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Influence of silicon and nitrogen on growth and phenological parameters of transplanted rice (*Oryza sativa* L.) under field conditions

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Abstract

The present study was conducted to evaluate the effect of silicon and nitrogen on growth and phenological parameters of transplanted rice (*Oryza sativa* L.) under field conditions. The experiment was laid out in a factorial randomized block design with four levels of silicon (0, 50, 75 and 100 kg ha⁻¹) and three levels of nitrogen (0, 50 and 100 kg ha⁻¹), replicated thrice. The results revealed that plant height was significantly influenced by different treatment combinations at all growth stages. The maximum plant height was recorded under S₃N₂ (100 kg Si + 100 kg N ha⁻¹), with values of 41.67 cm at 30 days after transplanting, 70.07 cm at 60 days after transplanting, 91.33 cm at 90 days after transplanting and 101.60 cm at harvest, whereas the minimum values were observed under control (S₀N₀). Phenological parameters were also significantly affected by the treatments. The minimum days to panicle initiation (54.67 days), flowering (80 days) and maturity (115 days) were recorded under S₃N₁ (100 kg Si + 50 kg N ha⁻¹), while the maximum duration was observed under control (63, 88 and 123 days, respectively). The reduction in crop duration under higher levels of silicon and nitrogen may be attributed to improved nutrient use efficiency, enhanced physiological activity and better metabolic functioning. Overall, the combined application of silicon and nitrogen showed a strong synergistic effect in improving growth and accelerating phenological development compared to their individual application. Among all treatments, S₃N₂ proved to be the most effective for maximizing plant growth, while S₃N₁ was more effective in reducing crop duration. Thus, integrated application of silicon and nitrogen can be considered a promising strategy for enhancing growth performance and optimizing phenology of transplanted rice under field conditions.

Keywords: Silicon, nitrogen, rice (*oryza sativa* l.), plant height, phenology, panicle initiation, flowering, maturity

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops, feeding more than half of the world's population, particularly in Asia. In India, rice occupies approximately 46.38 million hectares with a production of about 130.29 million tonnes, playing a crucial role in food security and rural livelihood ^[1]. However, productivity of rice is often constrained by nutrient imbalance, soil degradation, and environmental stresses such as salinity and nutrient depletion.

Nitrogen (N) is a key macronutrient required for vegetative growth, chlorophyll formation, and yield improvement in rice. However, inefficient nitrogen utilization leads to losses through leaching, volatilization, and denitrification, ultimately reducing nitrogen use efficiency (NUE) and causing environmental pollution ^[2].

Silicon (Si), although not considered an essential nutrient, has been recognized as a beneficial element for rice. Silicon deposition strengthens plant cell walls, improves plant architecture, enhances resistance against biotic and abiotic stresses, and improves nutrient uptake efficiency ^[3]. Under saline conditions, silicon reduces sodium uptake and improves potassium selectivity, thereby enhancing plant tolerance ^[4].

Several studies have demonstrated that silicon application significantly improves plant height, tillering, and yield attributes in rice ^[5, 6]. Similarly, nitrogen application enhances vegetative growth and biomass accumulation. However, combined application of silicon and nitrogen has shown synergistic effects by improving nitrogen uptake and utilization efficiency, leading to

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better growth and productivity ^[7].

Despite available studies, there is still limited understanding regarding the interactive effects of silicon and nitrogen on growth and phenological parameters of transplanted rice under field conditions, especially in factorial combinations. Therefore, the present investigation was undertaken to evaluate the effect of different levels of silicon and nitrogen on plant height and phenological traits of rice.

2. Materials and Methods

2.1 Experimental Site

The field experiment was conducted during the Kharif season at the experimental farm of the School of Agriculture, Galgotias University, Greater Noida, Uttar Pradesh, India (28.36° N latitude and 77.54° E longitude, at an altitude of approximately 200 m above mean sea level). The experimental site falls under the subtropical region characterized by hot summers and moderate rainfall during the cropping season. The soil of the experimental field was uniform in texture and fertility, ensuring minimal variability across treatment plots.

2.2 Experimental Design and Treatment Details

The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications to study the combined effect of silicon and nitrogen on rice. The treatments consisted of two factors, namely silicon (Factor A) and nitrogen (Factor B), each applied at different levels. Silicon was applied at four levels (0, 50, 75 and 100 kg/ha), while nitrogen was applied at three levels (0, 50 and 100 kg/ha).

A total of 12 treatment combinations were formed by combining the levels of silicon and nitrogen. These treatments were randomly allocated within each replication to minimize experimental error. The design allowed for the evaluation of individual as well as interaction effects of silicon and nitrogen. In total, 36 experimental plots (12 treatments × 3 replications) were maintained during the study.

Table 1: Treatment combinations (Factorial RBD)

Treatment	Silicon Level (Factor A)	Nitrogen Level (Factor B)
T ₁	S ₀ (Control)	N ₀ (Control)
T ₂	S ₁ (50 kg/ha)	N ₀ (Control)
T ₃	S ₂ (75 kg/ha)	N ₀ (Control)
T ₄	S ₃ (100 kg/ha)	N ₀ (Control)
T ₅	S ₀ (Control)	N ₁ (50 kg/ha N)
T ₆	S ₀ (Control)	N ₂ (100 kg/ha N)
T ₇	S ₁ (50 kg/ha)	N ₁ (50 kg/ha N)
T ₈	S ₁ (50 kg/ha)	N ₂ (100 kg/ha N)
T ₉	S ₂ (75 kg/ha)	N ₁ (50 kg/ha N)
T ₁₀	S ₂ (75 kg/ha)	N ₂ (100 kg/ha N)
T ₁₁	S ₃ (100 kg/ha)	N ₁ (50 kg/ha N)
T ₁₂	S ₃ (100 kg/ha)	N ₂ (100 kg/ha N)

2.3 Crop Details

The experimental crop was rice (*Oryza sativa* L.), and the variety used was CSR 76. Healthy seedlings were raised in a nursery and transplanted into the main field following recommended agronomic practices. All cultural operations such as irrigation, weed management, and plant protection measures were carried out uniformly for all treatments to ensure that the observed differences were due to treatment effects only.

2.4 Observations Recorded

2.4.1 Growth Parameters

- **Plant height at 30, 60, 90 DAT and at harvest:** Plant

height was measured in centimeters. Plant height is basically the shortest distance between the base of top most fully expanded leaf and the ground level. It will be measured with the help of meter scale and calculated by taking average height of three randomly selected plants from each of the three replications of each treatment at 30, 60, 90 DAT and at harvest

2.4.2 Phenological Parameters

- **Days to panicle initiation:** Days to panicle initiation was documented by calculating the number of days from the date of sowing to the date of appearance of panicle primordial. Panicle initiation is the stage when panicle appears initially in a dome shaped structure. It will be detected by keeping a regular check starting from 35 days from the date of transplanting to the appearance of the dome shaped structure. It will be done through the dissection of the panicle with the help of a blade.
- **Days to flowering and maturity:** Days to general flowering was recorded by calculating the number of days from the date of sowing to the date of heading. Days to maturity will be observed by calculating the number of days from the date of sowing to the date when 90% of the panicles turn yellow ripe.

2.5 Statistical Analysis

Data were statistically analyzed using analysis of variance (ANOVA) appropriate for a factorial randomized block design (RBD) ^[8]. The significance of treatment effects was tested at both 5 per cent ($P = 0.05$) and 1 per cent ($P = 0.01$) levels of probability.

3. Results and Discussion

Plant height, being an important indicator of vegetative growth, was significantly influenced by silicon and nitrogen levels as well as their interaction ($A \times B$) at all growth stages (30, 60, 90 DAT and at harvest). The analysis of variance revealed that the interaction effect was highly significant ($P < 0.01$), indicating that the combined application of silicon and nitrogen played a crucial role in determining plant growth.

At 30 DAT (Table 1), plant height increased significantly under different treatment combinations. The maximum plant height (41.567 cm) was recorded under treatment S₃N₂ (silicon 100 kg ha⁻¹ + nitrogen 100 kg ha⁻¹), whereas the minimum (32.733 cm) was observed under control (S₀N₀). This clearly indicates that the combined application of higher levels of silicon and nitrogen was more effective in enhancing early vegetative growth than their individual application. The increase in plant height under S₃N₂ may be attributed to improved nutrient uptake, enhanced cell division and elongation, and better physiological activity resulting from the synergistic effect of silicon and nitrogen.

A similar trend was observed at 60 DAT (Table 2), where the highest plant height (70.067 cm) was recorded under S₃N₂, while the lowest (64.667 cm) was recorded under control. The significant interaction effect suggests that silicon and nitrogen acted synergistically to promote vegetative growth. The enhanced plant height at this stage could be due to increased tillering, improved leaf area development and higher photosynthetic efficiency facilitated by nitrogen, along with improved structural rigidity and nutrient utilization efficiency imparted by silicon.

At 90 DAT (Table 3), plant height further increased, with the maximum value (91.333 cm) recorded under S₃N₁ and comparable values under S₃N₂, while the minimum (83.900 cm)

was observed under control. The significant interaction effect indicates that the combined application of silicon and nitrogen continued to influence plant growth during the reproductive stage. The increased plant height may be attributed to better assimilate partitioning, enhanced stress tolerance and improved metabolic activity under combined nutrient application.

At harvest (Table 4), plant height reached its maximum values, with the highest plant height (101.600 cm) recorded under S_3N_1 , followed closely by S_3N_2 , whereas the lowest (86.633 cm) was observed under control. The interaction between silicon and nitrogen remained highly significant, confirming the cumulative effect of both nutrients on plant growth. The superior performance of higher treatment combinations may be attributed to improved structural strength due to silicon deposition and enhanced nitrogen metabolism, resulting in better biomass accumulation.

Overall, the results clearly demonstrate that the combined application of silicon and nitrogen, particularly at higher levels, was more effective in improving plant height than their individual application. These findings are in close agreement with those of Wei *et al.* (2025) [9] and Dorairaj *et al.* (2020) [15], who reported significant improvement in growth parameters of rice under integrated nutrient management involving silicon and nitrogen.

Table 1: Effect of silicon and nitrogen on plant height (cm) at 30 DAT

Silicon (A)	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	31.6	32.633	33.967	32.733
S ₁ (A2)	35.533	36.7	38.433	36.889
S ₂ (A3)	39.167	40.3	40.233	39.9
S ₃ (A4)	41.267	41.767	41.667	41.567
Mean (B)	36.892	37.85	38.575	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.547	0.262	0.185
Factor(B)	0.474	0.227	0.161
Factor(A X B)	0.948	0.454	0.321

Table 2: Effect of silicon and nitrogen on plant height (cm) at 60 DAT

Silicon (A)	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	64.667	65.300	65.967	65.311
S ₁ (A2)	66.500	67.000	67.600	67.033
S ₂ (A3)	68.000	68.500	68.833	68.444
S ₃ (A4)	69.233	69.633	70.067	69.644
Mean (B)	67.100	67.608	68.117	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.05	0.024	0.017
Factor(B)	0.043	0.021	0.015
Factor(A X B)	0.087	0.041	0.029

Table 3: Effect of silicon and nitrogen on plant height (cm) at 90 DAT

Silicon (A)	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	83.9	84.867	85.6	84.789
S ₁ (A2)	86.3	86.533	87.767	86.867
S ₂ (A3)	88.567	87.9	89.567	88.678
S ₃ (A4)	88.567	91.333	89.133	89.678
Mean (B)	86.833	87.658	88.017	

Factors	C.D.	SE(d)	SE(m)
Factor (A)	0.545	0.261	0.185
Factor (B)	0.472	0.226	0.16
Factor (A X B)	0.943	0.452	0.32

Table 4: Effect of silicon and nitrogen on plant height (cm) at harvest

Silicon (A)	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	86.633	88.6	90.367	88.533
S ₁ (A2)	92.633	93.833	95.3	93.922
S ₂ (A3)	97.067	96.267	99.033	97.456
S ₃ (A4)	98.267	101.6	99.567	99.811
Mean (B)	93.65	95.075	96.067	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.578	0.277	0.196
Factor(B)	0.501	0.24	0.17
Factor(A X B)	1.002	0.48	0.339

3.2 Days to panicle initiation

Days to panicle initiation, an important phenological parameter indicating the transition from vegetative to reproductive stage, was significantly influenced by different treatment combinations of silicon and nitrogen. The analysis of variance revealed that the interaction effect (A × B) was highly significant ($P < 0.001$), indicating that the combined application of silicon and nitrogen played a crucial role in regulating crop development.

A perusal of data (Table 5) revealed that the minimum number of days to panicle initiation (54.667 days) was recorded under treatment S_3N_1 (silicon 100 kg ha⁻¹ + nitrogen 50 kg ha⁻¹), which was closely followed by other higher treatment combinations such as S_3N_0 and S_3N_2 . In contrast, the maximum number of days (63 days) was recorded under control (S_0N_0). This clearly indicates that the combined application of silicon and nitrogen significantly accelerated the onset of reproductive stage compared to untreated control.

The significant interaction effect suggests that silicon and nitrogen acted synergistically in reducing the duration required for panicle initiation. The reduction in days to panicle initiation under higher treatment combinations may be attributed to enhanced physiological efficiency, improved nutrient uptake and accelerated metabolic activity. Silicon is known to improve plant vigor and stress tolerance, while nitrogen enhances vegetative growth and assimilate production, thereby promoting earlier transition from vegetative to reproductive phase.

Overall, the results demonstrate that integrated application of silicon and nitrogen was more effective in reducing days to panicle initiation than their individual application. These findings are in conformity with earlier research [10], which indicated that combined nutrient management enhances crop growth and accelerates phenological development in rice.

Table 5: Effect of silicon and nitrogen on days to panicle initiation

Silicon (A)	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	63	62	61	62
S ₁ (A2)	61	60	60	60.333
S ₂ (A3)	59	58	59	58.667
S ₃ (A4)	57	54.667	59	56.889
Mean (B)	60	58.667	59.75	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.511	0.245	0.173
Factor(B)	0.443	0.212	0.15
Factor(A X B)	0.886	0.424	0.3

3.3 Days to flowering

Days to flowering, an important phenological parameter, was significantly influenced by different treatment combinations of silicon and nitrogen. The analysis of variance indicated that the

interaction effect ($A \times B$) was statistically significant, suggesting that the combined application of silicon and nitrogen played a crucial role in regulating flowering behavior in rice.

The data presented in Table 6 revealed that the minimum number of days to flowering (80 days) was recorded under treatment S_3N_1 (silicon 100 kg ha⁻¹ + nitrogen 50 kg ha⁻¹), whereas the maximum (88 days) was observed under control (S_0N_0). Other higher treatment combinations such as S_2N_1 and S_3N_0 also recorded comparatively fewer days to flowering, indicating a consistent trend of earliness with increased levels of silicon and nitrogen.

The significant interaction effect clearly indicates that silicon and nitrogen acted synergistically in reducing the time required for flowering. The reduction in flowering duration under higher treatment combinations may be attributed to improved nutrient availability, enhanced metabolic activity and better physiological efficiency. Silicon contributes to improved plant vigor and stress tolerance, while nitrogen enhances photosynthetic activity and biomass production, thereby accelerating plant development and promoting early flowering. Overall, the results demonstrate that the combined application of silicon and nitrogen was more effective in inducing earliness in flowering compared to their individual application. These findings are in conformity with earlier studies, which reported that integrated nutrient management involving silicon and nitrogen promotes faster growth and early flowering in rice under favorable conditions.

Table 6: Effect of silicon and nitrogen on days to flowering

	N ₀ (B1)	N ₁ (B2)	N ₂ (B3)	Mean (A)
S ₀ (A1)	88	87	86	87
S ₁ (A2)	86	85	85	85.333
S ₂ (A3)	84	83	84	83.667
S ₃ (A4)	82	80	84	82
Mean (B)	85	83.75	84.75	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.91	0.436	0.308
Factor(B)	0.788	0.378	0.267
Factor(A X B)	1.577	0.755	0.534

3.4 Days to maturity

Days to maturity, an important parameter determining crop duration and harvest time, was significantly influenced by different treatment combinations of silicon and nitrogen. The analysis of variance revealed that the interaction effect ($A \times B$) was statistically significant ($P < 0.01$), indicating that the combined application of silicon and nitrogen played a vital role in regulating crop maturity.

A perusal of data (Table 7) indicated that the minimum number of days to maturity (115 days) was recorded under treatment S_3N_1 (silicon 100 kg ha⁻¹ + nitrogen 50 kg ha⁻¹), whereas the maximum (123 days) was observed under control (S_0N_0). Other higher treatment combinations such as S_2N_1 and S_3N_0 also recorded comparatively fewer days to maturity, indicating a consistent trend of reduced crop duration with increased levels of silicon and nitrogen.

The significant interaction effect suggests that silicon and nitrogen acted synergistically in accelerating crop maturity. The reduction in days to maturity under higher treatment combinations may be attributed to enhanced metabolic activity, improved nutrient use efficiency and better physiological functioning. Silicon improves plant structural integrity and stress tolerance, while nitrogen enhances growth and assimilate

production, thereby facilitating faster completion of the crop life cycle.

Overall, the results clearly demonstrate that the combined application of silicon and nitrogen was more effective in reducing crop duration compared to their individual application. These findings are in agreement with earlier experimenT₁₁, who reported improved crop development and early maturity in rice with silicon application.

Table 7: Effect of silicon and nitrogen on days to maturity

	N ₀ B1	N ₁ B2	N ₂ B3	Mean A
S ₀ (A1)	123	122	121	122
S ₁ (A2)	121	120	120	120.333
S ₂ (A3)	119	118	119	118.667
S ₃ (A4)	117	115	119	117
Mean (B)	120	118.75	119.75	

Factors	C.D.	SE(d)	SE(m)
Factor(A)	0.91	0.436	0.308
Factor(B)	0.788	0.378	0.267
Factor(A X B)	1.577	0.755	0.534

Conclusion

The present investigation clearly demonstrated that both silicon and nitrogen significantly influenced the growth and phenological parameters of transplanted rice. Plant height increased progressively with advancing growth stages and higher levels of silicon and nitrogen. Among the treatments, the application of silicon at 100 kg/ha (S_3) consistently recorded the highest plant height at all stages (30, 60, 90 DAT and at harvest), while nitrogen at 100 kg/ha (N_2) also showed a marked improvement in plant growth.

Phenological parameters such as days to panicle initiation, flowering and maturity were significantly reduced with increasing levels of silicon and nitrogen, indicating accelerated crop development. The combined application of silicon and nitrogen exhibited a synergistic effect, resulting in better growth performance and earlier crop maturity compared to their individual application.

The interaction effect ($Si \times N$) was found to be highly significant for all parameters studied, confirming that integrated nutrient management involving silicon and nitrogen plays a crucial role in improving crop performance. Among all treatment combinations, S_3N_2 (Silicon 100 kg/ha + Nitrogen 100 kg/ha) emerged as the most effective treatment, producing maximum plant height and reducing crop duration.

Thus, it can be concluded that the combined application of silicon and nitrogen not only enhances vegetative growth but also improves crop phenology, making it a promising strategy for improving rice productivity under field conditions.

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