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Silicon and Nitrogen Influence on Lodging Resistance and Productivity of Rice (*Oryza sativa* L.)

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ABSTRACT

*Nitrogenous fertilizers may cause lodging which is one of the most serious problems facing rice cultivation worldwide. Lodging could be minimized by increasing the mechanical or physical strength of the rice culm, and silicon (Si) is the element associated with sturdiness and rigidity. Therefore, a field experiment was carried out in two phases with the objective to evaluate the synergistic effect of silicon and nitrogen application on lodging parameters and productivity of rice. At first phase a survey was conducted across the rice ecosystems of Telangana, and revealed that rice grown soils were low in available Si (73.62 to 96.41 kg SiO_2 ha^{-1}), whereas the rice genotypes ranged from 1.54 to 3.15% of its Si concentration and overall rice grain yield ranged from 3157 kg ha^{-1} to 6709 kg ha^{-1}. Further, observed a positive and significant correlation (r=0.55**) between the rice yields (kg ha^{-1}) and the Si concentration (%). Based on initial phase of results, a field experiment was conducted with each four levels of N (0, 80, 120 & 160 kg ha^{-1}) and Si (0, 200, 400 & 600 kg ha^{-1}) along with two genotypes having high Si content (3.20%) i.e., JGL-3855 and another with low Si (2.15%) i.e., RNR-2354. Conjunctive application of N and Si to both genotypes, JGL-3855 recorded significantly higher grain and straw yields compared to RNR-2354. Among the different combinations of Si and N, application of 160 kg N + 600 kg Si ha^{-1} recorded significantly higher grain and straw yields (7180 and 9693 kg ha^{-1}) and on par with other treatments which received N @ 120 and 160 kg ha^{-1} along with Si @ 200, 400 and 600 kg ha^{-1}. The lodging resistance parameters i.e., plant height (cm), stem length (cm), number of nodes and internodal length (cm), stem diameter (mm), linear density of culm (mg dwt cm^{-1}) and physical strength of the culm at ripening stage of the crop influenced by different N and Si levels, but not by the varieties. Even the interaction effects of the genotypes and combination of N and Si levels did not significantly influence the lodging resistance parameters.*

Keywords: *Silicon, nitrogen, rice genotypes, culm, internodal length and lodging resistance*

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INTRODUCTION

Rice (*Oryza sativa* L.) is an important crop which feeds more than half population of the world, and it requires nitrogen for its growth and development. The role of nitrogen is to attain optimum yield of rice is undeniable, further its higher application rate may cause lodging which is one of the most serious problems facing rice cultivation worldwide. To date, three types of lodging have been recorded, namely, bending of stems at the base, breakage of stems at any point along the length, and root lodging [5]. Excess N application leads to poor lodging resistance by increasing plant height, internodal length and gravity center height, as well as decreasing the thickness of culm wall and leaf sheath strength [30], which instigate the poor grain quality and lower yields. Proper management of nitrogenous fertilizers may promote the uptake of K, Si, and other nutrients that improve the stem strength *i.e.*, bending or breaking strength of the culm, which is important for lodging resistance. The stem strength of cereal plants is primarily determined by plant architecture at the cellular level, such as cell division, cell growth and cell spatial arrangement parameters closely related to environmental factors [14]. Therefore, judicious application of N fertilizers plays a significant role in dictating the physical and mechanical strength of plant stems, also affecting the morphology traits of basal internodes in rice [21]. Thus, we focused on expanding the lodging resistance of rice crop by adopting advanced agronomic and soil fertility techniques by use of Silicon (Si). However, intensification of production system calls for the best nutrient management practices, which could restore soil fertility and productivity. Silicon is the second most abundant element after oxygen in the earth's crust, and is a main component of plant tissues as well as epidermal cells which provide structural rigidity to the plant. As a typical silicon-accumulating crop, rice plants contain large amounts of silicon and are greater than the sum of the contents of nitrogen, phosphorus, and potassium [2]. Generally, the SiO_2 content in stems and leaves reaches 10%–20% on dry weight basis, so rice is a representative siliciceous plant [32]. Although silicon is not a constituent of any cellular component, but supply of soluble silicon in plants provides stronger, tougher and rigid cell walls which serves as a mechanical barrier against lodging and attack of sucking and piercing insects. Silicon based fertilizers have many advantages including reducing nutrient loss, improving nutrient use efficiency, and decreasing groundwater pollution [11 & 1].

Further, rice genotypes are known to differ with respect to acquisition, translocation and accumulation of Si [31]. Evaluation of rice genotypes for Si acquisition and its use efficiency is necessary in characterizing the association of Si accumulation and resistance to biotic and abiotic stress without compromising on the qualitative and quantitative traits. However, information on extent of silicon accumulation at different rice genotypes under different rice ecosystems is limited. Now, it is important to know the variation in accumulation of Si among different rice genotypes under various rice ecosystems. Keeping in view the role of silicon, a field experiment was carried out in two phases with the objectives to evaluate the synergistic effect of silicon and nitrogen application on lodging parameters and productivity of rice.

MATERIALS AND METHODS

The experiment was conducted in two phases. During the first phase of the study, rice index leaf samples were collected at tillering stage from different promising varieties at Agricultural Research Institute (ARI) Rajendranagar, Regional Agricultural Research Station (RARS), Jagtial, Regional Agricultural Research Station, Warangal and Regional Sugarcane & Rice Research Station (RS & RRS), Rudrur of Telangana state, simultaneously soil samples also collected to access Si content. Further yields were recorded at harvest stage from all the display plots at various locations and were correlated with Si content in rice index leaves which were collected at tillering stage. Out of all 133 varieties assessed, only two varieties were selected for the second phase of field experiment which having high Si content (3.20%) *i.e.,* JGL-3855 and another with low Si (2.15%) *i.e.,* RNR-2354 with four levels of Nitrogen (0, 80, 120 and 160 kg ha^{-1}) and four levels of Silicon (0, 200, 400 and 600 kg ha^{-1}) consisting of sixteen treatments, replicated thrice in strip-plot design at RARS, Jagtial, Karimnagar, Telangana. The experimental soil was sandy clay loam in texture, slightly alkaline (pH 7.61) in reaction, non-saline (0.27 dSm^{-1}), low in organic carbon (0.48 percent), available N (194.61 kg ha^{-1}) and available Si (82.17 kg SiO_2 ha^{-1}), high in available P_2O_5 (29.53 kg ha^{-1}) and medium in K_2O (170.28 kg ha^{-1}). Later, the field was laid out into 96 plots as per the strip plot design norms by providing bunds for individual plots and applied recommended doses of phosphorus and potassium (60 and 40 kg ha^{-1}) were applied uniformly to all treatments in the form of single super phosphate (SSP) and muriate of potash (MOP) as basal. Nitrogen was applied in the form of urea in three equal splits (1/3 basal, 1/3 at active tillering stage and 1/3 at the panicle initiation stage). Finally, silicon was applied as basal in the form of silica gel and with 99.71, 0.02, 0.03, 0.1, 0.09, 0.01 and 0.02% of SiO_2, Na_2O, Fe_2O_3, Al_2O_3, TiO_2, CaO and ZrO_2.

The pH of the soil was estimated in 1:2 ratio of soil and water suspension by using digital pH meter and the electrical conductivity estimated with the same soil water supernatant solution of 1:2 using an electrical conductivity meter. The organic carbon content was estimated by wet oxidation method [29], available (mineralizable) N estimated with alkaline 0.32% $KMnO^4$ in Kelplus distillation unit [27], and available P extracted with 0.5 M $NaHCO_3$ (pH 8.5) and estimated spectrophotometrically [20]. Whereas the available K was extracted with neutral 1N NH_4OAC and estimated by flame emission spectroscopy [16] and available micronutrients (Zn, Mn, Fe and Cu) were extracted by DTPA solution [12] and estimated by atomic absorption spectrophotometer (Varian spectra AA 20 plus). Finally, the available silicon content was estimated by the ammonium molybdate method using a UV visible Spectrophotometer [9]. Further, the physical and mechanical parameters such as plant height (cm), stem length (cm), number of nodes and internodal length (cm), stem diameter (mm), linear density of culm (mg dwt cm^{-1}) and physical strength of the culm were recorded. The physical strength of the culm was measured [8] with 'prostrate tester'2 (DIK-7401, Daiki Rika Kogyo Co., Tokyo, Japan). The data on various parameters were statistically analyzed by feeding replicated data into INDOSTAT software and critical difference for examining treatment means and their significance was calculated at 5 percent probability level [4].

RESULTS AND DISCUSSION

Silicon Content in Index Leaf Samples and Soils

The index leaf Si content among the various locations of the present study across the three different agro-climatic zones in Telangana region presented in Table. 1. The Si content in the index leaf of promising varieties at tillering ranged from 1.50 to 3.20 (mean value of 2.50) percent at RARS, Jagtial, 1.60 to 3.15 (mean value of 2.47) percent at RARS, Warangal, 1.49 to 3.20 (mean value of 2.51) percent at ARI, Rajendranagar and 1.55 to 3.06 (mean value of 2.43) percent at RS & RRS, Rudrur. The Si content of index leaves were slightly more (2.51%) at ARI, Rajendranagar followed by RARS, Jagtial as 2.50%, RARS, Warangal (2.47%) and RS & RRS, Rudrur as 2.43%. The variation in Si concentration in plant species was due to the difference in the efficiency of plant roots for Si acquisition [33]. Among the soils of the research stations studied, the available Si content was observed to be low to medium considering 40 ppm as critical limit using acetate buffer extraction method [25].

Correlation of Grain Yields with Si Content in Index Leaves

Across the locations (Table. 2), the grain yields varied from 2886 to 7198 kg ha^{-1} at RARS, Jagtial, from 2693 to 6831 kg ha^{-1} at RARS, Warangal, from 2653 to 6860 kg ha^{-1} at ARI, Rajendranagar and from 4399 to 5950 kg ha^{-1} at RS & RRS, Rudrur depending on the potentiality of varieties. The lowest and highest mean yields 5069 and 5871 kg ha^{-1} were recorded at RS & RRS, Rudrur, and RARS, Warangal respectively. The overall rice grain yield from four locations ranged from 3157 to 6709 kg ha^{-1} with a mean of 4933 kg ha^{-1}. These variations in yields might have been due to the genotypic variations and also due to variations in climatic and soil conditions of different locations. Considering the high degree of correlation between Si content of varieties and grain yields, a positive and significant correlation (r=0.55**) observed between the rice yields (kg ha^{-1}) and the Si concentration (%). The soils selected for this study varied in texture from sandy loam to clay having different levels of Si supplying power, and lateral roots also played a vital role in silicon accumulation in rice genotypes [23].

Influence of Different Levels of Silicon and Nitrogen on Grain and Straw Yield and Available Silicon Status

Among the varieties, JGL-3855 showed a significantly higher mean grain yield of 6779 kg ha^{-1} compared to 6460 kg ha^{-1} produced by RNR-2354, which could be due to the high efficiency of JGL-3855 in remobilizing N from vegetative parts to the grains (Table. 3). The mean grain yields with different combinations of silicon and nitrogen varied from 5622 to 7180 kg ha^{-1}. Among all the treatments, N_{160} + Si_{600} treatment recorded significantly higher grain yield of 7180 kg ha^{-1} and was on par with the yield obtained from other treatments receiving N@120 and 160 kg ha^{-1} along with Si@200, 400 and 600 kg ha^{-1}. Even the treatments with N@120 and 160 kg ha^{-1} without any silicon supplementation recorded significantly lower grain yields of 6466 and 6477 kg ha^{-1} respectively compared to the treatments which received silicon along with nitrogen. This might be due to the increased phosphate uptake with the application of silicon [10] and excess N also prolongs the vegetative growth at the cost of reproductive growth which diminishing the production of carbohydrates [17]. When the effect of nitrogen across the Si levels is considered, it was observed that graded levels of N application at 80, 120 and 160 kg ha^{-1} showed an increase in the

Table 1. Mean values of Si content and Yield status at different rice growing areas of Telangana

S. No	Location	Yield (kg ha^{-1})		Silicon (%)		Ava. Si (kg ha^{-1})	
		Range	Mean	Range	Mean	Range	Mean
1	RARS, Jagtial	2886-7198	5845	1.50-3.20	2.50	80.16-87.53	84.83
2	RARS, Warangal	2693-6831	5871	1.60-3.15	2.47	77.51-83.18	80.80
3	ARI, Rajendra nagar	2653-6860	5646	1.49-3.20	2.51	87.53-96.41	92.71
4	RS&RRS, Rudrur	4399-5950	5069	1.55-3.06	2.43	73.63-80.73	77.80
Mean		3157-6709	4933	1.54-3.15	2.48	82.12-85.54	84.03

Table 2. Correlation coefficients between Si concentration in index leaves of different genotypes and their grain yields

Parameters	Yield (kg ha^{-1})	Si (%)
Yield (kg ha^{-1})	1.00	0.55**
Si (%)		1.00

Table 3. Influence of different levels of nitrogen and silicon on grain and straw yields of two different rice genotypes

Treatments	Grain yield	Straw yield	Ava. Silicon (SiO_2)
		(kg ha^{-1})	
Varieties			
JGL 3855	6779	8949	109.51
RNR 2354	6460	8530	110.78
S.Em ±	8.53	10.66	5.46
C.D (0.05)	36.73	45.89	NS
Fertility levels			
T_1 (N 0 + Si 0)	5622	7197	87.65
T_2 (N 0 + Si 200)	5937	7719	96.24
T_3 (N 0 + Si 400)	6167	8079	103.16
T_4 (N 0 + Si 600)	6360	8331	110.89
T_5 (N 80 + Si 0)	6027	7775	84.09
T_6 (N 80 + Si 200)	6305	8259	102.78
T_7 (N 80 + Si 400)	6609	8724	110.02
T_8 (N 80 + Si 600)	6927	9213	116.58
T_9 (N 120 + Si 0)	6466	8406	80.27
T_{10} (N 120 + Si 200)	7155	9594	131.79
T_{11} (N 120 + Si 400)	7165	9597	131.93
T_{12} (N 120 + Si 600)	7172	9611	131.97
T_{13} (N 160 + Si 0)	6477	8420	78.93
T_{14} (N 160 + Si 200)	7172	9601	131.90
T_{15} (N 160 + Si 400)	7169	9607	132.78
T_{16} (N 160 + Si 600)	7180	9693	132.94
S.Em ±	36.88	176.40	0.63
CD (0.05)	75.24	356.34	1.20
Varieties within the Fertility level			
S.Em ±	135.02	176.40	17.81
C.D (0.05)	296.51	356.34	NS
Fertility levels within the Variety			
S.Em ±	17.80	23.39	0.46
C.D (0.05)	55.01	72.07	NS

Fig.1-7: Influence of different levels of nitrogen and silicon on lodging resistance parameters of two different rice genotypes

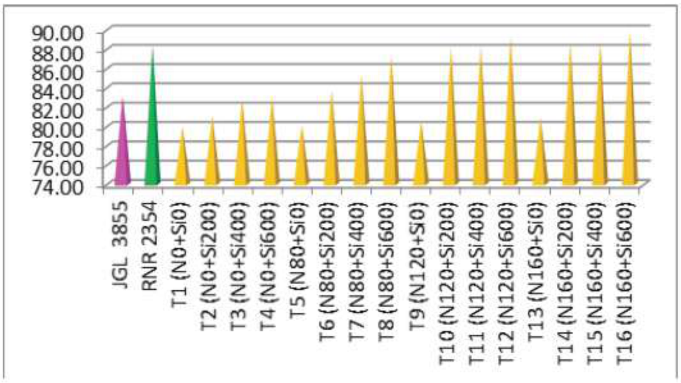

Fig.1: Plant Height (cm)

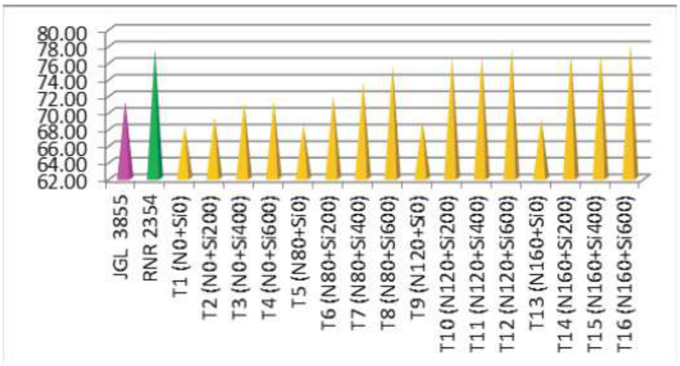

Fig.2: Stem length (cm)

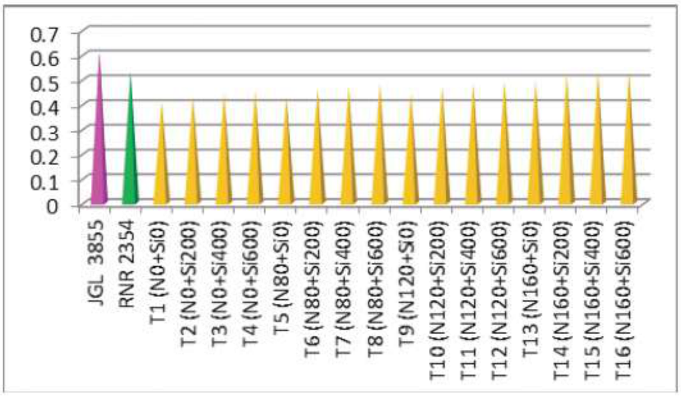

Fig.3: Stem diameter (mm)

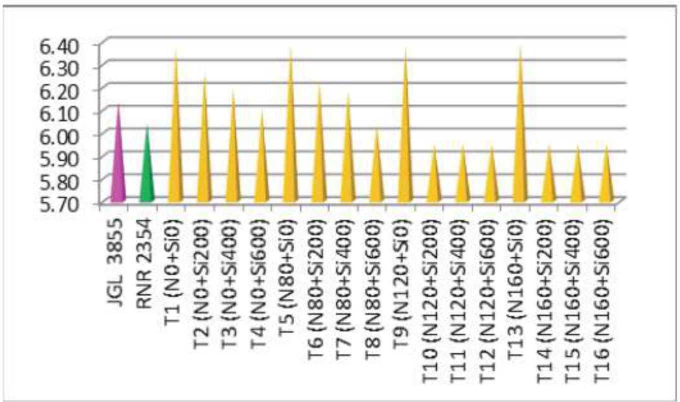

Fig.4: No.of internodes

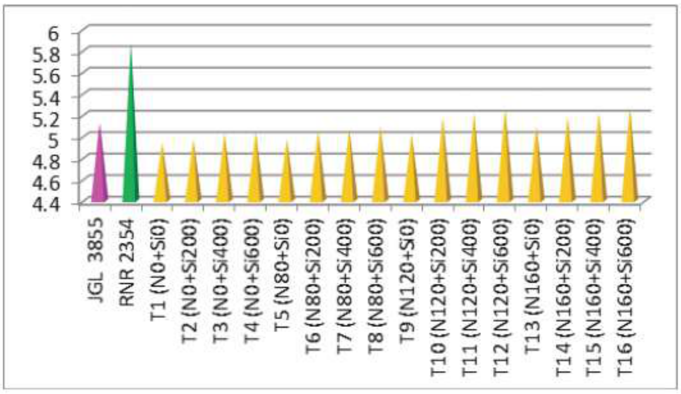

Fig.5: Internodal length (cm)

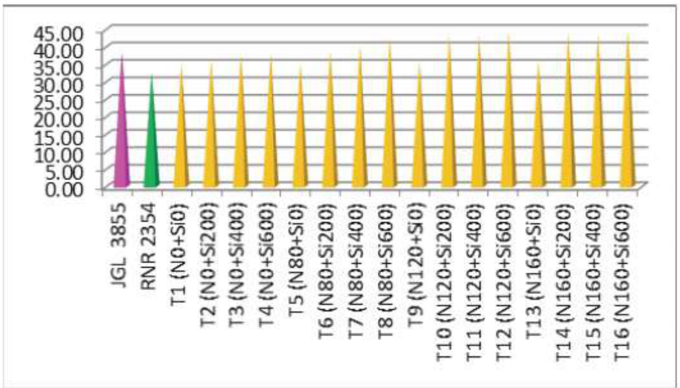

Fig.6: Linear density of culm (mg dwt cm-1)

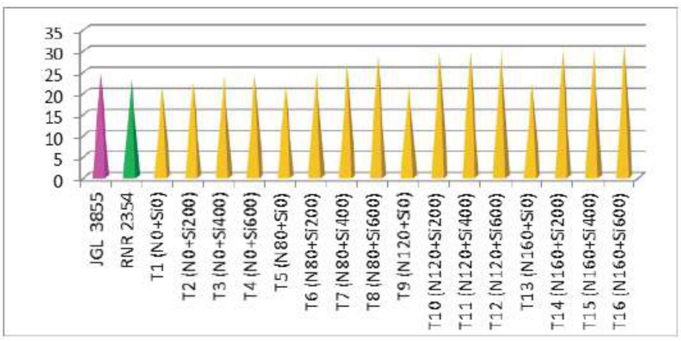

Fig.7: Physical strength of the culm

mean straw yields; the percent increase over the N_0 level being 8.43, 18.76 and 19.12 respectively. Similarly, the effect of Si across N levels indicated that the mean straw yields increased by 10.6, 13.23 and 15.87 percent respectively with Si application at 200, 400 and 600 kg ha^{-1} over Si_0. Silicon application was effective in increasing dry matter production in the rice crop and there are numerous reports of beneficial effects of silicon in rice crops [6].

From the perusal of the data (Table. 3), available

Si in soil at harvest was influenced significantly by different fertility levels, and varieties could not influence significantly in the soil. Significantly lower available Si of 87.65 kg ha^{-1} present in soil when both N and Si were withheld from the fertilizer schedule (N_0 + Si_0) which increased to 132.94 kg ha^{-1} with the conjunctive use of N at 160 and Si at 600 kg ha^{-1}. However, it was on par with the treatments receiving N at 120 or 160 kg ha^{-1} along with Si at 200 or 400 or 600 kg ha^{-1}. The mean available Si status increased from 99.48 to 103.36, 118.99 and 119.13 kg ha^{-1} with the graded levels of N application from 0 to 80, 120 and 160 kg ha^{-1}, while the increase with Si application was from 82.73 to 115.67, 119.47 and 123.09 kg ha^{-1} due to the application of 600 kg Si ha^{-1}. There was a built up to an extent of 0.68 percent in available Si content of the soil when compared to the initial status even without its fertilization. This could be due to the reason that Si is released into soil solution after flooding as well as with organic matter content of soil as reported earlier [22]. A built up in available Si was observed with Si fertilization to the extent of 49.79 percent with the application of Si at 600 kg ha^{-1} as against Si_0 level treatments. This was attributed to the possibility of sorption and desorption of silicate fertilizer under wetland rice ecosystem of present study. At any level of N, application of Si @ 0, 200, 400 and 600 kg ha^{-1} increased the available Si of soil from 99.48 to 103.36, 118.99 and 119.13 kg ha^{-1}. However, significant response was observed only up to 200 kg Si ha^{-1} level when applied in integration with either 120 or 160 kg N ha^{-1}.

Influence of Different Combinations of N and Si on Lodging Resistance Parameters at Ripening Stage

The data on lodging resistance parameters *i.e.,* plant height (cm), stem length (cm), number of nodes and internodal length (cm), stem diameter (mm), linear density of culm (mg dwt cm^{-1}) and physical strength of the culm at ripening stage of the crop presented in Fig. 1 to 7. From the perusal of the data, it was observed that the lodging resistance parameters at ripening stage of the crop significantly influenced by different N and Si levels but not by the varieties. Even the interaction effects of the varieties as well as different N and Si levels did not significantly influence the lodging resistance parameters at ripening stage of the crop.

Plant height and Stem length (cm) at ripening stage of the crop did not show any significant difference among the varieties (Fig. 1 and 2). Among the fertility levels, with increase in the level of Si application from 0 to 200, 400 and 600 kg ha^{-1} across N levels for the two varieties increased the mean plant height from 80.30 to 85.36, 86.23 and 87.31 cm, and stem length from 68.64 to 73.70, 74.57 and 75.65 cm of the crop. Further, the percent increase of plant height (8.72 %) and stem length (10.21 %) at ripening stage of the crop increased due to the application of 600 kg Si ha^{-1} as against Si_0 level. With this, the present study accepts the general statement that reduced plant height and shorter stalks improves lodging resistance in cereals [3 & 13], and mutant lines also controls the culm diameter and culm morphology by encoding an F-box domain containing protein [24] affecting strigolactone signaling pathway [15], cell wall cellulase microfilaments and cell wall thickening [28] leading to lodging resistance in rice.

Mean stem diameter (mm) of the crop showed an increase from 0.41 to 0.53 mm, showing improvement from 19.51, 20.93, 20.45 and 17.78 percent when Si application increased from 0 to 600 kg ha^{-1} (Fig. 3). In rice, the cellulose content mainly determines the physical strength of the stem by serving as a link and support [13], and with silicon fertilization the carbohydrate components were increased which ultimately increased stem diameter of the crop. With increase in N level, the mean stem diameter increased from 0.04 to 0.05 mm, showing a percent increase of 09.76, 11.63, 11.36 and 8.16 mm when N application increased from 0 to 120 kg ha^{-1}.

A perusal of the data (Fig. 4 and 5) indicated that neither the varieties nor different N and Si levels showed a significant influence on number of nodes. Further, the internodal length (cm) revealed that there was significant influence by different treatments over control (4.94 cm). The internodal length varied from 4.94 to 5.27 cm). The highest internodal length was obtained 5.27cm in T_{16} (N_{160} + Si_{600}) fertility level, which was on par with T_{15} (N_{160} + Si_{400}), T_{14} (N_{160} + Si_{200}), T_{12} (N_{120} + Si_{600}), T_{11} (N_{120} + Si_{400}) and T_{10} (N_{120} + Si_{200}) with corresponding to 5.22, 5.18, 5.26, 5.21 and 5.17 cm respectively. The primary factor in the variation in lengths of basal internodes is light intensity in the lower part of the canopy [26], whereas the sparse planting density and low N input at early growth stage resulted in short basal internodes and increased lodging resistance in consequence of reduced LAI and greater light transmission at jointing stage [3]. The elongation of basal internodes closely correlated with light environment expressed as light intensity (L_b) and light quality (R/FR).

Significantly lower linear density of culm (34.94 mg dwt cm^{-1}) and physical strength (21.17) of the culm observed when both N and Si were withheld from the fertilizer schedule (N_0 + Si_0), which increased to 44.88 mg dwt cm^{-1} and 31.11 with the conjunctive use of N at 160 and Si at 600 kg ha^{-1} at ripening stage of the crop (Fig. 6 and 7). However, it was on par with the treatments receiving N at 120 or 160 kg ha^{-1} along with Si at 200 or 400 or 600 kg ha^{-1}. These findings agree with the earlier reports [18 & 7], which indicate that higher the linear density higher the lodging resistance. Out of all parameters linear density of the culm, outer diameter of the basal internode appear to be best indices of physical strength of rice culms in other words lodging nature of rice [34]. At any level of N, application of Si @ 0, 200, 400 and 600 kg ha^{-1} increased the linear density of culm from 1.19 to 11.99, 9.28 and 11.49 percent, and physical strength of the culm increased from 4.35 to 33.96, 24.86 and 28.3 percent. However, significant response was observed only up to 200 kg Si ha^{-1} level when applied in integration with either 120 or 160 kg N ha^{-1}.

CONCLUSION

Taking into consideration of results obtained by the experiment, a high amount of variation was noticed among the rice genotypes in respect of silicon acquisition and accumulation, and plant available Si content under different rice ecosystems of Telangana state. The graded levels of Si application@200, 400 and 600 kg ha^{-1} have resulted in the increase in mean grain yields by 8.03, 10.24 and 12.39 percent respectively over the Si_0. Out of all lodging resistance parameters *i.e.,* linear density of culm (mg dwt cm^{-1}) and physical strength of the culm appear to be best indices to improve lodging nature of rice and required much scientific work in this area. Finally, the application of Si@200 kg ha^{-1} along with N@120 kg ha^{-1} can be recommended for rice crops grown in three Agro-Climatic Zones of the Telangana region in India.

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