

Effect of Silicon Nutrition on Yield, Uptake and Agronomic efficiency of Paddy in Acid Lateritic Soils of Odisha

ABSTRACT

A field experiment was conducted in the central farm, Regional Research and Technology Transfer Station, Coastal Zone OUAT, Bhubaneswar during *khariif* 2020 using *cv-Lalat* variety of Rice. The experiment was laid out in randomized block design (RBD) with ten treatments and three replications. In this experiment BOF (Basic Oxygen Furnace) slag was used as a source of silica for application to rice crop. 200, 300 and 400 kg SiO₂/ha was applied in combination with 50% STD and 75% STD in order to assess the efficacy of Silica with reduction in fertilizer dose by 50% and 25%. It was shown in case of grain yield, straw yield, and harvest index, 100% STD (T₄) registered maximum (36.9q/ha) grain yield which was 29.4% more than that of control. Of course, grain yield in case of T₉ i.e., 75% STD+300kg SiO₂/ha was at par 36.2q/ha indicated efficacy of silica application by reducing fertilizer dose. Harvest index was not significantly affected by Si treatments. However, maximum HI (0.478) was observed in T₉. Available N, P, K and S status in post-harvest soil was increased significantly due to application of silica along with fertilizer over control indicated better availability of nutrients which plays a vital role in increasing production and productivity of rice. The content and uptake of N, P, K and Si was significantly increased over control due to application of silica with fertilizer. Though 100% STD (T₄) was found to be very effective as compared to other treatments but 75% STD+300kgSiO₂/ha was also equally effective so far as yield, yield attributing characters, available nutrient status, N, P, K and Si content and uptake along with Relative Agronomic Efficiency (RAE), Agronomic Efficiency (AE), Apparent Recovery (%) AR and Production Efficiency (PE) are concerned.

Keywords: Rice, Silicon, Yield, Nutrient uptake, Agronomic efficiency

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop in India. The rice production technology in this region has been discriminatory against the resource-scarce small and marginal farmers of the state due to constraints of indiscriminate use of synthetic chemicals, injudicious nutrient and water management. It is high time to focus on the resource conservation technologies for higher input use efficiency emphasizing our efforts on the conservation of renewable farm sources for achieving a sustainable agricultural production system in long run. The accessibility of Si to plant greatly depends on weathering rate of silicate minerals and release of Si to the soil solution. Plants absorb Si as a monosilicic acid (H₄SiO₄) (orthosilicic acid) by diffusion and mass flow process. The response of crops to Si application particularly rice and sugarcane have been studied by several investigators [1, 2]. Rice is having the ability to absorb and accumulate Si metabolically while many upland crop plants seem to lack such ability. Numerous experiments have shown that Si deposition in the plant tissues can improve yield, lodging resistance, insect pest and disease resistance in rice plants. So, Si has long been recognized as a beneficial element for rice, although it has not yet been proved as an essential element. The use of silica fertilizers in the form either soluble silicates or of calcium silicate

slag is still very restricted. Hence, effective practical means of application and affordable sources of Si are needed. With this backdrop, the present investigation was aimed to find out a suitable dose of SiO₂ to rice for increasing yield and uptake of paddy as well as the agronomic efficiency along with the amelioration effect of Calcium Silicate in acid soil.

2. MATERIALS AND METHODS

The experiment was conducted in Central Farm, Regional Research and Technology Transfer Station, O.U.A.T, Bhubaneswar between latitude 20.2961° N and longitude 85.8245° E and an average altitude of 45 m (148 ft) above sea level. The experiment was carried out in a Randomised Block Design (RBD) with ten treatments replicated thrice. The treatments were T1- Control, T2- 50% STD (Soil Test Dose), T3- 75% STD, T4- 100% STD, T5- 50% STD+200kg SiO₂/ha, T6- 50% STD+300kg SiO₂/ha, T7- 50% STD+400kg SiO₂/ha, T8- 75% STD+200kg SiO₂/ha, T9- 75% STD+300kg SiO₂/ha, T10- 75% STD+400kg SiO₂/ha. The soil of the experimental site was sandy, acidic reaction (pH 5.67), EC (0.16dS/m), O.C(0.41%), Av. N(178kg/ha), Av. P(13.5kg/ha), Av. K (83kg/ha), Av. S (6.8kg/ha), DTPA extractable Fe(78.8ppm), Mn(1.32ppm), Cu (0.21ppm) and Zn(0.35ppm). In the experiment BOF (Basic Oxygen Furnace) slag a byproduct of Jindal Steel Pvt. Ltd. was used as a source of silica for application to rice crop. 200, 300 and 400 kg SiO₂/ha was applied in combination with 50% STD and 75% STD to assess the effect of Silica with reduction in fertilizer dose by 25% and 50%. Rice cv. Lalat was selected for the research purpose since it suits for the medium land situation. The nutrients were applied in form of Urea, DAP and MOP and Silicate Slag as per the experimental plan. The requirement of nitrogen by the crop was supplemented in the form of DAP and Urea in three splits viz, 25% basal, 50% at active tillering stage and finally 25% at panicle initiation stage. Required amount of phosphorus were applied as 100% basal in each plot. Total amount of potassium in form of Muriate of Potash (MOP) was applied in two splits i.e., 50% at basal and 50% at PI stage. Soil application of Silicate Slag was made @ 200, 300 and 400 kg SiO₂/ha at the time of transplanting as per the treatment imposed. Soil samples and plant samples were analysed for available nutrient status by following the suitable protocol and expressed as kg ha⁻¹. The results obtained were statistically analysed using statistical analysis software (SAS).

3. RESULTS AND DISCUSSION

3.1 Effect of Silica on yield of paddy

The experimental data presented in Table 1 and Figure 1 indicates influence of Silica on plant yield attributing characters like grain yield, straw yield, and Harvest Index. Grain yield, straw yield and harvest index as influenced by application of Silica has been presented in Table 5. There was significant increase in yield over control due to application of different doses of Silica along with 50%/75% STD. Maximum grain and straw yield i.e., 36.9q/ha and 40.8q/ ha was obtained due to application of 100% STD closely followed by 36.2q/ha and 39.6q/ha due to application of. But Harvest Index was maximum (0.478) in 75%STD+300kg SiO₂/ha. This indicates though 100% STD registered maximum yield but by reducing fertilizer dose by 25% along with supplemental dose of Silica i.e., 300kgSiO₂/ha we could achieve almost equal yield.

Table 1: Effect of Silica on grain yield, straw yield, and Harvest Index of paddy

Treatment details	Grain yield(q/ha)	Straw yield (q/ha)	Harvest Index
T ₁ = Absolute Control	28.5	33.0	0.463
T ₂ = 50% STD	32.8	36.8	0.472
T ₃ = 75% STD	33.1	37.7	0.468
T ₄ = 100% STD	36.9	40.8	0.475
T ₅ = T ₂ + 200kg SiO ₂ /ha	33.7	38.0	0.470
T ₆ = T ₂ + 300kg SiO ₂ /ha	35.5	39.1	0.476
T ₇ = T ₂ + 400kg SiO ₂ /ha	34.3	38.4	0.472
T ₈ = T ₃ + 200kg SiO ₂ /ha	34.9	38.8	0.473
T ₉ = T ₃ + 300kg SiO ₂ /ha	36.2	39.6	0.478
T ₁₀ = T ₃ + 400kg SiO ₂ /ha	35.6	39.3	0.476

SE (M)	1.37	1.32	-
CD (0.05)	4.09	3.94	NS

Grain yield of rice presented in Table 4.2 revealed that there was a variation in yield from 28.5q/ha to 36.9q/ha so far as different treatments are concerned. Grain yield was maximum (36.9q/ha) in T₄(100% STD) which was almost 30% more than that of control (28.5q/ha) but it was at par (36.2q/ha) with T₉ (75% STD+300kg SiO₂/ha). All the treatments registered significantly higher yield over Control. There was a continuous increase in yield as the dose of the fertilizer increased. Application of silica along with 50% STD/75% STD did not have any significant effect on yield increase however, yield was decreased when silica application went beyond 300 kg/ha. This improvement in grain and straw yields might be due to an enhanced growth, yield components and nutrient uptake of rice with the addition of Si. Some scientists have also reported a significant increase in grain and straw yields of rice with increasing Si level [3, 4]

Variation in straw yield ranged from 33q/ha to 40.8q/ha. Maximum straw yield was obtained in T₄(100% STD) and minimum in control(33q/ha). Around 24% yield increase was observed due to application of fertilizer i.e., 100% STD over no nutrition. Of course, straw yield in 100% STD (T₄) was at par with 75% STD+300kg SiO₂/ha (T₉). An increased trend was marked when dose of fertilizer was increased. Like grain yield, application of silica in different dose along with 50%/75% STD did not have any significant effect on yield increase but straw yield was decreased over and above 300kg SiO₂/ha. The increases in both grain and straw yields might be attributed to the positive effect of Si in increasing growth and yield characteristics [4, 5], enhancing the pollen viability and photosynthetic activity [6], reducing abiotic and biotic stress, improving structural support and biomass [7] and improving nutrient uptake [4, 8]

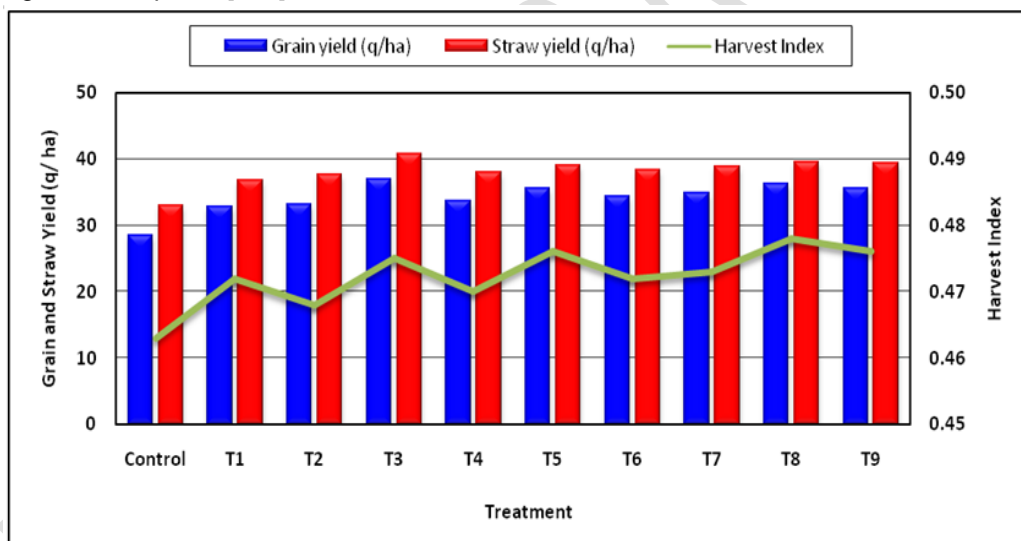


Figure 1: Grain yield, straw yield, and Harvest Index

Harvest index was almost equal irrespective of treatments imposed. But maximum HI was obtained in T₉ (0.478) which was at par with T₄ (0.475) and T₁₀ (0.476) and minimum in Control (0.463). There was no significant difference between the treatments so far as HI was concerned. Though Harvest index was maximum due to application of 75% STD+300kg SiO₂/ha but no significant difference was obtained among the treatments. This contradicts the findings of some researchers, who reported an increased harvest index of rice with Si application [4, 6].

3.2. Effect of Silica Application on Nutrient content (%) and Uptake (Kg/ha) of Paddy

3.2.1 Nitrogen content (%) in Grain and Straw

The experimental data presented in Table 2 and Figure 2 indicates influence of Silica on Nitrogen content (%) and Uptake (Kg/ha) of paddy. Different Si doses in combination with 50% STD and 75% STD had a significant effect on nitrogen content and uptakes by both grain and straw of rice

(Table 3). An increased dose of Si resulted in an increased absorption and accumulation of N in grain and straw, and consequently in total biomass. Nitrogen content in grain revealed that there was a variation in nitrogen content of grain ranged from 0.61 % to 1.28 % so far as different treatments are concerned. Nitrogen content was maximum (1.28%) in T₁₀ (75% STD +400kg SiO₂/ha) which was closely followed by T₄ and T₉ and minimum (0.61%) in control T₁ i.e., no fertilizer. All the treatments registered significantly higher Nitrogen content over Control. There was a continuous increase in Nitrogen content as the dose of the fertilizer increased. Application of silica along with 50% STD/75% STD shows increasing Nitrogen content with increased doses of silica. Application of T₂+300kg SiO₂/ha and T₃ +400kgSiO₂/ha silica shows significantly higher N content in grain over 50% STD/75% STD.

Likewise, Nitrogen content in straw varied from 0.33 % to 0.63 % in which maximum content of N (0.63%) was observed in T₁₀ (75% STD +400kg SiO₂/ha) closely followed by T₉ (0.62%) and T₄ (0.61%) and minimum N content of straw was observed in absolute control T₁(0.33%). All the treatments registered significantly higher Nitrogen content over control except T₂. There was a continuous increase in Nitrogen content in straw as the dose of the fertilizer increased. Application of silica along with 50% STD/75% STD showed an increasing trend with increased doses of silica. Application of T₂+300kg SiO₂/ha and T₃+400kg silica sustained significantly higher N content over 50% STD/75% STD and their combination with 200 kg SiO₂/ha.

The study shows an increased dose of Si resulted in an increased absorption and accumulation of N in grain and straw, and consequently in total biomass. This might be due to its potential to raise the soil-available N and N-use efficiency, which increases with increase in Si concentration, as the Si-fertilized plant gained maximum benefits of ample N availability [9]. It also found that application of Si enhanced the use of applied N to rice [10, 11].

Table 2: Nitrogen content (%) and Uptake (Kg/ha) of paddy as influenced by application of Silica

Treatments details	Content (%)		Uptake (Kg/ha)		
	Grain	Straw	Grain	Straw	Total
T ₁ = Absolute Control	0.61	0.33	17.5	11.0	28.49
T ₂ = 50% STD	0.85	0.41	28.0	15.1	43.11
T ₃ = 75% STD	0.92	0.45	30.4	17.0	47.42
T ₄ = 100% STD	1.27	0.61	46.9	25.1	72.03
T ₅ = T ₂ + 200kg SiO ₂ /ha	0.91	0.45	30.8	17.1	47.84
T ₆ = T ₂ + 300kg SiO ₂ /ha	1.13	0.57	40.1	22.2	62.30
T ₇ = T ₂ + 400kg SiO ₂ /ha	1.18	0.59	40.4	22.8	63.18
T ₈ = T ₃ + 200kg SiO ₂ /ha	0.95	0.49	33.3	19.2	52.55
T ₉ = T ₃ + 300kg SiO ₂ /ha	1.26	0.62	45.8	24.7	70.47
T ₁₀ = T ₃ + 400kg SiO ₂ /ha	1.28	0.63	45.6	24.6	70.16
SE (M)	0.04	0.031	2.11	1.52	2.96
CD (0.05)	0.119	0.092	6.29	4.52	8.79

3.2.2 Nitrogen uptake (Kg/ha) in Grain and Straw

Nitrogen uptake in grain presented in Table 2 revealed that there was a variation from 17.5 kg/ha to 46.9 kg/ha so far as different treatments are concerned. Nitrogen uptake by grain was maximum (46.9 kg/ha) in T₄(100% STD) closely followed by T₉ and T₁₀ and minimum in control (17.5 kg/ha). All the treatments registered significantly higher Nitrogen uptake by grain over Control T₁. There was a continuous increase in Nitrogen uptake in grain as fertilizer dose increased. Application of silica along with 50% STD/75% STD showed increasing Nitrogen uptake by grain. Application of T₂+300kg SiO₂/ha and T₃+400kgSiO₂/ha silica showed significantly higher N uptake over 50% STD/75% STD.

Nitrogen uptake in straw indicated a variation from 11 kg/ha to 25.1 kg/ha with respect to imposition of different treatments. Nitrogen uptake by grain was maximum (25.1 kg/ha) in T₄(100% STD) closely followed by T₉ and T₁₀ and minimum in control (11 kg/ha). All the treatments registered significantly higher Nitrogen uptake by straw over Control T₁ except T₂. There was a continuous

increase in Nitrogen uptake in straw with increased fertilizer dose. Application of silica along with 50% STD/75% STD showed increasing Nitrogen uptake by straw with increased doses of silica. Application of T₂+300kg and T₃+400kg SiO₂/ha indicated significantly higher N uptake over 50% STD/75% STD. Application of 300 and 400 kg SiO₂/ha registered significantly higher uptake over 200 kg SiO₂/ha irrespective of treatment combination.

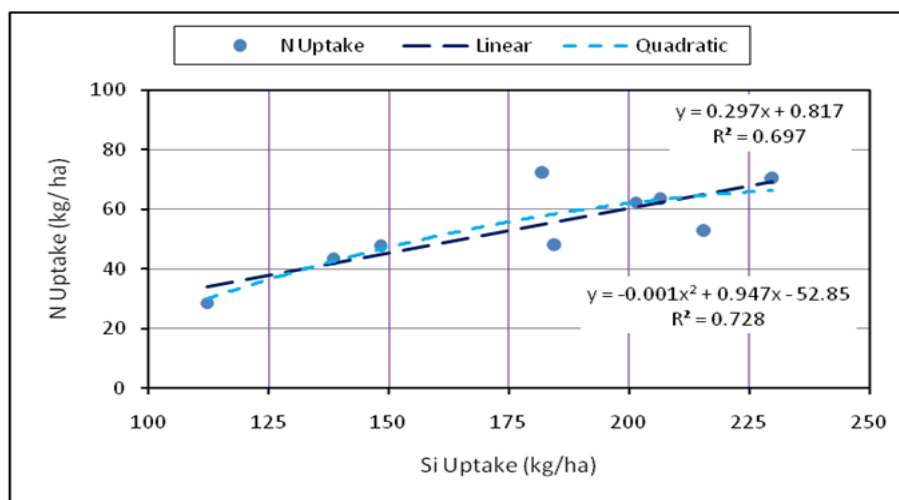


Fig. 2. Indicated better positive linear relationship ($R^2=0.69$) between total uptake of Silica and total uptake of Nitrogen.

Total uptake of Nitrogen (Grain+Straw) varied from 28.5 to 72 kg/ha i.e., maximum in T₄(100% STD) and minimum in Control. All the treatments registered significantly higher uptake over control. However, no significant variation was observed between 300 and 400kgSiO₂/ha irrespective of treatment combination. Whereas significant variation was marked between 200 and 300/400 kgSiO₂/ha. Of course, the increased trend in T₂ combination Silica treatment was not same as that of T₃ combination Silica.

3.2.3 Phosphorous content (%) in Grain and Straw

The experimental data presented in Table 3 and Figure 3 indicated influence of Silica on Phosphorous content (%) and Uptake (Kg/ha) of paddy. Phosphorous content in grain indicated a variation ranged from 0.16 % to 0.31 % so far as different treatments are concerned. Phosphorous content was maximum (0.31%) in 100% STD (T₄) closely followed by T₁₀ (75% STD +400kg SiO₂/ha) T₉(75% STD +300kg SiO₂/ha) and minimum (0.16%) in control. All the treatments registered significantly higher Phosphorous content over Control T₁ (no fertilizer). There was a continuous increase in Phosphorous content in grain as the fertilizer dose increased. Application of 300/400kg SiO₂/ha along with 50% STD/75% STD did not show any significant variation in Phosphorous content of grain. However, it was increased with increasing doses of silica.

Table 3: Phosphorous content (%) and Uptake (Kg/ha) of paddy as influenced by application of Silica

Treatment details	Content (%)		Uptake (Kg/ha)		
	Grain	Straw	Grain	Straw	Total
T ₁ = Absolute Control	0.163	0.077	4.64	2.52	7.16
T ₂ = 50% STD	0.257	0.133	8.44	4.93	13.37
T ₃ = 75% STD	0.267	0.149	8.87	5.66	14.53
T ₄ = 100% STD	0.310	0.186	11.41	7.57	18.99
T ₅ = T ₂ + 200kg SiO ₂ /ha	0.247	0.130	8.33	4.93	13.26
T ₆ = T ₂ + 300kg SiO ₂ /ha	0.262	0.157	9.30	6.12	15.42
T ₇ = T ₂ + 400kg SiO ₂ /ha	0.290	0.170	9.94	6.52	16.46
T ₈ = T ₃ + 200kg SiO ₂ /ha	0.260	0.143	9.07	5.59	14.66
T ₉ = T ₃ + 300kg SiO ₂ /ha	0.300	0.181	10.83	7.17	18.01

T ₁₀ = T ₃ + 400kg SiO ₂ /ha	0.303	0.183	10.80	7.16	17.96
SE (M)	0.014	0.012	0.53	0.47	0.77
CD (0.05)	0.041	0.035	1.59	1.40	2.30

Phosphorous content in straw varied from 0.07 % to 0.18 % in which maximum content of P (0.18%) was observed in T₄ (100% STD) which is followed by T₁₀ (75% STD+400kg SiO₂/ha) and T₉ (75% STD+300kg SiO₂/ha) and minimum P content was observed in absolute control T₁ (0.07%). All the treatments registered significantly higher P content in straw over Control T₁. There was a continuous increase in content of P as the dose of the fertilizer increased. Application of silica along with 50% STD/75% STD showed increasing P content with increased doses of silica. However, no significant difference was marked between 300 and 400kg SiO₂/ha with respective combination. The results indicated that better response of rice crops with respect to P nutrition was observed in Si-fertilized soils, which might be due to increase in root growth and enhanced soil P availability with Si application, the decreased in P-retention capacity of soil, and the increased solubility of P, leading to increased efficiency of phosphatic fertilizers [12].

3.2.4. Phosphorous uptake (Kg/ha) in Grain and Straw

Phosphorous uptake in grain presented in Table 3 indicated that there was a variation ranged from 4.64 kg/ha to 11.41 kg/ha so far as different treatments are concerned. Phosphorous uptake by grain was maximum (11.41 kg/ha) in T₄ (100% STD) and minimum in control (4.64 kg/ha) but it was at par with T₉ (75% STD+300kg SiO₂/ha) and T₁₀ (75% STD+400kg SiO₂/ha). All the treatments registered significantly higher Phosphorous uptake by grain over Control T₁. There was an increase in P uptake in grain with increased dose of fertilizer. Application of silica along with 50% STD/75% STD showed increasing P uptake with increased doses of silica which was not significant in case of 50% STD with its different combination of Silica.

Phosphorous uptake in straw varied from 2.52 kg/ha to 7.57 kg/ha in which maximum uptake of P was observed (7.57 kg/ha) in T₄ (100% STD) and minimum uptake of P (2.52kg/ha) by straw was observed in absolute control T₁ i.e., no fertilizer. However, P uptake by straw in T₉ (75% STD +300kg SiO₂/ha). and T₁₀ (75% STD +400kg SiO₂/ha) were at par with T₄. All the treatments registered significantly higher P uptake in straw over Control T₁. There was an increase in Phosphorous uptake by straw as the dose of the fertilizer increased. No significant difference was marked with application of 300kg and 400kg SiO₂/ha silica along with 50% STD/75% STD. However, application of 400kg SiO₂/ha silica registered significantly higher P uptake by straw over 200 kg SiO₂/ha irrespective of 50%/75% STD combination.

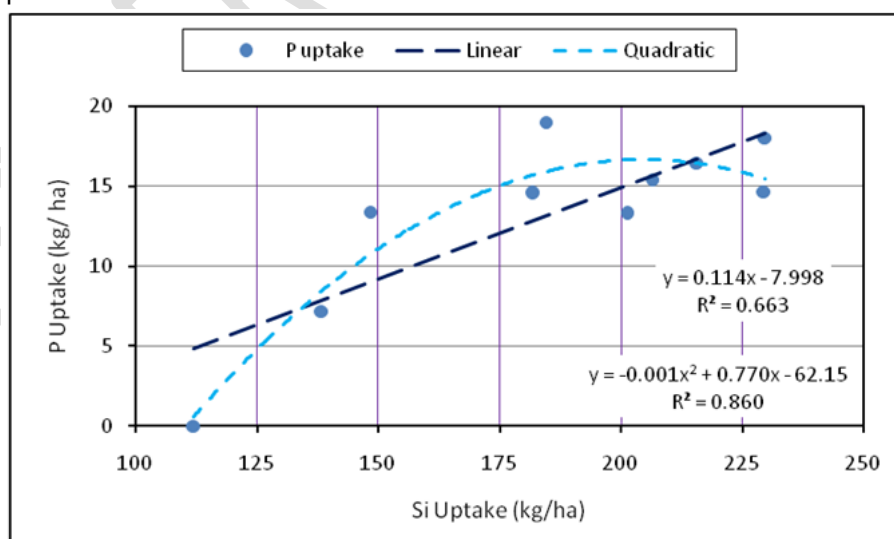


Fig. 3. Indicated better positive linear relationship ($R^2=0.66$) between total uptake of Silica and total uptake of Phosphorous.

Total uptake of Phosphorous (grain+straw) varied from 7.16 kg/ha to 18.99 kg/ha in which maximum total uptake of P was recorded in T₄ (100% STD) which was closely followed by (75% STD +300kg SiO₂/ha) and minimum uptake of P (7.16kg/ha) was observed in absolute control T₁. All the treatments registered significantly higher total Phosphorous uptake over Control. There was an increase in total Phosphorous uptake as the dose of the fertilizer increased. With application of 200kg SiO₂/ha and 300kg SiO₂/ha silica along with 50% STD/75% STD, there was no significant increase in total Phosphorous uptake. However, with application of 400kg SiO₂/ha silica, total Phosphorous uptake recorded significant increase over 200 kg SiO₂/ha irrespective of 50% STD/75% STD.

3.2.5. Potassium content (%) in Grain and Straw

The experimental data presented in Table 4 and figure 4 indicates influence of Silica on Potassium content (%) and Uptake (Kg/ha) of paddy. Potassium content in grain indicated that there was a variation ranged from 0.29 % to 0.47 % so far as different treatments are concerned. Potassium content in grain was maximum (0.47%) in T₄(100% STD) and minimum in control (0.29%). All the treatments registered significantly higher Potassium content over Control T₁ (no fertilizer). There was a continuous increase in Potassium content in grain as the dose of the fertilizer increased. Application of silica along with 50% STD/75% STD reflected increasing Potassium content with increased doses of silica, but it was not significant.

Table 4: Potassium content (%) and Uptake (Kg/ha) of paddy as influenced by application of Silica

Treatment details	Content (%)		Uptake (Kg/ha)		
	Grain	Straw	Grain	Straw	Total
T ₁ = Absolute Control	0.29	0.71	8.16	23.59	31.75
T ₂ = 50% STD	0.41	1.22	13.42	44.67	58.09
T ₃ = 75% STD	0.44	1.27	14.52	47.86	62.38
T ₄ = 100% STD	0.47	1.60	17.43	65.27	82.70
T ₅ = T ₂ + 200kg SiO ₂ /ha	0.38	1.30	12.90	49.35	62.25
T ₆ = T ₂ + 300kg SiO ₂ /ha	0.40	1.38	14.22	54.05	68.27
T ₇ = T ₂ + 400kg SiO ₂ /ha	0.43	1.40	14.60	53.97	68.57
T ₈ = T ₃ + 200kg SiO ₂ /ha	0.39	1.52	13.72	59.11	72.82
T ₉ = T ₃ + 300kg SiO ₂ /ha	0.46	1.60	16.86	63.48	80.34
T ₁₀ = T ₃ + 400kg SiO ₂ /ha	0.47	1.61	16.65	63.49	80.14
SE (M)	0.026	0.079	1.07	3.11	3.38
CD (0.05)	0.078	0.235	3.20	9.25	10.04

Potassium content in straw varied from 0.71 % to 1.61 % in which maximum content of K was observed in T₁₀ (75% STD+400kg SiO₂/ha) closely followed by T₄ and T₉ and minimum K content of straw was observed in absolute control T₁. All the treatments registered significantly higher K content of straw over Control T₁. There was a continuous increase in K content of straw as the dose of the fertilizer increased. Application of gradual increase in silica along with 50% STD/75% STD didn't show any significant difference in K content by straw. Also, the positive response of greater Si application towards K concentration was observed and can be linked to silicification of the cell wall [4]. It was reported that application NPK fertilizer in combination with Si significantly increased total N, P, and K content of rice [13]. Furthermore, it should be noted that Si application can alleviate the K-deficiency-induced growth inhibition by improving plant-water status via enhancement of stomatal conductance and transpiration rates [14]

3.2.6 Potassium uptake (Kg/ha) in Grain and Straw

Potassium uptake in grain presented in Table 4 revealed that grain uptake of Potassium varied from 8.16 kg/ha to 17.43 kg/ha i.e. maximum(17.43kg/ha) in T₄(100%STD) and minimum(8.16kg/ha) in T₁(Control). K uptake in grain in T₉ (75% STD+300kg SiO₂/ha) and T₁₀ (75% STD+400kg SiO₂/ha) were at par with T₄ (100% STD). All the treatments registered significantly higher K uptake by grain over Control T₁. Potassium uptake in grain was increased significantly with increased dose of the fertilizer. Application of silica along with 50% STD/75% STD showed non-significant increase in Potassium uptake. with increased doses of silica.

Potassium uptake in straw varied from 23.59 kg/ha to 65.27 kg/ha in which maximum (65.27 kg/ha) uptake of K by straw was observed in T₄ (100% STD) and minimum uptake of K was observed in absolute control T₁ i.e., no fertilizer. However, K uptake by straw in T₉ (75% STD+300kg SiO₂/ha) and T₁₀ (75% STD+400kg SiO₂/ha) were at par with T₄(100% STD. There was a continuous increase in Potassium uptake in straw as the dose of the fertilizer increased from 0 to 100% STD. In case of application of silica in combination with 50 % STD, it was observed that Potassium uptake in straw was increased with increased application of silica, but it was decreased over and above 300kg SiO₂/ha. However, in case of application of silica in combination with 75 % STD, Potassium uptake by straw was significantly increased with increased application of silica.

Total uptake (grain+ straw) of Potassium varied from 31.75 to 82.7 kg/ha in which maximum uptake of K was recorded in T₄ (100% STD) and minimum uptake of K was observed in absolute control T₁ i.e., no fertilizer. However, total K uptake in T₉ (75% STD+300kg SiO₂/ha) and T₁₀ (75% STD+400kg SiO₂/ha) were at par with T₄(100% STD. All the treatments registered significantly higher total Potassium uptake over Control. There was an increase in total uptake of Potassium as the dose of the fertilizer increased. Application of silica in different dose along with 50%/75% STD didn't show any significant difference in total uptake of K.

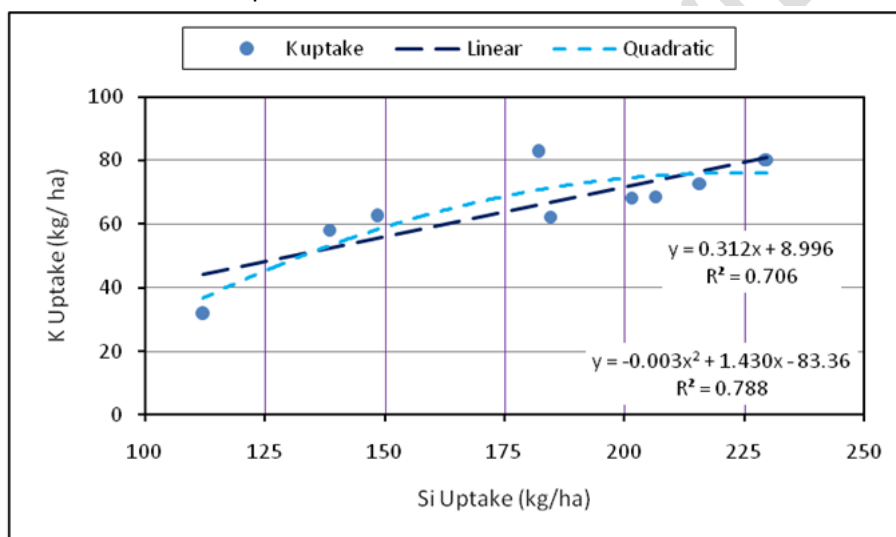


Fig. 4. Indicated better positive linear relationship ($R^2=0.70$) between total uptake of Silica and total uptake of Potassium

3.2.7. Silicon content (%) in Grain and Straw

The experimental data presented in Table 5 and Figure 5 indicates influence of Silica on Silicon content (%) and Uptake (Kg/ha) of paddy. Silicon content in grain presented in Table 6 indicated a variation ranged from 1.12 to 2.12 % so far as different treatments are concerned. There was a steady increase in silicon content in grain from T₁ (Control) to T₁₀ (75% STD + 400kg SiO₂/ha). Of course, minimum silicon content (1.12) in grain was observed in T₁ (Control) and maximum in T₁₀ (75% STD+400kg SiO₂/ha). 100% STD registered significantly higher Silicon content in grain over Control. No significant difference in silicon content of grain was marked between 50% STD and 75% STD. The treatment applied with Silica in combination with 50%/75% registered significantly higher silicon content over 100% STD.

Table 5: Silicon content (%) and Uptake (Kg/ha) of paddy as influenced by application of Silica

Treatment details	Content (%)		Uptake (Kg/ha)		
	Grain	Straw	Grain	Straw	Total
T ₁ = Absolute Control	1.12	2.43	32.06	80.09	112.15
T ₂ = 50% STD	1.18	2.71	38.82	99.65	138.47
T ₃ = 75% STD	1.24	2.85	41.05	107.33	148.38
T ₄ = 100% STD	1.41	3.19	52.05	129.99	182.04
T ₅ = T ₂ + 200kg SiO ₂ /ha	1.59	3.45	53.43	131.12	184.55

T ₆ = T ₂ + 300kg SiO ₂ /ha	1.72	3.61	61.13	140.24	201.37
T ₇ = T ₂ + 400kg SiO ₂ /ha	1.90	3.69	65.13	141.35	206.48
T ₈ = T ₃ + 200kg SiO ₂ /ha	1.97	3.78	68.80	146.91	215.71
T ₉ = T ₃ + 300kg SiO ₂ /ha	2.09	3.88	75.65	153.81	229.46
T ₁₀ = T ₃ + 400kg SiO ₂ /ha	2.12	3.91	75.85	153.90	229.75
SE (M)	0.045	0.169	2.99	5.05	6.32
CD (0.05)	0.135	0.503	8.90	15.02	18.79

Silicon content in straw varied from 2.43 % to 3.91 % in which maximum content of Si was observed in T₁₀ (75% STD+400kg SiO₂/ha) closely followed by T₉ and minimum Si content (2.43%). No significant variation between 50% STD and 75% STD was observed. However, 100% STD registered significantly higher Silicon content in straw over Control. No significant difference in silicon content of straw was observed within 50%/75% STD along with different doses of silica application. Results from the experiment showed that application of Si caused a significantly increased content and uptake of Si in both grain, straw, and total uptake of paddy. This increased Si uptake might be related to the increased Si availability in soil and enhanced root system, which stimulates the plant to absorb more Si from soils [4]. It was also expressed that although Si is an abundant element in soil, plant-available Si usually presents at low concentration in the soil solution and its uptake is mainly dependent on the Si-supplying ability of the soil [15, 16]

3.2.8. Silicon uptake (Kg/ha) in Grain and Straw

Silicon uptake in grain presented in Table 5 revealed that grain uptake of silicon varied from 32 kg/ha to 75.85 kg/ha i.e., maximum(75.85kg/ha) in T₁₀ (75% STD+400kg SiO₂/ha) and minimum (32kg/ha) in T₁(Control). Si uptake in grain in T₉ (75% STD+300kgSiO₂/ha) was at par with T₁₀. All the treatments registered significantly higher Si uptake by grain over Control T₁ except T₂. Silicon uptake in grain was increased with increased dose of the fertilizer. Application of silica along with 50% STD/75% STD didn't show any significant difference in Si uptake with increased doses of silica.

Si uptake in straw varied from 80 kg/ha to 153.9 kg/ha in which maximum (153.9 kg/ha) uptake of Si by straw was observed in T₁₀ (75% STD+400kg SiO₂/ha) and minimum uptake of Si was observed in absolute control T₁ i.e., no fertilizer. However, Si uptake by straw in T₉ (75% STD+300kg SiO₂/ha) was at par with T₁₀(75% STD+400kg SiO₂/ha). All the treatments showed significant increase in Si uptake by straw over Control (T₁). There was a continuous increase in Si uptake in straw as the dose of the fertilizer increased from 0 to 100% STD. In case of application of silica in combination with 50 %/75% STD, it was observed that Silicon uptake in straw was increased with increased application of silica.

Total Si uptake (grain + straw) in paddy varied from 112 kg/ha to 229.7 kg/ha in which maximum (229.7kg/ha) total uptake of Si was observed in T₁₀ (75% STD+400kg SiO₂/ha) and minimum total uptake of Si was observed in absolute control T₁ i.e., no fertilizer. However, total Si uptake by paddy in T₉ (75% STD+300kg SiO₂/ha) was at par with T₁₀(75% STD+400kg SiO₂/ha). All the treatments showed significant increase in total Si uptake over Control (T₁). There was a continuous increase in total Si uptake as the dose of the fertilizer increased from 0 to 100% STD. In case of application of silica in combination with 50 %/75% STD, it was observed that total Silicon uptake by paddy was increased with increased application of silica.

3.3. Apparent recovery, Relative Agronomic Efficiency (RAE) Agronomic Efficiency (AE) and Production efficiency (PE) as influenced by application of Silica

Apparent recovery, Relative Agronomic Efficiency (RAE) Agronomic Efficiency (AE) and Production efficiency (PE) has been calculated taking experimental data which was depicted in table 6.

3.3.1 Apparent recovery (AR) (%): -This is nothing but a relation between total quantity of nutrient uptake with respect to total quantity of nutrient applied.

$$AR(\text{Silicon}) = \left(\frac{\text{Total Uptake of Silica in treatment (kg/ha)} - \text{Total Uptake of Silica in control (kg/ha)}}{\text{Total Silica Applied (Kg/ha)}} \right) \times 100$$

Apparent recovery of Silica varied from 36.4 to 71.7% i.e., maximum in 75% STD + 200kg SiO₂/ha closely followed by 75% STD + 300kg SiO₂/ha and minimum in T₂+400kg SiO₂/ha. There was gradual decline in % recovery of Silica when application of Silica increased from 200 to 400kg SiO₂/ha irrespective of treatment combination.

3.3.2. Relative Agronomic Efficiency (RAE): - It is a comparison of treatments by selecting one treatment giving highest yield. In this case 100% STD is considered the best treatment amongst all.

$$\text{RAE \%} = \frac{\text{Yield obtained in Treatment (Kg/ha)} - \text{Yield obtained in Control (Kg/ha)}}{\text{Highest yield in treatment (Kg/ha)} - \text{Yield in Control (Kg/ha)}} \times 100$$

Table 4.9 Indicated maximum RAE (%) in T₉ i.e., 75% STD+300kg SiO₂/ha closely followed by T₁₀ (75% STD+400kg SiO₂/ha) and T₆ (50% STD+ 300kgSiO₂/ha). There was a gradual increase in RAE (%) as the fertilizer dose increased.

3.4.3. Agronomic Efficiency (AE): -Agronomic efficiency (AE) is calculated as Kg grain produced per Kg nutrient applied. It more closely reflects the direct production impact of an applied nutrient and relates directly to economic return.

$$\text{AE} = \frac{\text{Yield obtained in Treatment (Kg/ha)} - \text{Yield obtained in Control (Kg/ha)}}{\text{Silica applied (Kg/ha)}} \times 100$$

In this case Silica is taken as a nutrient and there is a treatment combination of 50% STD and 75% STD, hence while calculating AE control yield is taken as the yield of 50% STD/75% STD because Silica is applied along with 50%/75% STD. Agronomic Efficiency varied from 0.92 to 2.18 i.e., minimum in 50% STD+200kg SiO₂/ha and maximum in 75% STD+300kg SiO₂/ha.

Table 6: Efficiency and recovery of Silica when applied along with different combination with fertilizer dose.

Treatment details	Grain Yield (kg/ha)	Total Silica applied (Kg/ha)	Total Si Uptake (Kg/ha)	Apparent Recovery (%)	RAE	AE	PE
T ₁ = Absolute Control	2850	-	112.15	-	-	-	-
T ₂ = 50% STD	3287	-	138.47	-	51.6	-	-
T ₃ = 75% STD	3317	-	148.38	-	55.1	-	-
T ₄ = 100% STD	3697	-	182.04	-	100.0	-	-
T ₅ = T ₂ + 200kg SiO ₂ /ha	3373	93.46	184.55	49.2	61.7	0.92	1.87
T ₆ = T ₂ + 300kg SiO ₂ /ha	3553	140.19	201.37	44.2	83.0	1.90	4.23
T ₇ = T ₂ + 400kg SiO ₂ /ha	3433	186.92	206.48	36.4	68.8	0.78	2.15
T ₈ = T ₃ + 200kg SiO ₂ /ha	3490	93.46	215.71	71.7	75.6	1.85	2.57
T ₉ = T ₃ + 300kg SiO ₂ /ha	3623	140.19	229.46	57.8	91.3	2.18	3.77
T ₁₀ = T ₃ + 400kg SiO ₂ /ha	3567	186.92	229.75	43.3	84.7	1.34	3.07

3.3.4. Production Efficiency (PE): -Production efficiency (PE) is calculated as Kg grain produced per Kg nutrient uptake. It more closely reflects the direct production impact of uptake of nutrient and relates directly to economic return.

$$\text{PE} = \frac{\text{Yield obtained in Treatment (Kg/ha)} - \text{Yield obtained in Control (Kg/ha)}}{\text{Total uptake of Silica in treatment (Kg/ha)} - \text{Total uptake of Silica in Control (Kg/ha)}} \times 100$$

While calculating PE control yield is taken as the yield of 50% STD/75% STD because Silica is applied along with 50%/75% STD. Similarly Total uptake of Silica in Control indicates total uptake of Silica by 50%/75% STD. Production Efficiency varied from 1.87 to 4.23 i.e., minimum in 50% STD+200kg SiO₂/ha and maximum in 50% STD+300kg SiO₂/ha closely followed by 75% STD+300kg SiO₂/ha.

4. CONCLUSION

Rice is considered as Si accumulator and a high Si demanding crop. Increasing rice yield per unit area is associated with Si depletion, which is a matter of concern. Rice plant contains 1-10% silica considered as a major source of silica needs to be incorporated for replenishment. This suggests that Si may become a yield-limiting element for rice production, therefore, application of exogenous Si fertilizer may be necessary for an economic and sustainable rice production system. The content and uptake of N, P, K and Si was significantly increased over control due to application of silica with fertilizer. Application of 75% STD +300 kg SiO₂ / ha i.e., treatment T9 was found to be very effective in increasing yield and yield attributing character, amelioration of acidic soil and reduction in Iron and Manganese toxicity. Maximum Harvest Index (HI), Relative Agronomic Efficiency (RAE) and Agronomic Efficiency (AE) seems to be maximum in case of 75% STD+300kg SiO₂/ha (T9). It has also a positive effect on increasing available N, P, K and S status in post-harvest soil as compared to initial soil test value. The content and uptake of N, P, K and Si was also increased by reducing fertilizer dose by 25% i.e., T9 (75% STD+300kg SiO₂/ha) with supplemental dose of silica i.e., 300kg SiO₂/ha. Hence it is recommended to go for application of silica with a dose of 300kg SiO₂/ha along with 75% STD.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. 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.

REFERENCES

1. Padmaja P and Verghese EJ (1972). Effect of Ca, Mg and Si on the uptake of plant nutrients and availability of straw and grain of paddy. *Agri. Res. J. Kerala*, **10**: 100-105.
2. Dong CT, Liu ZG, Zou BJ, Zhu C, Zhang CL and Liang W. (1981). 1. Study on the nutrition of rice. 2. Effect of Zinc and Silicon in increasing rice yield. *Lianing Agri. Sci.* **4**: 13-18.
3. Deren CW, Datnoff LE, Snyder GH and Martin FG. (1994). Silicon concentration, disease response and yield components of rice genotypes grown on flooded organic histosols. *Crop Science*, **34**(3): 733–737.
4. Pati S, Pal B, Badole S, Hazra GC & Mandal B (2016). Effect of Silicon Fertilization on Growth, Yield, and Nutrient Uptake of Rice, *Communications in Soil Science and Plant Analysis*, **47**:3, 284-290.
5. Prakash NB, Chandrashekar N, Mahendra C, Patil SU, Thippeshappa GN, Laane HM (2011). Effect of foliar spray of soluble silicic acid on growth and yield parameters of wetland rice in hilly and coastal zone soils of Karnataka, South India. *Journal of Plant Nutrition*, **34**(12):1883-1893.
6. Detmann K C, Araújo W L, Martins S C V, Sanglard L M V P, Reis J V, Detmann E, Rodrigues F Á, Nunes-Nesi A, Fernie A R, DaMatta F M. 2012. Silicon nutrition increases grain yield, which, in turn, exerts a feed-forward stimulation of photosynthetic rates via enhanced mesophyll conductance and alters primary metabolism in rice, *The New Phytologist Vol. 196*, No. **3** (November 2012), pp. 752-762 (11 pages).
7. Meharg C, Meharg AA. 2015. Silicon, the silver bullet for mitigating biotic and abiotic stress, and improving grain quality, in rice? *Environmental and Experimental Botany*, **120**, 8-17.
8. Crooks R and Prentice P (2017). Extensive investigation into field-based responses to a silica fertilizer. *Silicon*, **9**(2): 301–304.
9. Singh AK, Singh R and Singh K (2005). Growth, yield and economics of rice (*Oryza sativa*) as influenced by level and time of silicon application. *Indian Journal of Agronomy*. **50**(3):190-193.

10. Sadanandan AK and Verghese EJ (1969) Role of Silicate in the uptake of nutrients by rice plants in the lateritic soils of Kerala. *Agric. Res. J. Kerala*. **7**: 91-96.
11. Sawant NK, Datnoff LE, and Snyder GH (1997). Depletion of plant available silicon in soils: A possible cause of declining rice yields. *Communications in Soil Science and Plant Analysis*, **28**:1245–52.
12. Subramanian S, and Gopalswamy A (1991). Effect of moisture, organic matter, phosphate, and silicate on availability of silicon and phosphorus in rice soils. *Journal of the Indian Society Soil Science*, **39**:99–103
13. Chanchareonsook J, Suwannarat C, Thongpae S, Chanchareonsook S, and Thinyai P (2002). Effects of application of chemical fertilizer in combination with silicon on yield and nutrient uptake of rice in an acid sulfate soil. *Paper presented in Symposium on 17th WCSS*, 14–21st August 2002, Thailand.
14. Chen DQ, Cao BB, Wang SW, Liu P, Deng XP, Yin LA and Zhang SQ (2016). Silicon moderated the K deficiency by improving the plant-water status in sorghum. *Scientific Reports*, **6**: 22882.
15. Jawahar S and Vaiyapuri V (2013). Effect of sulphur and silicon fertilization on yield, nutrient uptake, and economics of rice. *International Research Journal of Chemistry*, **1**:34–43.
16. Nagula S, Joseph B and Gladis R (2016). Silicon Nutrition to Rice (*Oryza sativa* L.) Alleviates Fe, Mn and Al Toxicity in Laterite Derived Rice Soils. *Journal of the Indian Society of Soil Science*, Vol. 64, No. **3**, pp 297-301.