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Exploring the varietal responses of maize to nitrogen fertilization and understanding growth dynamics

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Abstract. Maize productivity, reliant on nitrogen availability, is crucial for the Indonesian economy. Previous research found organic fertilizers had minimal effects on the Local variety 'Tambin', widely used by small-scale farmers. This study explored varietal responses to nitrogen fertilization using a split-plot randomized complete design with four nitrogen rates (0, 46, 138, and 184 kg N ha⁻¹) as main plots, and maize varieties (Hybrid 'BISI-18', Composite 'Sukumaraga', and Local 'Tambin') as sub-plots. Results showed significant effects of nitrogen rates and maize varieties on growth variables (plant height, stem diameter, and number of leaves). The 'Tambin' variety performed best at 138 kg N ha⁻¹, with higher plant heights, while Hybrid 'BISI-18' and Composite 'Sukumaraga' showed the greatest increases in height and stem diameter at 46 kg N ha⁻¹.

1 Introduction

In Indonesia, maize is a vital crop, ranked second to rice, making diverse contributions to human consumption, a feed source for animals/livestock, offers economic value, and raw materials for energy, and industrial purposes [1-4]. The productivity of maize heavily relies on nutrient availability, with nitrogen playing a critical role. Nitrogen fertilizer is integral in enhancing biomass increase, promoting leaf area, and facilitating biological processes such as photosynthesis, ultimately impacting overall yield[2,3]. Despite its importance, nitrogen remains a scarce resource in cereal cultivation, particularly affecting maize. However, excessive nitrogen application can not only diminish grain yield but also contribute to environmental pollution [4–6].

According to Aakash et al. [1], a local maize variety 'Tambin'' adapted to local conditions has been characterized by significant differences in plant growth and yield aspects such as plant height, leaf number, and cob characteristics among others for these traits, showing promise for genetic improvement. With medium heritability for most traits and high heritability for leaf numbers, 'Tambin' is a valuable resource for breeding.

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The study by Adhikari et al. [7] on Composite variety 'Sukumaraga' and Hybrid variety 'BISI-18', while in terms of growth potential, and yield 'BISI-18' generally outperformed 'Sukumaraga'. 'BISI-18' exhibited longer ears, larger stem diameter, more kernels per ear and row, and higher weight of 1000 kernels compare to 'Sukumaraga', indicating a superior yield potential for 'BISI-18'. When considering the response to nitrogen fertilization with identical regimes, both varieties possess similar overall growth and yield parameters. Moreover, 'BISI-18' is uniquely superior in traits like ear length, ear diameter, kernel number, and kernel weight. Notably, 'Sukumaraga' generally falls short in these traits.

In Indonesia, as mentioned earlier, maize is a crucial commodity after rice, playing a central role in agricultural development and the country's economy [8–10]. Regions like West Nusa Tenggara rely significantly on maize, contributing to national food security [11–13]. Interestingly, less than 25% of local maize varieties are extensively cultivated in provinces like East Nusa Tenggara, South Sulawesi, and Madura, often replacing hybrid, composite, and transgenic varieties in many regions[10]. Despite the importance of local maize for Indonesia's food security, a knowledge gap is evident. For example, Tetik et al. [14]focused on a local variety 'Tambin' using various organic fertilizers and found insignificant effects on morphological and physiological traits. To fill this gap in optimizing maize production in Indonesia, this study aims to explore the varietal responses of maize to nitrogen fertilization and understand the growth dynamics.

2 Materials and Methods

The study was conducted at the Leuwikopo station, IPB University, Bogor District, from June to September 2023. Soil samples collected before the experiment were analysed at the soil Laboratory, Department of Agronomy and Horticulture, IPB University, in May 2023.

2.1 Plant materials and experimental design

The study adopted a split-plot randomized complete block design (RCBD), the main plots were assigned nitrogen fertilizer treatments at four rates: 0 kg N ha^{-1}, 46 kg N ha^{-1}, 138 kg N ha^{-1} and 184 kg N ha^{-1}, three maize varieties (Hybrid 'BISI-18', Composite 'Sukumaraga', and Local 'Tambin') were allocated as sub-plots, the experiment included three replications, resulting into 12 main-plots, and a total of 36 experimental sub-plots.

2.2 Cultivation standards

2.2.1 Land preparation

Land preparation began one month before the experiment, the process included clearing of vegetation, debris and obstacles from the land to create a clean experimental area, followed by ploughing and harrowing the area into a smooth seedbed for optimal seed-soil contact to enhance quick germination. The experimental area was plotted following the recommended experimental design, with each sub-plot occupying 16 m^2. The distance between sub-plots was 30 cm, and the distance between main-plots was 1 m, with each replication occupying 193 m^2.

2.2.2 Planting

Seeds of each variety were prepared in separate, in a clearly labelled container. Two seeds per hole were sown, spaced at 80 cm x 25 cm, and thinned to one healthy plant per hole after three weeks.

2.2.3 Fertilization

Nitrogen was applied in split doses, half applied during sowing, and the final dose applied at the knee-height growth stage, using urea (46% N). Additionally, fertilization included 50 kg ha^{-1} SP-36 (36% P_2O_5) and 50 kg ha^{-1} KCl (60% K_2O) applied once at sowing.

2.3 Observations

Throughout the experiment, plant growth measurements were performed. Plant growth parameter included the number of leaves counted during the R1 and V6 stages, plant height measured using measuring tape, and stem diameter using a Venier caliper. The V6 stage (Vegetative Stage 6) is a vegetative growth phase characterized by the plant having developed six fully emerged leaves. The R1 stage (Reproductive Stage 1) corresponds to the silking stage. During R1, the silk emerges from the ear and grows out, crucial for pollination and subsequent kernel development. Plant heights were measured at 3, 4, 6, and 8 weeks after planting (WAP), and stem diameter measured during the 4, 6, and 8 weeks after planting (WAP)

2.4 Statistical analysis

Data analysis was contacted using Minitab 16 software and SAS Software version 9.4. ANOVA was performed to identify significant differences between treatments means, followed by Tukey's HSD test at a 5% probability level.

3 Results

3.1 Analysis of variance of growth parameters characters of maize varieties under different nitrogen rates

The results in Table 1 showed a low coefficient of variation (0.19 – 19.79%), which is less than 25%. This result implies the low diversity of data, influenced by external factors, enhancing the validity of the conclusions drawn from the analysis. While maize varieties significantly influenced plant height at multiple observation times (i.e., 3, 4, 6, and 8 weeks after planting), indicating genetic differences in growth patterns. The stem diameter was also significantly influenced at 4 and 6 weeks after planting (WAP), highlighting potential variations in stem development during the early growth stages. Notably, while plant height at 8 WAP and stem diameter at 6 WAP were significantly influenced by nitrogen application, the interaction between maize variety and nitrogen rates significantly influenced plant height during 6 WAP and the number of leaves during the silking stage (R1).

Table 1. Summary of ANOVA on growth parameters and physiology characters of maize varieties under different nitrogen rates

Variables	Nitrogen	Variety	Variety x Nitrogen	CV (%)
Plant Height at 3 WAP	ns	**	ns	8.49
Plant Height at 4 WAP	ns	**	ns	7.85
Plant Height at 6 WAP	ns	**	*	0.19
Plant Height at 8 WAP	*	*	ns	6.73
Stem diameter at 4 WAP	ns	**	ns	13.11
Stem diameter at 6 WAP	*	**	ns	5.49
Stem diameter at 8 WAP	ns	ns	ns	6.23
Number of leaf at V6	ns	ns	ns	19.79
Number of leaves at R1	ns	ns	**	16.34

Note: * = significant at $p<0.05$, ** = significant at $p<0.01$, ns = not significant, CV = coefficient of variation, WAP = weeks after planting.

3.2 Varieties and nitrogen rates on leaf numbers at silking (R1) growth stage

In Table 2, a significant interaction was observed between maize varieties and nitrogen levels on the number of leaves during the silking growth stage (R1). The local variety ‘Tambin’ produced more leaves (10.33) when planted at the 138 kg N ha^{-1} dose compared to the control conditions (9.83) and the highest nitrogen dose of 184 kg N ha^{-1} (8.5). Higher leaf count under 138 kg N ha^{-1} nitrogen dose did not differ significantly from the rest of the nitrogen rates (Table 2). In contrast, the composite variety ‘Sukumaraga’ showed the highest leaf count (12.5) under the highest nitrogen dose (184 kg N ha^{-1}) compared to the control conditions (11 leaves). This variety also showed a high leaf count under 138 kg N ha^{-1} (11.6), which did not differ significantly from the one under 184 kg N ha^{-1}. The number of leaves of the hybrid variety ‘BISI-18’ during the silking (R1) stage did not differ significantly across nitrogen levels. However, there was a tendency to produce more leaves (11) when treated with 138 kg N ha^{-1} dose.

3.3 Effects of nitrogen rates and maize varieties on plant height (cm) and stem diameter (mm)

Table 3 shows that while plant heights during 3, 4, and 8 WAP did not differs significantly across nitrogen rates, plant height differed significantly across nitrogen rates at 6 WAP. Generally, nitrogen application influences plant height and other growth parameters of maize plants [3]. Results in Table 3 show that the application of 46 kg N ha^{-1} resulted in taller plants (230.4 cm) compared to the control conditions (202.7 cm) and higher and highest nitrogen doses. Notably, 138 kg N ha^{-1} also enhanced plant height (222 cm), although this was not significantly different from the plant height recorded under 46 kg N ha^{-1}.

Table 2. Interaction between maize varieties and nitrogen rates on leaf number at silking (R1) stage

Variety	Nitrogen rates (kg N ha^{-1})	Number of leaves at R1 Stage
Local	0	9.83ab
	46	7.33b
	138	10.33ab
	184	8.50ab
Composite	0	11ab
	46	9.67ab
	138	11.67ab
	184	12.50a
Hybrid	0	9.50ab
	46	10.83ab
	138	11.00ab
	184	9.89ab

Note: Number followed by the same letter in the same column were not significantly different according to HSD 5% level. WAP = weeks after planting.

Table 3. Response of plant height on nitrogen rates at 3, 4, 6, and 8 weeks after planting (WAP)

Nitrogen levels (kg N ha^{-1})	Plant height (cm)			
	3 WAP	4 WAP	6 WAP	8 WAP
0	48.922^{a}	79.867^{a}	202.77b	168.666a
46	54.796^{a}	88.051^{a}	230.45a	183.301a
138	53.652^{a}	87.806^{a}	222.01ab	183.069a
184	51.153^{a}	84.903^{a}	221.34ab	179.083a

Note: Number followed by the same letter in the same column were not significantly different according to HSD 5% level. WAP = weeks after planting.

In Table 4, we observed significant differences in plant height at specific growth stages: 3, 4, 6, and 8 WAP. The local variety 'Tambin' was significantly taller during 3 WAP (64 cm), 4 WAP (105.4 cm), and 6 WAP (205.5 cm) compared to the hybrid variety 'BISI-18', which recorded plant heights of 53.3 cm at 3 WAP, 84.5 cm at 4 WAP, 178.6 cm at 6 WAP, and 229.1 cm at 8 WAP. The composite maize variety 'Sukumaraga' was the shortest among the tested maize varieties during 3 WAP (38.9 cm), 4 WAP (65.4 cm), 6 WAP (151.3 cm), and 8 WAP (209 cm).

Table 4. Response of maize varieties on plant height at 3, 4, 6, and 8 weeks after planting (WAP)

Variety	Plant height (cm)			
	3 WAP	**4 WAP**	**6 WAP**	**8 WAP**
Local	64.087a	105.441a	205.555a	
Composite	38.935c	65.483c	151.389c	209.094b
Hybrid	53.372b	84.546b	178.645b	229.196a

Note: Number followed by the same letter in the same column were not significantly different to HSD 5% level. WAP = weeks after planting.

The interaction between nitrogen rates and maize varieties (Table 5) on plant height differed significantly at 6 WAP. The local variety 'Tambin' showed a positive response to nitrogen fertilization, particularly at 138 kg N ha^{-1}, exhibiting higher plant heights (213.8 cm) at 6 WAP of observation compared to the control treatment with plant heights of 208.2 cm. While the highest plant heights of the local variety 'Tambin' did not differ significantly with the highest nitrogen dose (184 kg N ha^{-1}), they did differ significantly from those under a moderate dose of 46 kg N ha^{-1}.

Table 5. Interaction between maize varieties and nitrogen rates on plant height at 6 weeks after planting (WAP)

Variety	Nitrogen rates (kg N ha^{-1})	Plant height (cm)
Local	0	208.2a
	46	189.4bc
	138	213.8a
	184	210.6a
Composite	0	143.4e
	46	161.7cde
	138	156.8de
	184	143.5e
Hybrid	0	154.2de
	46	198.6ab
	138	178.5bcd
	184	183.1bc

Note: Number followed by the same letter in the same column was not significantly different based on HSD 5% level.

For the hybrid variety 'BISI-18', a trend of increasing plant heights was observed with nitrogen application, peaking at 46 kg N ha^{-1}, with the highest observed plant heights of 198.6 cm. This result differed significantly from the plant heights under the control conditions. Notably, higher nitrogen doses had a diminishing return, suggesting a potential threshold effect beyond which additional nitrogen may not yield further growth benefits. Likewise, the composite maize variety 'Sukumaraga' displayed a significant increase in plant heights with increased nitrogen levels, particularly at 46 kg N ha^{-1}, which influenced the highest plant heights (161.7 cm) compared to the control treatment (143.4 cm) and higher doses of 138 kg N ha⁻¹ (156.8 cm) and 184 kg N ha⁻¹ (143.5 cm), respectively. Results in Table 6 show that stem diameter differed significantly during both 4 and 6 WAP among the maize varieties. However, there was no significant difference of stem diameter during 8WAP. Notably, At 4 WAP, the local variety 'Tambin' demonstrated the thickest stem (12.6 mm), followed by the hybrid variety 'BISI-18' (11.1 mm), with the composite variety 'Sukumaraga' being the least (8.4 mm). At 6 WAP, the hybrid variety 'BISI-18' had the thickest stem (22.5 mm), followed by the composite variety 'Sukumaraga' (21.8 mm), and the local variety 'Tambin' produced the thinnest plant stems (18.3 mm). Additionally, the stem thickness of the local variety at 4 WAP differed significantly from that of the composite variety 'Sukumaraga' but not that of the hybrid variety 'BISI-18'. Similarly, the local 'Tambin' stem thickness at 6 WAP differed significantly from both the composite and hybrid varieties.

Table 6 Response of maize varieties on stem diameter at 3, 4, 6, and 8 weeks after planting (WAP)

Variety	**Stem diameter (mm)**		
	4 WAP	**6 WAP**	**8 WAP**
Local	12.636a	18.350b	-
Composite	8.493b	21.813a	22.27[a]
Hybrid	11.191a	22.542a	22.150[a]

Note: Number followed by the same letter in the same column were not significantly different to HSD 5% level. WAP = weeks after planting.

Table 7 demonstrates that nitrogen application significantly affected stem thickness in maize plants, which differed significantly during 6 WAP. Plants treated with a moderate dose of 46 kg N ha⁻¹ developed thicker stems (22 mm) compared to those under control conditions (19.43 mm), and higher doses of 138 kg N ha⁻¹ (21.12 mm) and 184 kg N ha⁻¹ (21.02 mm). The thicker plant stems recorded under the moderate nitrogen dose differed significantly from those under control conditions but did not differ significantly from those under higher nitrogen doses. Notably, stem diameter during 4 and 8 weeks after planting (WAP) did not differs significantly

Table 7. Response of stem diameter on nitrogen rates at 4, 6, and 8 weeks after planting (WAP)

Nitrogen rates (kg N ha^{-1})	Stem diameter (mm)		
	4 WAP	6 WAP	8 WAP
0	9.45[a]	19.43[b]	21.15[a]
46	11.71[a]	22.01[a]	22.61[a]
138	11.41[a]	21.12[a]	22.45[a]
184	10.50[a]	21.02[a]	22.63[a]

Note: Number followed by the same letter in the same column were not significantly different to HSD 5% level. WAP = weeks after planting.

4 Discussion

Nitrogen is a critical nutrient for plant growth, influencing the development of vegetative structures such as leaves. Higher nitrogen availability often promotes increased leaf production due to enhanced chlorophyll content and photosynthetic activity; likewise, different maize varieties have varying genetic capacities for nitrogen uptake and utilization[15,16]**.** Hybrid varieties often have improved genetic traits for efficient nitrogen use, leading to higher leaf counts under optimal and high nitrogen conditions compared to local varieties[17]. This explains why the hybrid variety 'BISI-18' showed higher leaf counts under moderate nitrogen dose 46 kg N ha^{-1} compared to the local variety and composite varieties. The observed trends in plant height across different maize varieties under observation suggest distinct growth patterns influenced by genetic factors. The local variety 'Tambin' exhibited the most rapid early growth, as evidenced by its significantly greater height at 3, 4 and 6 weeks after planting (WAP). This early vigor may confer advantages in resource competition and stress resilience during critical early developmental stages. In contrast, the hybrid variety 'BISI-18' showed a slower initial growth rate but surpassed 'Tambin' in height by 8 WAP. This growth pattern indicates a potential for prolonged vegetative growth and possibly higher final biomass accumulation, which could be beneficial under certain agronomic conditions.The composite maize variety 'Sukumaraga' consistently demonstrated the shortest plant height at all observed intervals. This trend may reflect a more compact growth habit or genetic traits favoring resource allocation to other physiological processes. While shorter stature (height) in maize varieties could be disadvantageous in terms of light competition, it may offer benefits such as reduced lodging risk and suitability for high-density planting. While lodging constrain yield reduction in crop plants, understanding the morphological traits that influence lodging resistance is crucial. Numerous morphological traits, including plant height, have been discussed in relation to their influence on lodging resistance, making shorter varieties advantageous in certain agronomic conditions[18]

Both composite and hybrid varieties exhibited higher plant heights under 46 kg N ha^{-1} compared to the control treatments. The hybrid variety, in particular, demonstrated superior growth characteristics with optimal nitrogen application levels. It is noteworthy that while the hybrid variety 'BISI-18' reached its maximum plant height (198.6 cm) under 46 kg N ha^{-1} at 6 WAP, a previous study by Adhikari et al. [2] noted optimal nitrogen levels of 220 kg N ha^{-1} for maximum plant height in various hybrid varieties.

The observed trends suggest a significant interaction between nitrogen and maize varieties, with the local variety 'Tambin' showing a positive response to nitrogen fertilization, particularly at 138 kg N ha^{-1}. This indicates that 'Tambin' may have higher nitrogen use efficiency or different nitrogen requirements compared to the hybrid and composite varieties. The diminishing returns observed in 'BISI-18' and 'Sukumaraga' at higher nitrogen levels suggest a threshold effect, beyond which additional nitrogen does not contribute to further growth. This could be due to several factors, including nutrient uptake efficiency and genetic limitations.

Moreover, the observed trends in stem diameter across the different maize varieties highlight the influence of genetic factors and growth stages on plant structural development. At 4 WAP, the local variety 'Tambin' demonstrated the thickest stems, suggesting an early allocation of resources to structural growth, which may enhance stability and support for further vegetative growth. This characteristic could provide advantages in environments prone to lodging or mechanical damage. The hybrid variety 'BISI-18', while initially having thinner stems than 'Tambin' at 4 WAP, exhibited the thickest stems by 6 WAP. This trend indicates a different growth strategy, where the hybrid variety may initially prioritize other physiological processes before investing in structural robustness. The significant increase in stem thickness of 'BISI-18' by 6 WAP suggests a potential for greater resilience and mechanical strength as the plant matures. The composite variety 'Sukumaraga', which consistently showed the thinnest stems at 4 WAP, displayed a substantial increase in stem thickness by 6 WAP, surpassing the local variety 'Tambin'. This suggests that 'Sukumaraga' may have a delayed but effective response in structural growth, potentially balancing early vegetative growth with later structural development.

The significant differences in stem thickness among the varieties at both observation stages highlight the importance of variety selection based on specific agronomic needs. The results indicate that moderate nitrogen application (46 kg N ha^{-1}) significantly enhances the stem thickness of the varieties evaluated compared to control conditions, suggesting an optimal dose for structural growth. Interestingly, higher nitrogen doses did not result in significantly thicker stems than the moderate dose, implying a potential threshold beyond which additional nitrogen does not further benefit stem development. These findings are consistent with the observation by[19], that maximum stem diameter (3.68 cm) was achieved with the highest nitrogen dose of 180 kg ha^{-1}, followed by 160 kg ha^{-1} (3.51 cm) and 130 kg ha^{-1} (3.46 cm), while the smallest diameter (2.58 cm) was recorded with no fertilizer, and 70 kg ha^{-1} resulted in a diameter of 2.89 cm. This suggests that an increased nitrogen supply may promote cell division, leading to consistent stem diameter expansion. Moderate nitrogen levels often optimize plant height due to balanced nutrient availability, which promotes vigorous vegetative growth without causing excessive foliage or nutrient imbalances. This explains why plants treated with 46 kg N ha^{-1} were taller than those under control conditions or higher nitrogen doses, excessive nitrogen application can lead to a diminishing returns effect, where additional nitrogen does not proportionally increase plant height. This is often due to potential nutrient imbalances or luxury consumption, where plants absorb more nitrogen than they can efficiently utilize [8]. This supports the findings that 138 kg N ha^{-1} enhanced plant height but did not significantly differ from the effect of 46 kg N ha^{-1}. Plant height plays a crucial role in defining plant architecture, and plant growth, and can be influenced by factors like nutrient availability, and genetic make-up, among others.[20].

5. Conclusions

This study has demonstrated the significant influence of maize varieties and nitrogen rates on growth of maize plant. Generally, the application of 46 kg N ha^{-1} is optimal for maximizing plant height and stem thickness across all varieties studied. However, the interaction effects reveal more nuanced responses where higher nitrogen levels (i.e., 138 and 184 kg N ha^{-1}) can further enhance specific growth parameters like plant height, number of leaves among Hybrid 'BISI-18', Composite 'Sukumaraga', and Local 'Tambin' varieties, though sometimes with diminishing returns. This suggest that while a moderate nitrogen rate (46 kg N ha^{-1}) is broadly effective, tailored nitrogen application rates based on specific variety responses can optimize growth and yield outcomes more precisely.

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