicon content

All the Si treatments increased the shoot silicon content over control (T_1) but the extent of increment was not significant. Shoot Si content varied from 1.29 to 1.42 % over the treatments and it progressively increased with the increase of the rate of Si (Table 3). The highest shoot Si content was found in 400 mg Si kg^{-1} soil treatment and the lowest was found in control treatment. Silicon application significantly increased the root Si content over control having varied from 1.88 to 2.89 % over the treatments (Table 3). The highest root silicon content was further found in 400 mg Si kg^{-1} soil treatment. The lowest root silicon content was found in control treatment. Similar to shoot Si content, the root Si content also progressively increased with increasing dose of Si. The increasing trend of root Si content by application of increased level of Si follows quadratic model (R^2= 0.880) rather than linear model (Figure 2). Therefore, Si treatment strongly affected plant Si content, although increasing rates of Si showed diminished increases in plant Si (Limmer et al. 2022).

Table 3. Effects of different doses of Si on Si content and uptake of rice (cv. BRRI dhan73)

Treatment	Shoot Si content (%)	Root Si content (%)	Shoot Si uptake (mg pot^{-1})	Root Si uptake (mg pot^{-1})	Total Si uptake (mg pot^{-1})
T_1: 0 mg Si kg^{-1} soil	1.29	1.88 b	103.9 d	21.7 c	125.6 c
T_2: 5 mg Si kg^{-1} soil	1.32	2.07 ab	111.8 d	26.9 c	138.7 c
T_3: 10 mg Si kg^{-1} soil	1.32	2.09 ab	124.0 cd	26.8 c	150.8 c
T_4: 20 mg Si kg^{-1} soil	1.34	2.20 ab	137.1 cd	30.7 bc	167.8 c
T_5: 50 mg Si kg^{-1} soil	1.35	2.63 ab	177.6 bc	54.0 ab	231.6 b
T_6: 100 mg Si kg^{-1} soil	1.35	2.68 ab	208.4 ab	60.3 a	268.7 ab
T_7: 200 mg Si kg^{-1} soil	1.38	2.80 a	223.5 ab	64.5 a	288.0 ab
T_8: 400 mg Si kg^{-1} soil	1.42	2.89 a	238.8 a	73.9 a	312.7 a
Significance level	ns	**	***	***	***
CV (%)	7.98	12.15	12.86	18.56	10.13

Means with the same letter are not significantly different. CV: Coefficient of variation
- Significant at 1% level, *-Significant at 0.1% level, ns-Not significant

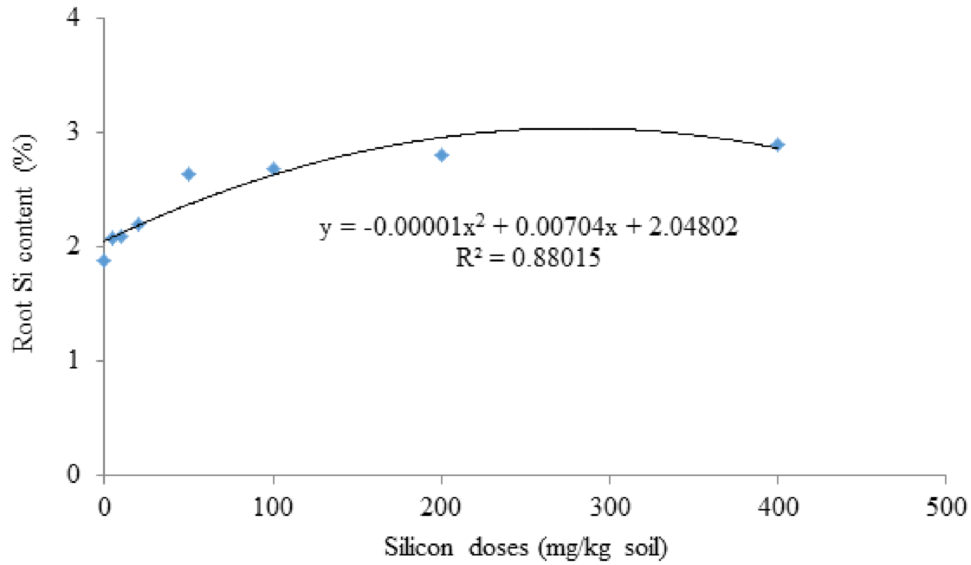

Figure 2. Trend of increasing root Si content under different increasing doses of Si in rice

Silicon uptake

The shoot and root silicon uptake significantly varied by different doses of Si; increasing the Si doses progressively increased both parameters (Table 3). Shoot silicon uptake varied from 103.9 to 238.8 mg pot^{-1} over the treatments. Highest shoot Si uptake was found in 400 mg Si kg^{-1} soil treatment, although 100 to 400 mg Si kg^{-1} soil treatments had statistically similar shoot Si uptake. The root Si uptake varied from 21.7 to 73.9 mg Si pot^{-1} having lowest was in control treatment and highest was in 400 mg Si kg^{-1} soil treatment. However, root Si uptake found in 50 to 400 mg Si kg^{-1} soil treatment had statistically similar. Total Si uptake significantly and progressively increased with the increase of the rate of Si application, and highest uptake was found in 400 mg Si kg^{-1} soil treatment, although it was statistically similar with 100 and 200 mg Si kg^{-1} soil treatments. The significant increase in Si uptake by Si application in rice was also reported by Pan et al. (2021). The increased Si uptake with the application of Si fertilizer might be due to the increased Si availability in soil and enhanced root system, which might in turn stimulate the plant to uptake more Si from the soil solution (Kumar et al. 2021).

Chlorophyll content

Chlorophyll a, chlorophyll b and total chlorophyll content didn't varied significantly with different silicon doses (Table 4). However, although not significant but increasing Si doses progressively increased the chlorophyll contents. Chlorophyll a content varied from 3.49 mg g^{-1} fresh leaf in control treatment to 3.76 mg g^{-1} fresh leaf in 400 mg Si kg^{-1} soil dose (Table 4). Similarly, chlorophyll b content varied from 0.780 mg g^{-1} fresh leaf in control treatment to 0.883 mg g^{-1} fresh leaf in 400 mg Si kg^{-1} soil dose. Regarding total chlorophyll content similar pattern was observed. Singh et al. (2020) reported that Si application helps to produce chlorophyll granules which ultimately improve the photosynthetic products. By addition of higher level of Si to the soil increased the Chlorophyll a, Chlorophyll b and total chlorophyll content in leaves (Verma et al. 2019).

Table 4. Effects of different doses of Si on chlorophyll content of rice (cv. BRRI dhan73)

Treatment	Leaf chlorophyll a content (mg/g fresh leaf)	Leaf chlorophyll b content (mg/g fresh leaf)	Total chlorophyll (mg/g fresh leaf)
T_1: 0 mg Si kg^{-1} soil	3.49	0.780	4.27
T_2: 5 mg Si kg^{-1} soil	3.51	0.803	4.32
T_3: 10 mg Si kg^{-1} soil	3.54	0.817	4.36
T_4: 20 mg Si kg^{-1} soil	3.53	0.817	4.34
T_5: 50 mg Si kg^{-1} soil	3.65	0.827	4.48
T_6: 100 mg Si kg^{-1} soil	3.67	0.843	4.52
T_7: 200 mg Si kg^{-1} soil	3.70	0.847	4.55
T_8: 400 mg Si kg^{-1} soil	3.76	0.883	4.64
Significance level	ns	ns	ns
CV (%)	8.94	14.80	9.81

Means with the same letter are not significantly different. CV: Coefficient of variation
ns-Not significant

Estimation of Pearson correlation coefficients

Correlation co-efficient is a measure of intensity or degree of linear relationship between two variables. Relationship between yield and yield contributing attributes was studied through analysis of correlation between them. The positive and significant associations referred information of inherent relation among the pairs of combination. The correlation among the growth, yield related parameters, Si content, and chlorophyll content of rice genotypes under different treatments at reproductive stage has been shown in Table 5. Shoot dry weight is the most important parameter in this study which was positively and significantly correlated with plant height (r=0.719***), number of tillers per hill (r=0.839***), root dry weight (0.947***), root volume (0.925***), leaf area index (r= 0.700***), root Si content (r= 0.799***), shoot Si uptake (0.967***), root Si uptake (0.929***) and total Si uptake (0.985***). However, there was a significant but negative relation of shoot dry weight with first leaf angle (r= -0.694***) and second leaf angle (r= -0.768***) of T. Aman rice.

Table 5. Pearson correlation coefficients between different plant parameters of rice under different silicon fertilizer treatments

Variables	PH	NT	SDW	RDW	RV	FLA	SLA	LAI	SSC	RSC	SSU	RSU	TSU	ChA	ChB
NT	0.527**														
SDW	0.719***	0.839***													
RDW	0.709***	0.787***	0.947***												
RV	0.766***	0.818***	0.925***	0.913***											
FLA	-0.556**	-0.64***	-0.694***	-0.731***	-0.711***										
SLA	-0.4255*	-0.790***	-0.768***	-0.789***	-0.793***	0.828***									
LAI	0.617***	0.549**	0.700***	0.749***	0.737***	-0.58**	-0.533**								
SSC	-0.049^{ns}	0.2084^{ns}	0.2752^{ns}	0.2178^{ns}	0.068***	-0.329^{ns}	-0.2823^{ns}	-0.023^{ns}							
RSC	0.733***	0.621***	0.799***	0.829***	0.859***	-0.666***	-0.688***	0.627***	0.031ns						
SSU	0.635***	0.795***	0.967***	0.900***	0.842***	-0.706***	-0.760***	0.616***	0.501**	0.72***					
RSU	0.729***	0.755***	0.929***	0.979***	0.933***	-0.734***	-0.786***	0.744***	0.129ns	0.916***	0.861***				
TSU	0.680***	0.807***	0.985***	0.949***	0.892***	-0.735***	-0.789***	0.671***	0.409*	0.797***	0.989***	0.925***			
ChA	0.260^{ns}	0.261^{ns}	0.314ns	0.341ns	0.265ns	-0.352ns	-0.217ns	0.244ns	0.243ns	0.209ns	0.357ns	0.294ns	0.349ns		
ChB	0.077ns	0.286ns	0.258ns	0.275ns	0.174ns	-0.2948 ns	-2511ns	0.205ns	0.314ns	0.168ns	0.319ns	0.228ns	0.302ns	0.886***	
TCh	0.218ns	0.275ns	0.306ns	0.332ns	0.248ns	-0.343ns	-0.232ns	0.238ns	0.265ns	0.205ns	0.354ns	0.284ns	0.344ns	0.991***	0.938***

*, ** and *** indicate significant at 5%, 1% and 0.1% level of probability, respectively and ns means not significant

PH- Plant height, NT- Number of tiller, SWD-Shoot dry weight, RDW-Root dry weight, RV-Root volume, FLA-First leaf angle, SLA- Second leaf angle, LAI- leaf area index, SSC-Shoot silicon content, RSC-Root silicon content, SSU-Shoot silicone uptake, RSU-Root silicon uptake, TSU- Total silicon uptake, ChA-Chlorophyll A, ChB-Chlorophyll B, TCh-Total chlorophyll content.

Conclusion

From the above findings it can be concluded that the 100 mg Si kg^{-1} soil is an optimal Si dose for producing higher biomass yield, leaf erectness, and Si uptake of rice. From the current findings of the experiment it can be recommended that rice could be cultivated using 100 mg Si kg^{-1} soil to achieve higher growth and yield. However, the present finding generated from the pot culture experiment, therefore this finding should be validated by conducting experiment in the field condition. A multi-location trial is therefore suggested to obtain concrete recommendation.

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Conflict of interest

The authors have declared no conflict of interest.

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