

Effects of Nitrogen Rates on Yield and Yield Components of Low-Nitrogen-Tolerant Maize (*Zea mays* L.) Varieties

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Abstract

Maize (*Zea mays* L.) is an important cereal crop in sub-Saharan Africa whose productivity is strongly influenced by nitrogen (N) availability. However, the high cost and limited accessibility of nitrogen fertilizers among smallholder farmers necessitate the identification of maize varieties capable of producing reasonable yields under reduced nitrogen input. This study evaluated the effects of different nitrogen rates on the yield and yield components of low-nitrogen-tolerant maize varieties. Six maize varieties (M0926-6, M0926-9, M1026-10, OBA 98, SUWAN-1-SX, and OBA SUPER 2) were evaluated during the 2012 cropping season at two locations: the Teaching and Research Farm of the Institute of Food Security, Environmental Resources and Agricultural Research, Federal University of Agriculture, Abeokuta (Opeji), and MATKIS Farm, Eruwa, Oyo State, Nigeria. Four nitrogen fertilizer rates (0, 15, 30, and 45 kg N ha⁻¹) were applied using urea. The experiment consisted of a factorial combination of variety × nitrogen rate × location (6 × 4 × 2) arranged in a randomized complete block design with three replicates. Data were collected on cob yield, grain yield, 100-grain weight, stover yield, and harvest index. The results showed that location significantly influenced most yield parameters, with higher cob yield (2599 kg ha⁻¹), grain yield (1348 kg ha⁻¹), and 100-grain weight (15.74 g) recorded at Opeji compared with Eruwa. Interaction effects of nitrogen rate, variety, and location significantly affected cob and grain yield. The highest cob yield (2239 kg ha⁻¹) and grain yield (1901 kg ha⁻¹) were obtained with the application of 30 kg N ha⁻¹ to variety M1026-10 at Opeji, while the highest grain yield at Eruwa (1490 kg ha⁻¹) was recorded with application of 30 kg N ha⁻¹ to M0926-9. The results indicate that moderate nitrogen application combined with suitable maize varieties can enhance yield and yield components under low-nitrogen conditions.

Keywords: Nitrogen Rates, Maize Yield, Yield Components, Low-Nitrogen Tolerance, Smallholder Farming, Sub-Saharan Africa.

Introduction

Maize (*Zea mays* L.) is a staple cereal crop in sub-Saharan Africa, playing a central role in food security and rural livelihoods. Despite occupying a large proportion of cultivated land in Nigeria, national maize yields remain low, averaging about 2–3 t ha⁻¹, which is far below the global average of 6–8 t ha⁻¹ (Badu-Apraku et al., 2023; Tofa et al., 2025; FAO, 2023). This yield gap has been attributed to several factors, including declining soil fertility, low fertilizer use, erratic rainfall, poor agronomic practices, and biotic stresses such as pests,

diseases, and parasitic weeds like *Striga hermonthica* (Badu-Apraku et al., 2023; Tofa et al., 2022).

Among essential nutrients, nitrogen (N) is the most limiting element for maize production in the savanna agro-ecological zones of Nigeria due to inherently low soil organic matter and nutrient reserves (Tofa et al., 2022; Beah et al., 2021). Continuous cropping and the removal of crop residues without adequate nutrient replenishment further exacerbate soil nutrient depletion, leading to significant nitrogen losses estimated to range widely in smallholder systems across the region (Tofa et al., 2022; Bougma et al., 2025). These nutrient deficits reduce soil fertility and crop productivity over time, particularly among smallholder farmers who often operate under limited resource conditions and cannot afford optimal fertilizer use, improved crop management, or mechanized weed control (Leitner et al., 2020; Sheahan & Barrett, 2017). As a result, maize yields remain relatively low, reinforcing the persistent yield gap.

Nitrogen fertilization is widely recognized as one of the most effective strategies for improving maize productivity, as nitrogen plays a key role in vegetative growth, chlorophyll synthesis, photosynthesis, and grain formation. Recommended nitrogen application rates in the moist and Guinea savanna agro-ecological zones of West Africa typically range between 60 and 120 kg N ha⁻¹, depending on soil fertility status, climatic conditions, and management practices (Tofa et al., 2022; Abdul-Aziz et al., 2025). Numerous studies have demonstrated that nitrogen application within this range significantly enhances maize growth and yield, highlighting the need for site-specific nitrogen management to optimize productivity while minimizing environmental losses.

Maize is well known for its strong response to nitrogen fertilization, with yield improvements commonly observed at application rates between 30 and 50 kg N ha⁻¹ under smallholder farming conditions. Several field studies have reported yield increases ranging from 6% to over 100% following nitrogen fertilizer application. Nevertheless, many farmers remain hesitant to apply nitrogen fertilizers due to their high cost and the potential risk of crop failure under rain-fed conditions (Liverpool-Tasie et al., 2025; Essel et al., 2020).

Therefore, the development and evaluation of maize cultivars capable of producing reasonable yields under low nitrogen conditions is essential for achieving sustainable increases in maize productivity in low-input farming systems.

The varieties evaluated in this study are still relevant in smallholder farming today to improve agricultural sustainability. Maize generally are high nitrogen consuming crops and is one of the major staple foods in the world. The experiment aimed at reducing nitrogen fertilizer application while obtaining maximum yield. This is still relevant till today.

Objective

The objective of the study is to evaluate the effects of different nitrogen rates on yield and yield components of low-nitrogen-tolerant maize varieties.

Materials and Methods

Study area:

The experiments were conducted at the Teaching and Research Farm of Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR), Federal University of Agriculture, Abeokuta (FUNAAB) and MATKIS Farm Lanlate, Oyo State. IFSERAR is in a rainforest/transition zone while MATKIS is in a rainforest zone of Nigeria. At both sites, the experiments were laid out on a degraded soil. South – West is characterized by bimodal rainfall pattern with a long rainy season which usually starts in late March while the short rainy season extends from September to early November after a short dry spell in August.

Land Preparation

Conventional tillage operations which include ploughing and harrowing were carried out to conserve the soil and its nutrient availability.

Field layout

The experiments were laid out in a Randomized Completely Block Design. The experiments were replicated three times with total land area of 14m by 83.5m (1169 m²). Each plot size was 4m by 3m (12 m²). Inter-row spacing was 0.75m while intra-row spacing was 0.25m.

Treatments

Maize varieties used for the experiment were Mo926-6, Mo926-9, M1026-10, OBA 98, SUWAN-1-SX and OBA SUPER 2 (hybrid). The first four varieties were sourced from the International Institute of Tropical Agriculture (IITA), while the remaining two (SUWAN-1-SX and OBA SUPER 2) were sourced from the Ogun State Agro-service Centre.

Fertilizer

Four nitrogen levels in the form of urea were used (0, 15, 30 and 45 kg N/ha). The rates were arrived at based on soil test and recommended rates as indicated in the Manual of Soil Fertility Assessment edited by Association of Nigeria Soil Scientists (2004).

Pre-planting soil analysis

SCode	N%	Pppm	Kcmol
Eruwa	1.02	39.42	0.50
Opeji	1.29	46.66	0.55

The reason for the 13-year gap before the publication is that the project was not presented for publication previously and the fact that I have not been in the teaching line previously, so I was not enlightened on the importance of paper publication.

Data Collection

Stand count:

Stand count was determined at three weeks after planting (3 WAP) by counting the number of plants that emerged per plot and expressing it as a percentage of the total number of plants expected. $\text{Percentage emergence} = \frac{\text{Total number of plants expected}}{\text{Number of plants emerged per plot}} \times 100$

Plant height (cm):

Plant height was measured from five plants randomly selected from the net plot (2 m × 3 m) at two-week intervals until maturity. The height of each plant was measured from the ground surface to the tip of the longest leaf using a measuring tape, and the mean value was recorded.

Number of leaves per plant:

The number of leaves per plant was determined from five randomly selected plants in the net plot at two-week intervals until maturity. Leaves were counted manually, and the mean number of leaves per plant was calculated.

Leaf Area Index (LAI):

Leaf area index was determined at the flag leaf stage. Leaf length (from the base to the tip) and maximum leaf width were measured for all leaves on five sampled plants. Leaf area was estimated using the formula:

$$\text{Leaf area} = \text{Leaf length} \times \text{Leaf width} \times 0.75$$

Total leaf area per plant was obtained by summing the leaf areas of all leaves. Leaf Area Index was calculated as:

$$\text{LAI} = \frac{\text{Total leaf area}}{\text{Land area}}$$

Days to 50% tasseling:

This was determined as the number of days from planting to the date when 50% of the plants in the net plot had produced tassels.

Days to 50% anthesis:

This was recorded as the number of days from planting to the date when 50% of the plants in the net plot began shedding pollen.

Days to 50% silking:

This was determined as the number of days from planting to the date when 50% of the plants in the net plot had emerged silks.

Anthesis–Silking Interval (ASI):

Anthesis–silking interval was calculated as the difference between the number of days to 50% silking and the number of days to 50% anthesis.

$$\text{ASI} = \text{Days to 50\% silking} - \text{Days to 50\% anthesis}$$

Stem diameter (mm):

Stem diameter was measured at maturity from five randomly selected plants in the net plot using a vernier caliper. Measurements were taken immediately below the point of ear attachment, and the mean value was recorded.

Stover yield (kg ha⁻¹):

Stover yield was determined by harvesting five randomly selected plants at maturity after removing the dehusked cobs. The remaining plant material was oven-dried to a constant weight and expressed as grams per square meter.

Cob yield per plot (kg ha⁻¹):

Cob yield was determined by weighing the total number of cobs harvested from each plot and converting the value to kilograms per hectare.

Grain yield (kg ha⁻¹):

Grain yield was determined by weighing the dried grains obtained from each experimental plot and converting the value to kilograms per hectare.

Hundred-grain weight (g):

One hundred grains were randomly counted from a grain sample obtained from five plants within the net plot and weighed using a precision balance.

Harvest index (%):

Harvest index was calculated as the ratio of grain yield to total above-ground biomass obtained from five sampled plants and expressed as a percentage.

$$\text{HI} = \frac{\text{Grain yield}}{\text{Total above-ground biomass}} \times 100$$

Results and Discussion

Growth Traits

Leaf Area Index

Leaf area index (LAI) was not significantly influenced by nitrogen fertilizer rates or maize variety across the sampling periods (Table 1). However, location significantly ($p \leq 0.05$) affected LAI at 4, 8, and 12 weeks after planting (WAP). At both locations, LAI increased progressively with crop age, reaching maximum values at 12 WAP. The highest LAI values were recorded at Opeji (0.2014) and Eruwa (0.1236) at 12 WAP.

The significant effect of location on LAI suggests that environmental conditions such as soil fertility status, rainfall distribution, and microclimatic factors may have influenced canopy development. Higher LAI observed at Opeji may be attributed to relatively better soil fertility and moisture availability, which enhanced vegetative growth and leaf expansion. Previous studies have reported that environmental factors and soil nutrient availability strongly influence canopy development and leaf area formation in maize (Vanlauwe et al., 2020; Bationo et al., 2021).

Nitrogen fertilizer rates also had no significant effect on the number of leaves per plant at 4, 8, and 12 WAP (Table 1). However, maize variety significantly ($p \leq 0.05$) influenced the number of leaves per plant at 4 WAP. Variety Mo926-9 produced the highest number of leaves (7.63), followed by M1026-10 and SUWAN-1-SX with 7.50 and 7.46 leaves per plant, respectively, while OBA SUPER 2 recorded the lowest number of leaves (6.88). These differences among varieties may be attributed to inherent genetic variations in vegetative growth characteristics.

Location also significantly ($p \leq 0.05$) affected the number of leaves per plant at 4, 8, and 12 WAP. Opeji recorded significantly higher numbers of leaves (9.03, 12.69, and 14.18) compared with Eruwa, which produced 5.51, 9.01, and 9.13 leaves per plant at 4, 8, and 12 WAP, respectively. The superior vegetative growth observed at Opeji further highlights the influence of environmental conditions on maize growth and development. Similar findings have been reported by Ciampitti and Vyn (2012), who noted that leaf development and canopy structure in maize are strongly influenced by environmental conditions and nutrient availability.

Table 1. Effects of nitrogen rates, variety and location on number of leaves and leaf area index of low-nitrogen-tolerant maize

Factor	Number of leaves @ 4WAP	Number of leaves @ 8WAP	Number of leaves @ 12 WAP	Leaf area index (4 WAP)	Leaf area index (8 WAP)	Leaf area index (12 WAP)
Nitrogen (kg N ha⁻¹)						
0	7.06	10.19	11.02	0.100	0.111	0.134
15	7.22	10.92	11.61	0.116	0.144	0.153
30	7.19	10.67	11.42	0.126	0.122	0.164
45	7.31	10.94	11.69	0.136	0.134	0.169
SED± (p ≤ 0.05)	ns	ns	ns	Ns	ns	ns
Variety						
Mo926-6	7.00	10.67	11.38	0.110	0.117	0.154
Mo926-9	7.63	10.83	11.79	0.113	0.142	0.167
M1026-10	7.50	11.21	11.88	0.112	0.146	0.167
OBA 98	7.17	10.83	11.58	0.112	0.125	0.154

Factor	Number of leaves @ 4WAP	Number of leaves @ 8WAP	Number of leaves @ 12 WAP	Leaf area index (4 WAP)	Leaf area index (8 WAP)	Leaf area index (12 WAP)
SUWAN-1-SX	7.46	10.83	11.63	0.133	0.138	0.167
OBA SUPER 2	6.88	10.75	11.71	0.103	0.130	0.167
SED± (p ≤ 0.05)	0.256*	ns	ns	Ns	Ns	Ns
Location						
Opeji	9.03	12.69	14.18	0.104	0.153	0.201
Eruwa	5.51	9.01	9.14	0.124	0.113	0.124
SED± (p ≤ 0.05)	0.148**	0.249**	0.171**	0.00703**	0.00709**	0.0082**

Notes:

- WAP = Weeks After Planting
- ns = Not significant at $p \leq 0.05$
- *Significant at $p \leq 0.05$
- **Significant at $p \leq 0.01$

Phenological Traits

Days to 50% Tasseling

The number of days to 50% tasseling was significantly ($p \leq 0.05$) influenced by location (Table 2). Maize varieties planted at Eruwa reached 50% tasseling at 56.10 days after planting (DAP), which was later than those planted at Opeji, where tasseling occurred at 52.06 DAP. The delayed tasseling observed at Eruwa may be attributed to differences in environmental conditions such as soil nutrient status and climatic factors, which can influence crop developmental rates.

Days to 50% Anthesis

Similarly, location significantly ($p \leq 0.05$) affected the number of days to 50% anthesis (Table 2). At Opeji, maize varieties attained 50% anthesis earlier (54.13 DAP) than those planted at Eruwa (58.14 DAP). Among the varieties evaluated, Mog26-6 and SUWAN-1-SX attained 50% anthesis earlier (56.04 DAP) compared with the other varieties. Earliness in anthesis is often considered an important adaptive trait for maize grown under variable environmental conditions, as it may reduce exposure to late-season stress.

Days to 50% Silking

The number of days to 50% silking was also significantly ($p \leq 0.05$) influenced by location. Maize varieties planted at Opeji attained 50% silking earlier (57.08 DAP) compared with those planted at Eruwa, which reached 50% silking at 60.22 DAP. Differences in silking time

among locations may be attributed to variations in environmental conditions such as temperature, soil fertility, and moisture availability. Similar observations have been reported by Hirel et al. (2021), who noted that environmental factors significantly influence reproductive development in maize.

Anthesis–Silking Interval (ASI)

Location also had a significant ($p \leq 0.05$) effect on the anthesis–silking interval (ASI). The ASI observed for maize varieties grown at Eruwa (2.08 days) was shorter than that recorded for varieties grown at Opeji (2.94 days). The anthesis–silking interval is an important indicator of reproductive synchrony and stress tolerance in maize. Shorter ASI is generally associated with better pollination efficiency and improved grain set under stress conditions (Bänziger et al., 2020).

Table 2. Effects of nitrogen rates, variety, and location on number of days to 50% tasseling, 50% anthesis, 50% silking, and anthesis–silking interval of low-nitrogen-tolerant maize

Factor	Days to 50% tasseling (DAP)	Days to 50% anthesis (DAP)	Days to 50% silking (DAP)	Anthesis–silking interval (days)
Nitrogen (kg N ha⁻¹)				
0	54.06	56.14	58.67	2.56
15	54.11	56.11	58.64	2.50
30	54.06	56.11	58.59	2.53
45	54.08	56.17	58.72	2.47
SED± (p ≤ 0.05)	Ns	ns	Ns	Ns
Variety				
M0926-6	54.00	56.04	58.54	2.54
M0926-9	54.13	56.18	58.67	2.54
M1026-10	54.08	56.13	58.71	2.50
OBA 98	54.08	56.17	58.63	2.50
SUWAN-1-SX	54.04	56.04	58.63	2.58
OBA SUPER 2	54.13	56.25	58.75	2.42
SED± (p ≤ 0.05)	Ns	ns	Ns	Ns
Location				
Opeji	52.06	54.13	57.08	2.94
Eruwa	56.10	58.14	60.22	2.08
SED± (p ≤ 0.05)	0.048**	0.069**	0.082**	0.040**

DAP = Days After Planting

ns = Not significant at $p \leq 0.05$

** = Highly significant at $p \leq 0.01$

Means with the same letters within a column are not significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test

Interaction Effects

The interaction of nitrogen rate $\times$ variety $\times$ location significantly ($p \leq 0.05$) influenced the number of days to 50% anthesis (Table 3). At Opeji, the application of 45 kg N ha⁻¹ to variety OBA SUPER 2 resulted in earlier attainment of anthesis (54.00 DAP) compared with other varieties. In contrast, the application of the same nitrogen rate to OBA SUPER 2 at Eruwa delayed the attainment of 50% anthesis to 59.33 DAP. This interaction suggests that the response of maize varieties to nitrogen fertilization may vary depending on environmental conditions. Similar genotype $\times$ environment $\times$ nutrient interactions have been reported in maize production systems, where nitrogen availability and environmental conditions jointly influence crop growth and developmental patterns (Mueller et al., 2023).

Table 3. Interaction of nitrogen rates $\times$ variety $\times$ location on days to 50% anthesis of low-nitrogen-tolerant maize

Location / Nitrogen (kg N ha ⁻¹)	Mog26-6	Mog26-9	M1026-10	OBA 98	SUWAN-1-SX	OBA SUPER 2
Opeji						
0	54.33 c	54.00 c	54.33 c	54.00 c	54.00 c	54.00 c
15	54.00 c	54.00 c	54.67 c	54.00 c	54.00 c	54.33 c
30	54.00 c	54.67 c	54.00 c	54.00 c	54.00 c	54.33 c
45	54.00 c	54.00 c	54.00 c	54.33 c	54.00 c	54.00 c
Eruwa						
0	58.00 b	58.33 b	58.00 b	58.67 ab	58.00 b	58.00 b
15	58.00 b	58.00 b	58.00 b	58.33 b	58.00 b	58.00 b
30	58.00 b	58.00 b	58.00 b	58.00 b	58.33 b	58.00 b
45	58.00 b	58.33 b	58.00 b	58.00 b	58.00 b	59.33 a
SED $\pm$ ($p \leq 0.05$)	0.337*					

Notes:

- Means within the same column followed by the same letter are not significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test.
- *Significant at $p \leq 0.05$

Effect of Nitrogen Rate, Variety, and Location on Yield and Yield Components of Low-Nitrogen Tolerant Maize Varieties

Cob Yield (kg ha⁻¹):

As shown in Table 4, only location had a significant ($p \leq 0.05$) effect on cob yield. The highest cob yield of 2599 kg ha⁻¹ was recorded at Opeji, while Eruwa recorded a lower cob yield of 1475 kg ha⁻¹.

The interaction of fertilizer rate $\times$ variety $\times$ location had a highly significant ($p \leq 0.05$) effect on maize cob yield. Application of 30 kg N ha⁻¹ to M1026-10 at Opeji produced the highest cob yield of 2239 kg ha⁻¹ (Table 5) compared to other fertilizer rates at both locations. At Eruwa, application of 30 kg N ha⁻¹ to Mog26-9 produced the highest cob yield of 1136 kg ha⁻¹.

One Hundred Grain Weight:

Location had a highly significant ($p \leq 0.05$) effect on one hundred grain weight. Maize harvested at Opeji had a higher one hundred grain weight (15.74 g) compared to maize harvested at Eruwa (12.65 g) (Table 5).

Stover Yield (kg ha^{-1}):

Location also had a highly significant ($p \leq 0.05$) effect on stover yield. Opeji recorded the highest stover yield of 59.4 kg ha^{-1} , while Eruwa recorded 24.5 kg ha^{-1} . Fertilizer rates and variety types did not significantly ($p \leq 0.05$) affect stover yield; however, application of 45 kg N ha^{-1} produced the highest stover yield of 45.6 kg ha^{-1} . Among the varieties, OBA 98 produced the highest stover yield of 44.2 kg ha^{-1} , while OBA SUPER 2 produced the lowest at 39.6 kg ha^{-1} .

Harvest Index:

Location had a highly significant ($p \leq 0.05$) effect on the harvest index of the low-nitrogen tolerant maize. Varieties planted at Opeji attained a higher harvest index value (0.769) compared to those planted at Eruwa (0.487). Variety and application of fertilizer at different rates did not have a significant effect on the harvest index.

Grain Yield (Kg ha^{-1})

Likewise, location had a highly significant ($p \leq 0.05$) effect on grain yield. Grain yield at Eruwa were relatively lower (1258.00) than that observed at Opeji (1348.00). this could be attributed to low soil fertility, reduced organic matter, and lower nutrient retention capacity observed at Eruwa.

Table 4: Effects of Nitrogen Rates, Variety, and Location on Yield and Yield Components of Low-Nitrogen Tolerant Maize

Treatment	Cob Yield (kg ha^{-1})	Grain Yield (kg ha^{-1})	100-Grain Weight (g)	Stover Yield (kg ha^{-1})	Harvest Index
Nitrogen (kg N ha^{-1})					
0	1118.00	831.00	14.54	41.60	0.332
15	1025.00	833.00	13.89	36.80	0.410
30	1009.00	774.00	14.57	43.70	0.501
45	996.00	772.00	13.79	45.60	0.502
SED $\pm$ ($p < 0.05$)	ns	Ns	Ns	Ns	Ns
Variety					
Mog26-6	989.00	782.00	14.02	39.70	0.425
Mog26-9	1137.00	855.00	13.69	43.70	0.521
M1026-10	1164.00	894.00	14.40	41.10	0.625
OBA 98	1069.00	826.00	14.57	44.20	0.243
SUWAN-1-SX	913.00	703.00	14.28	43.20	0.451
OBA SUPER 2	950.00	757.00	14.23	39.60	0.532
SED $\pm$ ($p < 0.05$)	ns	Ns	Ns	Ns	Ns
Location					

Treatment	Cob Yield (kg ha ⁻¹)	Grain Yield (kg ha ⁻¹)	100-Grain Weight (g)	Stover Yield (kg ha ⁻¹)	Harvest Index
Opeji	2599.00a	1348.00a	15.74a	59.40a	0.769a
Eruwa	1475.00b	1258.00b	12.65b	24.50b	0.487b
SED ± (p < 0.05)	81.10**	67.50**	0.502**	3.33**	0.080**

Means with the same letters within a column are not significantly different at $p < 0.05$ (Duncan Multiple Range Test). ns – not significant;

** – highly significant.

Interactions of fertilizer rate × variety × location had a highly significant ($p \leq 0.05$) effect on stover yield. At Opeji, application of 30 kg N ha⁻¹ to M1026-10 produced the highest stover yield of 70.0 kg ha⁻¹, while at Eruwa, the highest stover yield of 52.0 kg ha⁻¹ was obtained with application of 30 kg N ha⁻¹ to Mog26-9 (Table 6).

Similarly, interactions of fertilizer rate × variety × location had a highly significant ($p \leq 0.05$) effect on harvest index. At Opeji, application of 30 kg N ha⁻¹ to M1026-10 produced the highest harvest index of 0.82, whereas at Eruwa, the highest harvest index of 0.62 was obtained with application of 30 kg N ha⁻¹ to Mog26-9 (Table 6).

Table 5: Interaction of Nitrogen Rates × Variety × Location on Cob Yield of Low-Nitrogen Tolerant Maize (kg ha⁻¹)

Opeji

Nitrogen Rate (kg N ha ⁻¹)	Mog26-6	Mog26-9	M1026-10	OBA 98	SUWAN-1-SX	OBA SUPER 2
0	1357.00a-g	1817.00a-d	1524.00a-f	1526.00a-f	1380.00a-g	2132.00ab
15	1916.00a-d	1588.00a-e	1694.00a-d	1864.00a-d	2103.00a-c	1095.00d-k
30	678.00e-k	1321.00a-i	2239.00a	1723.00a-d	1268.00a-j	1926.00a-d
45	1702.00a-d	1752.00a-d	1392.00a-g	1840.00b-k	1205.00a-k	1332.00a-h

Eruwa

Nitrogen Rate (kg N ha ⁻¹)	Mog26-6	Mog26-9	M1026-10	OBA 98	SUWAN-1-SX	OBA SUPER 2
0	1053.00d-k	310.00jk	1269.00a-j	383.00h-k	363.00i-k	298.00jk
15	309.00jk	616.00f-k	340.00jk	228.00k	328.00jk	221.00k
30	445.00g-k	1136.00c-k	267.00k	435.00g-k	359.00i-k	307.00jk
45	451.00g-k	553.00g-k	586.00f-k	557.00g-k	294.00jk	288.00jk

*SED ($p \leq 0.05$): 789.2

Means with the same letters within a column are not significantly different at $p \leq 0.05$ (Duncan Multiple Range Test).

ns = not significant; * = significant.

Grain Yield (kg ha⁻¹):

Interactions of fertilizer rate × variety × location were highly significant ($p \leq 0.05$) on grain yield. Generally, maize varieties planted at Opeji produced higher grain yields compared to

the same varieties planted at Eruwa. At Opeji, application of 30 kg N ha⁻¹ to M1026-10 produced the highest grain yield of 1901 kg ha⁻¹, while at Eruwa, the highest grain yield of 1490 kg ha⁻¹ was obtained with application of 30 kg N ha⁻¹ to Mog26-9 (Table 7).

Table 6: Interaction of Nitrogen Rates × Variety × Location on Grain Yield of Low-Nitrogen Tolerant Maize (kg ha⁻¹)

Opeji

Nitrogen Rate (kg N ha ⁻¹)	Mog26-6	Mog26-9	M1026-10	OBA 98	SUWAN-1-SX	OBA SUPER 2
0	1076.00b-h	1520.00a-e	1164.00a-g	1202.00a-f	1143.00a-g	1782.00a-c
15	1692.00a-d	1361.00a-e	1443.00a-e	1583.00a-e	1847.00ab	899.00d-j
30	841.00e-j	1025.00c-i	1901.00a	1428.00a-e	1056.00b-h	1627.00a-e
45	1472.00a-e	1514.00a-e	1171.00a-g	1579.00a-e	923.00d-j	1106.00a-g

Eruwa

Nitrogen Rate (kg N ha ⁻¹)	Mog26-6	Mog26-9	M1026-10	OBA 98	SUWAN-1-SX	OBA SUPER 2
0	559.00f-j	127.00j	821.00e-j	218.00j	196.00j	168.00j
15	137.00j	425.00f-j	211.00j	142.00j	122.00j	138.00j
30	217.00j	1490.00f-j	144.00j	207.00j	178.00j	180.00j
45	259.00j	380.00f-j	299.00h-j	250.00ij	156.00j	157.00j

*SED ($p \leq 0.05$): 330.7

Means with the same letters within a column are not significantly different at $p \leq 0.05$ (Duncan Multiple Range Test).

ns = not significant; * = significant.

Conclusion

The findings of this study indicate that low-nitrogen tolerant maize varieties can achieve relatively high yield and yield components under reduced nitrogen inputs. Although the highest yields were not necessarily observed at the highest N rates, the significant interaction effects between fertilizer rate, variety, and location suggest that variety-specific responses to nitrogen must be considered when making recommendations. This outcome aligns with evidence that maize yield responses to N fertilization exhibit an initial increase followed by stabilization or decrease beyond an optimal rate, and that nitrogen use efficiency varies among genotypes and environments.

Excessive nitrogen application, while capable of increasing biomass, can reduce nitrogen remobilization efficiency and harvest index, potentially diminishing returns on yield and increasing environmental risk, as shown in long-term cropping systems research. Therefore, an optimal, rather than maximal nitrogen application approach is advisable, emphasizing efficient utilization over quantity.

Recommendations:

1. **Location-Specific N Management:** Nitrogen fertilizer recommendations should be tailored to local soil fertility status and maize genotypes, since significant location $\times$ variety $\times$ rate interactions impact both yield and yield components. Precision management will improve both yield and nitrogen use efficiency (NUE).
2. **Optimal N Rates Over Maximum Rates:** Rather than applying universally high nitrogen rates, identify an economically and environmentally optimal nitrogen rate for each variety and agroecological zone. Long-term research suggests that moderate N rates can achieve high yields with better NUE and reduced environmental loss (Zhang et al., 2025).
3. **Breeding and Selection:** Continue breeding and selection for low-N tolerant varieties with high nitrogen recovery efficiency, as these hybrids often maintain yield with reduced N input and sustain protein content under low N conditions.
4. **Integrated Soil Fertility Management:** Integrate organic amendments and biologicals (e.g., inoculants or biological preparations) to enhance soil N availability and plant N uptake, which can reduce the need for high inorganic N inputs and improve sustainability.
5. Adopting an integrated, data-driven nitrogen management strategy that considers genotype, environment, and targeted N inputs can improve maize production sustainability while minimizing input costs and environmental impacts.

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