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Christin Imelda Girsang, Sry Artawati Manik, Handayani Saragih, Fransiskus Xaverius Aryadani Saragih, Muhammad Reza Aulia, Yusdiana (2025)

Growth and Yield Responses and Their Implications for Farm Efficiency of Several Hybrid Maize Varieties as Affected by NPK Fertilizer Rates

Christin Imelda Girsang[1*], Sry Artawati Manik [2], Handayani Saragih[1], Fransiskus Xaverius Aryadani Saragih[1], Muhammad Reza Aulia[3], Yusdiana[4]

[1)] Agrotechnology Study Program, Faculty of Agriculture, University Simalungun, Indonesia, 21139.
[2)] Agribusiness Study Program, Faculty of Agriculture, University Simalungun, Indonesia, 21139.
[3)] Agribusiness Department, Faculty of Agriculture, University Teuku Umar, Indonesia, 23616
[4)] Agriculture Science Department, Faculty of Agriculture and Animal Husbandy Science, University Islam Kebangsaan Indonesia, Aceh, 24264

Corresponding Author: christinimelda98@gmail.com

Abstract

This study aimed to evaluate the growth and yield responses of several hybrid maize varieties to NPK fertilizer application and to assess their implications for fertilizer-use efficiency. The experiment was conducted from January 2025 to May 2025 at the experimental field of the Faculty of Agriculture, Universitas Simalungun. A randomized block design with two factors was used, consisting of three hybrid maize varieties (Pioneer 32, BISI 18, and NK 6232) and three NPK fertilizer rates (200, 250, and 300 kg/ha). Growth and yield parameters were observed and analyzed using analysis of variance followed by the Least Significant Difference test at 5%. The results showed that maize varieties and NPK fertilizer rates significantly affected most growth and yield parameters. Fertilizer-use efficiency, measured using partial factor productivity (PFP) and marginal product (MP), generally declined as NPK rates increased: PFP ranged from 53.40–60.80 kg kg $^{-1}$ at 200 kg ha $^{-1}$ to 36.18–42.89 kg kg $^{-1}$ at 300 kg ha $^{-1}$, with the highest PFP observed in NK 6232 at 200 kg ha $^{-1}$ (60.80 kg kg $^{-1}$). NK 6232 produced the highest yield at 300 kg ha $^{-1}$ (12.87 t ha $^{-1}$) but with a lower PFP (42.89 kg kg $^{-1}$), indicating a trade-off between maximizing yield and maximizing fertilizer-use efficiency. MP analysis showed that marginal gains were variety-specific, with the largest response at NK 6232 for the 200→250 kg ha $^{-1}$ step (MP = 9.87 kg grain per kg additional NPK) and at BISI 18 for the 250→300 kg ha $^{-1}$ step (MP = 10.13). Overall, hybrid varieties that achieved high yield performance at moderate fertilizer rates demonstrated better fertilizer-use efficiency, indicating that optimal input management is essential for sustainable maize production.

Keywords: hybrid maize, NPK fertilizer, growth, yield, fertilizer-use efficiency.

1. INTRODUCTION

Efforts to raise maize output still lean heavily on two levers that farmers can adopt quickly: planting improved hybrids and supplying nutrients through inorganic fertilizers, especially NPK. Hybrids are widely valued because their genetics allow faster biomass accumulation, stronger sink formation, and a clearer yield response when nutrients are not limiting. In Indonesian field research, for example, hybrid maize growth and yield components increased with NPK up to a point, and the "middle" dose often performed better than pushing fertilizer to the highest rate an early signal that "more input" does not always translate into "more benefit" (Pusparini et al., 2018).

In practice, however, the success of maize cultivation cannot be judged only by tall plants or high grain yield. What matters for farmers is whether those outputs are achieved with efficient input use

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meaning the costs of seed, fertilizer, labor, and crop protection remain proportional to the value of additional yield. Studies on farm performance show that many maize farmers still operate below efficient frontiers: inputs are either overused (raising costs) or underused (limiting yield), and both conditions reduce profitability. This gap is visible in Indonesian efficiency analyses where only a small share of respondents reached technical efficiency, and fertilizer use was among the most influential factors affecting production outcomes (Galingging, 2020).

Fertilizer is often the largest cash expense in maize farming. When fertilizer prices rise or when farmers apply fertilizer beyond the crop's economically optimal requirement profit margins can shrink quickly even if yield increases slightly. Evidence from Ghana demonstrates a classic diminishing-returns pattern: yield gains were large when nitrogen moved from zero to moderate levels, but became marginal as nitrogen rates increased further, and the economically optimal nitrogen rate fell well below the blanket "recommended" rate in that context. This matters because small differences in yield rarely compensate for large increments in fertilizer cost when the response curve is already flattening (Essel et al., 2020).

Beyond cost, efficiency is also shaped by nutrient use efficiency (NUE), how much grain is produced per unit nutrient applied, and how much applied nutrient is actually recovered by the crop. Work in India shows that while very high fertilizer levels can increase maize productivity, nutrient use efficiency does not necessarily improve in the same direction; in other words, higher fertilizer rates may boost yield but can weaken the "return per kilogram of nutrient" and reduce overall bio-economic efficiency once the crop approaches saturation (Hulmani et al., 2022).

Another practical complication is that hybrid varieties do not respond identically to the same fertilizer rate. Differences in phenology, root architecture, biomass partitioning, and sink strength can produce different yield responses under the same nutrient environment. Indonesian experimental work illustrates that growth and yield traits can peak at moderate NPK rates and that variety effects can be significant for yield components, implying that uniform fertilization across varieties may be inefficient for some and insufficient for others. Likewise, agronomic trials using NPK-based fertilization have documented measurable changes in physiological and yield-related responses, reinforcing that nutrient source and dosage interact with crop condition and management (Purba et al., 2020).

Because of these realities, "efficiency" in maize farming should be seen as a combination of (1) agronomic efficiency (how yield responds to added nutrients), (2) economic efficiency (whether added yield pays for added costs), and (3) management efficiency (timing, placement, and adjustment to crop demand). Recent evidence from Ghana underscores that fertilizer decisions must be evaluated with profitability metrics (e.g., value-cost ratios and net benefit), not yield alone because the same yield gain can be attractive or unattractive depending on price relationships and response strength (Fayaz et al., 2025).

This is why "blanket recommendations" are increasingly questioned, and why site-specific or need-based nutrient management is becoming more relevant. One accessible example is real-time nitrogen adjustment using simple diagnostic tools (e.g., leaf color chart approaches). Open-access evidence from hybrid maize trials indicates that need-based nitrogen scheduling can raise yield while improving nitrogen use efficiency and benefit–cost outcomes, aligning crop demand with fertilizer supply more closely than fixed-rate strategies (Fayaz et al., 2025).

Against this background, the present study"Growth and Yield Responses and Their Implications for Fertilizer-Use Efficiency of Several Hybrid Maize Varieties as Affected by NPK Fertilizer Application" is designed to move beyond the question *"Which treatment yields the most?"* toward the more farmer-relevant question *"Which treatment yields well with rational input use?"* Specifically, the study aims to: (1) compare vegetative growth and yield performance among selected hybrid maize varieties; (2) quantify varietal responses to different NPK fertilizer rates; (3) test for variety × NPK interaction effects on growth and yield; and (4) interpret these biological responses through an efficiency lens identifying combinations that provide high and stable output with reasonable fertilizer input, supporting better farm profitability and sustainability.

2. METHOD

2.1 Research Model and Hypotheses

The materials used in this study included hybrid maize seeds, NPK fertilizer, pesticides, and water for irrigation. The hybrid maize seeds consisted of three varieties, namely Pioneer 32, BISI 18, and NK 6232. These varieties were selected because they are commonly cultivated by farmers and exhibit different growth characteristics and yield potential. The fertilizer applied was a compound NPK fertilizer serving as a source of the primary macronutrients nitrogen, phosphorus, and potassium.

The equipment used in this study included hoes, measuring tapes, digital scales, vernier calipers, stationery, treatment labels, and other supporting tools required during crop cultivation, field observations, and data collection processes.

Based on the theoretical foundation and conceptual framework described above, the hypotheses of this study are formulated as follows:

1. It is hypothesized that there are differences in growth responses among hybrid maize varieties.
2. It is hypothesized that the growth and yield responses of hybrid maize varieties differ as a result of NPK fertilizer application at different dosage levels.
3. It is hypothesized that there is an interaction between hybrid maize varieties and NPK fertilizer rates affecting maize growth and yield.
4. It is hypothesized that the growth and yield responses of hybrid maize varieties to NPK fertilizer application have implications for maize fertilizer-use efficiency.

2.2 Data Collection

The research was carried out for 5 (five) months, from January 2025 to May 2025 at the experimental field of the Faculty of Agriculture, Universitas Simalungun. The sample of this research at the experimental field of the Faculty of Agriculture, Universitas Simalungun, located at an altitude of 427 meters above sea level.

2.3 Data Analysis

This study was conducted as a field experiment using a Randomized Complete Block Design (RCBD) with two factors. The factors examined were the responses of several hybrid maize varieties and different rates of compound fertilizer application. The treatment factors tested in this study were as follows:

1) Variety factor (V)

V_1 = Pioneer 32 variety
V_2 = BISI 18 variety
V_3 = NK 6232 variety

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2) NPK fertilizer rate factor (M)

M_1 = 200 kg/ha (120 g/plot)
M_2 = 250 kg/ha (150 g/plot)
M_3 = 300 kg/ha (180 g/plot)

The treatment combinations consisted of nine treatments, as follows:

V_1M_1	V_2M_1	V_3M_1
V_1M_2	V_2M_2	V_3M_2
V_1M_3	V_2M_3	V_3M_3

The data obtained from this study were statistically analyzed using a Randomized Complete Block Design (RCBD) as follows: $\mathbf{Yijk = \mu + \alpha i + \beta j + \rho k + \beta\rho(jk) + \varepsilon ijk}$

Yijk = the observed value in the *i*-th block receiving the *j*-th hybrid maize variety treatment and the *k*-th NPK fertilizer rate.
μ = the overall treatment mean
αi = the response of the *i*-th block
βj = the response of the *j*-th hybrid maize variety
ρk = the effect of the NPK fertilizer dosage at the *k*-th level
βρ(jk) = the interaction effect between the *i*-th hybrid maize variety and the *j*-th NPK fertilizer rate
εijk = the experimental error associated with the *j*-th block, the *i*-th hybrid maize variety treatment, and the *k*-th NPK fertilizer rate.

Determine the effects of treatments on the observed plant parameters, the data were analyzed using a systematic statistical model and analysis of variance (ANOVA). When the ANOVA results indicated significant treatment effects, further mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level.

Number of blocks	= 3 blocks (replications)
Plot size	= 3 × 2.5 m
Plant spacing	= 70 × 20 cm
Total number of experimental plots	= 27 plots
Distance between blocks	= 100 cm
Distance between plots	= 100 cm
Number of plants per plot	= 40 plants
Number of sample plants per plot	= 4 plants

Efficiency Analysis

To operationalize fertilizer-use efficiency, agronomic indicators were calculated from dry grain yield and NPK fertilizer rate. Two indicators were used: Partial Factor Productivity (PFP) and Marginal Product (MP) of NPK fertilizer. Where price and cost data are available, economic indicators such as Value–Cost Ratio (VCR) and Revenue–Cost Ratio (R/C) can also be calculated to support profitability-based recommendations.

Yield basis and unit conversion. Dry grain yield was recorded as kg $plot^{-1}$ and converted to a hectare basis using the plot area (3 × 2.5 m = 7.5 m^2) as follows:

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Yield conversion (plot → ha)

$$Y_{ha} = Y_{plot} \times \frac{10{,}000}{7.5}$$

$Y_{ha}\,(\mathrm{kg\,ha^{-1}}),\ Y_{plot}\,(\mathrm{kg\,plot^{-1}})$

Partial Factor Productivity (PFP) of NPK fertilizer expresses grain output per unit of fertilizer product applied (compound NPK):

Partial Factor Productivity (PFP)

$$PFP_{NPK} = \frac{Y_{ha}}{F}$$

$F\,(\mathrm{kg\,ha^{-1}}) \Rightarrow PFP\,(\mathrm{kg\,kg^{-1}})$

where Y is dry grain yield (kg ha^{-1}) and F is the NPK fertilizer rate (kg ha^{-1}). Units are kg grain per kg NPK fertilizer.

Marginal Product (MP) of NPK fertilizer describes the incremental yield response to an additional unit of fertilizer input between two consecutive fertilizer rates within the same variety:

Marginal Product (MP)

$$MP_{NPK} = \frac{Y_k - Y_{k-1}}{F_k - F_{k-1}}$$

$MP\,(\mathrm{kg\,kg^{-1}}),\ \Delta F = 50\ \mathrm{kg\,ha^{-1}}$

In this study, MP was calculated for the 200→250 and 250→300 kg ha^{-1} steps (ΔF = 50 kg ha^{-1}). Units are kg grain per kg additional NPK fertilizer.

Optional economic indicators (if price/cost data are available). The Value–Cost Ratio (VCR) can be computed to evaluate whether incremental yield gains pay for incremental fertilizer costs:

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Value–Cost Ratio (VCR)

$$VCR = \frac{\Delta Y \times P_y}{\Delta F \times P_f}$$

$P_y\,(\mathrm{IDR\,kg^{-1}}),\ P_f(\mathrm{IDR\,kg^{-1}})$

where ΔY is incremental yield (kg ha^{-1}), P_y is farm-gate maize grain price (IDR kg^{-1}), ΔF is the incremental fertilizer amount (kg ha^{-1}), and P_f is fertilizer price (IDR kg^{-1}). Overall profitability can be summarized using the revenue–cost ratio (R/C):

where TR is total revenue (TR = Y × P_y) and TC is total production cost (IDR ha^{-1}).

Statistical analysis. PFP should be calculated at the plot (replication) level and analyzed using the same factorial RCBD ANOVA model used for other response variables. When ANOVA indicates significant effects ($p \le 0.05$), mean comparisons can be performed using LSD at 5%. MP (and VCR) are stepwise indicators and are primarily presented descriptively unless computed per replication.

2.4 RESULT AND DISCUSSION

The results of the mean comparison tests for all observed parameters are presented in Table 1. The parameters observed in this study were plant height, stem diameter, harvest age, ear length, ear diameter, dry grain yield per plot, and thousand-kernel weight.

Table 1. Mean Comparison Results As Affected By Varietal Differences And NPK Fertilizer Application

Treatment	Plant Height (cm)	Diameter Stem (mm)	Harvest Age	Ear length (cm)	Ear Diameter (mm)	Dry Grain Yield per Plot	Weight of 1,000 kernel
V1	191.66 c	4.13 b	96.36 c	15.41 c	50.76 c	8.08 c	262.31 c
V2	194.39 b	4.19 b	99.76 b	16.20 b	52.60 b	8.45 b	291.78 b
V3	198.79 a	4.32 a	101.78 a	16.94 a	54.39 a	9.42 a	307.52 a
M1	193.75 c	0.08	99.00 b	15.96 c	51.95 c	8.48 c	279.00 c
M2/0	195.22 b	4.18	100.89 a	16.19 b	52.61 b	8.66 b	288.18 b
M3	195.87 a	4.20	98.00 b	16.40 a	53.19 a	8.86 a	294.43 a
BNT 5%	**0.51**	**4.27**	**0,88**	**0.11**	**0.35**	**0.04**	1.63
V1M1	190.98	4.12	96.33 f	15.25	50.07	8.01 h	250.82 g
V1M2	191.72	4.14	95.33 g	15.34	50.77	8.09 g	264.23 f
V1M3	192.28	4.15	97.40 e	15.62	51.43	8.14 g	271.87 e
V2M1	193.27	4.17	98.33 d	15.94	51.91	8.32 f	284.27 d
V2M2	194.63	4.19	101.67 b	16.25	52.74	8.40 e	291.37 c
V2M3	195.26	4.22	99.28 c	16.40	53.15	8.78 d	299.72 b
V3M1	196.98	4.25	99.33 c	16.68	53.86	9.12 c	301.92 b

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V3M2	199.32	4.27	105.67 a	16.97	54.32	9.49 b	308.93 a
V3M3	200.07	4.44	100.33 b	17.18	55.00	9.65 a	311.70 a
BNT 5%			**1,52**			**0.06**	**2.82**

Description: Values followed by different letters in the same column indicate significant differences at the 5% level.

Fertilizer-use efficiency indicators (PFP and MP)

Partial Factor Productivity (PFP) and Marginal Product (MP) of NPK fertilizer were calculated from dry grain yield to support the interpretation of "efficiency" beyond absolute yield. Yield was converted to a hectare basis using plot area (7.5 m²) and then used to calculate PFP (kg grain per kg NPK fertilizer) and MP (incremental kg grain per kg additional NPK fertilizer) between consecutive fertilizer rates within each variety.

Table 2. Partial Factor Productivity (PFP) and Marginal Product (MP) of NPK fertilizer based on dry grain yield

Note: MP at 200 kg ha^{-1} is not computed (baseline). MP at 250 kg ha^{-1} = (Yield250 − Yield200) / 50; MP at 300 kg ha^{-1} = (Yield300 − Yield250) / 50.

Treatment	Variety	NPK rate (kg ha^{-1})	Dry grain yield (kg $plot^{-1}$)	Yield (t ha^{-1})	PFP (kg kg^{-1})	MP (kg kg^{-1})
V1M1	Pioneer 32	200	8.01	10.68	53.40	–
V1M2	Pioneer 32	250	8.09	10.79	43.15	2.13
V1M3	Pioneer 32	300	8.14	10.85	36.18	1.33
V2M1	BISI 18	200	8.32	11.09	55.47	–
V2M2	BISI 18	250	8.40	11.20	44.80	2.13
V2M3	BISI 18	300	8.78	11.71	39.02	10.13
V3M1	NK 6232	200	9.12	12.16	60.80	–
V3M2	NK 6232	250	9.49	12.65	50.61	9.87
V3M3	NK 6232	300	9.65	12.87	42.89	4.27

Across varieties, increasing NPK rate tended to increase yield; however, PFP generally declined as NPK rate increased, indicating diminishing grain output per unit of fertilizer input. The highest yield was observed in NK 6232 at 300 kg ha^{-1} (V3M3), whereas the highest PFP was observed in NK 6232 at 200 kg ha^{-1} (V3M1). These results indicate a trade-off between maximizing yield and maximizing fertilizer-use efficiency.

Statistical inference for PFP requires calculating PFP for each experimental plot (per replication) and analyzing it using factorial RCBD ANOVA. Because Table 2 is derived from treatment means reported in Table 1, the values are presented descriptively.

2.4.1 Plant Height

The analysis of variance indicated that maize variety and NPK fertilizer application had a significant effect on plant height, whereas the interaction between maize variety and NPK fertilizer rate did not significantly affect plant height. To identify differences among treatments, mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level, as presented in Table 1.

Table 1 shows that during the growth phase when corn plants reached 75% male flowering, there were significant differences in plant height between the varieties tested. This indicates that in the early generative phase, the genetic influence of the varieties began to have a more pronounced effect on plant growth.

As the observation period progressed to 75% male flowering age, the results showed significant differences in plant height, with the tallest plants (198.79 cm) produced by the NK 6232 (V_3) variety. The plant height of the NK 6232 variety differed significantly from the BISI 18 (V_2) and Pioneer 32 (V_1) varieties. The growth potential of each variety will bring out the respective advantages of those varieties. The NK 6232 variety produced better plant height than the BISI 18 and Pioneer 32 varieties.

Differences in plant height between the present study and the varietal descriptions are likely to occur. These differences may be attributed to variations in experimental location, cultivation practices, and fertilization techniques applied during the study. Variations among maize varieties can result in significant differences in plant height. The NK 6232 variety outperformed the other varieties; however, at the 75% tasseling stage, plant height growth began to slow as more assimilates were allocated to tassel and ear development. This finding indicates that fertilization during the vegetative phase plays a crucial role in promoting early plant growth, whereas during the generative phase, environmental and genetic factors become more dominant in determining final plant performance (Gharge et al., 2020).

Table 1 shows that different NPK fertilizer rates resulted in significant differences in maize plant height at the 75% tasseling stage. The tallest plants (195.87 cm) were obtained at the NPK fertilizer rate of 300 kg/ha (M_3), followed by 250 kg/ha (M_2) with a plant height of 195.22 cm, while the lowest plant height (193.75 cm) was observed at the rate of 200 kg/ha (M_1). During the vegetative phase, maize plants exhibited a significant increase in height before growth gradually slowed at later stages. The application of NPK fertilizer significantly influenced sweet corn (*Zea mays* Saccharata Sturt) growth and yield, including plant height, stem diameter, and other agronomic parameters. These results indicate that balanced NPK fertilization can improve overall plant performance by enhancing nutrient availability and uptake. These findings align with the role of nitrogen, phosphorus, and potassium in promoting vegetative growth and reproductive development in maize (Harini et al., 2023).

2.4.2 Stem Diameter

The results of the analysis of variance indicated that maize variety had a significant effect on stem diameter at 6 weeks after planting (WAP). In contrast, NPK fertilizer rates and the interaction between maize variety and NPK fertilizer application did not have a significant effect on stem diameter. To determine differences among treatments, mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level,

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Table 1 shows that stem diameter was significantly influenced by maize variety. The NK 6232 variety (V3) recorded the largest mean stem diameter (4.32 cm), which was significantly higher than Pioneer 32 (V1, 4.13 cm) and BISI 18 (V2, 4.19 cm) based on the LSD test at the 5% level. This suggests that genetic differences among hybrids contributed to stem robustness under the study conditions. At the treatment-combination level, the maximum stem diameter was observed in V3M3 (4.44 cm).

A larger stem diameter indicates stronger plant growth and greater structural support for leaf sheaths and leaf blades. Thicker stems generally reflect better vegetative development. The mean stem diameter under fertilizer treatment M_1 was 4.18 cm, which increased to 4.20 cm under M_2 and reached the highest value under M_3 at 4.27 cm. This pattern reinforces that increasing NPK fertilizer rates tended to enhance maize stem diameter.

NPK fertilization contributes to stem development through complementary roles of primary macronutrients. Balanced supply of N, P, and K supports plant vigor, and phosphorus nutrition is commonly associated with improved root growth, which enhances nutrient and water uptake. Robust stems are important because lodging can cause major yield losses, and lodging resistance is supported by traits such as stem diameter and stem strength (Mustikarini et al., 2020). In maize, the application of an NPK fertilizer (ENTEC) increased stem diameter compared with the unfertilized control, indicating that adequate nutrient availability supports growth processes in stem tissues (Girsang et al., 2021).

2.4.3 Harvest Age

Maize variety, NPK fertilizer rate, and the interaction between the two had significant effects on maize harvest age. To further examine differences among treatments, mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level, as presented in Table 1.

The variety that exhibited the shortest harvest age was V1 (Pioneer 32), reaching harvest at 96.36 days, which was significantly different from BISI 18 (99.76 days) and NK 6232 (101.78 days). Based on varietal descriptions, the expected harvest ages of Pioneer 32, BISI 18, and NK 6232 are approximately 100 days, 105 days, and 115 days, respectively.

The results of this study indicate that the observed harvest ages of maize were generally consistent with the descriptive data for each variety. Varieties with shorter harvest periods are considered more advantageous for farmers, as earlier harvesting allows products to be marketed sooner and enables faster turnover for subsequent cropping cycles.

Varietal treatment had a significant effect on maize harvest age. The shortest harvest age was observed in the Pioneer 32 variety (V1), which reached harvest at 96.36 days, whereas the longest harvest age was recorded in the NK 6232 variety (V3) at 101.78 days. These results are consistent with the varietal descriptions of Pioneer 32, which generally has a harvest age of approximately 100 days, while in this study it was harvested at 96.36 days. The BISI 18 variety is described as having a harvest age of approximately 100 days, and in the present study its harvest age reached 99.76 days. Meanwhile, the NK 6232 variety is reported to have a harvest age of around 105 days; however, in this study it required only 101.78 days to reach harvest. Therefore, the harvest ages observed in this study can be considered within a reasonable and acceptable range based on varietal characteristics. Early-maturing maize varieties contribute to improved fertilizer-use efficiency by enabling faster harvest cycles, quicker capital turnover, and reduced production risks, which are particularly important in smallholder farming systems (Wulansari & Rezamela, 2020).

Based on these results, it can be concluded that variety selection is a key factor in determining maize harvest age. Therefore, maize cultivation strategies should carefully consider the choice of variety in order to align production objectives with local environmental conditions and farming system requirements. Appropriate varietal selection can improve fertilizer-use efficiency by optimizing harvest timing, reducing production risks, and enhancing overall management effectiveness.

NPK fertilizer rate also significantly influenced harvest age. The earliest harvest age (98.00 days) was observed at the NPK rate of 200 kg/ha (M1), which was significantly earlier than the higher NPK rates. In contrast, application at 250 kg/ha (M2) resulted in the longest harvest age (100.89 days). These results indicate that increasing fertilizer rates may delay physiological maturity due to prolonged vegetative growth, whereas lower fertilizer inputs may accelerate crop maturity under the study conditions.

The interaction between maize variety and NPK fertilizer rate also had a significant effect on harvest age. The shortest harvest age was recorded for the combination of the Pioneer 32 variety with an NPK fertilizer rate of 200 kg/ha (V_1M_1), reaching 95.33 days after planting, which was significantly different from the other treatment combinations. Conversely, the longest harvest age was observed in the NK 6232 variety combined with an NPK fertilizer rate of 300 kg/ha (V_3M_3), with a harvest age of 105.67 days after planting.

2.4.4 Ear length

Differences in maize variety and NPK fertilizer rate had significant effects on ear length. However, the interaction between maize variety and NPK fertilizer rate did not show a significant effect on ear length. Varietal treatment had a significant effect on maize ear length. The variety that produced the longest ears was NK 6232 (V_3), with an average ear length of 16.94 cm, which was significantly different from BISI 18 (16.20 cm) and Pioneer 32 (15.41 cm). Differences in ear length among maize genotypes/varieties are largely determined by genetic factors, although environmental conditions may influence the expression of these traits (Jayanti et al., 2020).

Genetic variation in key genes associated with ear development contributes significantly to differences in ear length and yield traits in maize, demonstrating that ear morphology is strongly influenced by genetic factors (Luo et al., 2022). In maize, variation in ear diameter is often primarily associated with genotype (varietal genetics), whereas environmental effects may play a comparatively smaller role (Yuranto et al., 2018).

NPK fertilizer rate had a significant effect on maize ear length. The longest ears were obtained at the NPK fertilizer rate of 300 kg/ha (M_3), with an average ear length of 16.40 cm. This finding is consistent with (Wang et al., 2023) who reported that although nutrients are essential for plant growth, genetic factors play a more dominant role in determining maize ear size than external factors such as fertilization. Ear morphological traits in maize, including ear length, exhibit high heritability, suggesting that genetic factors play a more dominant role than external inputs such as fertilization.

The interaction between NPK fertilizer and maize variety did not have a significant effect on ear length. The longest ears were observed in the NK 6232 variety combined with an NPK fertilizer rate of 300 kg/ha (V_3M_3), reaching 17.18 cm; however, this value was not significantly different from those of other treatment combinations. In contrast, the shortest ear length was recorded in the Pioneer 32 variety combined with an NPK fertilizer rate of 200 kg/ha (V_1M_1), measuring 14.50 cm.

These results indicate that increasing NPK fertilizer rates tend to increase maize ear length, although differences among several treatment combinations were not statistically significant. In addition, genetic factors associated with maize varieties play an important role in determining ear length, while environmental factors, including soil nutrient availability, influence the ability of plants to optimally express their genetic potential.

2.4.5 Maize Ear Diameter

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Based on the results of the analysis of variance, maize variety and NPK fertilizer rate had significant effects on ear diameter. However, the interaction between maize variety and NPK fertilizer rate did not have a significant effect on ear diameter. Varietal treatment resulted in significant differences in ear diameter, with the largest ear diameter recorded in the NK 6232 variety (V_3) at 54.39 mm, which was significantly different from Pioneer 32 (50.76 mm) and BISI 18 (52.60 mm).

When ear diameter is considered together with ear length, the results show a relatively consistent pattern. The NK 6232 variety produced both the longest ears (16.94 cm) and the largest ear diameter (54.39 mm). The ear length and ear diameter of NK 6232 were significantly greater than those produced by the BISI 18 and Pioneer 32 varieties. These findings indicate that the ears produced by the NK 6232 variety were considerably larger than those of BISI 18 and Pioneer 32. Variation in maize ear size among varieties reflects differences in genetic potential, while adequate nutrient availability, particularly nitrogen, supports optimal plant growth and enhances the expression of yield components such as ear development (Prasetyo et al., 2023).

NPK fertilizer rate had a significant effect on maize ear diameter, with the largest ear diameter observed at the fertilizer rate of 300 kg/ha (M_3), reaching 53.19 mm, while the smallest ear diameter was recorded at 200 kg/ha (M_1), measuring 51.95 mm. Increased ear diameter reflects improved kernel development, which is closely associated with adequate nutrient availability, particularly nitrogen, phosphorus, and potassium. Balanced NPK fertilization enhances cell division and enlargement during ear development, thereby contributing to larger ear size; however, the magnitude of this response is also strongly influenced by varietal genetic potential (Mawaddah et al., 2025)

The combination of NPK fertilizer treatment and maize variety resulted in variation in ear diameter. The largest ear diameter was obtained from the combination of the NK 6232 variety with an NPK fertilizer rate of 300 kg/ha (V_3M_3), measuring 53.19 mm, while the smallest ear diameter was observed in the Pioneer 32 variety combined with an NPK fertilizer rate of 200 kg/ha (V_1M_1), measuring 50.07 mm. Although the interaction between maize variety and NPK fertilizer rate did not have a statistically significant effect on ear diameter, the V_3 variety under the M_3 treatment consistently produced the best ear diameter compared to other treatment combinations.

2.4.6 Dry Grain Production per Plot

The analysis of variance showed that maize variety, NPK fertilizer rate, and the interaction between variety and NPK fertilizer rate had significant effects on yield production.

Maize variety resulted in significant differences in dry grain yield per plot. The highest dry grain yield was produced by variety V_3 (NK 6232), reaching 9.42 kg per plot, followed by BISI 18 with 8.45 kg per plot and Pioneer 32 with 8.08 kg per plot. When converted to a per-hectare basis, the NK 6232 variety produced 12,560 kg/ha of dry grain, while BISI 18 and Pioneer 32 yielded 11,266 kg/ha and 10,773 kg/ha, respectively. The higher yield obtained from the NK 6232 variety is consistent with its larger ear size, both in terms of ear length and ear diameter, compared to the other two varieties. Larger ear size logically contributes to greater dry grain production due to increased kernel number and improved kernel development.

Differences among maize varieties significantly affected dry grain yield per plot. The highest dry grain yield was produced by the NK 6232 variety (V_3), reaching 9.42 kg per plot, while the lowest yield was recorded in the Pioneer 32 variety (V_1), with 8.08 kg per plot. Based on varietal descriptions, Pioneer 32 is reported to produce dry grain yields of up to approximately 11 ton/ha; however, in this study, the yield obtained was 8.08 kg per plot, which corresponds to about 10.7 ton/ha when converted to a per-hectare basis.

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Similarly, the BISI 18 variety is described as having an average yield potential of around 12 ton/ha, whereas in this study it produced 8.45 kg/plot, equivalent to approximately 11.2 ton/ha. The NK 6232 variety is generally reported to produce about 11 ton/ha; however, in the present study, its dry grain yield reached 9.42 kg/plot, corresponding to an average of approximately 12.5 ton/ha. Ear length and ear diameter show strong positive associations and direct effects on ear weight, indicating that larger ears generally contribute to higher yield potential (Mukhlisin et al., 2025).

NPK fertilizer treatment significantly affected dry grain yield per plot. The highest dry grain yield was obtained at the NPK fertilizer rate of 300 kg/ha (M_3), reaching 8.86 kg per plot, whereas the lowest yield was recorded at 200 kg/ha (M_1), with 8.48 kg per plot. In general, higher NPK fertilizer rates tended to increase dry grain yield per plot. This finding is consistent with previous reports indicating that proper management of nitrogen application rate and timing can improve nutrient uptake and fertilizer use efficiency, thereby supporting increased crop yield (Flatian et al., 2020).

The interaction between NPK fertilizer and maize variety had a significant effect on dry grain yield per plot. Although one of the highest yields was recorded in the NK 6232 variety combined with an NPK fertilizer rate of 300 kg/ha (V_3M_2), reaching 9.49 kg per plot, this value was not statistically different from several other treatment combinations. The highest dry grain yield was observed in the combination of the NK 6232 variety with an NPK fertilizer rate of 300 kg/ha (V_3M_3), reaching 9.65 kg per plot. In contrast, the lowest dry grain yield was recorded at the NPK fertilizer rate of 200 kg/ha combined with the Pioneer 32 variety (V_1M_1), with a yield of 8.01 kg per plot.

2.4.7 Thousand Kernel Weight (g)

The results of the analysis of variance showed that maize variety, NPK fertilizer dosage, and their interaction significantly influenced the weight of 1,000 kernels. Differences among maize varieties had a significant effect on thousand-kernel weight. The heaviest thousand-kernel weight was recorded for the NK 6232 variety (V_3), reaching 307.52 g, whereas the lowest value was observed for the Pioneer 32 variety (V_1), with 262.31 g. Based on varietal descriptions, the thousand-kernel weight of Pioneer 32 is reported to be approximately 270 g; however, in the present study it reached only 262.31 g. Similarly, the BISI 18 variety is described as having a thousand-kernel weight of around 300 g, whereas in this study it reached 291.78 g. The NK 6232 variety is generally reported to achieve a thousand-kernel weight of up to approximately 330 g; however, in this study it reached 307.52 g. These differences indicate that genetic factors play an important role in determining kernel weight among maize varieties.

The table shows that the interaction between maize variety and NPK fertilizer rate had a significant effect on thousand-kernel weight. The highest thousand-kernel weight was recorded for the NK 6232 variety at an NPK fertilizer rate of 300 kg/ha (V_3M_3), reaching 311.7 g; however, the differences compared to other treatments were relatively small. This outcome is likely due to the relatively similar adaptive capacity of the maize varieties in responding to fertilization, resulting in comparable kernel weight responses across treatments.

The combination of NPK fertilizer treatments and maize varieties resulted in variation in thousand-kernel weight. The NK 6232 variety receiving the highest NPK fertilizer rate produced the heaviest kernels at 300 kg/ha (V_3M_3), with a thousand-kernel weight of 311.7 g, whereas the lowest value was observed in the Pioneer 32 variety at the NPK fertilizer rate of 200 kg/ha (V_1M_1), with a thousand-kernel weight of 250.82 g.

These results indicate that each maize variety exhibits a different level of responsiveness to NPK fertilization. Higher kernel weight observed in certain varieties is likely influenced by genetic capacity to absorb and efficiently utilize available nutrients. In addition, NPK fertilizer plays an essential role during both vegetative and generative growth stages, where nitrogen supports leaf development,

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phosphorus strengthens root and stem growth, and potassium facilitates kernel filling. The effectiveness of fertilization depends on appropriate application timing and dosage, as nutrient supply aligned with crop demand enables optimal vegetative growth that subsequently supports increased overall yield. These findings further emphasize that the selection of maize variety and fertilizer management should be adjusted to specific site conditions in order to achieve optimal harvest performance (Aji & Arifin, 2024).

2.4.8 Implications of Growth and Yield Responses for Maize Fertilizer-Use Efficiency

To make the term "fertilizer-use efficiency" operational, this study interprets efficiency primarily as fertilizer-use efficiency, quantified using Partial Factor Productivity (PFP) and Marginal Product (MP) of NPK fertilizer (Table 2). These indices complement yield comparisons by expressing (i) grain output per unit fertilizer input (PFP) and (ii) incremental yield response to additional fertilizer (MP).

Across varieties, increasing NPK rate tended to increase dry grain yield; however, PFP generally declined as fertilizer rate increased (Table 2). This indicates diminishing returns: additional fertilizer still increased yield, but the grain produced per kilogram of fertilizer became smaller at higher rates. Therefore, treatments identified as "best" based solely on maximum yield are not necessarily the most efficient on an input–output basis.

Varietal differences were evident in both yield level and efficiency indices. NK 6232 produced the highest yields across fertilizer rates and also achieved the highest PFP at 200 kg ha^{-1} (V3M1 = 60.80 kg kg^{-1}). When NPK increased from 200 to 250 kg ha^{-1} in NK 6232, MP was relatively high (9.87 kg kg^{-1}), but MP declined at the 250→300 kg ha^{-1} step (4.27 kg kg^{-1}), indicating that the response curve began to flatten (Table 2).

For BISI 18, MP was low at the 200→250 kg ha^{-1} step (2.13 kg kg^{-1}) but increased at the 250→300 kg ha^{-1} step (10.13 kg kg^{-1}), suggesting a stronger yield response at the higher rate within the tested range. In contrast, Pioneer 32 showed relatively small MP values at both increments (2.13 and 1.33 kg kg^{-1}), implying limited yield gains from additional NPK beyond 200 kg ha^{-1} under the study conditions (Table 2).

From a farm perspective, agronomic efficiency should ideally be complemented with economic indicators such as Value–Cost Ratio (VCR) and R/C ratio, because profitability depends on price relationships between grain and fertilizer (not yield response alone). Where price and cost data are available, VCR can be computed using the observed incremental yield gains relative to incremental fertilizer costs, and R/C ratio can summarize overall profitability. Without such data, the present discussion emphasizes agronomic efficiency based on PFP and MP.

Overall, the results emphasize that improving maize fertilizer-use efficiency requires matching the right hybrid with a rational NPK rate. Treatments that maintain high yield while preserving higher PFP and favorable MP (Table 2) are more likely to provide better input-use efficiency and potentially better economic resilience when fertilizer prices are high or grain prices are uncertain.

3. CONCLUSION

The effects of NPK fertilizer application and maize variety on the growth and yield of maize can be summarized as follows:

1. Based on the observed parameters, maize variety had a significant effect on plant height, stem diameter, harvest age, ear length, ear diameter, dry grain yield per plot, and thousand-kernel weight. The highest mean values for all parameters were consistently recorded in treatment V3 (NK 6232), including plant height (198.79 cm), stem diameter (4.32 cm), longest harvest age (101.78 days), longest ear length (16.94 cm), largest ear diameter (54.39 mm), highest dry grain yield per plot (9.42 kg), and greatest thousand-kernel weight (307.52 g).
2. NPK fertilizer application significantly affected plant height, harvest age, ear length, ear diameter, dry grain yield per plot, and thousand-kernel weight, but did not significantly affect stem diameter. The highest mean values for most yield-related parameters were obtained at the NPK fertilizer rate of 300 kg ha^{-1}, including plant height (195.87 cm), stem diameter (4.27 cm), longest ear length (16.40 cm), largest ear diameter (53.19 mm), highest dry grain yield per plot (8.86 kg), and greatest thousand-kernel weight (294.43 g). The longest harvest age was observed at the NPK fertilizer rate of 250 kg ha^{-1} (100.89 days).
3. The interaction between maize variety and NPK fertilizer rate did not significantly affect plant height, stem diameter, ear length, or ear diameter, but had a significant effect on harvest age, dry grain yield per plot, and thousand-kernel weight. The highest interaction means were observed in the NK 6232 variety at the NPK fertilizer rate of 300 kg ha^{-1}, including plant height (200.07 cm), stem diameter (4.44 cm), ear length (17.18 cm), ear diameter (55.00 mm), dry grain yield per plot (9.65 kg), and thousand-kernel weight (311.7 g). The shortest harvest age as recorded in the Pioneer 32 variety at the NPK fertilizer rate of 250 kg ha^{-1} (95.33 days).
4. Based on the results and discussion, it can be concluded that the growth and yield responses of hybrid maize varieties to NPK fertilizer application have important implications for maize fertilizer-use efficiency. Efficiency in this study is determined not only by high yield levels, but also by the ability of plants to achieve optimal growth and production using fertilizer inputs in a rational and efficient manner (as reflected by PFP and MP indicators).
5. From a farm-efficiency (economic) perspective, the most appropriate recommendation is not based on maximum yield alone, but on the cost-effectiveness of additional fertilizer inputs. The fertilizer-use efficiency patterns (PFP and MP) indicate that yield gains can diminish at higher NPK rates, suggesting that moderate fertilizer rates (e.g., 200–250 kg ha^{-1})—especially when paired with a high-performing variety such as NK 6232—may provide a more efficient balance between productivity and input use.

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