Journal of Natural Science Review

Vol. 2, Special Issue, 2024
https://kujnsr.com
e-ISSN: 3006-7804

Influence of Silicon Application Timing on the Performance of Rice Under Limited Water Supply

Hayat Ullah

Asian Institute of Technology, Pathum Thani 12120, Thailand
✉Email: hayatbotanist204@gmail.com (corresponding author)

ABSTRACT

The beneficial impact of Silicon (Si) in mitigating diverse abiotic stresses, such as drought stress, has been extensively recorded across various crops. A pot experiment was conducted at the Asian Institute of Technology, Thailand, to evaluate the performance of a popular Thai rice variety (RD57) commonly cultivated in Thailand's central plains under three soil moisture levels as affected by five Si application timings. Si was added to the soil at 300 kg Si ha^{-1}. Reduced water supply (75% field capacity [FC] and 50% FC) caused lengthening of the growth period with reduced yield and its components. Si application resulted in an enhanced root and shoot growth irrespective of application timings, compared with the control. However, Si application with split doses of 25% at basal, 50% at panicle initiation (PI), and 25% at the heading stage was found to be the most effective. Even under severe water stress, more root growth and panicle numbers were found during this application timing. Si absorption was also found more for all application timings than the control; however, the same application timing resulted in the highest absorption (8.62%). A strong positive correlation was observed between Si uptake and grain and straw yield under all moisture-deficient conditions. Si application can be recommended in split doses for rice cultivation under a limited water supply.

ARTICLE INFO

Article history:
Received: Oct 9, 2023
Revised: Jul 11, 2024
Accepted: Nov 3, 2024

Keywords:
Field capacity; RD57; Si accumulation; Water stress; Yield

To cite this article: Hayat ullah, Influence of Silicon Application Timing on the Performance of Rice Under Limited Water Supply. *Journal of Natural Science Review*, *2*(Special Issue), 1–7.
https://doi.org/10.62810/jnsr.v2iSpecial.Issue.109
Link to this article: https://kujnsr.com/JNSR/article/view/109

Introduction

Rice (*Oryza sativa* L.) is Afghanistan's second most important staple food crop after wheat and significantly contributes to the country's economy (Kakar et al., 2019). More than 80% of the marginal population of Afghanistan depends on agriculture as their main source of sustenance, and rice is a major player. However, the average rice yield in Afghanistan is approximately 2.8 t/ha, which is significantly lower than the average rice yield in neighboring countries such as Pakistan, where the average yield is about 3.5 t/ha (Kakar et al., 2019).

Afghanistan faces formidable challenges in its agriculture sector, with recurring droughts posing a significant threat to crop productivity and food security. The arid climate, coupled with erratic rainfall patterns, has led to prolonged periods of water scarcity, severely impacting the growth and yield of crops. In the struggle to combat the adverse effects of drought, the role of Silicon (Si) in agriculture emerges as crucial. Silicon, when applied as a soil amendment, plays a vital role in mitigating the impacts of drought stress on plants. It improves the plant's capacity to endure water scarcity by enhancing water-use efficiency and reinforcing the plant's structural integrity. Additionally, Si application has been shown to reduce transpiration rates, thus conserving water within the plant. As Afghanistan seeks sustainable solutions to address its agricultural challenges, harnessing the benefits of Silicon could prove instrumental in building resilience against drought and ensuring a more secure and productive future for its agricultural sector.

Water deficit is one of the most damaging abiotic stresses that adversely affects many physiological processes in plants and severely reduces crop yield (Farooq et al., 2009). As a semi-aquatic crop that depends on a plentiful water supply for cultivation, rice is notably more susceptible to soil water deficit conditions than other arable crops. Therefore, it is crucial to assess the drought susceptibility of newly introduced rice varieties to choose the most suitable ones for specific geographical locations, particularly given the growing concern about irrigation water scarcity (Bouman., et al., ., 2007). Despite not being classified as an essential element, Si proves advantageous for most higher plants, particularly under abiotic and biotic stress conditions. Repeated demonstrations have showcased increased rice yield from applying Si fertilizer and enhanced Si-induced drought tolerance observed in Si-accumulator crops, including rice (Nollah et al., 2012; Jakeline et al., 2016). This implies that a shortage of Si presents a critical limitation to optimizing rice productivity, emphasizing the importance of supplemental Si fertilization at the right time and dosage in rice cultivation. However, the positive role of Si in improving rice growth and productivity is often overlooked because it is considered a trace element.

Nevertheless, in the current concept of climate-smart agriculture, applying Si in optimum and stressed conditions is imperative to maintain productivity even under stressful conditions. Despite the widespread cultivation of the newly introduced RD57 rice variety in irrigated areas of the central plain of Thailand due to its high yield potential, its sensitivity to drought has not been thoroughly explored. The current study was designed to evaluate whether the application of Si and its application timings impact rice growth and productivity under drought stress. This study aimed to assess the impact of Si fertilizer application at different times on the growth, productivity, and Si uptake of the RD57 rice variety under conditions of limited water supply.

Methods and Materials

Seeds of the RD57 rice variety were obtained from the Pathum Thani Rice Research Center. They underwent surface sterilization with a 10% H_2O_2 solution for 10 minutes, followed by thorough rinsing with distilled water. Following a soaking period of 24 hours in distilled water, the seeds were planted in nursery trays. After reaching fifteen days of growth, the seedlings were transferred into plastic pots and housed in a polyhouse environment. Each pot was filled with 7 kg of Bangkok-type clay soil, characterized by a pH of 5.7 and consisting of 5.26% sand, 30.68% silt, 64.06% clay, and 2.6% organic matter. The pots were supplemented with the recommended dose of fertilizer containing nitrogen (N), phosphorus (P), and potassium (K). The experiment utilized a completely randomized design with three replications for each treatment. The experimental therapies involved five different application timings of Silicon (Si): a control group receiving no Si, 100% Si applied at the basal stage, 50% Si at the basal stage combined with 50% Si at panicle initiation (PI), 25% Si at the basal stage combined with 75% Si at PI, and 25% Si at the basal stage combined with 50% Si at PI and 25% Si at maturity. These treatments were tested under three soil moisture regimes: 100% field capacity (FC), 75% FC, and 50% FC. Silicon was added to the soil at 300 kg per hectare. Harvest data included measurements of the root system, including root dry matter and root volume, as well as the number of panicles per plant and Si absorption. The Si concentration in rice shoots was determined using the gravimetric method outlined by Elliott et al. (1988). Statistical analysis was conducted using the ANOVA function of SPSS 16.0 software. Significant treatment effects were compared using Fisher's least significant difference (LSD) test at a significance level of 5%.

Results and Discussion

Reduced water availability of 75% FC and 50% FC adversely affected the growth duration, and it was longer than the plants maintained under FC in both of the limited soil moisture regimes (Figure. 1).

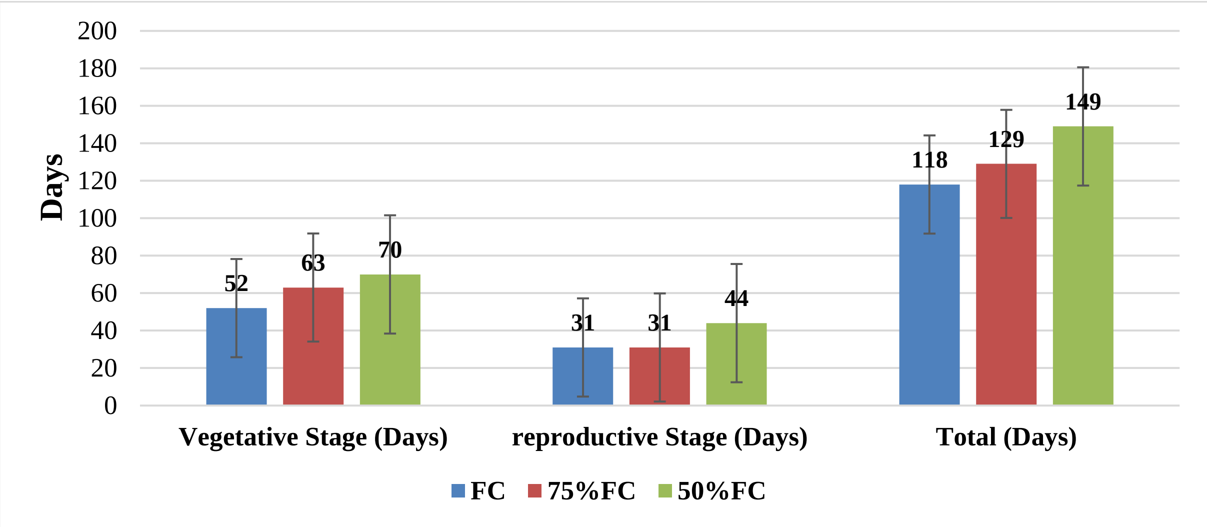

Figure 1. Effect of water stress on growth duration of RD57 rice variety in a polyhouse experiment at the Asian Institute of Technology, Thailand

However, the growth duration under the three soil moisture regimes was not statistically significant. The length of both the vegetative and reproductive stages was determined by calculating the time from the sowing date to panicle initiation (PI) for the vegetative stage and from PI to the heading date for the reproductive stage. All treatments were harvested 35 days after the anthesis, ensuring uniform ripening across all conditions. The current findings align closely with earlier research. For example, (Liu., et al., 2011) demonstrated a drought-induced delay in heading time in a pot experiment, where rice plants subjected to a mere 3-day drought before heading exhibited a delay of four to five days compared to well-watered control plants. Similarly, the present study observed retardation in flowering under water-deficit conditions, indicating the drought susceptibility of rice (Davatgara, 2009).

Si application improved the growth and development of the root system regardless of the timings of the application (Table 1).

Table 1: Effect of Si application (300 kg ha^{-1}) timings on root dry matter and root volume of RD57 rice variety in a polyhouse experiment at the Asian Institute of Technology, Thailand

Si Application timings	Root dry matter (g)	Root volume (cm^3)
Control (no Si)	7.16	81.1
100% basal	7.25	84.3
50% basal + 50% PI	7.52	85.0
25% basal + 75% PI	7.58	85.6
25% basal + 50% PI + 25%heading	7.97	86.7
P<0.05	ns	ns

PI, Panicle initiation; ns, non-significant

However, a split dose of 25% at basal +50% at PI + 25% at maturity was found more effective for both root dry matter and root volume, although statistically, the difference among these split doses was non-significant. Root growth plays a crucial role in the overall performance of plants. It has been suggested that plants cultivated in plastic containers exhibit a higher fine root mass than plants grown in field conditions (Lesley et al.,., 2015). The present study found the Si application effective for root system development.

The interaction between Si application timings and moisture levels exhibited a significant two-way in Table 2: Effect of Si application timings (300 kg ha^{-1}) on the number of panicle $plant^{-1}$ of RD57 rice variety under different soil moisture regimes in a polyhouse experiment at the Asian Institute of Technology, Thailand. FC, field capacity; PI, Panicle initiation; LSD (0.05), least significant difference at P < 0.05; data are the average of three replications.

Table 2. Influence on panicle number $plant^{-1}$

Si application timings	**Number of panicle $plants^{-1}$**		
	FC	**75% FC**	**50% FC**
No Si	19.0	17.0	15.7
100% basal	20.3	18.3	16.3
50% basal + 50% PI	21.7	19.0	15.0
25% basal + 75% PI	22.0	16.3	17.0
25% basal + 50% PI + 25% heading	23.5	19.7	18.0
LSD (0.05)	0.80		

Panicle number is intricately linked to rice yield as it directly governs grain production (Ikeda et al., 2010). Under water-deficit conditions, particularly with severe water stress at 50% FC, there was a notable decrease in panicles per plant (Table 2). Similar findings were reported by (Cha-um., et al., 2010) for Pathum Thani 1, a local rice variety with phenological characteristics almost identical to RD57, showing a 30% reduction in panicle number compared to well-watered plants. Among the different water-deficit regimes, the severe 50% FC condition resulted in the most significant decline in panicle number, approximately 23%. The moderate 75% FC deficit led to a 15% reduction compared to the control 100% FC regime. This reduction is attributed to a pronounced drought-induced inhibition of photosynthesis in the rice plants. Like root dry matter and root volume, a split dose of 25% at basal + 50% at PI + 25% at maturity was found more effective in maintaining higher panicle number pant^{-1}.

The drought significantly reduced Si uptake in the rice plant, as expected, given that the absorption of plant nutrients occurs only when the ions are present in the soil solution (Jakeline., et al., 2016). Consequently, reduced water availability in the soil could lead to decreased solubility of applied Si fertilizer, resulting in a decline in Si accumulation in the rice shoot. Conversely, Si fertilization has been extensively documented to enhance Si accumulation in the rice plant. A study (Pati., et al., 2016) observed a 33.8% increase in Si accumulation in rice grain and a 56.6% increase in straw due to Si application. Similarly, (Marxen., et al., 2016) reported that the application of silica gel in a field improved Si accumulation by 28–120% compared to the control without supplemental Si. These findings align with the results of the present study, as depicted in Fig. 2. The control treatment yielded the lowest Si content, approximately 7%. At the same time, all other Si applications significantly increased the amount, ranging from 12.5% with the split application of 50% at basal + 50% at PI to 20.3% with the split application of 25% at basal + 50% at PI + 25% at heading (Fig. 2).

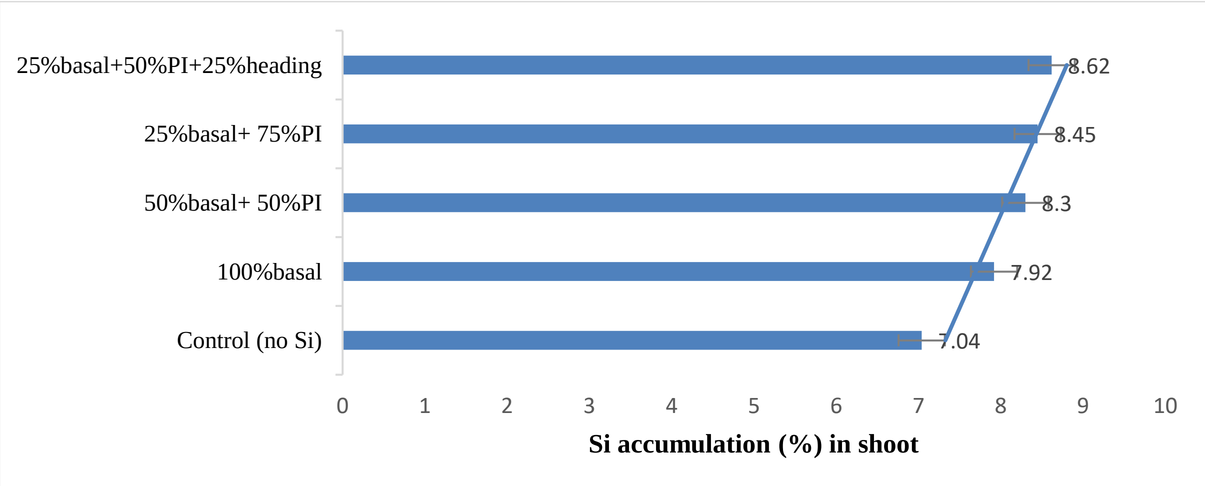

Figure 2. Effect of Si application timings on Si accumulation in the shoot of RD57 rice variety in a polyhouse experiment at the Asian Institute of Technology, Thailand.

The correlation between grain yield and Si accumulation in rice shoots was highly significant ($P < 0.01$), as depicted in Figure 3.

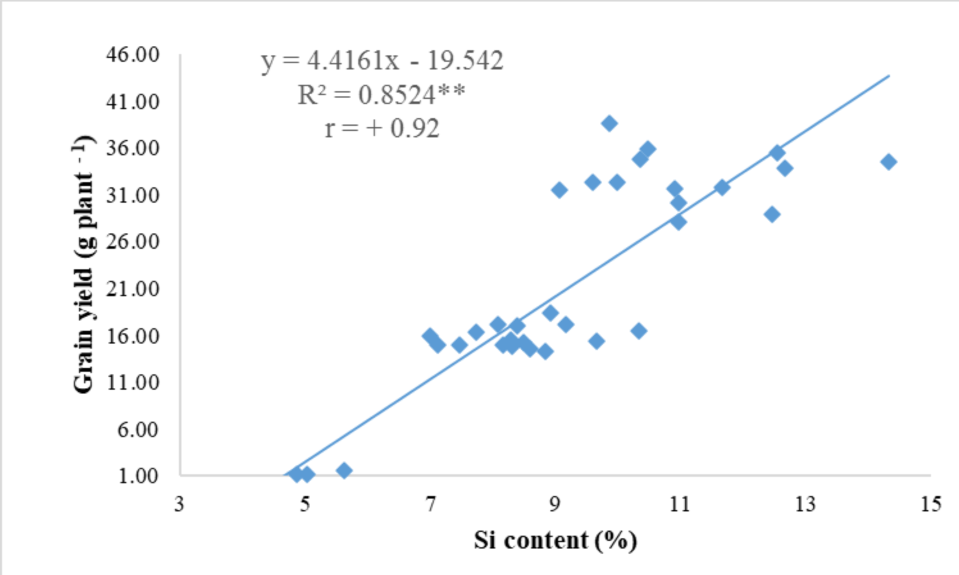

Figure 3. Relationship between grain yield and Si content of RD57 rice variety in a polyhouse experiment at the Asian Institute of Technology, Thailand.

With an R^2 value of 0.85, it is evident that the accumulated Si can account for 85% of the variability in grain yield in the straw. The relationship between grain yield and Si accumulation exhibited a positive linear trend, with a highly significant and positive response to the increase in Si content (r = +0.92). This observation aligns with previous findings, where researchers have noted a similar trend of increasing Si accumulation correlating with higher yields. For instance, (Crooks., et al., 2016) observed that the uptake of Si by rice plants is influenced by the soil's Si status, which can be notably enhanced through Si fertilization. Therefore, incorporating Si as a fertilizer is crucial in improving Si availability in the soil, boosting Si uptake by rice plants and ultimately leading to higher grain yields.

Conclusion

The drought regimes applied in this study had a detrimental impact on the growth and yield potential of the rice plant, highlighting the high susceptibility of RD57 to drought conditions. Nevertheless, the introduction of Si fertilizer into the soil significantly boosted Si uptake by the rice plant. However, splitting Si doses into various growth stages was more effective than its 100% application as basal dose. Similar studies under controlled and field conditions using rice varieties from Afghanistan are highly recommended to sustain rice productivity, close the yield gap, and prepare for the changing climate, all of which will contribute to a green revolution for self-sufficient Afghanistan.

Conflict of Interest: The author(s) declared no conflict of interest.

References

Bouman, B. A. M., Humphreys, E., Tuong, T. P., & Barker, R. (2007). Rice and water. *Advances in Agronomy*, *92*, 187–237.

Cha-um, S., Yooyongwech, S., & Supaibulwatana, K. (2010). Water deficit stress in the reproductive stage of four indicia rice (Oryza sativa L.) genotypes. *Pakistan Journal of Botany, 42*(5), 3387–3398.

Crooks, R., & Prentice, P. (2016). Extensive investigation into field-based responses to a silica fertilizer. *Silicon, 8*, 1–4.

Davatgara, N., Neishabouria, M. R., Sepaskhahb, A. R., & Soltanic, A. (2009). Physiological and morphological responses of rice (Oryza sativa L.) to varying water stress management strategies. *International Journal of Plant Production, 3*(4), 19–32.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms, and management. *Agronomy for Sustainable Development, 29*, 185–212.

Ikeda, M., Hirose, Y., Takashi, T., Shibata, Y., Yamamura, T., Komura, T., Doi, K., Ashikari, M., Matsuoka, M., & Kitano, H. (2010). Analysis of rice panicle traits and detection of QTLs using an image analyzing method. *Breeding Science, 60*, 55–64.

Jakeline, R. O., Marcio, K., Edna, M. B. S., & Tonny, J. A. S. (2016). Silicon fertilization and soil water tensions on rice development and yield. *Revista Brasileira de Engenharia Agricola e Ambiental, 20*(2), 138–143.

Kakar, K., Xuan, T. D., Haqani, M. I., Rayee, R., Wafa, I. K., Abdiani, S., & Tran, H. D. (2019). Current situation and sustainable development of rice cultivation and production in Afghanistan. *Agriculture, 9*(3), Article 49.

Lesley, A. J., Brian, E. J., & William, C. F. (2015). Advancements in root growth measurement technologies and observation capabilities for container-grown plants. *Plants, 4*, 369–392. https://doi.org/10.3390/plants4030369

Liu, J. X., & Bennett, J. (2011). Reversible and irreversible drought-induced changes in the anther proteome of rice (Oryza sativa L.) genotypes IR64 and Moroberekan. Molecular Plant, 4(1), 59–69.

Manal, M. E., Hemmat, E. K., Nesma, M. H., & Abdelsalam, E. D. (2014). Effect of selenium and silicon on yield quality of rice plant grown under drought stress. *Australian Journal of Crop Science, 8*(4), 596–605.

Marxen, A., Klotzbucher, T., Jahn, R., Kaiser, K., Nguyen, V. S., Schmidt, A., Schädler, M., & Vetterlein, D. (2016). Interaction between silicon cycling and straw decomposition in a silicon deficient rice production system. *Plant and Soil, 398*, 153–163.

Nolla, A., Faria, R. J., Korndorfer, G. H., & Silva, T. R. B. (2012). Effect of silicon on drought tolerance of upland rice. *Journal of Food, Agriculture and Environment, 10*, 269–272.

Pati, S., Pal, B., Badole, S., Hazra, G. C., & Mandal, B. (2016). Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. *Communication in Soil Science and Plant Analysis, 47*(3), 284–290.