



Influence of Silicon Fertilization on Nitrogen Fractions and Nutrient Status of Rice Grown Soils in Telangana State

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Authors' contributions

This work was carried out in collaboration among all authors. Author KR carried out the research work under the supervision of author GBR. Data curation and statistical analysis were carried out by author KR and wrote the first draft of the manuscript. Author BHK helped in drafting of the paper. All authors read and approved the final manuscript.

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ABSTRACT

Excessive N application may limit the crop yields, and it could be minimized by the use of Silicon in rice ecosystem. Initially, a survey was conducted and revealed that rice grown soils were low in available Si (73.62 to 96.41 kg SiO₂ ha⁻¹). As well as Si concentration of rice genotypes ranged from 1.54 to 3.15% and grain yield ranged from 2653 to 6860 kg ha⁻¹ and exerted a significant positive correlation ($r = 0.55^{**}$). 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). Among the N and Si doses, application of T₁₆(N₁₆₀ + Si₆₀₀) recorded highest grain yield (7180 kg ha⁻¹) and was on par with the treatments received N@120 and 160 kg ha⁻¹ along with Si@200, 400 and 600 kg ha⁻¹. The status of available nutrients viz., N, P₂O₅, K₂O, SiO₂, Zn, Cu, and N-fractions were obtained high with T₁₆ (N₁₆₀ + Si₆₀₀), which was at par with the treatments of T₁₅ (N₁₆₀ + Si₄₀₀) > T₁₄ (N₁₆₀ + Si₂₀₀) > T₁₂ (N₁₂₀ + Si₆₀₀) > T₁₁ (N₁₂₀ + Si₄₀₀) > T₁₀ (N₁₂₀ + Si₂₀₀).

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of half of the world's population, and we accomplished self-sufficiency in rice production and exported an appreciable quantity of rice in nineties due to the introduction of high yielding varieties, chemical fertilizers and their widespread adoption in the sixties. This gigantic achievement compelled with intensive farming over a period of time and further crop has set a declining yield trend as well as deterioration of soil productivity even with optimum use of fertilizers in the post-green revolutionary period. It, therefore necessitates the adoption of advanced soil fertility techniques for narrowing the yield gap and ceiling on yield can be broken by adopting new eco-friendly technologies which can boost the present rice yield by 15-20 percent with the present level of input use. Nature has provided bountiful of Silicon (Si) resources which can meet the requirement of various inputs required for sustainable farming.

At high doses of Nitrogen (N) application, the N use efficiency may be low and also leading to lodging and susceptibility to pests and diseases. These effects could be minimized by the use of Silicon (Si), so the application of Si is found to improve N use efficiency besides imparting resistance to pests and diseases. Rice is a known silicon accumulator [1] and the plant is benefited from Si nutrition [2] and it has been considered to be a quasi-essential element for plants growth [3].

Rice genotypes are known to differ with respect to the acquisition, translocation, and accumulation of silicon [4]. However, information on the extent of accumulation of silicon in different rice genotypes under different rice ecosystems is limited. Now, it is important to know the variation in the accumulation of Si among different rice genotypes under various rice ecosystems. In order to achieve an intensive production of grain with good quality, this experiment was proposed with different levels of silicon and nitrogen in judicious combinations to sustain the productivity to improve soil fertility.

2. 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 from all the display plots at various locations and were correlated with Si content in rice index leaves at the tillering stage.

Out of all 133 varieties assessed, only two varieties were selected for the second phase of field experiment which was 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 SiO₂ ha⁻¹), high in available P₂O₅ (29.53 kg ha⁻¹) and medium in K₂O (170.28 kg ha⁻¹). Later, the field was laid out into 96 plots as per the design 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 3 equal splits (1/3 basal, 1/3 at active tillering stage and 1/3 at the panicle initiation stage). 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 SiO₂, Na₂O, Fe₂O₃, Al₂O₃, TiO₂, CaO and ZrO₂.

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 was estimated with the same soil water supernatant solution of 1:2 using an electrical conductivity meter. Organic carbon content estimated by the wet oxidation method [5]. Available (mineralizable) N was estimated with alkaline 0.32% KMnO₄ in the Kelplus distillation unit [6], and available P was extracted with 0.5 M NaHCO₃ (pH 8.5) and estimated spectrophotometrically [7]. Whereas available K was

extracted with neutral 1N NH_4OAC and estimated by flame emission spectroscopy [8] and available micronutrients (Zn, Mn, Fe and Cu) were extracted by DTPA solution using the method [9] and estimated by atomic absorption spectrophotometer (Varian spectra AA 20 plus). The inorganic nitrogen fractions viz., exchangeable NH_4^+ -N and Nitrate-N were estimated using the standard method [10,11]. Finally, available silicon content estimated by the ammonium molybdate method using a UV visible Spectrophotometer [12]. The data on various parameters were statistically analyzed by feeding the replicated data into INDOSTAT software and critical difference for examining treatment means and their significance was calculated at 5 percent probability level [13].

3. RESULTS AND DISCUSSION

3.1 Silicon Content in Index Leaf Samples and Soils

Among the various locations of the present study from three different agro-climatic zones of Telangana region (Table 1), the Si content in the index leaf of the 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 was (2.47%) and RS & RRS, Rudrur has (2.43%). The variation in Si concentration in plant species was due to the difference in the efficiency of plant roots for Si acquisition [14]. Among the soils of the research stations studied, the available Si content was observed to be in low to medium considering 40 ppm as critical limit using acetate buffer extraction technique [15].

3.2 Correlation of Grain Yields with Si Content in Index Leaves

Across the locations (Table 2), the grain yields ranged 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 kg ha^{-1} 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 the Si content of varieties and the grain yields, a positive and significant correlation ($r=0.55^{**}$) existed between the rice yields (kg ha^{-1}) and the Si concentration (%). The soils selected for the study varied in texture from sandy loam to clay having different Si supplying power and lateral roots played a vital role in silicon accumulation in rice plants [16].

3.3 Effect of Different Levels of Silicon and Nitrogen on Grain and Straw Yields

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 (Fig. 1). The mean grain yields with different combinations of silicon and nitrogen varied from 5622 to 7180 kg ha^{-1} . Among all the treatments, $\text{N}_{160} + \text{Si}_{600}$ treatment recorded a significantly higher grain yield of 7180 kg ha^{-1} and was on par with the yield obtained from other treatments receiving $\text{N}@120$ and 160 kg ha^{-1} along with $\text{Si}@200$, 400 and 600 kg ha^{-1} . Even the treatments with $\text{N}@120$ 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 [17] and excess N also prolongs the vegetative growth at the cost of reproductive growth, thus, diminishing the production of carbohydrates [18].

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 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. There are also

numerous reports of beneficial effects of silicon in rice crops [19,20].

3.4 Effect of Different Combinations of N and Si on Macro-Nutrient Status of Soil at Harvest

From the perusal of the data (Table 3), it was observed that though the available N, P, K and Si contents remaining in the soil were low when JGL-3855 was taken up, compared to RNR-2354, and the effect was statistically non-significant. There was a significant influence of different N and Si levels on the nutrient status of the soil at harvest. However, the interaction effects of varieties with fertility levels with regard to N and Si levels did not show any significant influence.

Among the fertility levels, with an increase in the level of N application from 0 to 80, 120 and 160 kg ha⁻¹ across Si levels, increased the mean available N status of the soil from 178.2 to 205.42, 224.19 and 224.56 kg ha⁻¹ against N₀ level. When compared to the initially available N status, there was 9.2 percent depletion in the N₀ level and 15.38 percent built up in available status at N₁₆₀ fertility level. It could also be observed that, with the increase in N levels, the nutrient contents also increased accordingly. The improved nitrogen status in soil by the use of N and Si fertilization can be explained by high adsorption capacity of Si and increased microbial activity, which might have hastened the process of mineralization during crop growth period resulting in high accumulation of N in soil in the Si treated soil [21].

Table 1. Mean values of Si content in index leaves and Yield at different locations of the Telangana State

S. No	Location	No of Varieties screened	Yield (kg ha ⁻¹)		Silicon (%)	
			Range	Mean	Range	Mean
1	RARS, Jagtial	41	2886-7198	5845	1.50-3.20	2.50
2	RARS, Warangal	32	2693-6831	5871	1.60-3.15	2.47
3	ARI, Rajendra nagar	48	2653-6860	5646	1.49-3.20	2.51
4	RS&RRS, Rudrur	12	4399-5950	5069	1.55-3.06	2.43
Mean		133	3157-6709	4933	1.54-3.15	2.48

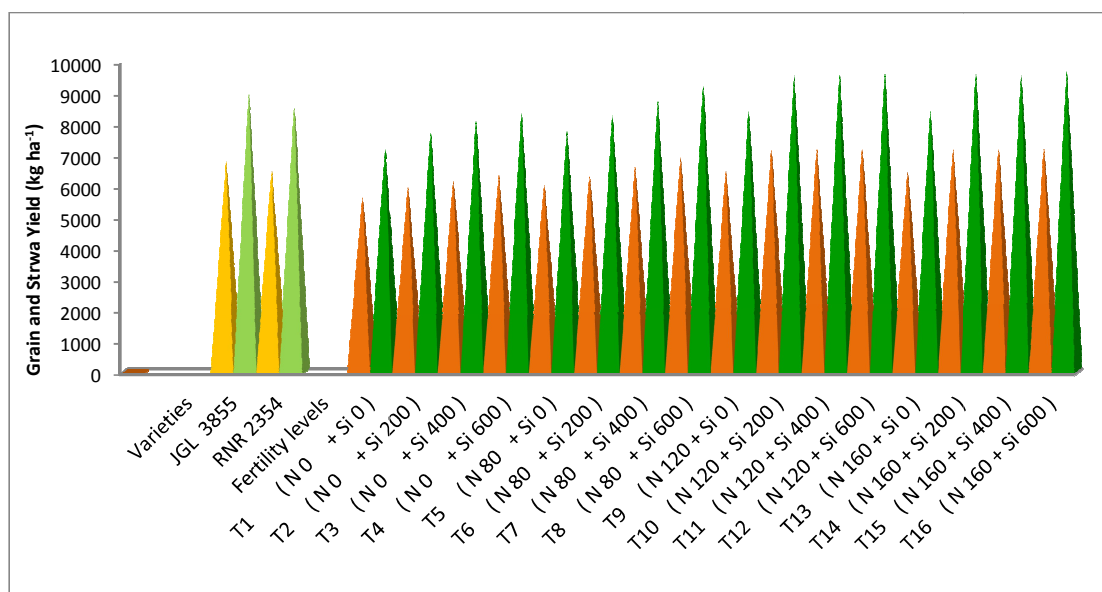


Fig. 1. Influence of Si and N levels on grain and straw yields of rice genotypes

Table 2. Correlation coefficients of various genotypes silica concentration in index leaves and their grain yields

Parameters	Yield (kg/ha)	Si (%)
Yield (kg ha ⁻¹)	1.00	0.55**
Si (%)		1.00

Table 3. Effect of different N and Si levels on available nitrogen, phosphorus, potassium and silicon content of soil at harvest

Treatments	Available Nutrients (kg ha ⁻¹)			
	Nitrogen (N)	Phosphorus (P ₂ O ₅)	Potassium (K ₂ O)	Silicon (SiO ₂)
Varieties				
JGL 3855	201.48	32.18	177.52	109.51
RNR 2354	205.27	34.63	179.63	110.78
S.Em ±	5.61	3.52	5.39	5.46
C.D (0.05)	NS	NS	NS	NS
Fertility levels				
T ₁ (N 0 + Si 0)	191.52	29.05	175.15	87.65
T ₂ (N 0 + Si 200)	188.41	30.20	176.03	96.24
T ₃ (N 0 + Si 400)	172.38	31.89	176.44	103.16
T ₄ (N 0 + Si 600)	160.51	32.11	177.71	110.89
T ₅ (N 80 + Si 0)	222.73	29.19	175.43	84.09
T ₆ (N 80 + Si 200)	213.49	32.83	176.67	102.78
T ₇ (N 80 + Si 400)	196.62	34.42	177.48	110.02
T ₈ (N 80 + Si 600)	188.85	36.43	178.71	116.58
T ₉ (N 120 + Si 0)	228.71	29.65	175.88	80.27
T ₁₀ (N 120 + Si 200)	227.54	37.30	179.65	131.79
T ₁₁ (N 120 + Si 400)	221.73	37.41	179.91	131.93
T ₁₂ (N 120 + Si 600)	218.81	38.37	180.03	131.97
T ₁₃ (N 160 + Si 0)	237.58	29.97	175.92	78.93
T ₁₄ (N 160 + Si 200)	224.46	37.78	179.96	131.90
T ₁₅ (N 160 + Si 400)	219.38	37.86	180.57	132.78
T ₁₆ (N 160 + Si 600)	216.84	38.99	180.89	132.94
S.Em ±	0.75	0.88	0.61	0.63
CD (0.05)	1.21	1.73	1.85	1.20
Varieties within the Fertility level				
S.Em ±	15.48	10.16	13.62	17.81
C.D (0.05)	NS	NS	NS	NS
Fertility levels within the Variety				
S.Em ±	0.37	0.29	0.41	0.46
C.D (0.05)	NS	NS	NS	NS

Mean available P status of the soil showed an increase from 30.8 to 36.15 kg ha⁻¹, when N application increased from 0 to 160 kg ha⁻¹ and similarly with an increase in Si level, the available P increased from 29.47 to 36.48 kg ha⁻¹ when Si application increased from 0 to 600 kg ha⁻¹. The increased available P with Si application could be due to the release of adsorbed P by anion exchange. Due to application Si compounds and their large surface area, they increase the soil adsorption capacity [22].

When Si was not applied, an increase in the level of N from 0 to 160 kg ha⁻¹ did not show any

significant influence on the available K status of the soil. At 0 and 80 kg ha⁻¹ level of N, available K increased significantly due to integration with Si at 0 to 600 kg ha⁻¹ 175.2 to 177.7 and 175.4 to 178.7 kg ha⁻¹ respectively. However, this increase was significant only up to 200 kg Si ha⁻¹ when applied in combination 120 or 160 kg N ha⁻¹, the values being 179.7 and 180 kg ha⁻¹ respectively. The increased available K with Si application could be ascribed to the alterations in crystal structures of clay lattices which might have resulted in a reduction in K fixation thus releasing potassium [23].

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 fertilizers increased the content of plant-available Si compounds [24] in the soil. This was attributed to the possibility of sorption and desorption of silicate fertilizer under the wetland rice ecosystem of the present study.

3.5 Influence of Different Combinations of N and Si on Micro-Nutrient Status of Soil at Harvest

The results related to available Zn, Fe, Cu and Mn content at harvest was not significantly

influenced by both varieties. But, the fertility levels of N and Si showed significant results on available soil Zn, but the interaction effect found non-significant between varieties and N and Si levels (Table 4).

The data pertaining to available Zn content revealed that there was significant influence by different treatments over control (0.58 ppm) where N & Si was not applied. The Zn content varied from 0.58 to 0.64 ppm. The highest Zn content was obtained 0.64 ppm at N₁₆₀ + Si₆₀₀ fertility level, which was on par with N₁₆₀ + Si₄₀₀, N₁₆₀ + Si₂₀₀, N₁₂₀ + Si₆₀₀, N₁₂₀ + Si₄₀₀ and N₁₂₀ + Si₂₀₀ fertility levels with corresponding to 0.64, 0.63, 0.64, 0.63 and 0.63 ppm respectively. In soil solution, a low concentration of monosilicic acids leads to formation of complexes of a Zn with a silicic acid anion. As a result of this reaction, the content of Zn increases if the concentration of monosilicic acid in the solution slightly increases [20].

Table 4. Effect of different N and Si levels on available zinc, iron, copper and manganese content of soil at harvest

Treatments	Available Nutrients (mg kg ⁻¹)			
	Zn	Fe	Cu	Mn
Varieties				
JGL 3855	0.60	5.53	2.13	5.27
RNR 2354	0.62	5.49	2.14	5.23
S.Em ±	0.01	0.02	0.04	0.13
C.D (0.05)	NS	NS	NS	NS
Fertility levels				
T ₁ (N 0 + Si 0)	0.58	5.70	2.10	5.43
T ₂ (N 0 + Si 200)	0.59	5.67	2.11	5.40
T ₃ (N 0 + Si 400)	0.59	5.59	2.12	5.32
T ₄ (N 0 + Si 600)	0.60	5.43	2.13	5.17
T ₅ (N 80 + Si 0)	0.59	5.69	2.11	5.41
T ₆ (N 80 + Si 200)	0.60	5.63	2.13	5.37
T ₇ (N 80 + Si 400)	0.61	5.56	2.14	5.29
T ₈ (N 80 + Si 600)	0.62	5.41	2.15	5.14
T ₉ (N 120 + Si 0)	0.60	5.69	2.12	5.41
T ₁₀ (N 120 + Si 200)	0.63	5.38	2.15	5.12
T ₁₁ (N 120 + Si 400)	0.63	5.38	2.15	5.12
T ₁₂ (N 120 + Si 600)	0.64	5.38	2.16	5.11
T ₁₃ (N 160 + Si 0)	0.60	5.69	2.12	5.41
T ₁₄ (N 160 + Si 200)	0.63	5.38	2.15	5.12
T ₁₅ (N 160 + Si 400)	0.64	5.37	2.16	5.12
T ₁₆ (N 160 + Si 600)	0.64	5.37	2.16	5.11
S.Em ±	0.003	0.004	0.008	0.04
CD (0.05)	0.01	0.01	0.01	0.09
Varieties within the Fertility level				
S.Em ±		0.05	0.006	0.12
C.D (0.05)		NS	NS	NS
Fertility levels within the Variety				
S.Em ±		0.002	0.002	0.004
C.D (0.05)		NS	NS	NS

The results related to available Fe content revealed that there was significant influence by different treatments over control (5.70 ppm). Among the different N and Si level treatments, $N_{160} + Si_{600}$, $N_{160} + Si_{400}$, $N_{160} + Si_{200}$, $N_{120} + Si_{600}$, $N_{120} + Si_{400}$ and $N_{120} + Si_{200}$ with corresponding to 5.37, 5.37, 5.38, 5.38, 5.38 and 5.38 ppm recorded the lowest Fe content compared to other treatments which received lower levels of nitrogen + silicon doses. Si substances for reducing Fe toxicities were very effective [25], the monosilicic acid can be adsorbed on Fe hydroxides, impairing their mobility [26].

The data pertaining to available Cu content revealed that there was significant influence by different treatments over control (2.10 ppm). The highest Cu content was obtained 2.16 ppm at $N_{160} + Si_{600}$ fertility level, which was on par with $N_{160} + Si_{400}$, $N_{160} + Si_{200}$, $N_{120} + Si_{600}$, $N_{120} + Si_{400}$ and $N_{120} + Si_{200}$ with corresponding to 2.15, 2.15, 2.16, 2.15 and 2.15 ppm respectively. Silicon fertilization has been reported to result in increased soil exchange capacity, improved water, and air regimes. Silicon substances usually exhibit very good adsorption ability. Due to this, Si fertilization reduced the leaching of Cu and increases the quantity of mobile Cu in the soil [27].

The results pertaining to available Mn content revealed that there was significant influence by different treatments over control (5.43 ppm). Among the different N and Si level treatments, $N_{160} + Si_{600}$, $N_{160} + Si_{400}$, $N_{160} + Si_{200}$, $N_{120} + Si_{600}$, $N_{120} + Si_{400}$ and $N_{120} + Si_{200}$ with corresponding to 5.11, 5.12, 5.12, 5.11, 5.12 and 5.12 ppm

recorded the lowest Mn content compared to other treatments which received lower levels of nitrogen + silicon doses. Interaction between Si and Mn occurs in solution, probably by the formation of Mn-Si complexes, a non-toxic form. However, monosilicic acid concentration in the soil initiated the decomposition of secondary minerals that control numerous soil properties [28].

3.6 Effect of Different Combinations of N and Si on Inorganic N Fractions in Soil at Harvest

From the perusal of the data, the treatments receiving only N, from 0 to 80, 120 and 160 kg ha⁻¹, the mean NH_4^+ -N, NO_3^- -N and total inorganic N fractions were increased from 32.39 to 36.62, 38.67 and 43.67 mg kg⁻¹; 13.86 to 15.09, 16.17 and 19.14 mg kg⁻¹; 46.25 to 51.71, 54.84 and 62.81 mg kg⁻¹ across the treatments and also increased the percent of mean NH_4^+ -N, NO_3^- -N and total inorganic N fractions in the soil from 29.34 to 32.82, 38.45 and 40.06; 11.56 to 12.47, 16.38 and 16.94; 40.91 to 45.29, 54.83 and 57 (Fig. 2). It could also be observed that, with an increase in N levels, the inorganic N fractions also increased accordingly. This trial conducted in the field with differing amounts of N indicated that the N fertilizers were directly proportioned to Si and optimum levels of N and Si is much more effective than using only Si [29] because high adsorption capacity of Si hastened the process of mineralization during crop growth period resulting in high accumulation of inorganic N fractions in soil [21].

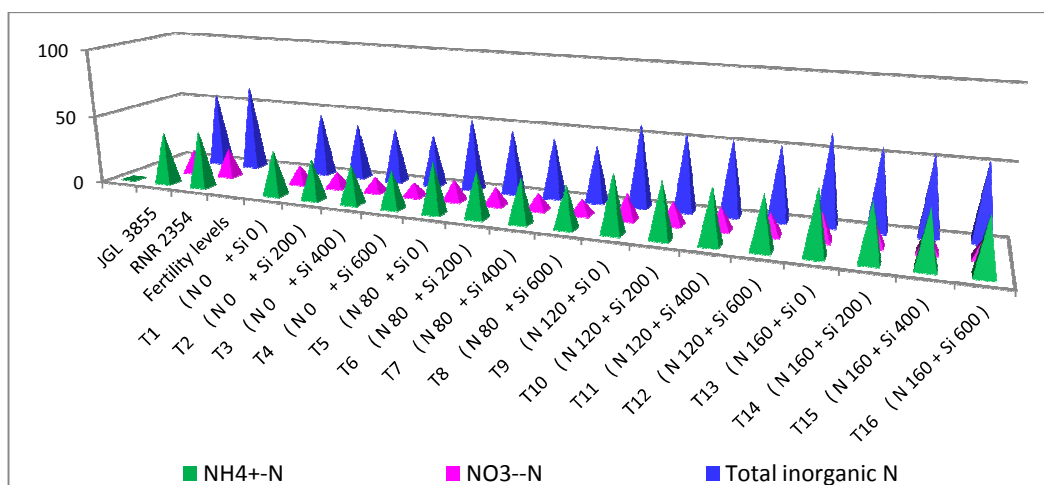


Fig. 2. Inorganic N fractions in soil as influenced by nitrogen and silicon at harvest of rice crop

4. 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 of 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 Si₀. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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