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VEGETATIVE AND GENERATIVE GROWTH AND YIELD OF UPLAND RICE SITU BAGENDIT VARIETY WITH NPK AND SILICA FERTILIZERS ON OLDEMAN'S CLIMATE ZONE-E

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SUMMARY

The upland rice cultivar Situ Bagendit, developed in Indonesia, is well-known for drought tolerance, rapid growth, high yield, and palatability. This study assessed its productivity under different fertilization treatments during the rainy season in an Oldeman's E climate zone (3–4 wet months with ≥ 200 mm rainfall, followed by prolonged drought). Research began from October 15, 2022, until January 25, 2023, at the Class-1 Climatology Station, North Sumatra, Indonesia. A non-factorial randomized complete block design comprised four fertilization treatments (0%, 33%, 66%, and 100% of recommended N, P, K, and SiO₂ doses) and three replications. Fertilization treatments did not significantly affect plant height, nutrient uptake, tiller count, root volume, dry weight, generative-phase shoot dry weight, harvesting, flowering age, and production. However, the 100% dose (1.11 g N, 0.55 g P, 0.27 g K, and 2.55 g SiO₂ per plant) yielded the highest averages for root volume and dry weight, vegetative-phase shoot dry weight, filled grain weight, and reduced unfilled grain weight. This study highlights Situ Bagendit's strong adaptability in the Oldeman's E climate, demonstrating its potential for upland rice cultivation in such conditions.

Keywords: Upland rice cultivar Situ Bagendit, climate zone, fertilizers, phenology, growth and yield traits

Key findings: The upland rice Situ Bagendit variety demonstrated significant drought tolerance and rapid growth in Oldeman's climate zone E. By applying 100% recommended doses of nitrogen, phosphorus, potassium, and silica, these considerably improved the growth and yield traits.

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INTRODUCTION

Climate is one of the determining factors in achieving optimal plant growth and production. The Oldeman's climate classification is a widely applied method in the agriculture sector in Indonesia (Aldiansyah and Risna, 2023). Oldeman's system classifies the climate by using rainfall elements as a basis for distinguishing one climate class from another. In Oldeman's classification, a wet month is a month with a total cumulative rainfall equal to or more than 200 mm/month. However, a dry month is a month with a total cumulative rainfall of less than 100 mm/month. The humid month is a month with a total rainfall of 100–200 mm/month (Estiningtyas *et al.*, 2024). Oldeman's dry climate Zone E occurs in areas with fewer than three rainy months, based on the water needs of rice plants. However, the classification system has a structure based on the number of consecutive wet and dry months.

The Oldeman's classification system application is highly effective in categorizing agricultural climate (Harahap *et al.*, 2022). The Oldeman's climate classification revealed Deli Serdang Regency has climate types C1, D1, D2, E2, and E3, with a recent shift to types D and E. Type D has 3–4 wet months, while Zone E has only 0–2 wet months. In Zone E, the cultivation relies on considering the crop type and its planting time. Groundwater represents a critical water source for crop plants, especially during the drought period, with continuous groundwater availability widely associated with the ecological refugia (Glanville *et al.*, 2023) and the morphophysiological variations and expression of transcription factors (Salsinha *et al.*, 2024). Situ Bagendit, a drought-tolerant upland rice variety, faces water scarcity and nutrient limitations in Zone E, which can reduce soil moisture, nutrient uptake, and yield potential (Sadok *et al.*, 2020). However, this variety can also adapt to lowland rice fields, making it suitable for both upland and irrigated conditions. Under optimal conditions, Situ Bagendit can yield 5–6 t/ha, but in dryland conditions, its yields typically range from 3–5 t/ha (Karman *et al.*, 2021).

In cultivated rice, fertilization significantly influences grain yield; however, inappropriate application can negatively impact organisms and the environment (Zhao *et al.*, 2021). Nitrogen (N), phosphorus (P), and potassium (K) are essential macro-elements for enhancing rice growth; N promotes vegetative development, P aids root formation, energy transfer, and rice production (Rakotoson *et al.* 2022), and K boosts disease resistance (Tripathi *et al.*, 2022). Additionally, rice is a silicon (Si) accumulator, requiring larger amounts of Si for optimal growth and production (Al-Sahmani and Al-Juthery, 2021; Syamsiyah *et al.*, 2023). Silicon integration into cell walls increases rigidity and provides physical protection against microbial infections and herbivores (Wan *et al.*, 2023). Rice plants can accumulate Si (0.1% to 10%) as per their dry weight; however, it significantly varies by species (Kuhla *et al.*, 2021).

This study commenced during the rainy season in an Oldeman-E climate zone, with typical characteristics of a short rainy season and a long dry period. Although water availability was sufficient during the research period, nutrient dynamics in such climates can still incur effects from factors like leaching due to heavy rainfall or reduced microbial activity during drier months. Understanding the response of upland rice to N, P, K, and Si fertilization in this climatic condition is crucial for optimizing nutrient management and ensuring sustainable productivity.

Silicon, though not essential for plant growth, enhances drought resistance in rice by improving water relations, nutrient uptake, and stress tolerance (Irfan *et al.*, 2023). Silicon application during the reproductive stage optimizes the nutrient uptake and improves agronomic parameters in rice (Dorairaj *et al.*, 2020). Exogenous silicon application is a promising method to improve environmental adaptation and grain yield in rice cultivation (Singh *et al.*, 2020). These findings highlighted the importance of silica fertilization in enhancing rice productivity and stress tolerance. Exploring the potassium use efficiency has also progressed in the maize and wheat cropping systems (He *et al.*, 2022). A

thorough understanding of the correct fertilization can considerably contribute to increased productivity with good quality in rice.

Rice cultivation success depends on the climate, soil, and plant interactions. The promising study aimed to develop an efficient upland rice system for dry lands using the rice Situ Bagendit variety. The fertilizer treatments N, P, K, and SiO₂ incurred assessment to investigate the phenology of vegetative and generative growth and improve rice adaptability and productivity through field trials during the rainy season at the Oldeman's dry climate zone E.

MATERIALS AND METHODS

Experimental procedure

The presented research transpired at the Meteorology and Geophysics Agency's Class-1 Climatology Station, North Sumatra Province, Indonesia, approximately 20 masl (3°37'14" N, 98°42'53" E). The study ran from October 15, 2022, to January 25, 2023, during the rainy season. Weather data included rainfall, air temperature, humidity, solar radiation intensity, and sunlight duration, collected from the station's equipment park.

This study employed a non-factorial randomized complete block design with three replications to assess the effects of different fertilizer treatments on the upland rice Situ Bagendit variety. Four applied treatment levels

comprised P4 (control with basic fertilizer only), P3 (33% of the recommended dose), P2 (66% of the recommended dose), and P1 (100% of the recommended dose) for N, P, K, and SiO₂ fertilizers. The nitrogen source was urea, phosphorus came as the triple superphosphate (TSP), potassium as the potassium chloride (KCl), and silicon as a granular SiO₂ fertilizer. Fertilizer application occurred at specific growth stages: applying TSP, KCl, and SiO₂ once at one week after transplanting (1 WAT), while applying urea in three split doses at 1 WAT, 4 WAT, and 7 WAT to optimize nitrogen uptake. Fertilizer applications manually consisted of placing them near the plant base and incorporating them into the soil to minimize nutrient loss. The application rates per plant for each treatment level were as follows: urea = 0.36, 0.73, and 1.11 g (for 33%, 66%, and 100% doses, respectively); TSP = 0.18, 0.36, and 0.55 g; KCl = 0.09, 0.18, and 0.27 g; and SiO₂ = 0.84, 1.68, and 2.55 g.

Soil analysis

Before conducting the study, the soil fertility analysis revealed that nitrogen (N) and potassium (K) levels were low, while phosphorus (P) was medium (Table 1). Organic carbon content categorization was very low, based on the soil fertility criteria from the Indonesian Agro Climatic and Agricultural Hydrology Instrument Testing Center.

Table 1. The soil analysis of the study site.

No.	Type of analysis	Mark	Indicator (Indonesian Agro-climate and Agricultural Hydrology Instrument Testing Center)		
			Very low	Low	Current
1	C-organic (%)	0.84	<1.00	1.00–2.00	2.01–3.00
2	N-total (%)	0.11	<0.10	0.10–0.20	0.21–0.50
3	P-Bray I (ppm P)	17.60	<8.0	8.0–15	16–25
4	K-dd (me/100 g)	0.20	<0.10	0.10–0.20	0.30–0.50
5	Ph	6.14	Neutral		
	Sand (%)	74.64	-		
6	Dust (%)	16.91	-		
	Clay (%)	8.45	-		

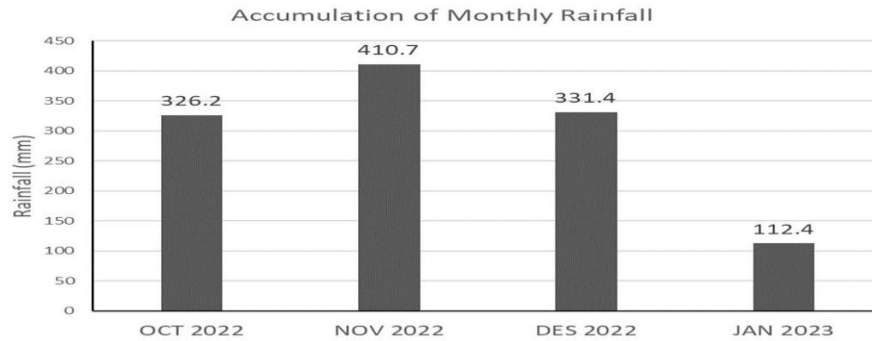


Figure 1. Graph of average monthly rainfall during the study.

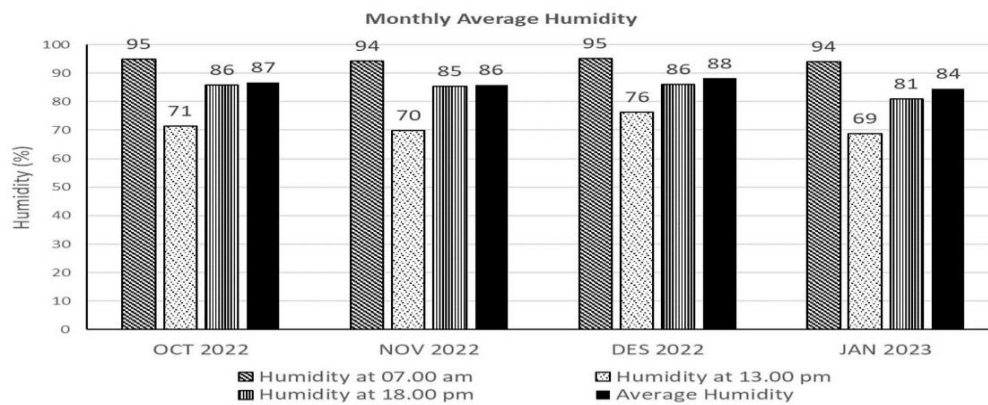


Figure 2. Graph of monthly average air humidity during the study.

Weather observations

Rainfall

From October to December 2022, the accumulated monthly rainfall ranged from 326.2 to 410.7 mm, which is a high rainfall category according to the Meteorology, Climatology, and Geophysics Agency, Indonesia. However, in January 2023, rainfall decreased significantly to 112.4 mm, indicating a transition to lower rainfall conditions (Figure 1).

Humidity

Air humidity measurement comprised calculating the temperature using wet-bulb and dry-bulb thermometers. Air humidity (relative humidity) recording continued daily at 07.00,

13.00, and 18.00 WIB (Western Indonesian Time). The air humidity observed in the morning at 07.00 WIB showed the highest value compared with other times. The average annual air humidity at the study site ranged from 85% to 90% (Figure 2).

Air temperature

Air temperature observations occurred three times a day, i.e., at 07.00, 13.00, and 18.00 WIB. The air temperature during the day generally showed the highest values. The average air temperature during the study was in the range of 25.5 °C–26.9 °C. The range for the average maximum temperature was 30.9 °C–31.3 °C, while the average minimum temperature had the range from 23.8 °C–24.4 °C (Figure 3).

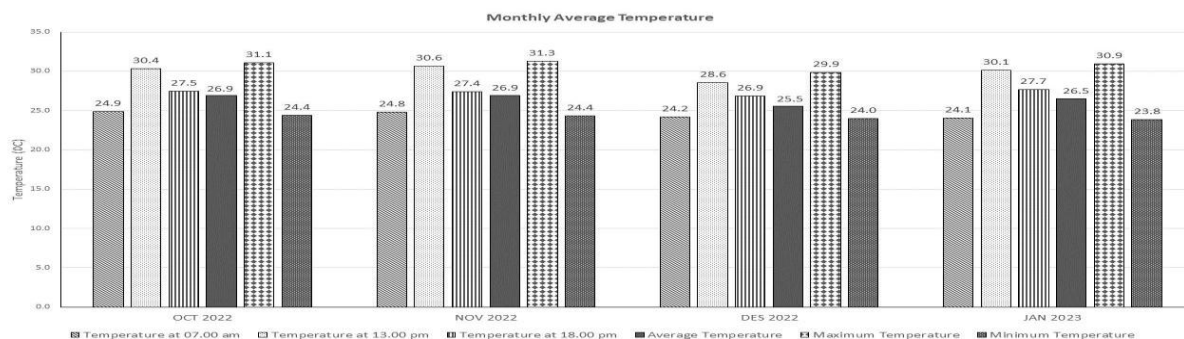


Figure 3. Average monthly temperature at the research location.

RESULTS AND DISCUSSION

Plant height

The plant height is a visual representation of the vegetative, generative, and yield phases, and the better vegetative growth also influences the generative conditions. In upland rice Situ Bagendit variety, the plant height ranged from 82 to 87 cm (Table 2). Past studies detailed that plant height influences came from various factors, including the genetic makeup of genotypes (Lan *et al.*, 2023), soil conditions, fertilizer type and dosage (Hlisnikovský *et al.*, 2020), weather (Saha *et al.*, 2022), pest and disease pressures (He *et al.*, 2023), and yield performance (Hafi *et al.*, 2024).

The lack of significant effects of N, P, K, and SiO₂ fertilization on plant height in the rice Situ Bagendit variety is ascribable to the adequate phosphorus level in the experimental soil (Table 1). Phosphorus is crucial for growth, and its uptake can be slow in nutrient-deficient soils. Additionally, the highest rainfall and humidity during the vegetative phase likely hindered transpiration and nutrient absorption, resulting in similar nutrient uptake between fertilized and unfertilized plants. Excess humidity negatively affects photosynthesis and nutrient balance, along with lower transpiration, which can impede growth (Wang *et al.*, 2021; Zhao *et al.*, 2022). Furthermore, Si and P interact within plant tissues, where Si can alter P distribution and utilization efficiency (Carvalho *et al.*, 2022). Moreover, P and Si

interactions could also contribute to the observed nonsignificant effect. Reports have disclosed silicon has been enhancing phosphorus availability by reducing its fixation in the soil; however, in soils with already sufficient phosphorus levels, additional Si may not significantly impact plant growth. Furthermore, under high humidity conditions, the reduced transpiration rate might have limited the synergistic effects of Si and P, leading to similar growth responses across treatments (Liu *et al.*, 2021).

High humidity reduces the transpiration rates, limiting nutrient uptake by decreasing the water potential gradient between the plants and their surrounding environment. Consequently, nitrogen, phosphorus, and potassium uptake was similar for both fertilized and unfertilized plants (Table 3). Reportedly, nutrient mass flow relies heavily on transpiration, and the low transpiration rates hinder the nutrient absorption, influencing overall plant health (Valdez-Aguilar *et al.*, 2024).

Air humidity levels significantly influence plant nutrient uptake through transpiration processes. High humidity (>80% RH) reduces transpiration rates, limiting nutrient transport via mass flow, especially for N, P, and K elements (Giday *et al.*, 2013). Conversely, a very low humidity (<40% RH) triggers stomatal closure, which also restricts nutrient uptake (Taiz *et al.*, 2021). The optimal range of 50%–70% RH supports efficient fertilizer absorption by balancing transpiration and water loss (Giday *et al.*, 2013).

Table 2. Plant height of upland rice Situ Bagendit on the treatment of nitrogen, phosphorus, potassium, and silica fertilizers for 7–11 weeks after transplantation.

Urea, TSP, KCl, and silica fertilizer treatments	Average plant height (cm)				
	7 WAP	8 WAP	9 WAP	10 WAP	11 WAP
P1 (100% dose)	68.61	73.51	82.27	82.60	82.82
P2 (66% dose)	68.46	75.52	82.57	83.23	83.47
P3 (33% dose)	66.90	74.53	82.14	82.60	82.75
P4 (0% dose)	70.09	78.34	86.58	87.06	87.24

Note: WAP = Weeks after Planting

Table 3. The nutrient uptake of nitrogen, phosphorus, and potassium by upland rice Situ Bagendit under N, P, K, and silicon fertilizer treatments.

Urea, TSP, KCl, and silica fertilizer treatments	Average Nutrient Uptake (%)		
	N	P	K
P1 (100%)	34.55	8.64	55.51
P2 (66%)	37.35	9.48	52.40
P3 (33%)	32.77	8.67	48.66
P4 (0%)	20.16	8.79	53.08

Latest research indicates that under high humidity conditions, foliar nutrient uptake may occur, particularly at night, through deliquescent salts on leaf surfaces. This phenomenon has been evident in phosphorus-deficient plants, where ambient aerosols and foliar P application enhanced nocturnal transpiration, potentially improving nutrient availability (Vega *et al.*, 2023). Thus, high humidity does not always limit nutrient uptake but instead could alter absorption pathways, especially through stomatal uptake of hygroscopic aerosols.

The N, P, and K uptake analysis revealed nonsignificant differences between fertilized and unfertilized plants (Table 3). High humidity reduced the transpiration, thereby decreasing nutrient uptake, though plants could adapt to low transpiration rates. Plant height influences came from genetic factors, soil conditions, fertilizer type and dosage, and the weather conditions (Hlisnikovský *et al.*, 2020; He *et al.*, 2023; Lan *et al.*, 2023). The nonsignificant effects of N, P, K, and SiO₂ fertilization on plant height of upland rice Situ Bagendit variety may refer to the adequate phosphorus availability, as indicated earlier in the soil analysis. Despite P's importance for plant growth, deficiencies are common due to

its slow diffusion and soil fixation (Thrupthi *et al.*, 2023).

Root volume is vital for seedlings' nutrient and water absorption, affecting their metabolic activities. Overall, maximizing root volume is crucial for effective nutrient absorption and seedling growth. Recent past research showed enhanced nitrogen and phosphorus levels improved root traits and boosted nutrient uptake (Xu *et al.*, 2024). Optimal nursery conditions also support root development, further enhancing root volume (Valverde-Barrantes *et al.*, 2023). Additionally, suitable soil properties influence the root volume and nutrient dynamics (Forster *et al.*, 2020).

Humidity and air temperature display an inverse correlation. During the study period, the average monthly temperature was around 26 °C, with a minimum of about 23 °C. Rice thrives best at temperatures between 25 °C and 35 °C; however, low temperatures can hinder growth (Sanadya *et al.*, 2023). Rice can adapt to high temperatures, and the cumulative heat stress affecting its photosynthesis and growth during the booting stage, with photosynthetic capacity sustained longer at higher temperatures during grain filling (Oh *et al.*, 2023). Heat stress weakens

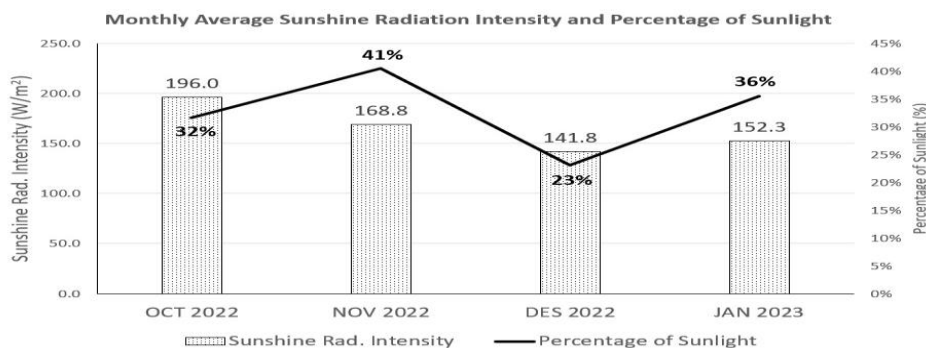


Figure 4. The average intensity of solar radiation and the percentage of sunlight exposure during the study.

plant growth, nutrient absorption, and crop quality (Mishra *et al.*, 2023).

Solar radiation significantly influences plant growth and nutrient uptake. Optimal light enhances photosynthesis (Khan *et al.* 2023), while insufficient light reduces growth and nutrient absorption (Zhao *et al.*, 2022). The varied light quality and quantity can also be harmful for these processes and lead to photo-destruction and photo-inhibition of photosynthetic apparatus. The excess of light decreases the photosynthetic rate in plants due to photo-oxidative damage to photosynthetic apparatus, photo-inhibition of photoperiod sensitivity II (PSII), and damage to PS I (Sharma *et al.*, 2023). In the presented study, the solar radiation intensity varied from 141.8 to 196.0 W/m², with durations of 23% to 40.5% (Figure 4), highlighting that low sunlight disrupts photosynthesis and decreases the biomass and grain yield in crop plants (Wang *et al.*, 2021).

The number of tillers

Rice saplings emerge from the main stem and can develop multiple tillers, which are essential for panicle formation. However, fertilizer treatments did not significantly affect the number of tillers, which remained relatively stable, averaging between 14 and 17 in the first week (Table 4). In the upland rice Situ Bagendit variety, tiller formation showed no noteworthy variation between plants aged seven to 11 weeks after planting, consistent with previous descriptions of this genotype.

Prior research has highlighted that tiller number plays a crucial role in determining canopy architecture and seed production in rice crops (Prakash and Kumara, 2021).

One possible explanation for the lack of response to fertilization is the sufficient soil P content observed at the start of the experiment (Table 1). With adequate phosphorus availability, plants likely did not experience nutrient limitations that would have otherwise influenced growth and tiller formation. Additionally, as this study progressed during the rainy season within the Oldeman-E climate, ample water availability may have supported stable nutrient uptake, further reducing the impact of fertilizer treatments on tiller production. These findings suggest that the already sufficient soil nutrient levels render additional fertilization no relevant enhancement on rice tillering, emphasizing the importance of site-specific nutrient management strategies.

Root growth

The measurement of root growth and proliferation of the upland rice Situ Bagendit variety by root volume and dry weight reflected their nutrient and water absorption capacity, as influenced by root diameter, density, and soil properties (Kim *et al.*, 2021). Fertilizer significantly enhanced root growth during the vegetative phase, though it had no effect during the generative phase, as and when the plant energy shifts to flowers, fruits, and seeds (Table 5). The highest root volume

Table 4. Effect of nitrogen, phosphorus, potassium, and silica fertilizer treatments on the tiller number of upland rice Situ Bagendit for 7–11 weeks after transplantation.

Urea, TSP, KCl, and silica fertilizer treatments	Average number of tillers (stem)			
	7 WAP	8 WAP	9 WAP	10 WAP
P1 (100% dose)	15.00	15.30	15.33	15.50
P2 (66% dose)	15.03	15.96	16.13	16.23
P3 (33% dose)	13.36	14.46	14.60	14.63
P4 (0% dose)	15.76	16.90	17.16	17.20

Note: WAP = Weeks after Planting

Table 5. Effect of nitrogen, phosphorus, potassium, and silica fertilizer treatments on the root volume and root dry weight of upland rice Situ Bagendit during vegetative and generative phases.

Urea, TSP, KCl, and silica fertilizer treatments	Vegetative		Generative	
	Volume (ml)	Dry weight (g)	Volume (ml)	Dry weight (g)
P1 (100% dose)	38.33c	26.82d	20.00	7.00
P2 (dose 66%)	34.00bc	23.89c	21.67	10.57
P3 (dose 33%)	30.00ab	21.48b	20.00	8.07
P4 (0% dose)	22.67a	18.03a	20.00	8.00
LSD _{0.05}	5.34	0.54	ns	ns

Note: ns = not significant.

Table 6. Effect of nitrogen, phosphorus, potassium, and silica fertilizer treatments on the shoot dry weight at vegetative and generative phases of the upland rice Situ Bagendit.

Urea, TSP, KCl, and silica fertilizer treatments	Vegetative (g)	Generative (g)
P1 (100% dose)	50.63cd	27.87
P2 (dose 66%)	45.83c	24.83
P3 (dose 33%)	33.29b	23.20
P4 (0% dose)	21.28a	22.97
LSD _{0.05}	15.77	ns

Note: ns = not significant.

and dry weight resulted in rice plants treated with 100% of the recommended fertilizer dose, while the unfertilized plants (control) showed the lowest values. Optimal fertilization, especially with nitrogen, phosphorus, and potassium, promotes root growth, with root expansion correlated with increased nutrient availability up to a certain threshold (Xie *et al.*, 2021; Lopez *et al.*, 2022). Enhanced root weight appeared positively associated with improved shoot biomass and the overall productivity in cereals (Bektas *et al.*, 2023).

Shoot growth

The results of the analysis revealed fertilization treatment impacts on the shoot dry weight occurred only during the vegetative phase, with no effect during the generative phase (Table 6). The root and shoot growth followed a similar trend in the vegetative phase, and the root volume and dry weight reached their peak with the application of 100% of the recommended fertilizer doses (Table 5).

Table 7. Effect of nitrogen, phosphorus, potassium, and silica fertilizer treatments on the average flowering age and harvest age of upland rice Situ Bagendit.

Urea, TSP, KCl, and silica fertilizer treatments	Average Age of Flowering (days)	Harvest age (days)
P1 (100%)	60.66	93.66
P2 (66%)	60.66	93.66
P3 (33%)	60.66	93.66
P4 (0%)	61.00	94.00

Table 8. Effect of nitrogen, phosphorus, potassium, and silica fertilizer treatments on the percentage of rice-containing grain of upland rice Situ Bagendit.

Urea, TSP, KCl, and silica fertilizer treatments	Average percentage of filled grains (%)	Empty grains (%)	Weight 1000 grains (g)	Average production per plot (g)
P1 (100% dose)	95.56	4.58	27.00	731.09
P2 (dose 66%)	93.89	6.13	28.00	674.83
P3 (dose 33%)	89.51	10.60	28.00	698.91
P4 (0% dose)	85.30	14.68	27.00	727.39
LSD _{0.05}	0.36	0.35	ns	

Note: ns = not significant.

Flowering and harvest age

Flowering age (HD) in upland rice, including the Situ Bagendit variety, has primary influences from basic vegetative growth, photoperiod sensitivity, and temperature sensitivity. In this study, the N, P, K, and Si fertilizations have no effects on the flowering and harvest time (Table 7). The said rice cultivar showed a 61-day flowering period, a 94-day harvest age, and a 33-day seed-filling phase, which was sufficient for proper seed development. Though the upland rice typically matures in 110–120 days, the presented study recorded earlier maturity in the Situ Bagendit variety (94 days). The genetic and environmental factors, like photoperiod, temperature, and drought stress, can affect the flowering age, and nutrient management supports overall plant adaptability (Syahril *et al.*, 2022).

Crop production

The study demonstrated that 100% fertilizer application increased the percentage of filled grains, while unfertilized rice plants showed the highest ratio and weight of unfilled grains.

However, fertilizer treatments did not have a statistically significant effect on the 1000-grain weight or the total production per plot (Table 8). Previous research has confirmed a positive relationship between soil fertility and rice yield (Rashid *et al.*, 2021; Hadi *et al.*, 2022). Although the full fertilizer application did improve the number of filled grains, both grain weight and overall production remained unchanged. These findings contrast with past studies suggesting that proper fertilization enhances both yield and grain quality (Takamitsu *et al.*, 2020), highlighting the importance of developing variety-specific fertilization strategies that account for the unique needs of different rice genotypes under varying environmental conditions.

CONCLUSIONS

Planting the upland rice Situ Bagendit variety during the rainy season in climate zone E with the recommended N, P, K, and Si fertilization had no significant effect on most growth and yield parameters. Specifically, these include plant height, nutrient uptake (N, P, and K), tiller count, generative-phase shoot dry weight,

plant development (flowering and harvesting time), 1000-grain weight, and total production per plot. However, fertilization remarkably influenced root volume, root dry weight, vegetative-phase shoot dry weight, and the percentage of filled and unfilled grains. The recommended fertilization treatment produced the heaviest filled grain weight and the lightest unfilled grain weight, indicating a potential improvement in grain quality. These findings suggest that while overall growth and yield differences were not significant, the appropriate NPKSi dosage improved grain filling and reduced unfilled grains. Further research is essential to determine the optimal fertilization strategy for maximizing rice yield and quality under specific environmental conditions.

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REFERENCES

- Aldiansyah S, Risna (2023). Mapping of Oldeman agro-climatic zone based on climate hazards group infrared precipitation with station database in Southeast Sulawesi. *J. Environ. Sci.* 17(2): 174–187. doi:10.24843/EJES.2023.v17.i02.p02.
- Al-Sahmani AMK, Al-Juthery HWA (2021). Response of rice (*Oryza sativa* L.) to silica fertilization and spraying with nano-potassium and calcium. *IOP Conf. Series: Earth Environ. Sci.* 735 (2021) 012068. <https://doi.org/10.1088/1755-1315/735/1/012068>.
- Bektas H, Hohn CE, Lukaszewski AJ, Waines JG (2023). On the possible trade-off between shoot and root biomass in wheat. *Plants* 12(13):2513. <https://doi.org/10.3390/plants12132513>.
- Carvalho JS de, Frazão JJ, Prado RDM, Souza Junior J (2022). Silicon modifies C:N:P stoichiometry and improves the physiological efficiency and dry matter mass production of sorghum grown under nutritional sufficiency. *Scien. Rep.* 12(1), 20662. <https://doi.org/10.1038/s41598-022-20662-1>.
- Dorairaj D, Ismail MR, Sinniah UR, Tan KB (2020). Silicon-mediated improvement in agronomic traits, physiological parameters, and fiber content in *Oryza sativa*. *Acta Physiol. Plant.* 42:38. <https://doi.org/10.1007/s11738-020-3024-5>.
- Estiningtyas W, Surmaini E, Suciantini, Susanti E, Mulyani A, Kartiwa B, Sumaryanto, Perdinan, Apriyana Y, Alifia AD (2024). Analysing food farming vulnerability in Kalimantan, Indonesia: Determinant factors and adaptation measures. *PLoS One* 19(1): e0296262. <https://doi.org/10.1371/journal.pone.0296262>.
- Forster M, Ugarte C, Lamandé M, Faucon MP (2020). Relationships between root traits and soil physical properties after field traffic from the perspective of soil compaction mitigation. *Agronomy* 10(11): 1697. <https://doi.org/10.3390/agronomy10111697>.
- Giday H, Kjaer KH, Fanourakis D, Ottosen CO (2013). Smaller stomata require less severe leaf drying to close: A case study in *Rosa hybrida*. *J. Plant Physiol.* 170(15), 1309–1316. <https://doi.org/10.1016/j.jplph.2013.04.007>.
- Glanville K, Sheldon F, Butler D, Capon S (2023). Effects and significance of groundwater for vegetation: A systematic review. *Sci. Total Environ.* 896: 162577. <https://doi.org/10.1016/j.scitotenv.2023.162577>.
- Hadi SS, Siti Fatimah I, Murtado A (2022). Integrated nutrient management for rice yield, soil fertility, and carbon sequestration. *Plants* 11(1): 138. <https://doi.org/10.3390/plants11010138>.
- Hafi Z, Mutther J, Javed A, Naeem S, Shaukat M, Makhdoom (2024). Exploring the relationship between plant height and yield-contributing attributes of wheat in drought conditions. *Biol. Clin. Sci. Res. J.* 2024(1). <https://doi.org/10.54112/bcsrj.v2024i1.854>.
- Harahap IS, Matondang IZ, Suryanto, Indah EK, Fitri I (2022). Mapping climate classification of Oldeman in agricultural resources management in South Tapanuli District. *IOP Conf. Ser.: Mat. Sci. Eng.* 1156 (2022) 012002. <https://doi.org/10.1088/1757-899X/1156/1/012002>.
- He P, Zhao S, Jin J, Zhou W, Li W, Cui R (2022). Long-term potassium fertilization effects on crop yield and potassium use efficiency in maize-wheat cropping systems. *Field Crops*

- Res. 276: 108367. <https://doi.org/10.1016/j.fcr.2022.108367>.
- Hlisnikovský L, Vach M, Abrham Z, Menšík L, Kunzová E (2020). The effect of mineral fertilizers and farmyard manure on grain and straw yield, quality, and economic parameters of winter wheat. *Plant Soil Environ.* 66(6): 249–256. <https://doi.org/10.17221/60/2020-PSE>.
- Irfan M, Maqsood MA, Rehman HU, Mahboob W, Sarwar N, Hafeez OBA, Hussain S, Ercisli S, Akhtar M, Aziz T (2023). Silicon nutrition in plants under water-deficit conditions: Overview and prospects. *Water* 15(4): 739. <https://doi.org/10.3390/w15040739>.
- Karman J, Suparwoto, Waluyo (2021). Adaptation of Situ Bagendit, Rindang 1, and Rindang 2 varieties in shallow swamp Ogan Komering Ilir District, South Sumatera. *E3S Web Conf.* 232: 03021. <https://doi.org/10.1051/e3sconf/202123203021>.
- Khan MI, Raza MA, Shah SZA, Arif M (2023). Solar radiation and its role in plant growth and development. *Agric. Rev.* 44(1): 1–12. <https://doi.org/10.18805/ag.R-3006>.
- Kim J, Lee S, Park Y (2021). The role of soil texture on root development and nutrient uptake in different crop species. *J. Soil Sci. Soc. Am.* 85(6): 1524–1532. <https://doi.org/10.1002/saj2.20489>.
- Kuhla J, Pausch J, Schaller J (2021). Effect on soil water availability, rather than silicon uptake by plants, explains the beneficial effects of silicon on rice during drought. *Plant, Cell Environ.* 44(10): 3336–3346. <https://doi.org/10.1111/pce.14155>.
- Lan D, Cao L, Liu M, Ma F, Yan P, Zhang X, Hu J, Niu F, He S, Cui J, Yuan X, Yang J, Wang Y, Luo X (2023). The identification and characterization of a plant height and grain length related gene hfr131 in rice. *Front. Plant Sci.* 14: 1152196. <https://doi.org/10.3389/fpls.2023.1152196>.
- Liu W, Ye T, Jägermeyr J, Müller C, Chen S, Liu X, Shi P (2021). Future climate change significantly alters interannual wheat yield variability over half of harvested areas. *Environ. Res. Lett.* 16(9), 094045. <https://doi.org/10.1088/1748-9326/ac1fbb>.
- Lopez G, Ahmadi SH, Amelung W, Athmann M, Ewert F, Gaiser T, Gocke MI, Kautz T, Postma J, Rachmilevitch S, Schaaf G, Schnepf A, Stoschus A, Watt M, Yu P, Seidel SJ (2022). Nutrient deficiency effects on root architecture and root-to-shoot ratio in arable crops. *Front. Plant Sci.* 13, 1067498. <https://doi.org/10.3389/fpls.2022.1067498>.
- Mishra S, Spaccarotella K, Gido J, Samanta I, Chowdhary G (2023). Effects of heat stress on plant-nutrient relations: An update on nutrient uptake, transport, and assimilation. *Int. J. Mol. Sci.* 24(21): 15670. <https://doi.org/10.3390/ijms242115670>.
- Oh D, Ryu JH, Jeong H, Moon HD, Kim H, Jo E, Kim BK, Choi S, Cho J (2023). Effect of elevated air temperature on the growth and yield of paddy rice. *Agronomy* 13(12): 2887. <https://doi.org/10.3390/agronomy13122887>.
- Prakash A, Kumara R (2021). Effective tillers in rice in HUR105. *Int. J. Eng. Sci. Comput.* 11(8). ISSN 2321-3361.
- Rakotoson T, Tsujimoto Y, Nishigaki T (2022). Phosphorus management strategies to increase lowland rice yields in sub-Saharan Africa: A review. *Field Crops Res.* 275: 108370. <https://doi.org/10.1016/j.fcr.2022.108370>.
- Rashid S, Biswas JC, Hossain MA, Gafur A, Uddin MF, Nahar A, Hamid A (2021). Response of upland rice landraces to fertilizers in shifting cultivation: Rate and application methods. *Ecol. J.* 3(2): 121–129.
- Saha S, Sehgal VK, Chakraborty D (2022). Influence of weather parameters on growth and yield of rice under climate change scenarios. *Theor. Appl. Climatol.* 147(3): 1029–1042. <https://doi.org/10.1007/s00704-021-03792-8>.
- Salsinha YCF, Sebastian A, Sutiyantri E, Purwestri YA, Indradewa D, Rachmawati D (2024). The relationship between morpho-physiological changes and expression of transcription factors in NTT local rice cultivars as a response to drought stress. *Indonesian J. Biotechnol.* 28(2): 65–72. <https://doi.org/10.22146/ijbiotech.65728>.
- Sanadya A, Yadu A, Raj J, Chandrakar H, Singh R (2023). Effect of temperature on growth, quality, yield attributing characters, and yield of rice – A review. *Int. J. Environ. Climate Change* 13(8), 804–814. <https://doi.org/10.9734/ijecc/2023/v13i82014>.
- Sharma N, Nagar S, Thakur M, Suriyakumar P (2023) Photosystems under high light stress: Throwing light on mechanism and adaptation. *Photosynthetica* 61(SI): 247–260. <https://doi.org/10.32615/ps.2023.021>.
- Singh V, Virendra S, Singh S, Khanna R (2020). Effect of zinc and silicon on growth and yield of aromatic rice (*Oryza sativa*) in North-Western Plains of India. *J. Rice Res. Dev.* 3(1): 82–86.
- Syahril M, Syukri DS, Siregar M, Murdiani (2022). Genetic analysis of upland rice F4

- populations (*Silesa* × *Ciherang*) for phenological and yield-related traits. *SABRAO J. Breed. Genet.* 54(3), 574–588. <https://doi.org/10.54910/sabrao2022.54.3.2>.
- Syamsiyah J, Herdiyansyah G, Hartati S, Suntoro, Widijanto H, Larasati I, Aisyah N (2023). Pengaruh substitusi pupuk kimia dengan pupuk organik terhadap sifat kimia dan produktivitas jagung di Alfisol Jumentono. *J. Tanah Sumberd. Lahan* 10(1): 57–64. <https://doi.org/10.21776/ub.jtsl.2023.010.1.6>.
- Taiz L, Zeiger E, Møller IM, Murphy A (2021). *Plant Physiology and Development* (7th Edition). Sinauer Associates.
- Takamitsu K, Kumano M, Tamaki M (2020). A study on rice growth and soil environments in paddy fields using different organic and chemical fertilizers. *J. Agric. Chem. Environ.* 9(4): 331–343. <https://doi.org/10.4236/jacen.2020.94024>.
- Thrupthi MG, Victor D, Darla H (2023). Influence of phosphorus and micronutrients on growth and yield of rice (*Oryza sativa* L.). *Int. J. Environ. Chem. Ecol.* 13(8): 162–169. <https://doi.org/10.9734/ijecc/2023/v13i82014>.
- Tripathi R, Tewari R, Singh KP, Keswani C (2022). Plant mineral nutrition and disease resistance: A significant linkage for sustainable crop protection. *Front. Plant Sci.* 13: 883970. <https://doi.org/10.3389/fpls.2022.883970>.
- Valdez-Aguilar LA, Hernández-Velázquez E, Hernández-García R, Pérez-Rodríguez P, Alvarado-Camarillo D (2024). La humedad relativa y concentración de la solución nutritiva afectan el rendimiento, calidad y estado nutrimental en pepino (*Cucumis sativus* L.). *Terra Latinoam.* 42: 1–14. <https://doi.org/10.28940/terra.v42i0.1968>.
- Valverde-Barrantes OJ, González RR, Johnson LA (2023). Environmental conditions in the nursery regulate root system development and architecture of forest tree seedlings: A systematic review. *New For.* 54: 317–335. <https://doi.org/10.1007/s11056-023-09972-0>.