Original Research Article

EFFECT OF SILICON NUTRITION ON GROWTH, YIELD AND NUTRIENT STATUS OF PADDY IN ACID LATERITIC SOILS OF ODISHA

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ABSTRACT

A field experiment was conducted in the central farm, Regional Research and Technology Transfer Station, Coastal Zone OUAT, Bhubaneswar during *kharif* 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 SiO_2/ha was applied in combination with 50% STD and 75% STD to assess the efficacy of Silica with reduction in fertilizer dose by 50% and 25%. It was shown that there was significant increase in number of effective tillers (7.8) per plant and length of the panicle (25.8 cm), but no significant increase was marked in case of 1000 grain weight (g~~m.~~) over control. In case of grain yield, straw yield and harvest index, 100% STD (T_4) registered maximum (36.9q/ha) grain yield which was 29.4% more than that of control. Of course, grain yield in case of T_9 i.e., 75% STD+300kg SiO_2/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 T_9. 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 study revealed that the DTPA extractable Fe and Mn content decreased, and Cu and Zn content increased with increased application of silica. Though 100% STD (T_4) was found to be very effective as compared to other treatments but 75% STD + 300kg SiO_2/ha was also equally effective so far as yield, yield attributing characters, available nutrient status of paddy.

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Keywords: *Rice, Silicon, Growth, Yield, Nutrient status*

1. INTRODUCTION

Silicon (Si) is graded as the second-most abundant element (after oxygen) in the earth's crust with nearly 29% mean content [1]. The predominant form of Si in soil solution is monosilicic acid (H_4SiO_4)

[2]. Iron and Al-oxides of soil have the capacity to adsorb a significant amount of Si on their surfaces. The potential of Si in improving crop yield has been established in many studies, especially under abiotic and biotic stress conditions like drought, heavy metals, salinity, and pathogens [3, 4, 5, 6]. Si is known for its role in alleviating the negative stress effects on many plant species. Rice (*Oriza sativa* L.) is a high Si accumulating plant [2]. Besides rice yield increase, Si has many fold advantages of increasing nutrient availability (N, P, K, Ca, Mg, S and Zn) [7], decreasing nutrient toxicity (Fe, Mn, and Al) and minimizing biotic and abiotic stress in plants [8]. Hence, the application of Si to soil or plant is practically useful in laterite derived rice soils, not only to increase yield but also to alleviate the Fe toxicity problems. In general farmers export silicon from field by removing straw residues with the harvest and the exogenous application of silicon in rice is overlooked. Therefore, a continued supply of Silicon would be required predominantly for the healthy and productive development of plant during all growth stages [9]. 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 background, the present study was undertaken to find out a suitable dose of SiO_2 for increasing growth and yield attributing character in rice by alleviating the toxicity of Fe, Mn, and Al in acidic soils.

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~~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 were analysed for available nutrient status before and after the harvest of the crop and expressed as kg ha-1. Biometric observations i.e., growth and yield attributing parameters like plant height, number of tillers and panicles per hill, panicle length, grains per panicle, 1000 grain weight etc. were recorded at different

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growth stage and at harvest. The results obtained were statistically analysed using statistical analysis software (SAS).

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3. RESULTS AND DISCUSSION

3.1. Effect of Silica on growth attributing characters of paddy

The experimental data presented in Table 1 indicates influence of Silica on plant growth attributing characters like number of effective tillers per plant, length of the panicle and 1000 grain weight.

Table 1: Effect of Silica on number of effective tillers per plant, length of the panicle and 1000 grain weight

Treatment details	Number of effective tillers per plant	Length of the panicle (cm)	1000 grain wt. (g~~m~~)
T_1 = Absolute Control	5.5	22.5	21.8
T_2= 50% STD	6.1	23.2	22.1
T_3= 75% STD	6.3	24.1	22.2
T_4= 100% STD	8.4	25.8	23.1
T_5= T_2+ 200kg SiO_2/ha	6.5	24.5	22.4
T_6= T_2+ 300kg SiO_2/ha	7.1	25.0	22.7
T_7= T_2+ 400kg SiO_2/ha	6.6	24.7	22.4
T_8= T_3+ 200kg SiO_2/ha	6.9	24.9	22.5
T_9= T_3+ 300kg SiO_2/ha	7.4	25.8	23.0
T_{10} = T_3+ 400kg SiO_2/ha	7.3	25.4	22.8
SE (M)	0.18	0.26	-
CD (0.05)	0.55	0.78	NS

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Number of effective tillers per plant varied from 5.5 to 8.4 in which lowest number of tillers was observed in T_1 i.e., Absolute control (No Fertilizer) and significantly maximum number of tillers was observed in T_4 i.e.,100% STD. Number of effective tillers increased as the fertilizer dose increased. In case of application of silica in combination with 50 and 75% STD, maximum number of tillers was obtained due to application of 300kg SiO_2/ha which was reduced with increased application of silica. 100% STD was superior to all other treatments but 75% STD+300kg SiO_2/ha was also equally effective when all the characters taken together. Hence, by reducing the fertilizer dose by 25% and applying 300kg SiO_2/ha we can achieve the desired quality. In our study, the increase in total number of effective tillers per plant might be attributed to increased availability of phosphorus and other beneficial effect of silicon on growth of paddy. These results are in confirmation with those reported by those who also reported the beneficial role of Si fertilizer in increasing number of effective tillers per plant [10, 11, 12, 13, 14, 15].

Length of the panicle was varied from 22.5 cm to 25.8 cm. with lowest in T_1 (Absolute control). 100% STD (T_4) and 75% STD + 300 kg SiO_2/ha (T_9) registered significantly maximum panicle length which is 14.6% more than that of control. There was gradual increase in panicle length as the fertilizer dose increased. Application of 300kg SiO_2/ha registered maximum panicle length when compared with 200 and 400kg SiO_2/ha irrespective of integration of fertilizer dose. Of course, there was no significant difference between 300 and 400 kg SiO_2/ha so far as length of the panicle is concerned. The study shows an increase in length of panicle which is also in confirmation with some experiments [13, 16]

1000 grain wt. varied from 21.8gm to 23.1 gm. Application of silica. Increased fertilizer dose did not have any significant effect on 1000 grain wt. It was lowest in absolute control i.e., 21.8 gm and highest in 100% STD i.e., 23.1 gm which was at par with 75% STD + 300kg SiO_2/ha. There was no significant difference between the treatments. Application of Silica which contradicts the findings of some research works, which shows significantly increased 1000-grain weight with application of Si fertilizer [17, 13, 18, 15]

3.2. Effect of Silica on pH, Electrical Conductivity and Organic Carbon content of post-harvest soil

The experimental data presented in Table 2 indicates effect of Silica on pH, Electrical Conductivity and Organic Carbon in post-harvest soil. The study shows increase in pH, Electrical Conductivity (EC) and Organic Carbon (OC) in post-harvest soil due to application of Silica.

It was observed that that there was a variation in pH value so far as different treatments are concerned. pH value decreased with T_2 (50% STD) over T_1 but increased with further application of fertilizer i.e., T_3 (75% STD) and T_4 (100% STD) over control. pH value was recorded maximum (5.98) in $T_{10.}$ Application of silicon in different doses along with T_2 (50% STD) and T_3 (75% STD) shows increase in pH value. However, this increase was not significant. This increase in soil pH could be attributed to the fact that silicate materials can increase soil reaction and help in correcting soil acidity by neutralizing exchangeable Fe, Al and Mn and other toxic elements [19]. These results were also in line with that reported by some scientists [20, 21, 22, 9]

Variation in Electrical Conductivity ranged from 0.118 dS/m to 0.148 dS/m. Electrical Conductivity was maximum in T_{10} (75% STD+400kg SiO_2/ha) and minimum in control (0.118 dS/m). There was gradual increase in Electrical Conductivity of post-harvest soil as the fertilizer dose increased. However, the increase was not significant. Application of silica in different doses along with T_2 (50% STD) or T_3 (75% STD) showed an increasing trend. The silicon application in soil resulted in increase in soil Electrical Conductivity (EC) after the experiment. This might be attributed to submergence, increase in solubility of salts present in the soil and due to the dissolution of silicon fertilizers.

There was a variation ranging from 0.31 % to 0.48 % of OC in post-harvest soil so far as different treatments are concerned. Maximum OC content (0.48%) in soil was recorded in T_4 (100% STD) and T_7 (50% STD+ 400kg SiO_2/ha) as compared to lowest in absolute control T_1. This increase in OC content in soil was 55% more over control. With increase in fertilizer doses, the percentage of OC was also increased. All the treatments registered significantly higher OC content over Control. In case of application of silica, in combination with 50% and 75% STD, the percentage of OC increases but the increase was not significant. Application of 400kg SiO_2/ha registered maximum organic carbon content in soil when compared with 200 and 300kg SiO_2/ha irrespective of integration of fertilizer dose. The increase in soil organic carbon (OC) was due to the reason that organic materials had direct impact on mineralization rate that increases soil organic carbon directly [23].

Table 2: Effect of Silica on soil pH, Electrical Conductivity and Organic Carbon content of post-harvest soil sample

Treatment details	pH	E.C(dS/m)	O.C (%)
T_1 = Absolute Control	5.41	0.118	0.31
T_2= 50% STD	5.20	0.121	0.42
T_3= 75% STD	5.48	0.130	0.45
T_4= 100% STD	5.64	0.135	0.48
T_5= T_2+ 200kg SiO_2/ha	5.71	0.120	0.41
T_6= T_2+ 300kg SiO_2/ha	5.85	0.124	0.44
T_7= T_2+ 400kg SiO_2/ha	5.91	0.136	0.48
T_8= T_3+ 200kg SiO_2/ha	5.89	0.142	0.42
T_9= T_3+ 300kg SiO_2/ha	5.90	0.146	0.43
T_{10} = T_3+ 400kg SiO_2/ha	5.98	0.148	0.46
SE (M)	0.13	0.006	0.03
CD (0.05)	0.39	0.018	0.09

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3.3. Effect of Silica on available soil nutrients in post-harvest soil

The experimental data presented in Table 3 indicates effect of Silica on available soil nutrients in post-harvest soils like Nitrogen (N), Phosphorous (P), Potash (K) and Sulphur (S). Analysis of initial soil sample indicated low available N (178 kg/ha), P (13.5kg/ha), K (83kg/ha) and S (6.8kg/ha) status which when compared with post-harvest soil analysis found a little increase due to application of Silica. Maximum available N(201.7kg/ha), P(14.5kg/ha), K (92.2 kg/ha) and S (16.2 kg/ha) status was observed in 75% STD+ 300kg SiO_2/ha which enlighten us about the beneficial effect of application of silica to soil when compared with control. It was stated that beside yield enhancement in rice, silicon also has many fold advantages of increasing availability of major nutrients and also alleviating iron toxicity problems in soil [24]. These results are confirmative with some findings [25, 26, 27, 9]

Available N status ranged from 170.5 kg/ha to 201.7 kg/ha with lowest in T_1 i.e., Absolute control (No Fertilizer) and significantly maximum in T_9 i.e., 75% STD+ 300kg SiO_2/ha. Increased trend in available N status was observed as the fertilizer dose increased. All the treatments registered significantly higher available Nitrogen over Control except T_2 (50% STD). In case of application of silica in combination with 50 % STD, it was observed that available N status was increased with increased application of silica, and it was found maximum due to application of 400kg SiO_2/ha, but the increase was not significant. However, in case of application of silica in combination with 75 % STD, available N status was maximum (201.7 kg/ha) due to application of 300kg SiO_2/ha which was reduced with further application of silica. The study shows an increased dose of Si have its potential to raise the soil-available N and N-use efficiency and plant gained maximum benefits of ample N availability [12]. It was also found that application of Si enhanced the use of applied N to rice [28, 29]. This was in conformity with findings that Si application has the potential in enhancing the availability of N in soil [30, 12]

Table 3: Effect of Silica on available soil nutrients in post-harvest soil

Treatment details	**Available Nutrients (~~Kg~~kg/ha)**			
	N	**P**	**K**	**S**
T_1 = Absolute Control	170.5	9.2	76.1	6.5
T_2= 50% STD	183.5	11.9	85.2	7.6
T_3= 75% STD	191.3	12.5	85.5	8.8
T_4= 100% STD	199.7	14.2	88.5	12.2
T_5= T_2+ 200kg SiO_2/ha	184.5	13.2	84.6	10.4
T_6= T_2+ 300kg SiO_2/ha	185.7	14.0	88.0	11.6
T_7= T_2+ 400kg SiO_2/ha	186.2	13.5	86.2	12.8
T_8= T_3+ 200kg SiO_2/ha	195.7	12.9	88.4	14.1
T_9= T_3+ 300kg SiO_2/ha	201.7	14.5	92.2	16.2
T_{10} = T_3+ 400kg SiO_2/ha	199.2	14.2	87.2	16.4
SE (M)	5.7	1.0	2.5	1.1
CD (0.05)	17.2	2.9	7.5	3.5

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Available P status varied from 9.2 kg/ha to 14.5 kg/ha with a lowest value observed in T_1 i.e., Absolute control (No Fertilizer) and significantly maximum available P (14.5kg/ha) was observed in T_9 i.e., T_3+ 300kg SiO_2/ha which was 58 % higher over Control. T_4 (100% STD) and T_{10} (75% STD+400kg SiO_2/ha) were at par with T_9. Available P status increased as the fertilizer dose increased. All the treatments registered significantly higher available P status over Control except T_2 (50% STD). In case of application of silica in combination with 50 % and 75 % STD, maximum available P (14.5kg/ha) was obtained due to application of 300kg SiO_2/ha which was reduced with further increased application of silica. It was also reported that better response of rice crops with

Comment [LV19]: add statistical information respect to P nutrition 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 [31]. It was also reported an enhanced availability of P with the addition of Si fertilizer [12, 15].

Available Potassium status was varied from 76.1 kg/ha to 92.2 kg/ha. Lowest available K status was observed in T_1 i.e., Absolute control (No Fertilizer) and T_9 i.e., T_3+ 300kg SiO_2/ha registered significantly maximum available K which was 21 % higher over Control. Available K status was increased as the fertilizer dose increased. All the treatments registered significantly higher available K status over Control T_1. In case of application of silica in combination with 50 % and 75 % STD, maximum available K was obtained due to application of 300kg SiO_2/ha which was reduced with increased application of silica. 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 [32]. The production of hydrogen ions during reduction of Fe and Al might have helped in the release of K from the exchange sites or from the fixed pool to the soil solution [9].

Available S status varied from 6.5 kg/ha to 16.4 kg/ha with lowest in T_1 i.e., Absolute control and maximum in T_{10} i.e., T_3+ 400kg SiO_2/ha. As the fertilizer dose increased, the available S status was also increased but no significant difference was marked up to 75% STD. In case of application of silica in combination with 50 % and 75 % STD, available S status was increased with increased application of silica which was significantly higher over Control. Application of 400kg SiO_2/ha registered maximum S status when compared with 200 and 300kg SiO_2/ha irrespective of integration of fertilizer dose.

3.4. Effect of Silica application on DTPA extractable micronutrients (Fe, Mn, Cu and Zn) in post-harvest soil

The experimental data presented in Table 4 indicates effect of Silica on DTPA extractable micronutrients in post-harvest soils like Fe, Mn, Cu and Zn. DTPA extractable micronutrient analysis indicated that high Fe (78.8ppm) and Mn (1.32ppm) content and low Zn (0.35ppm) and Cu (0.21ppm) content was found in initial soil sample. When the initial analysis value was compared with post-harvest analysis value of the same soil, it was observed that there was a decrease (9.6%) and (21.2%) in Fe (71.2ppm) and Mn content (1.04 ppm) respectively. Whereas an increasing trend was observed in Cu(0.46ppm) and Zn (0.56ppm) content in soil due to application of silica. The study revealed that DTPA extractable micronutrients like Fe and Mn in post-harvest soil showed a reverse trend with increased application of silica.

DTPA extractable Fe in post-harvest soil varied from 71.2 ppm to 79.7 ppm i.e., maximum in 100% STD and minimum in 75% STD+400kg SiO_2/ha. With increased fertilizer application, DTPA extractable Fe increased and reached maximum at T_4 (100% STD). In case of application of silica in combination with 50 %/75 % STD, the Fe content showed a reverse trend with increased application of silica. However, there was no significant difference between the treatments. Though DTPA extractable Fe content was reduced but it was not significantly affected by Si treatments. This is in contradiction with findings of scientists, who reported slight increase in the DTPA-Fe content in soil at harvest of rice plants due to application of silicon [33, 34, 35].

Available Mn in post-harvest soil was recorded minimum (1.04 ppm) in T_{10} (75% STD +400kg SiO_2/ha) and maximum (1.49 ppm) with T_4 (100% STD). With application of increased fertilizer doses, the available Mn content increased. There was a steady increase in Mn content of soil from Control to 75% STD+400kg SiO_2/ha. Increased application of Silica showed reverse trend in DTPA extractable Mn content ultimately showing a positive impact on reducing Mn toxicity in soil. The decrease in the DTPA-Mn content in soil at harvest of rice plants might be due to efficient utilization of Mn by rice plants. Similar results were also noticed [35].

Table 4: Effect of Silica on Fe, Mn, Cu and Zn in post-harvest soil

Treatment details	**DTPA Extractable Micronutrients (ppm)**			
	Fe	**Mn**	**Cu**	**Zn**
T_1 = Absolute Control	74.5	1.30	0.20	0.36
T_2= 50% STD	75.3	1.37	0.33	0.42
T_3= 75% STD	76.5	1.40	0.34	0.45
T_4= 100% STD	79.7	1.49	0.37	0.49
T_5= T_2+ 200kg SiO_2/ha	76.6	1.28	0.35	0.48
T_6= T_2+ 300kg SiO_2/ha	73.3	1.23	0.38	0.50
T_7= T_2+ 400kg SiO_2/ha	72.4	1.05	0.40	0.54
T_8= T_3+ 200kg SiO_2/ha	75.9	1.25	0.43	0.48
T_9= T_3+ 300kg SiO_2/ha	73.7	1.14	0.43	0.55
T_{10} = T_3+ 400kg SiO_2/ha	71.2	1.04	0.46	0.56
SE (M)	-	0.06	0.04	0.05
CD (0.05)	NS	0.17	0.13	0.15

Available Cu in post-harvest soil varied from 0.20 ppm to 0.46 ppm in which lowest Cu content was observed in T_1 i.e., Absolute control (No Fertilizer) and significantly maximum Cu content (0.46 ppm) was observed in T_{10}(75% STD+400kg SiO_2/ha). With increased fertilizer application the DTPA extractable Cu was increased. All the treatments registered significantly higher extractable Cu over control T_1 except T_2 (50% STD). In case of application of silica in combination with 50 % / 75 % STD, the Cu content increased with increased application of silica without any significant difference.

Available Zn in post-harvest soil varied from 0.36 ppm to 0.56 ppm so far as different treatments are concerned. DTPA extractable Zn was maximum (0.56 ppm) in T_{10} (75% STD + 400kg SiO_2/ha) which was almost 56% more than that of control T_1. With increased fertilizer application soil availability of Zn increased. No significant difference was marked in case of application of silica in combination with 50 % / 75 % STD. The study revealed that the DTPA extractable Cu and Zn content increased with increased application of silica. These results are in conformity with the findings [34].

3.5 Effect of Silica on yield attributing characters of paddy

The experimental data presented in Table 5 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 SiO_2/ha. This indicates though 100% STD registered maximum yield but by reducing fertilizer dose by 25% along with supplemental dose of Silica i.e., 300kg SiO_2/ha we could achieve almost equal yield.

Table 5: 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

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Grain yield of rice presented in Table 5 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 T_4 (100% STD) which was almost 30% more than that of control (28.5q/ha) but it was at par (36.2q/ha) with T_9 (75% STD+300kg SiO_2/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. It was also reported a significant increase in grain and straw yields of rice with increasing Si level [36, 15].

Variation in straw yield ranged from 33q/ha to 40.8q/ha. Maximum straw yield was obtained in T_4(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 (T_4) was at par with 75% STD+300kg SiO_2/ha (T_9). 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 SiO_2/ha. The increases in both grain and straw yields might be attributed to the positive effect of Si in increasing growth and yield characteristics [37, 15], enhancing the pollen viability and photosynthetic activity [38], reducing abiotic and biotic stress, improving structural support and biomass [39] and improving nutrient uptake [15, 40]

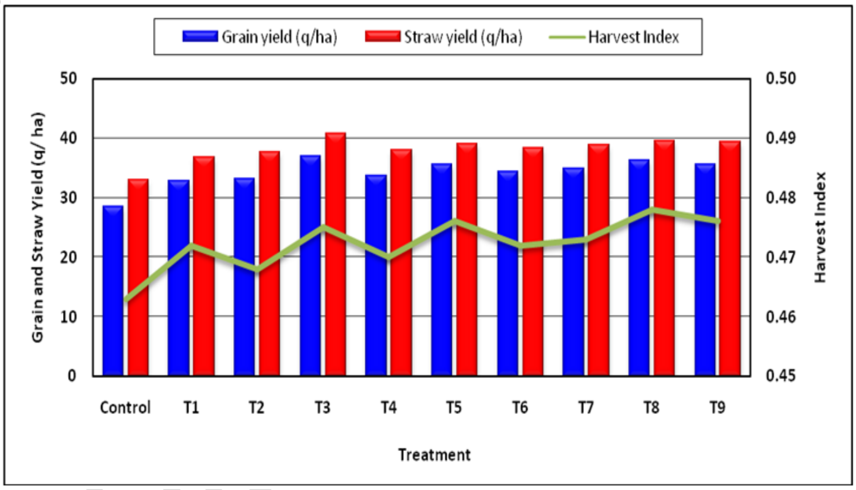

Figure 1: Grain yield, straw yield and Harvest Index

Harvest index was almost equal irrespective of treatments imposed. But maximum HI was obtained in T_9 (0.478) which was at par with T_4 (0.475) and T_{10} (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 SiO_2/ha but no significant difference was obtained among the treatments. This contradicts the findings of scientists, who reported an increased harvest index of rice with Si application [38, 15].

Based on the quadratic regression equation ($y = 0.00020x^2 + 0.05876x + 28.62182$), the grain yield when compared with fertilizer dose (without silica application), it was observed that maxima will not be reached since a is >0 (Fig. 2). However, there was steady increase in grain yield from control treatment to 100% STD and reached maximum i.e., 36.9q/ha.

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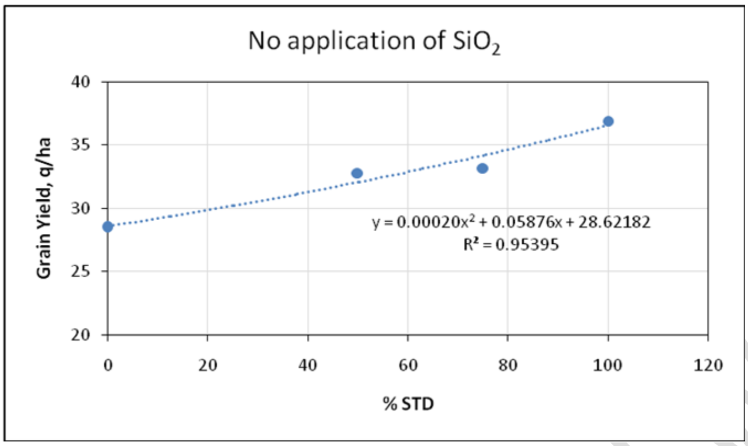

Figure 2: Maximum yield vs optimum level of fertilizer applied

Based on the quadratic regression equation (y = -0.00015x^2 + 0.09300x + 21.1) the vertex is the highest point on the graph of quadratic function (Fig. 3). The value of vertex (x = -b/2a) was 310 with Y max = a (X max)^2 + b (X max) + c= 35.51 Therefore. 310 kg/ha SiO_2 was the optimum level of Si fertilizer that could provide the maximum yield (35.51q/ha) in combination with 50% STD based on the quadratic regression model. From this point, more amount of Si fertilizer application could result in a decrease in the yield.

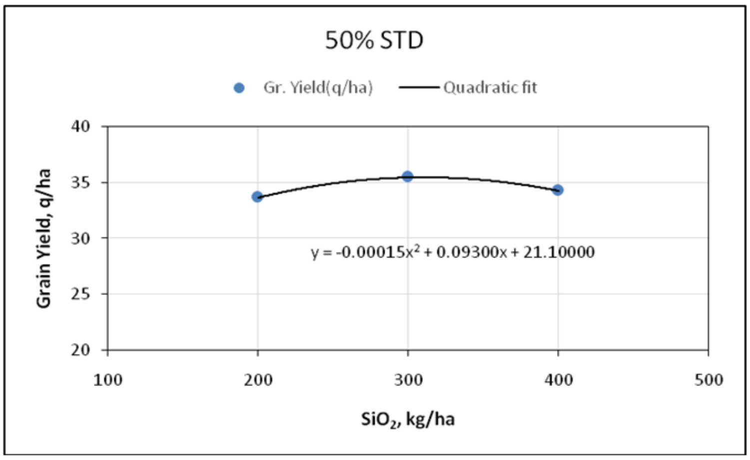

Figure 3: Maximum yield vs optimum level Silica applied along with 50% STD fertilizer

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Based on the quadratic regression equation (y = -0.00010x^2 + 0.06050x + 26.6) the vertex is the highest point on the graph of quadratic function (Fig. 4). The value of vertex (x = -b/2a) was 336.1 with Y max = a (X max)^2 + b (X max) + c= 36.76. Therefore, 336.1 kg/ha SiO_2 was the optimum level of Si fertilizer that could provide the maximum yield (36.76q/ha) in combination with 75% STD based on the quadratic regression model. From this point, more amount of Si fertilizer application could result in a decrease in the yield.

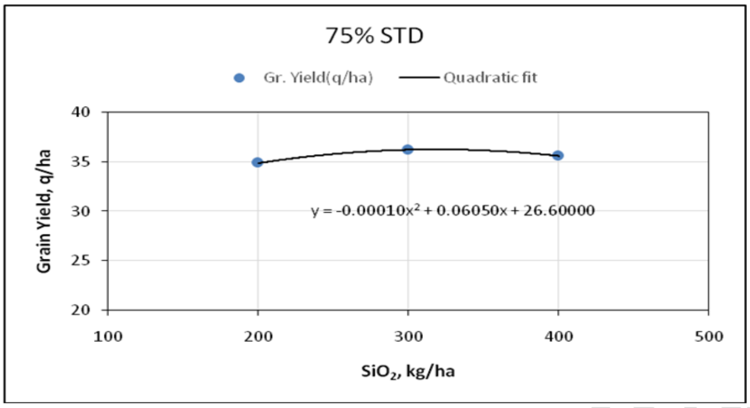

Figure 4: Maximum yield vs optimum level Silica applied along with 75% STD fertilizer

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Conclusion

Silicon nutrition significantly influenced the growth and yield attributing characteristics as well as the nutrient status in soil. Si is known for its role in alleviating the negative stress effects on many plant species. There was significant increase in number of effective tillers per plant, length of the panicle, grain yield and straw yield over control due to application of silica. However, in case of 1000 grain wt. and Harvest Index, there was no significant difference between the treatments. The study showed increase in pH and Organic Carbon (OC) in post-harvest soil due to application of Silica as compared to initial soil test value. Hence it was suggested to go for application of silica for correcting soil acidity and improving soil OC content in acidic laterite soils. Application of Silica was also effective in reducing the level of Fe and Mn content in post-harvest soil indicated better response in reducing Fe and Mn toxicity in soil. Available N, P, K and S status in post-harvest soil increased significantly due to application of silica along with fertilizer suggested integration of Silica with fertilizer dose without sole application. A reverse trend in DTPA extractable Fe and Mn toxicity was observed in silica application with fertilizer. But DTPA extractable Cu and Zn shows increasing trend due to application of silica. Application of silica along with STD would help in the sustainable production of rice. Future research is needed to find out the heavy metal analysis of the BOF slag to assess its impact on soil due to heavy dose of application. Multilocational trials under different agro-ecosystems with several test crops should be conducted to assess the best possible outcome.

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.

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