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Effects of Silicon and Multimolig-M Fertilizer on the Morphological Characteristics, Growth, and Yield of the VTNA6 Rice in Vietnam

Hien Huu Nguyen[1]*, Minh Xuan Tran[1] and Thanh Cong Nguyen[2]

[1]*School of Agriculture and Natural Resources, Vinh University, 182 Le Duan, Vinh City 43108, Vietnam*
[2]*Cyber School, Vinh University, 182 Le Duan, Vinh City 43108, Vietnam*

ABSTRACT

Multimolig-M and silicon are essential fertilisers that enhance crop growth and yield. Silicon provides structural and protective benefits, while Multimolig-M supplies crucial micronutrients for metabolic functions, improving yield and quality. This study aims to evaluate the effects of silicon and Multimolig-M on the morphological characteristics, growth, and yield of the VTNA6 rice variety in Nghe An Province, Central Vietnam. The experiments were conducted using a randomised complete block design (RCBD) with three replications. Three levels of Multimolig-M (M_1: 360 ml/ha; M_2: 420 ml/ha; M_3: 480 ml/ha) and silicon (Si_1: 120 kg/ha; Si_2: 160 kg/ha; Si_3: 200 kg/ha) were applied. The results indicated significant improvements in flag leaf length, flag leaf width, panicle length, plant height, number of leaves, number of tillers, and number of effective tillers applying fertilisers. The treatment combination of 420 ml/ha Multimolig-M and 200 kg/ha silicon (M_2Si_3) produced the highest theoretical yield of 10.32 tons/ha and a net yield of 7.93 tons/ha, suggesting a synergistic effect of the two fertilisers. These findings highlight the positive impact of combining 420 ml/ha Multimolig-M with 200 kg/ha silicon on optimising yield and growth characteristics for VTNA6 rice, making it a recommended approach for enhancing rice productivity under local conditions in Nghe An.

Keywords: Multimolig-M fertiliser, morphological characteristics, plant growth, silicon fertiliser, VTNA6 rice yield

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E-mail addresses:
hiennh@vinhuni.edu.vn (Hien Huu Nguyen)
minhtx@vinhuni.edu.vn (Minh Xuan Tran)
thanhnc@vinhuni.edu.vn (Thanh Cong Nguyen)
* Corresponding author

INTRODUCTION

Rice (*Oryza sativa* L.) is an essential food source for over half of the global population. It ranks among the five most widely cultivated crops worldwide, alongside maise, wheat, cassava, and potatoes (Mohidem et al., 2022). Originating in tropical and subtropical regions of Southeast Asia and Africa, rice supplies vital nutrients and

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calories to billions across continents, including Asia, Africa, the Americas, Australia, and Europe (Baltazar & De Datta, 2023).

In Vietnam, rice plays a crucial role in the agricultural sector and rural livelihoods (Tran, 2019), especially in regions like Nghe An Province, where challenging climatic and soil conditions affect rice productivity (Hạnh et al., 2020). High-yielding rice varieties, such as VTNA6, have contributed significantly to production increases, yet they encounter nutrient deficiency challenges that impact yield and quality (Đoàn et al., 2022). Effective nutrient management tailored to local conditions is essential to fully realise these varieties' growth and yield potential.

Nutrient application plays a key role in determining rice growth, morphology, and yield. Silicon (Si), for example, is well-documented for its beneficial effects on rice, fortifying leaves, stems, and roots to enhance growth and resilience (Meena et al., 2014). Research indicates that rice plants can absorb significant silicon, typically 230 to 470 kg/ha (Abdullah et al., 2021). Adequate silicon levels in rice plants lead to more upright leaves, which enhances sunlight absorption and improves photosynthetic capacity (Kheyri, 2022). Additionally, silicon-enriched leaves exhibit increased resistance to rice blast disease, while stronger stems reduce lodging, thereby decreasing the incidence of empty and shrivelled grains (Sheykhzadeh et al., 2022). Moreover, the application of silicon has been shown to reduce the prevalence of various diseases, such as brown spot disease, neck blast, sheath blight, leaf blight, and root nematodes, ultimately improving both the quality and yield of rice (Ma & Yamaji, 2006). However, rice response to silicon varies with environmental conditions and nutrient interactions.

Sustainable agriculture has increasingly been recognised as a crucial aspect of modern farming practices (Amrutha et al., 2022). Biofertilisers have become a promising approach for sustainable rice production, mitigating pollution (Pallarés et al., 2021) while significantly enhancing crop yields (Nosheen et al., 2021). Biofertilisers complement chemical fertilisers and serve as environmentally friendly supplements that promote healthy plant growth, making them a valuable resource for sustainable agriculture (Thomas & Singh, 2019). Multimolig-M is a biofertiliser that enhances soil quality and plant nutrition in organic agriculture. It can be applied to the soil to enhance its structure, nutrient uptake, and moisture retention, as well as to plant leaves to facilitate the rapid absorption of essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), boron (B), and molybdenum (Mo). It enhances plant strength and reduces the reliance on traditional fertilisers and pesticides. Multimolig-M can increase crop yields by 10-40%, improve product quality, lower production costs by 30-50%, and is environmentally friendly (Đỗ, 2018).

Despite the established benefits of silicon and micronutrient fertilisers, limited research exists on their combined effects on the VTNA6 rice variety in Nghe An Province. This study aims to fill this gap by evaluating the synergistic effects of silicon and Multimolig-M fertiliser on the VTNA6 rice variety. The findings are expected to provide valuable insights into optimising fertilisation strategies for improved rice production in Vietnam.

The objectives of this study are to (1) determine the effects of different levels of silicon and Multimolig-M fertiliser on the morphological traits, growth and yield of VTNA6 rice and (2) provide recommendations for effective fertiliser management practices in rice cultivation to enhance productivity and sustainability in Nghe An Province.

MATERIALS AND METHODS

Treatments and Experimental Design

The field experiments were conducted during the winter-spring season from December 2023 to May 2024 at the agricultural research station of the School of Agriculture and Natural Resources, Vinh University, located in Dien Chau district, Nghe An province, Central Vietnam (105.30-105.45°N, 18.20-19.50°E). Soil properties of the experimental site are shown in Table 1. The average temperature, rainfall and humidity during the experiments were 21.3°C, 91.7 mm and 84%, respectively (Figure 1). This study focused on the VTNA6 hybrid rice variety developed by the Nghe An Agricultural Materials Joint Stock Company (Ministry of Agriculture and Rural Development [MARD], 2018). Multimolig-M fertilizer is imported from Russia by UBB Trading and Service Co., Ltd., Dong Son silicon fertilizer is produced by Limex Vietnam Co., Ltd., Que Lam manure (cow dung) is manufactured by Que Lam Group, Vietnam, and Van Dien chemical fertilizer (N, P_2O_5, K_2O) is produced by Van Dien Fused Magnesium Phosphate Fertilizer Joint Stock Company, Vietnam.

The experiments were arranged as randomised complete block designs (RCBD) with three replications. The area of each plot was 25 m^2 (5 × 5 m). The rice was planted in rows of 13 × 20 cm spacing with one plant per cluster. Three levels of Multimolig-M (M_1: 360 ml/ha; M_2: 420 ml/ha; M_3: 480 ml/

Table 1
Soil properties of the experimental site

Properties	Values
pH (1: 2.5 soil water suspension)	5.20
ECe (mS/cm)	0.31
Organic carbon (%)	0.70
Total N (%)	0.13
Available P (mg/kg)	26.50
Exchangeable K (mg/kg)	90.50
Exchangeable Mg (mg/kg)	90.90
Available S (mg/kg)	62.30
DTPA-extractable Zn (mg/kg)	2.20
DTPA-extractable Mn (mg/kg)	63.30
Available B (mg/kg)	0.38
Available Si - $CaCl_2$ (mg/kg)	36.50
Soil Texture	
Sand (%)	62.00
Silt (%)	24.00
Clay (%)	14.00
Soil classification	Sandy loam

Note. Ece = Electrical conductivity at saturation point, N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, Cu = copper, Zn = zinc, Mn = manganese, B = boron, Si = silicon, DTPA = diethylenetriaminepentaacetic acid

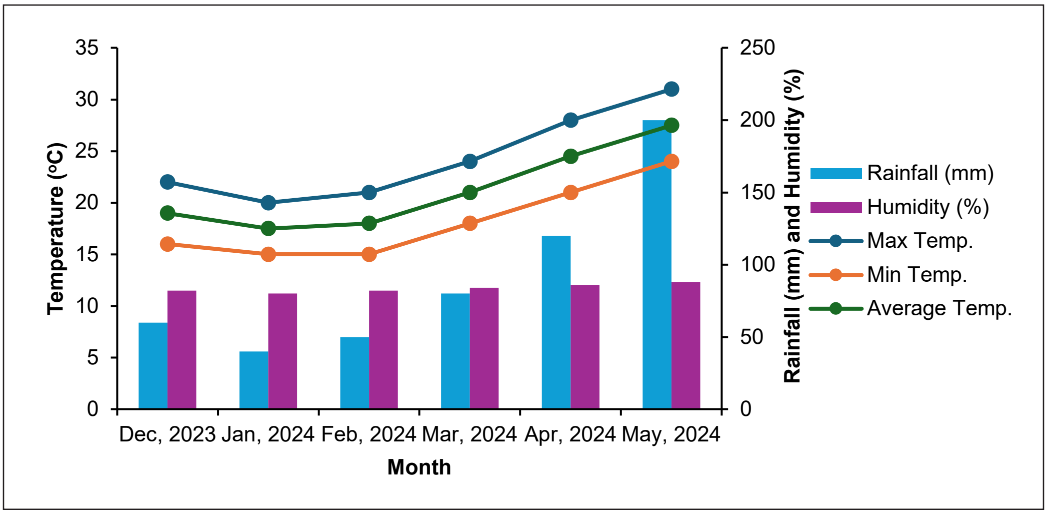

Figure 1. Temperature, rainfall and humidity variations during the experiment

ha) and silicon (Si_1: 120 kg/ha; Si_2: 160 kg/ha; Si_3: 200 kg/ha) fertilisers were used in this experiment. A total of 9 experimental units were involved in the study (Table 2).

Table 2
Fertiliser rates for each treatment

Treatment	Multimolig-M (ml/ha)	Silicon (kg/ha)
M_1Si_1	360	120
M_1Si_2	360	160
M_1Si_3	360	200
M_2Si_1	420	120
M_2Si_2	420	160
M_2Si_3	420	200
M_3Si_1	480	120
M_3Si_2	480	160
M_3Si_3	480	200

Note. M_1Si_1 is the control treatment, which represents the amount of fertiliser farmers are currently using

Multimolig-M and silicon are commercial fertilisers with a composition provided by the manufacturer as follows: 10.5% organic matter, 0.25% humic acid, 2% total nitrogen, 192 ppm calcium, 0.02% available phosphorus, 0.11% potassium, 1.88% sulphur, 2370 ppm magnesium, 3570 ppm iron, 590 ppm copper, 1000 ppm zinc, 2770 ppm manganese, and 892 ppm boron; pH (in water) is 5.5, with 400 ppm cobalt and 800 ppm molybdenum. The silicon fertiliser contains a minimum of 45% total silicon, at least 25% available silica (SiO_2), more than 10% available iron (Fe_2O_3), and more than 5% available magnesium (MgO). Multimolig-M, a liquid fertiliser with a concentration of 1 ml per 1 litre, was prepared and applied three times during the tillering, panicle initiation, and heading stages. Silicon fertiliser was applied as a basal dressing once before transplanting.

The experiment was conducted on a base fertiliser application used by local farmers, which included 10 tons of manure (cow dung), 50 kg N, 40 kg P_2O_5, and 40 kg K_2O per hectare. The basic fertiliser applications were 100 % manure, 100 % P_2O_5 and 30% N. The remaining fertiliser was applied twice to the top dressing. The first top dressing application was during the tillering with 50% K_2O and 40% N, and the second was at panicle initiation with 50% K_2O and 30% N.

Data Collection

Ten plants in each plot were randomly selected to record agronomic traits. These agronomic traits included morphological characteristics (heading duration, panicle exertion, culm strength, leaf senescence, flag leaf length, flag leaf width, panicle length); growth parameters (plant height, number of leaves, number of tillers, and number of effective tillers) and yield components and yield (number of effective panicles per square meter, number of grains per panicle, number of filled grains per panicle, weight of 1000 grains, theoretical yield, and net yield).

The agronomic traits were monitored under normal field conditions. Visual assessment methods were conducted by observing the entire experimental plot, individual plants, or plant parts. Quantitative indicators were measured on sample plants. Monitoring occurred 15, 30, 45, and 60 days after transplanting (DAT) and at harvest (125 DAT).

Statistical Analysis

The data were subjected to an analysis of variance (ANOVA) in an RCBD design that contained nine treatments and three replicates per treatment. Duncan's multiple range tests performed the mean separation at the 5% significance level. The correlations between silicon and Multimolig-M fertiliser agronomic traits on the VTNA6 rice were analysed after Pearson's test evaluated the data's normality.

RESULTS AND DISCUSSION

Morphological Characteristics

The research findings indicate that the interaction between Multimolig-M fertiliser and silicon significantly influences the morphological characteristics of the VTNA6 rice (Table 3). Specifically, applying Multimolig-M at level M_2 in combination with varying levels of silicon results in a concentrated heading duration of no more than three days and ensures complete panicle exertion. Culm strength is significantly enhanced when Multimolig-M levels are combined with silicon levels Si_2 and Si_3, thereby reducing lodging risk. Leaf senescence, however, remains unaffected by these treatments.

Multimolig-M fertiliser and silicon combination affect the length and width of flag leaves and the length of panicles (Table 3). The treatment combination M_3Si_3 resulted in the greatest flag leaf length (36.40 cm) and width (1.86 cm), with statistically significant differences ($p<0.05$) compared to other treatments. However, it did not show statistically

Table 3
Effects of silicon and Multimolig-M fertiliser on the morphological characteristics of the VTNA6 rice in Nghe An Province, Central Vietnam

Treatment	**Heading duration**	**Panicle exertion**	**Culm strength**	**Leaf senescence**	**Flag leaf length**	**Flag leaf width**	**Panicle length**
M_1Si_1	5	1	5	1	33.32[d]	1.23[e]	23.44[b]
M_1Si_2	1	1	1	1	34.05[cd]	1.30[de]	23.65[b]
M_1Si_3	1	1	1	1	34.96[bc]	1.42[cde]	25.02[ab]
M_2Si_1	1	1	5	1	34.01[cd]	1.43[cde]	24.76[b]
M_2Si_2	1	1	1	1	35.02[bc]	1.52[cd]	24.94[b]
M_2Si_3	1	1	1	1	36.06[ab]	1.60[bc]	27.50[a]
M_3Si_1	5	5	5	1	34.63[c]	1.60[bc]	22.54[b]
M_3Si_2	5	5	1	1	35.93[ab]	1.76[ab]	22.90[b]
M_3Si_3	5	5	1	1	36.40[a]	1.86[a]	23.21[b]
$LSD_{0.05}$	-	-	-	-	1.23	0.24	2.85
CV (%)	-	-	-	-	1.00	4.60	2.71

Note. Different letters within the columns denote significant differences ($p \leq 0.05$). The scoring criteria are as follows: (1) Heading duration: score 1 = concentrated (no more than 3 days), score 5 = intermediate (4–7 days), score 9 = extended (more than 7 days), (2) Panicle exertion: score 1 = complete exertion, score 5 = exertion just at the panicle neck, score 9 = partial exertion, (3) Culm strength: score 1 = strong (plants do not lodge), score 5 = intermediate (most plants are leaning), score 9 = weak (most plants lodge completely), (4) Leaf senescence: score 1 = late (leaves remain naturally green), score 5 = intermediate (leaves turn yellow), score 9 = early (all leaves turn yellow or die)

significant differences ($p<0.05$) compared to the M_3Si_2 and M_2Si_3 treatments. Regarding panicle length, the M_2Si_3 treatment achieved the longest panicle length (27.50 cm), also showing statistically significant differences ($p<0.05$) compared to other treatments, except for the M_1S_3 treatment. These findings confirm that the levels of Multimolig-M and silicon fertilisers, as well as their combinations, have a pronounced impact on the morphological characteristics of the VTNA6 rice.

Silicon plays an essential role in regulating the morphology of rice plants, particularly in the development of key structures such as leaves, stems, and roots. Silicon is absorbed and primarily accumulates in the outer parts of the plant, such as the flag leaf and the epidermis of the stem, enhancing rigidity and improving resilience against adverse conditions such as drought and pests (Mandloi et al., 2024; Snehalatha et al., 2023). Due to silicon, the flag leaf's thicker and more robust structure allows for optimised photosynthesis by keeping the leaf upright, thereby improving light absorption and photosynthetic efficiency (Ahmed et al., 2024). Studies have shown that rice varieties with larger flag leaf areas and smaller leaf angles exhibit higher photosynthetic efficiency and greater dry matter accumulation, which positively impacts yield (Wang et al., 2023). Silicon also reinforces the mechanical strength of rice stems, minimising lodging—a factor that often negatively impacts grain yield and quality (Yusob et al., 2023). A sturdier stem facilitates more efficient water and nutrient transport from the roots to the leaves and grains, promoting uniform development and higher yield (Snehalatha et al., 2023).

Multimolig-M, rich in micronutrients like Zn, Fe, and Mn, supports the balanced development of plant organs. These elements are crucial in forming enzymes that regulate cell division and elongation, impacting leaf and stem size. The observed increase in leaf length and width in this study may be attributed to the micronutrient supplementation from Multimolig-M, which optimises leaf surface area for photosynthesis. Additionally, Multimolig-M can improve the rice root system, enhancing water and nutrient uptake from the soil. It positively influences overall growth and plant morphology, including the number and size of tillers. The increase in productive tillers contributes to a higher number of rice panicles, resulting in a noticeable yield improvement. As indicated in the study, the combination of silicon and Multimolig-M led to an increase in flag leaf length and panicle length, demonstrating a synergistic effect in enhancing critical morphological traits of rice plants.

Number of Leaves on Main Stem

The application of Multimolig-M and silicon fertilisers significantly influenced the leaf count on the main stem of the VTNA6 rice variety (Table 4). The study found that the leaf count increased notably with higher levels of Multimolig-M fertiliser and increased silicon content. The greatest effect was observed in the M_3Si_3 treatment, with statistically significant differences ($p<0.05$) compared to other treatments. However, it did not show statistically significant differences ($p<0.05$) compared to the M_2Si_3 and M_3Si_2 treatments at harvest. It suggests combining Multimolig-M and silicon fertilisers

Table 4
Effects of silicon and Multimolig-M fertiliser on the number of leaves of the VTNA6 rice in Nghe An Province, Central Vietnam

Treatment	15 DAT	30 DAT	45 DAT	60 DAT	At harvest (125 DAT)
M_1Si_1	5.40^{c}	7.57^{b}	10.47^{c}	12.63^{c}	13.10^{c}
M_1Si_2	5.63^{abc}	8.37^{a}	11.13^{abc}	13.27^{bc}	13.97^{b}
M_1Si_3	5.90^{a}	8.63^{a}	11.50^{ab}	13.63^{ab}	14.47^{b}
M_2Si_1	5.47^{bc}	8.30^{a}	11.20^{abc}	13.43^{ab}	14.17^{b}
M_2Si_2	5.63^{abc}	8.57^{a}	11.47^{ab}	13.63^{ab}	14.43^{b}
M_2Si_3	5.83^{ab}	8.70^{a}	11.67^{ab}	13.87^{ab}	14.63^{ab}
M_3Si_1	5.43^{bc}	8.37^{a}	11.27^{ab}	13.50^{ab}	14.33^{b}
M_3Si_2	5.60^{abc}	8.60^{a}	11.60^{ab}	13.80^{ab}	14.70^{ab}
M_3Si_3	5.83^{ab}	8.80^{a}	11.87^{a}	14.17^{a}	15.40^{a}
$LSD_{0.05}$	0.41	0.61	0.78	0.75	0.79
CV (%)	2.17	1.75	1.35	1.48	1.67

Note. Different letters within the columns denote significant differences ($p\leq0.05$)

can enhance leaf production in the VTNA6 rice, potentially leading to improved growth and yield outcomes.

The growth and development of leaves, particularly the flag leaf, are crucial for determining the yield of rice crops as they influence the duration of flowering and seed formation (Kalaignan, 2024). Leaves are essential for photosynthesis, providing nutrients necessary for plant activity, and their physiological efficiency directly affects grain filling and yield potential (Rădoi et al., 2022). The use of biofertilisers and silicon has been found to significantly influence the leaf count of rice, promoting better leaf development and increasing the number of leaves, which ultimately enhances crop productivity and quality (Elekhtyar & Al-Huqail, 2023). Biofertilisers have been found to promote leaf growth. At the same time, silicon treatments, such as potassium silicate, positively affect leaf count, resulting in a higher leaf count compared to control groups (Ning et al., 2022).

Number of Tillers per Hill

The number of tillers per hill in the VTNA6 rice variety did not show statistically significant differences (p<0.05) between treatments from 15 to 60 DAT (Table 5). At harvest, the application of M_2Si_3 resulted in the highest number of effective tillers (5.80 tillers), demonstrating a significant difference (p<0.05) relative to other treatments, except for M_2Si_2. The effective tiller rate (%) tended to decrease when the amount of Multimolig-M was increased to 480 ml/ha. The effective tiller rate was highest with M_2Si_3, but there was no significant difference between M_2Si_3 and other treatments.

This study's findings demonstrate that silicon and Multimolig-M fertilisers positively impact the number of tillers per hill in VTNA6 rice, especially as the plants progress through different growth stages, from early tillering to maturity. These effects align with earlier studies highlighting the role of silicon in enhancing tillering and overall plant robustness and the complementary role of micronutrient-enriched fertilisers in promoting balanced growth. Pati et al. (2016) established that silicon application improves tiller numbers and plant structure, contributing to enhanced yield attributes. Specifically, treatments M_2Si_3 and M_3Si_3, with the highest silicon concentrations, produced more tillers and maintained these gains through later growth stages, showing silicon's role in supporting sustained tillering and plant stability. Silicon's known ability to reinforce cell walls and enhance resistance to environmental stress likely contributed to the increased tiller count and stability against lodging (Ma & Yamaji, 2006).

The addition of Multimolig-M enhanced tillering, particularly in combination with silicon, where M_2 and M_3 levels resulted in improved tiller production rates. Micronutrients such as zinc, manganese, and iron are vital in enzymatic and cellular functions essential for plant growth and nutrient uptake (Snehalatha et al., 2023). These micronutrients likely facilitated stronger root systems and enhanced leaf expansion, contributing to a more effective tillering process and increased nutrient uptake efficiency (Gabasawa & Yusuf, 2013).

Treatments with higher combined levels of silicon and Multimolig-M (notably M_2Si_3 and M_3Si_3) showed synergistic effects on tiller production. This synergistic effect aligns with findings from Monika and Malhotra (2022), who reported similar interactions where combined nutrient management strategies led to optimal tillering and yield outcomes. Biofertilisers combined with reduced chemical fertilisers significantly increase the number of effective tillers, resulting in higher grain yields. This effect is observed when biofertilisers use 50% to 75% of the recommended chemical fertiliser doses (Ghimire et al., 2021; Hindarwati et al., 2023). Furthermore, the combined application of silicon and biofertilisers has been found to improve soil physiochemical properties, increase available silicon content, and alter the soil microbiota structure, leading to an increase in the number of tillers per plant (Mallano et al., 2022).

Table 5
Effects of silicon and Multimolig-M fertiliser on the number of tillers per hill of the VTNA6 rice in Nghe An Province, Central Vietnam

Treatment	15 DAT	30 DAT	45 DAT	60 DAT	At harvest (125 DAT)	Effective tiller rate (%)
M_1Si_1	2.07^{a}	5.73^{a}	9.10^{a}	9.20^{a}	4.43^{bc}	48.23^{ab}
M_1Si_2	2.17^{a}	5.80^{a}	9.23^{a}	9.27^{a}	4.60^{bc}	49.12^{ab}
M_1Si_3	2.40^{a}	6.03^{a}	9.50^{a}	9.67^{a}	4.83^{bc}	50.00^{ab}
M_2Si_1	2.10^{a}	5.90^{a}	9.33^{a}	9.50^{a}	5.07^{bc}	53.35^{a}
M_2Si_2	2.23^{a}	6.03^{a}	9.60^{a}	9.80^{a}	5.17^{ab}	52.75^{a}
M_2Si_3	2.43^{a}	6.27^{a}	10.00^{a}	10.23^{a}	5.80^{a}	56.73^{a}
M_3Si_1	2.13^{a}	6.00^{a}	9.90^{a}	10.37^{a}	4.33^{c}	41.81^{b}
M_3Si_2	2.30^{a}	6.23^{a}	10.13^{a}	10.53^{a}	4.47^{bc}	42.43^{b}
M_3Si_3	2.47^{a}	6.50^{a}	10.43^{a}	10.77^{a}	4.70^{bc}	43.71^{b}
$LSD_{0.05}$	0.48	0.79	1.45	1.02	0.82	8.58
CV (%)	6.55	4.96	5.05	5.07	6.38	5.61

Note. Different letters within the columns indicate significant differences ($p \leq 0.05$)

Plant Height

Table 6 demonstrates a clear trend where increasing levels of Multimolig-M and silicon fertilisers lead to higher rice plant heights. The M_3Si_3 treatment produced the tallest plant height, with statistically significant differences ($p<0.05$) compared to other treatments, except for the M_2Si_3 and M_3Si_2 treatments. This result is consistent with findings from Chen et al. (2011) on silicon's role in enhancing cell wall structure, leading to steady growth that results in higher plant height as the crop matures. Pati et al. (2016) showed that silicon supports plant rigidity and improves nutrient absorption, increasing plant height and robust

Table 6
Effects of silicon and Multimolig-M fertiliser on the plant height of the VTNA6 rice in Nghe An Province, Central Vietnam

Treatment	15 DAT	30 DAT	45 DAT	60 DAT	At harvest (125 DAT)
M_1Si_1	24.50[a]	46.52[c]	64.53[d]	81.11[d]	121.89[e]
M_1Si_2	26.08[a]	48.57[bc]	66.69[bcd]	83.58[cd]	124.56[de]
M_1Si_3	27.27[a]	50.29[ab]	68.52[abc]	85.12[bc]	125.25[cde]
M_2Si_1	24.91[a]	47.93[bc]	66.26[cd]	83.49[cd]	124.72[de]
M_2Si_2	26.17[a]	49.29[abc]	67.72[abcd]	85.37[bc]	127.23[bcd]
M_2Si_3	27.34[a]	51.20[ab]	69.72a[b]	87.40[ab]	128.63[abc]
M_3Si_1	24.98[a]	48.00[bc]	66.61[bcd]	84.50[bcd]	126.04[bcd]
M_3Si_2	26.44[a]	50.25[ab]	68.96[abc]	86.98[abc]	128.99[ab]
M_3Si_3	27.52[a]	52.34[a]	71.23[a]	89.85[a]	131.74[a]
$LSD_{0.05}$	3.68	3.68	3.68	3.68	3.68
CV (%)	3.86	2.04	3.49	2.18	2.80

Note. Different letters within the columns indicate significant differences ($p \leq 0.05$)

growth. Barus et al. (2023) and Setiawati et al. (2023) reported increased rice plant height using PGPR biofertilisers in saline soils, particularly in early growth stages. Ning et al. (2022) also found that combining biochar with silicon-rich fertilisers significantly enhanced the leaves' silicon accumulation, potentially influencing rice plant height.

Yield Components and Yield

Number of Effective Panicle per m²

Multimolig-M and silicon fertilisers significantly influenced the number of effective panicles per m^2 in the VTNA6 rice (Table 7). Applying M_2Si_3 resulted in the highest number of effective panicles (261 panicles/m^2), significantly different ($p<0.05$) from other fertiliser levels.

Integrating silicon and biofertilisers significantly increased the number of effective panicles per m^2. Sheikhani et al. (2014) reported that biofertilisers and varying silicon rates improved grain yield, tiller number, and panicle number per square meter, with the highest results observed at a silicon application rate of 450 kg/ha combined with biofertiliser seed treatment. Another study demonstrated that the combination of silicon (600 kg/ha) and biofertilisers (10 tons/ha) significantly increased the number of tillers, which directly improved the number of effective panicles and overall grain yield (Naher et al., 2016).

Number of Grains per Panicle

Application of M_2Si_3 resulted in the highest grains per panicle (191.71), but there was no statistically significant difference between the treatments. Integrating silicon and biofertilisers has significantly enhanced the number of grains per panicle (Naher et al., 2016). Islam et al. (2012) found that using *Azospirillum* biofertiliser strains combined with silicon significantly increased the number of grains per panicle, increasing grain yield. Similarly, Bhuiyan et al. (2006) showed that combining the recommended $N\text{-}P_2O_5 – K_2O$ (5.5 - 2.75 - 2.4 kg $10a^{-1}$) with biofertilisers (500 kg/ha) produced growth and yield components, including the number of grains per panicle, comparable to $N\text{-}P_2O_5 – K_2O$ (11 – 5.5 – 4.8 kg $10a^{-1}$) application. Additionally, Cuong et al. (2017) reported that when applied during the reproductive growth stage with biofertilisers, silicon fertilisers significantly improved the number of grains per panicle and overall yield.

Number of Filled Grains per Panicle

The levels of Multimolig-M and silicon fertilisers affected the number of filled grains per panicle in the VTNA6 rice. The number of filled grains per panicle ranged from 144.09 to 164.29, with the M_2Si_3 combination yielding the highest and M_3Si_1 the lowest. However, no statistically significant differences were found between the treatments. Ghimire et al. (2021) showed that combining silicon with biofertilisers, specifically Azolla and NPK, resulted in the highest number of filled grains per panicle at 114.30. Additionally, Sheikhani et al. (2014) demonstrated that silicon fertilisation at 450 kg/ha, combined with biofertiliser seed treatment (*Azospirillum* spp. and *Azotobacter* spp.), significantly increased the number of filled grains per panicle.

Weight of 1,000 Grains

Applying 420 ml Multimolig-M per ha (M_3) in combination with different silicon levels resulted in the highest 1000-grain weight, but there was no significant difference compared to other fertiliser levels. However, the application of M_2Si_3 resulted in the highest grain weight (24.07 g), while the M_3Si_1 combination had the lowest (22.73 g).

The application of silicon fertilisers significantly enhances the 1000-grain weight of rice. Higher doses of silicon (up to 400 kg/ha SiO_2), when combined with standard fertiliser practices, have demonstrated notable improvements in grain weight (Pati et al., 2016). Additionally, biofertilisers used with reduced chemical fertilisers further increase the 1000-grain weight. Optimal results have been achieved with a 50% reduction in nitrogen and phosphorus fertilisers, supplemented with biofertilisers (Hapsoh et al., 2023; Noraida & Hisyamuddin, 2021). Sheikhani et al. (2014) found that while silicon application and biofertiliser independently significantly affected the 1000-grain weight, the interaction between silicon rate and biofertiliser application was not statistically significant.

Theoretical and Net Yield

When 420 ml of Multimolig-M per hectare was applied with different silicon levels, theoretical and net yields increased. Application of M_2Si_3 achieved the highest yields for both theoretical (10.32 tons/ha) and net (7.93 tons/ha), significantly surpassing other combinations.

Cuong et al. (2017) demonstrated that applying silicon-based fertiliser at an optimal dose of 329 kg/ha, along with standard fertiliser practices, can significantly boost rice yield and enhance nutrient uptake in the tropical zone of Vietnam. Pati et al. (2016) found that silicon fertilisation using diatomaceous earth at 600 kg/ha, combined with standard fertiliser practices, increased rice grain and straw yields. Bhuiyan et al. (2006) reported that a combined treatment of half the recommended fertiliser (HRF) and 500 kg/ha biofertiliser had similar effects on the growth and yield of rice as the full recommended fertiliser (RF). Moreover, Noraida and Hisyamuddin (2021) showed that a combination of 50% biofertiliser with 50% chemical fertiliser produced better growth and yield in rice. Integrating biofertilisers and silicon fertilisers leads to significant yield improvements, as silicon application enhances the effectiveness of biofertilisers, resulting in better nutrient uptake and higher grain yield (Sheikhani et al., 2014).

Silicon plays an essential role in improving soil structure and health. When added to soil, silicon enhances water retention, loosens soil texture, and boosts crop productivity by supporting microbial communities and reducing harmful heavy metal accumulation (Wang et al., 2020). Combining silicon with biochar also aids carbon storage and improves soil durability (Huang et al., 2020). For sustainable use, long-term research on silicon's effects on soil is necessary, as Si accumulation may alter soil properties and affect nutrient availability for plants (Szulc et al., 2016). Additionally, Multimolig-M provides essential micronutrients such as zinc, manganese, and iron that are critical for rice growth; however, excessive use of these micronutrients can lead to toxic buildup in soil, potentially harming crops and soil microorganisms. Therefore, controlling Multimolig-M application rates is vital to maintaining soil health and preventing harmful accumulation, contributing to a balanced soil ecosystem (Zhao et al., 2022).

The use of silicon in agriculture can indirectly help reduce greenhouse gas emissions. Silicon enhances drought and disease resistance in rice plants, reducing the need for pesticides and chemical fertilisers, which are significant sources of greenhouse gas emissions. Research shows that silicon helps rice improve drought tolerance by enhancing photosynthesis and regulating nutrient absorption under dry conditions, supporting plant health and growth (Chen et al., 2011). Additionally, silicon can improve carbon sequestration in rice roots, reducing atmospheric CO_2 emissions (Zhao et al., 2019).

Silicon also strengthens the disease resistance of plants, reducing the need for pesticides. Studies have shown that silicon can partially substitute for pesticides by boosting rice resistance to common diseases, thereby lowering the use of agricultural chemicals (Datnoff et al., 2001). However, Multimolig-M may contribute to greenhouse gas emissions if the plants do not fully absorb micronutrients and undergo chemical transformations in the soil.

Some micronutrients may engage in soil reactions that produce N_2O or CO_2, gases with a strong greenhouse effect. Therefore, optimising the dosage and application techniques of Multimolig-M is essential to minimising greenhouse gas emissions in rice cultivation (Zhang et al., 2021). The use of silicon fertiliser and Multimolig-M can potentially improve rice yields. It may bring environmental benefits, such as reducing the need for chemical fertilisers and enhancing plant resilience to adverse conditions. However, strict control measures are necessary to prevent negative impacts on soil health and greenhouse gas emissions. Long-term studies and sustainable management practices will help maximise these fertilisers' benefits while protecting the environment.

Table 7
Effects of silicon and Multimolig-M fertiliser on the yield components and yield of the VTNA6 rice in Nghe An Province, Central Vietnam

Treatment	No. of effective panicle/m²	No. of grains/ panicles	No. of filled grains/ panicles	1000-grain weight (g)	Theoretical yield (tons/ha)	Net yield (tons/ha)
M_1Si_1	199.50^{bc}	177.57^{a}	145.61^{a}	22.73^{a}	6.60^{b}	5.58^{ab}
M_1Si_2	207.00^{bc}	179.28^{a}	147.91^{a}	23.10^{a}	7.08^{b}	6.07^{ab}
M_1Si_3	217.50^{bc}	178.78^{a}	148.39^{a}	23.23^{a}	7.52^{b}	6.36^{ab}
M_2Si_1	228.00^{bc}	182.93^{a}	153.66^{a}	24.00^{a}	8.42^{ab}	6.88^{ab}
M_2Si_2	232.50^{ab}	188.10^{a}	159.89^{a}	24.03^{a}	8.94^{ab}	7.36^{ab}
M_2Si_3	262.00^{a}	191.71^{a}	164.29^{a}	24.07^{a}	10.32^{a}	7.93^{a}
M_3Si_1	195.00^{c}	169.52^{a}	144.09^{a}	22.73^{a}	6.39^{b}	4.93^{b}
M_3Si_2	201.00^{bc}	173.88^{a}	146.06^{a}	22.97^{a}	6.74^{b}	6.01^{ab}
M_3Si_3	211.50^{bc}	172.76^{a}	146.85^{a}	23.07^{a}	7.16^{b}	6.24^{ab}
$LSD_{0.05}$	36.85	44.07	40.47	1.71	2.73	2.77
CV (%)	4.38	5.47	5.44	1.93	7.97	7.36

Note. Different letters within the columns indicate significant differences ($p \leq 0.05$)

Correlation Matrix Between Agronomic Traits

The correlations between agronomic traits of silicon and Multimolig-M fertiliser on the VTNA6 rice are shown in Table 8. The plant height, number of leaves per plant, and panicle length were positively correlated with the net yield. However, these three correlation coefficients were not statistically significant. The theoretical and net yield was positively correlated with effective tiller rate, panicle length, number of effective panicles per m², number of grains per panicle, number of filled grains per panicle, and 1000-grain weight. The correlations indicated that these six traits were the best indicators of yield and contributed more to yield than other agronomic traits. Therefore, the application of silicon and Multimolig-M fertiliser for rice in Nghe An Province should be selected based on these traits. The effective tiller ratio showed a significant correlation with theoretical yield (r =

Table 8
Correlation coefficients between agronomic traits of silicon and Multimolig-M fertiliser on the VTNA6 rice

Traits	**Plant height (cm)**	**No. of leaves/ plant**	**Effective tiller rate (%)**	**Panicle length (cm)**	**No. of effective panicle/m²**	**No. of grains/ panicles**	**No. of filled grains/ panicles**	**1000-grain weight (g)**	**Theoretical yield (tons/ha)**	**Net yield (tons/ha)**
Plant height	1									
No. of leaves/plant	0.86^{**}	1								
Effective tiller rate	-0.25	-0.23	1							
Panicle length	0.08	0.09	0.86^{**}	1						
No. of effective panicle	0.27	0.22	0.84^{**}	0.92^{**}	1					
No. of grains/panicles	-0.05	-0.15	0.94^{**}	0.82^{**}	0.89^{**}	1				
No. of filled grains/ panicles	0.22	0.13	0.82^{**}	0.82^{**}	0.96^{**}	0.94^{**}	1			
1000-grain weight	0.20	0.24	0.83^{**}	0.73^{*}	0.87^{**}	0.83^{**}	0.85^{**}	1		
Theoretical yield	0.26	0.20	0.84^{**}	0.89^{**}	0.99^{**}	0.88^{*}	0.94^{**}	0.89^{**}	1	
Net yield	0.37	0.20	0.67^{*}	0.65^{*}	0.78^{*}	0.79^{*}	0.77^{*}	0.78^{*}	0.75^{*}	1

Note. $^{*}p<0.05$; $^{**}p<0.01$

0.84**) and net yield (r = 0.67*), consistent with findings by Rahman et al. (2014) and Oladosu et al. (2018), who noted that the effective tiller number directly influences yield and is an important factor in yield prediction. Panicle length also exhibited a significant positive correlation with theoretical yield (r = 0.89**) and net yield (r = 0.65*), indicating that longer panicles typically have higher numbers and weights of grains. Sharma et al. (2012) and Gudepu et al. (2022) also reported a positive relationship between panicle length and rice yield. Furthermore, the number of grains and filled grains per panicle were highly correlated with both theoretical and net yield, with values of (r = 0.88*) and (r = 0.79*), respectively. These traits are crucial for yield prediction, as the number of filled grains determines the harvested grain weight. This result aligns with the studies of Sharma et al. (2012) and Oladosu et al. (2018), where the number of grains and filled grain ratio were considered key factors affecting yield. The 1000-grain weight strongly correlated with theoretical yield (r = 0.89**) and net yield (r = 0.78*). Gudepu et al. (2022) and Kafi et al. (2021) showed the contribution of the 1000-grain weight to higher yield.

CONCLUSION

The study demonstrates that the combined application of silicon and Multimolig-M fertilisers significantly enhances the morphological characteristics, growth parameters, and yield of the VTNA6 rice variety in Nghe An Province, Vietnam. Although the M_2Si_3 treatment (420 ml/ha Multimolig-M and 200 kg/ha silicon) produced the highest theoretical and net yields (10.32 and 7.93 tons/ha, respectively), it was not consistently superior in all measured traits. Other treatments, particularly those with similar levels of Multimolig-M and silicon, such as M_2Si_2 and M_3Si_3, also showed positive effects, indicating that multiple combinations of these fertilisers can effectively improve rice productivity under local conditions.

These findings underscore the flexibility in fertiliser management practices, allowing for tailored combinations that suit specific growth requirements and environmental conditions. Integrating silicon and Multimolig-M fertilisers offers a sustainable approach to rice production, enhancing yield while potentially reducing reliance on chemical fertilisers. Further studies are recommended to explore long-term impacts and the economic feasibility of these practices across different rice varieties and agroecological zones in Vietnam and similar regions.

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