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RESEARCH ARTICLE

Effect of nitrogen fertilizer on the growth and yield of maize (*Zea mays* L.) under different cropping seasons in Abraka

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ABSTRACT

Maize (*Zea mays* L.) is an important staple in the tropics and subtropics, and has shown low productivity over the years in the tropics. This study evaluated the effect of nitrogen fertilizer on the growth and yield of maize. The experiment was carried out at the Research Farm of the Faculty of Agriculture, Delta State University, Abraka, Nigeria. The experiment consists of five nitrogen levels (0, 40, 80, 120, and 160) and two planting seasons, early (May-August) and late (August–November), with Urea (46% N) as the Nitrogen source. It was arranged in a Randomized Complete Block Design (RCBD) with three replicates. Vegetative, yield, and yield components variables were collected and analysed using ANOVA, and means were separated using Least Significant Differences at 5% significance level. At 12 Weeks After Planting (WAP), the plant height and number of leaves varied significantly amongst the treatments and ranged from 20.14cm (0kg/ha) to 100.64 cm (160kg/ha), 20.58cm (0 kg/ha) to 112.72cm (160 kg/ha), 9.77(0 kg/ha) to 13.11 (160kg/ha), 10.22 (0 kg/ha) to 13.55 (160 kg/ha) for early and late planting seasons respectively. The 100-grain yield also varied significantly amongst the treatments and ranged from 25.02 g (0 kg/ha) to 30.67 g (120 kg/ha) in the early planting season, and from 23.64 g (0 kg/ha) to 28.31 g (120 kg/ha) in the late planting season. At treatment 120 kgha-1, the maize crop performed optimally during the reproductive, yield, and yield components stages, respectively, compared to other treatments used during the planting seasons.

Keywords: agronomy efficiency, maize, nitrogen fertilizer, vegetative growth, yield; yield parameters

INTRODUCTION

Maize (*Zea mays* L.) is a staple crop and a major food source across diverse regions, particularly in Africa, Latin America, and parts of Asia, where it contributes significantly to food security and agricultural economies (Rajangam et al., 2024). It serves multiple purposes, including direct human consumption, animal feed, and industrial applications such as starch production and biofuel generation. Despite its widespread cultivation in Nigeria, the country continues to face challenges in meeting both domestic and international demand due to persistently low production outputs. Factors such as agro-climatic stress, limited access to inputs, and regional insecurity have contributed to this shortfall (Adebayo, & Olayemi et al., 2022). Nigeria experienced a 14.46% decline in maize production compared to the previous year, underscoring the need for strategic interventions to enhance productivity and resilience in the maize value chain. Figure 1 below illustrates the maize production trend in Nigeria from 2013 to 2023 (FAO, 2023).

One of the principal factors contributing to the recent decline in maize productivity in Nigeria is the influence of agroclimatic stressors on soil health. Soils in the savannah and rainforest regions are frequently depleted of essential nutrients—particularly nitrogen—and exhibit deficiencies in organic matter and imbalanced pH levels, which are critical for optimal maize growth (Yusuf, 2012). These challenges are exacerbated by poor soil management practices, leading to reduced fertility and compromised crop performance.

Nitrogen is a vital macronutrient that significantly influences vegetative growth, chlorophyll synthesis, leaf development, and grain maturation in maize (Omotoso, 2015). Among nitrogen sources, urea fertilizer is widely used due to its high nitrogen content (46%), making it one of the most efficient options for nutrient-deficient soils in Nigeria. However, recurrent issues of nutrient-poor soils and the indiscriminate application of nitrogen fertilizers have led to economic inefficiencies and environmental concerns (Adebayo, & Olayemi et al., 2022).

A meta-analysis conducted by Gotosa et al. (2019) in Zimbabwe evaluated maize responses to varying nitrogen application rates (<30, 30–100, and >100 kg N ha^{-1}). Their findings revealed that nitrogen fertilization significantly ($p < 0.001$) enhanced maize yields by 0.25 to 1.6 t ha^{-1} compared to control treatments, while also mitigating environmental pollution in maize-based systems. These insights underscore the importance of optimizing nitrogen use to balance productivity and sustainability. The objective of this study was to evaluate the effect of nitrogen fertilizer and seasonal variation on the vegetative growth and yield of maize, and to determine the agronomic efficiency of nitrogen fertilizer application under Nigerian field conditions.

MATERIALS AND METHODS

Experiment

This research was carried out at the Teaching and Research Farm of the Faculty of Agriculture, Delta State University, Abraka (Longitude 6 ° 6 ' 00" and 6° 6` 15" E and Latitude 5 47` 22" and 5° 47` 50"N of the Greenwich meridian). Abraka is located in the rainforest zone, with annual temperature, rainfall, and relative humidity of 25 ºC - 32 ºC, 1400 mm – 3000 mm, and 60% - 90% respectively. The existing vegetation was cleared manually at the experimental site. The soil was ploughed slightly to loosen it. The plot size was 27.43m × 18.28m, with a border space of 3m on both sides of the experimental site. Treated seeds were obtained from the Delta State Agriculture and Rural Development Agency (DARDA) research institute, Asaba.

The cultivar that was used for this experiment was Kapam-6, which is an early-maturing maize. Each of the fifteen (15) experimental units measured 4.5m × 3m. Inter-plot space in between each plot was 0.6m (60cm). Maize seeds were sown at a spacing of 90cm × 30cm. The treatments have five levels (0, 40, 80, 120, and 160). The experiment was conducted in the early planting season (May-August) and the late planting season (August-November). The source of nitrogen used was urea (46% N). The five (5) treatments were laid out in a randomized complete block design (RCBD), with three (3) replicates. Maize seeds were sown on flat ground. The seeds were planted at three per stand and later thinned to two per stand. Nitrogen fertilizers were applied in two equal splits three weeks after planting (vegetative stage) and six weeks after planting (silking stage). Regular weeding using a hoe (manual weeding) was done till the harvest period. During the experiment, morphological characteristics were collected from three (3) tagged maize plants within the middle row in each plot.

Data Collection and Analysis

Morphological characteristics were collected from three (3) tagged maize plants within the middle row in each plot. The following plant variables, such as plant height, number of leaves, leaf area, leaf area index, stem girth, number of cobs per plant, cob height, cob length, number of rows per cob, 100 grain weight, grain yield, and agronomic efficiency, were obtained for maize during the early and late planting seasons. Data collected were subjected to variance analysis using the statistical analysis system (SAS) program, and significant means were separated using the least significant difference at a 5% probability level.

RESULTS

The physicochemical properties of the experimental site

The physicochemical characteristics of the soil at the experimental site are summarized in Table 1. The soil exhibited a moderately acidic pH of 6.1, with an organic matter content of 20 g kg^{-1} and total nitrogen of 1.80 g kg^{-1}. Available phosphorus was measured at 14 mg kg^{-1}, while exchangeable potassium and cation exchange capacity (CEC) were 0.52 cmol kg^{-1} and 11.62 cmol kg^{-1}, respectively. Particle size analysis revealed a composition of 59% sand, 22% silt, and 19% clay, classifying the soil as sandy loam. These properties suggest a moderately fertile substrate suitable for maize cultivation, albeit with potential limitations in nutrient retention and buffering capacity.

Table 1. The physicochemical properties of the experimental site

Parameters	Values
Particle size distribution	
Sand (%)	59
Silt (%)	22
Clay (%)	19
Textural Class	Sandy loam
pH (H_2O)	6.1
Organic matter (gkg^{-1})	20.0
Total Nitrogen (gkg^{-1})	1.80
Available P (mg kg^{-1})	14.0
Exchangeable K (Cmol kg^{-1})	0.52
CEC (Cmol kg^{-1})	11.62

Effects of nitrogen on the plant height of maize for both cropping seasons

The statistical analysis presented in Table 2 indicates that nitrogen application levels significantly influenced plant height across both early and late cropping seasons throughout the growth period, except 2 weeks after planting (WAP) during the late season, where no significant differences were observed. At 4 WAP in the early cropping season, the highest mean plant height (12.57 cm) was recorded under the 160 kg N ha^{-1} treatment, followed by 11.85 cm and 11.28 cm for 120 kg N ha^{-1} and 80 kg N ha^{-1}, respectively. The lowest mean height (10.90 cm) was observed in plants treated with 40 kg N ha^{-1}. No statistically significant differences were found among the 0, 40, and 80 kg N ha^{-1} treatments; however, the 160 kg N ha^{-1} treatment differed significantly from all other levels. During the late cropping season, significant differences in plant height were observed among nitrogen treatments from 4 WAP to 12 WAP, and more distinctly from 6 WAP to 12 WAP. Notably, the mean plant heights recorded during the late season were consistently higher than those observed in the early season, suggesting a seasonal effect on vegetative growth response to nitrogen fertilization.

Effects of nitrogen fertilizer on the number of leaves per plant of maize for both cropping seasons.

The number of leaves per maize plant, as presented in Table 3, varied across nitrogen application rates and cropping seasons from 4 to 12 weeks after planting (WAP). At 4 WAP during the early cropping season, no significant difference was observed between the 160 kg N ha^{-1} and 120 kg N ha^{-1} treatments. A similar trend was noted at 6 WAP, where the leaf counts under 160 kg N ha^{-1} and 120 kg N ha^{-1} were statistically comparable.

However, a significant difference emerged between the 120 kg N ha^{-1} and 80 kg N ha^{-1} treatments at this stage. At 2 WAP, no significant differences were detected among treatments in either cropping season, although intra-treatment variation was evident during the late season. Across both seasons, the 160 kg N ha^{-1} treatment consistently produced the highest mean leaf counts at 4, 6, 8, 10, and 12 WAP. In the early season, the respective mean values were 5.66, 8.55, 11.00, 13.11, and 13.11 leaves per plant, while in the late season, they were slightly higher at 6.00, 8.77, 12.00, 13.55, and 13.55 leaves per plant. These results were followed in descending order by the 120 kg N ha^{-1} and 80 kg N ha^{-1} treatments. Notably, the cumulative leaf production across all weeks was greater in the late cropping season compared to the early season, with identical mean values recorded at 10 and 12 WAP.

Table 2. Effects of nitrogen on plant height (cm) of maize for both cropping seasons

Rate N(kgha^{-1})	Weeks after planting (WAP)					
	2	4	6	8	10	12
Early						
0	10.71^{a}	11.05^{bc}	12.14^{e}	15.55^{d}	19.95^{e}	20.14^{e}
40	10.11^{ab}	10.90^{bc}	13.17^{d}	27.46^{c}	30.34^{d}	30.52^{d}
80	9.79^{ab}	11.28^{bc}	16.15^{c}	30.33^{c}	38.72^{c}	39.01^{c}
120	10.20^{ab}	11. 85^{ab}	18.21^{b}	51.37^{b}	59.34^{b}	60.46^{b}
160	9.92^{ab}	12.57^{a}	19.15^{a}	97.48^{a}	100.45^{a}	100.64^{a}
Mean	10.15	11.53	15.76	44.44	49.76	50.15
LSD	0.87	0.90	0.20	5.44	3.22	3.09
Late						
0	12.88	13.75^{e}	16.05^{e}	18.57^{e}	20.32^{e}	20.58^{e}
40	13.13	14.68^{d}	17.23^{d}	36.20^{d}	39.00^{d}	39.30^{d}
80	13.05	16.00^{c}	18. 06^{c}	65.06^{c}	68.15^{c}	68.44^{c}
120	12.82	16.84^{b}	20.13^{b}	101.26^{b}	105.19^{b}	105.55^{b}
160	13.03	17.93^{a}	20.84^{a}	110.45^{a}	112.54^{a}	112.72^{a}
Mean	12.98	15.84	18.46	66.31	69.04	69.32
LSD	n.s	0.76	0.25	6.90	6.22	6.26

In each column, means with the same letter do not differ at 5% level of probability

Table 3. Effects of nitrogen fertilizer on the number of leaves per stand of maize for both cropping seasons

Rate N(kgha^{-1})	Weeks after planting (WAP)					
	2	4	6	8	10	12
Early						
0	2.00	3.44^{c}	5.88^{d}	8.33^{e}	9.77^{e}	9.77^{e}
40	2.00	4.22^{b}	7.33^{c}	9.33^{d}	10.44^{d}	10.44^{d}
80	2.00	4.44^{b}	7.66^{bc}	10.11^{c}	11.22^{c}	11.22^{c}
120	2.00	5.33^{a}	8.11^{ab}	10.55^{b}	12.55^{b}	12.55^{b}
160	2.00	5.66^{a}	8.55^{a}	11.00^{a}	13.11^{a}	13.11^{a}
Mean	2.00	4.62	7.51	9.86	11.42	11.42
LSD	n.s	0.54	0.54	0.35	0.44	0.44
Late						
0	2.21	3.64^{e}	6.77^{d}	9.11^{e}	10.22^{e}	10.22^{e}
40	2.10	4.22^{d}	7.55^{c}	10.00^{d}	11.22^{d}	11.22^{d}
80	2.21	5.00^{c}	8.00^{b}	10.66^{c}	12.22^{c}	12.22^{c}
120	2.22	5.55^{b}	8.55^{a}	11.11^{b}	13.11^{b}	13.11^{b}
160	2.11	6.00^{a}	8.77^{a}	12.00^{a}	13.55^{a}	13.55^{a}
Mean	1.73	4.88	7.93	10.58	12.06	12.06
LSD	n.s	0.22	0.31	0.35	0.35	0.35

In each column, means with same letter do not differ at 5% level of probability

Effect of Nitrogen Fertilizer on Stem Girth of Maize Across Cropping Seasons

The influence of nitrogen fertilizer on maize stem girth, as presented in Table 4, varied across treatments and cropping seasons. At 2 weeks after planting (WAP) during the early season, the highest mean stem girth (0.84 cm) was recorded under the 80 kg N ha^{-1} treatment, while the lowest (0.62 cm) was observed under 120 kg N ha^{-1}. However, statistical analysis revealed no significant differences among treatments at this stage. In the late cropping season at 2 WAP, the lowest mean stem girth (0.58 cm) was recorded under the 160 kg N ha^{-1} treatment, which differed significantly from the 120 kg N ha^{-1} treatment, although no significant differences were observed among the remaining treatments. At 4 WAP during the early season, no significant difference was found between the 160 kg N ha^{-1} and 120 kg N ha^{-1} treatments. However, both treatments differed significantly from the lower nitrogen levels. In contrast, the late cropping season at 4 WAP exhibited significant differences across all nitrogen treatments, indicating a stronger treatment effect under late-season conditions. The highest stem girth values at 4 WAP were recorded under the 160 kg N ha^{-1} treatment, with mean values of 2.43 cm and 2.52 cm for the early and late seasons, respectively. From 6 WAP to 12 WAP in both cropping seasons, significant differences were consistently observed among all nitrogen treatments. The 160 kg N ha^{-1} treatment maintained the highest stem girth values throughout this period, demonstrating its superior effect on vegetative growth under both seasonal conditions.

Table 4. Effects of nitrogen fertilizer on stem girth (cm) of maize for both cropping seasons

Rate N (kgha^{-1})	Weeks after planting (WAP)					
	2	4	6	8	10	12
Early						
0	0.67	1.66^{d}	2.14^{e}	3.85^{e}	5.53^{e}	5.71^{e}
40	0.71	1.94^{c}	2.55^{d}	4.47^{d}	6.48^{d}	6.72^{d}
80	0.84	2.11^{b}	3.02^{c}	5.09^{c}	8.10^{c}	8.35^{c}
120	0.62	2.36^{a}	3.53^{b}	5.91^{b}	8.93^{b}	9.22^{b}
160	0.77	2.43^{a}	3.79^{a}	6.31^{a}	9.31^{a}	9.85^{a}
Mean	0.72	2.10	3.01	5.13	7.67	7.97
LSD	n.s	0.13	0.16	0.21	0.22	0.31
Late						
0	1.00^{a}	1.73^{e}	2.16^{e}	4.16^{e}	6.29^{d}	6.37^{e}
40	0.83^{a}	2.01^{d}	2.70^{d}	5.32^{d}	7.09^{c}	7.37^{d}
80	1.00^{a}	2.21^{c}	3.17^{c}	6.37^{c}	8.12^{b}	8.31^{c}
120	0.82^{a}	2.40^{b}	3.60^{b}	7.32^{b}	9.24^{a}	9.71^{b}
160	0.58^{b}	2.52^{a}	3.89^{a}	7.88^{a}	9.53^{a}	10.19^{a}
Mean	0.85	2.17	3.10	6.21	8.05	8.39
LSD	0.24	0.08	0.17	0.21	0.42	0.36

In each column, means with same letter do not differ at 5% level of probability

Effect of nitrogen fertilizer on leaf area of maize across cropping seasons

The mean leaf area values presented in Table 5 indicate that maize plants grown during the late cropping season consistently exhibited higher leaf area measurements than those in the early season across all observed weeks (2, 4, 6, 8, 10, and 12 WAP). Significant differences among nitrogen treatments were observed from 4 WAP to 12 WAP during the late season. In contrast, during the early cropping season, significant differences were recorded from 6 WAP onward. At 4 WAP, the 160 kg N ha^{-1} and 120 kg N ha^{-1} treatments did not differ significantly from each other, although both were significantly higher than the remaining treatments. The lowest leaf area values across both seasons were consistently recorded under the 0 kg N ha^{-1} treatment. For the early season, the mean values were 72.75 cm^2, 87.79 cm^2, 123.08 cm^2, 153.68 cm^2, 153.68 cm^2, and 177.76 cm^2 from 2 to 12 WAP, respectively. In the late season, corresponding values were 84.00 cm^2, 90.14 cm^2, 129.59 cm^2, 196.19 cm^2, 277.78 cm^2, and 277.78 cm^2. Conversely, the highest leaf area values were consistently recorded under the 160 kg N ha^{-1} treatment in both seasons, as detailed in the table. Similar to the trend observed in leaf number, the leaf area values at 10 WAP and 12 WAP remained unchanged, indicating a plateau in leaf expansion during the latter growth stages.

Table 5. Effects of nitrogen fertilizer on leaf area (cm^2) of maize for both cropping seasons

Rate N($kgha^{-1}$)	Week after planting (WAP)					
	2	4	6	8	10	12
Early						
0	72.75ab	87.79d	123.08e	153.68e	177.76e	177.76e
40	81.17ab	133.24c	206.43d	252.82d	313.99d	313.99d
80	88.58a	222.35b	476.95c	501.80c	687.67c	687.67c
120	84.08a	260.89a	500.42b	751.74b	1013.53b	1013.53b
160	83.75ab	267.96a	596.65a	814.93a	1215.22a	1215.22a
Mean	82.07	194.45	380.71	494.99	681.63	681.63
LSD	13.50	33.05	21.12	37.50	7.45	7.45
Late						
0	84.00ab	90.14e	129.59e	196.19e	277.78d	277.78d
40	96.29ab	183.90d	209.17d	277.08d	776.94c	776.94c
80	88.23ab	241.84c	498.90c	615.80c	899.54b	899.54b
120	92.17ab	262.46b	663.51b	785.39b	1214.89a	1214.89a
160	99.25a	301.05a	721.62a	899.54a	1220.11a	1220.11a
Mean	91.99	215.88	444.56	554.80	877.85	877.85
LSD	12.78	11.05	35.13	14.46	12.72	12.72

In each column, means with same letter do not differ at 5% level of probability

Effect of Nitrogen on leaf area index (LAI) of maize across cropping seasons

Table 6 presents the mean leaf area index (LAI) values from 4 to 12 weeks after planting (WAP) for both early and late cropping seasons. Significant differences were observed among nitrogen treatments during both seasons, except between the 160 kg N ha^{-1} and 120 kg N ha^{-1} treatments, which did not differ significantly. At 2 WAP, no significant differences were recorded among treatments in either season. Interestingly, LAI values at 2, 4, and 8 WAP were higher in the early cropping season compared to the late season, suggesting a more favorable early-season response to nitrogen application during initial vegetative growth stages. These findings highlight the interaction between nitrogen levels and seasonal conditions in influencing canopy development and photosynthetic potential in maize.

Table 6. Effect of nitrogen on leaf area index (LAI) of maize in both cropping seasons

Rate N($kgha^{-1}$)	Weeks after planting (WAP)					
	2	4	6	8	10	12
Early						
0	0.05	0.11d	0.27e	0.47e	0.65e	0.65e
40	0.06	0.21c	0.56d	0.87d	1.21d	1.21d
80	0.07	0.37b	1.35c	1.88c	2.86c	2.86c
120	0.06	0.51a	1.50b	2.94b	4.71b	4.71b
160	0.24	0.56a	1.89a	3.32a	5.90a	5.90a
Mean	0.10	0.35	1.14	1.90	3.07	3.07
LSD	n.s	0.07	0.11	0.14	0.11	0.11
Late						
0	0.07	0.12e	0.32e	0.66e	1.05e	1.05e
40	0.07	0.29d	0.59d	1.03d	3.23d	3.23d
80	0.07	0.45c	1.48c	2.38c	4.07c	4.07c
120	0.08	0.54b	2.10b	3.23b	5.90b	5.90b
160	0.08	0.67a	2.34a	4.00a	6.12a	6.12a
Mean	0.07	0.41	1.37	2.26	4.07	4.07
LSD	n.s	0.03	0.15	0.13	0.14	0.14

In each column, means with same letter do not differ at 5% level of probability

Effect of Nitrogen fertilizer on yield and yield components of maize across cropping seasons

Maize cultivated during the early cropping season generally outperformed that of the late season in terms of yield and associated components, as presented in Table 7. Notably, the number of cobs produced and most yield variables were higher in the early season, except for cob height, which was greater in the late season. Significant differences were observed among treatment means for all yield parameters across both seasons.

Cob Length

Significant differences in cob length were recorded among nitrogen treatments in both cropping seasons, except between the 0 kg N ha^{-1} and 160 kg N ha^{-1} treatments during the early season, which were statistically similar. The highest mean cob lengths were observed under the 120 kg N ha^{-1} treatment, with values of 21.13 cm and 19.49 cm for early and late seasons, respectively. The lowest values were recorded under the 0 kg N ha^{-1} treatment (16.02 cm and 14.47 cm). Overall, the average cob length was greater in the early season.

Ear Height

Significant differences in ear height were observed among most treatment pairs during the early season, except between 0 and 40 kg N ha^{-1}, and between 80 and 160 kg N ha^{-1}. In contrast, the late season showed significant differences across all treatments except between 80 and 160 kg N ha^{-1}. The highest ear height was recorded under the 120 kg N ha^{-1} treatment, with mean values of 69.43 cm (early season) and 72.00 cm (late season), indicating a stronger vertical growth response in the late season.

Number of Rows per Cob

During the early cropping season, significant differences were observed among most treatment combinations, except between 40 and 160 kg N ha^{-1}. The highest mean number of rows per cob (16.07) was recorded under the 120 kg N ha^{-1} treatment, while the lowest (10.50) was under the 0 kg N ha^{-1} treatment. In the late season, significant differences were found between treatments 80 and 120 kg N ha^{-1}, 80 and 0 kg N ha^{-1}, 80 and 40 kg N ha^{-1}, 120 and 0 kg N ha^{-1}, 120 and 40 kg N ha^{-1}, and 120 and 160 kg N ha^{-1}. The early season recorded a higher overall mean compared to the late season.

Number of Cobs per Plant

The 120 kg N ha^{-1} treatment produced the highest number of cobs per plant, with mean values of 37.33 (early season) and 18.67 (late season). The total average number of cobs was higher in the early season (32.33) than in the late season (14.00). In the early season, no significant differences were observed between treatments 0 and 40 kg N ha^{-1}, 0 and 160 kg N ha^{-1}, and 40 and 160 kg N ha^{-1}. Significant differences were found between 80 and 120 kg N ha^{-1}, and between 80 kg N ha^{-1} and all lower treatments. In the late season, all treatments were significantly different except between 80 and 120 kg N ha^{-1}.

100-Grain Weight

Grain weight was higher in the early cropping season, with a total average of 28.07 g. The highest mean values were recorded under the 120 kg N ha^{-1} treatment (30.67 g and 28.31 g for early and late seasons, respectively), while the lowest were under the 0 kg N ha^{-1} treatment (25.02 g and 23.64 g). Significant differences were observed among all treatments during the late season. In the early season, all treatments were significantly different except among 40, 80, and 160 kg N ha^{-1}.

Grain Yield

In the early cropping season, grain yield did not differ significantly between treatments 0 and 40 kg N ha^{-1}, and between 80 and 160 kg N ha^{-1}. However, during the late season, all treatments showed significant differences. The highest grain yield in both seasons was recorded under the 120 kg N ha^{-1} treatment. As shown in Table 8, the t-value of 1.63 indicates that grain yield in the early cropping season was significantly higher than that of the late season at the 5% probability level.

Table 7. Effects of nitrogen fertilizer on yield and yield components of maize for both cropping seasons

Rate N (kg ha^{-1})	Weeks after planting (WAP)					
	2	4	6	8	10	12

Early						
0	16.02[d]	57.67[c]	10.50[d]	29.67[c]	25.02[c]	1494.20
40	17.16[c]	60.13[c]	11.57[c]	31.00[c]	28.05[b]	1576.10
80	19.09[b]	63.10[b]	13.73[b]	33.67[b]	28.47[b]	1802.40
120	21.13[a]	69.43[a]	16.07[a]	37.33[a]	30.67[a]	2485.60
160	17.60[d]	63.52[b]	11.80[c]	30.00[c]	28.15[b]	2074.10
Mean	18.20	62.77	12.73	32.33	28.07	1886.48
LSD	1.00	2.51	0.93	1.63	0.70	n.s
Late						
0	14.47[e]	58.38[d]	8.97[bc]	9.67[c]	23.64[e]	1159.56[d]
40	16.65[c]	62.22[c]	10.33[bc]	14.33[b]	24.61[d]	1299.14[c]
80	17.34[b]	68.81[b]	11.20[b]	17.33[a]	26.88[b]	1606.03[b]
120	19.49[a]	72.00[a]	14.17[a]	18.67[a]	28.31[a]	1980.89[a]
160	15.75[d]	69.56[b]	10.80[bc]	10.00[c]	25.49[c]	1647.15[b]
Mean	16.74	66.19	11.09	14.00	25.79	1538.55
LSD	0.55	1.40	1.60	2.97	0.85	83.90

In each column, means with the same letter do not differ at 5% level of probability

Table 8. Comparison between early cropping yield and late cropping yield

Yield	N	Mean	SD	DF	t-value	Sig
Early season	15	1886.48	403.56			
				14	1.63	0.1254
Late season	15	1538.55	321.31			

Agronomic Efficiency of Nitrogen Fertilizer in Maize Across Cropping Seasons

The agronomic efficiency (AE) of nitrogen fertilizer varied across application rates and cropping seasons, as presented in Table 9. The highest AE was recorded at the 120 kg N ha^{-1} rate, with values of 8.26 and 6.84 for the early and late cropping seasons, respectively. In contrast, the lowest AE during the early season was observed at 40 kg N ha^{-1} (2.05), while in the late season, the 160 kg N ha^{-1} treatment yielded the lowest AE value (3.05). These results suggest that moderate nitrogen application (120 kg N ha^{-1}) optimizes nutrient use efficiency and yield response in maize under both seasonal conditions. Interestingly, the overall mean AE was slightly higher in the late cropping season (4.73) compared to the early season (4.45), indicating a marginally improved nitrogen utilization under late-season environmental conditions.

Table 9. Agronomic Efficiency of nitrogen fertilizer of maize for both cropping seasons

Rate ($kgha^{-1}$)	Early cropping season	Late cropping season
40	2.05	3.45
80	3.85	5.58
120	8.26	6.84
160	3.62	3.05
Mean	4.45	4.73

DISCUSSION

Vegetative Growth Response to Nitrogen Fertilization

This study revealed that maize planted during the late cropping season (August) exhibited superior vegetative growth compared to early-planted maize (May). Enhanced performance in stem girth, leaf area, and leaf number was attributed to favorable agroclimatic conditions—particularly rainfall, temperature, and relative humidity—which improved nitrogen availability and uptake (Zhang et al., 2021). These conditions may have also impeded the uptake of other nutrients, leading to nutrient imbalances that favored vegetative expansion.

Plant Height

Plant height was consistently greater in the late cropping season across all growth stages. This finding aligns with Saddiq et al. (2014), who reported increased height in maize planted in August in the Sudan savanna zone. The interaction between nitrogen application and environmental factors such as temperature, photoperiod, and soil moisture likely promoted stem elongation. The highest plant height was recorded under the 160 kg N ha^{-1} treatment, consistent with Undie et al. (2012), who found similar results at 100 kg N ha^{-1}. Lower plant height in the early season may be attributed to nitrogen leaching due to higher rainfall (Shahadha et al., 2021).

Leaf Number and Stem Girth

The number of leaves per plant and stem girth were significantly higher in the late cropping season. These findings corroborate Saddiq et al. (2014) and Oladimeji et al. (2017), who reported enhanced vegetative traits in late-planted maize. The increased stem girth under late-season conditions may reflect improved nitrogen assimilation and favorable growth dynamics.

Leaf Area and Leaf Area Index (LAI)

Treatment with 160 kg N ha^{-1} consistently produced the highest leaf area and LAI values across both seasons. These results are in agreement with Undie et al. (2012) and Liu et al. (2020), who emphasized the role of nitrogen in promoting leaf expansion and photosynthetic capacity. The higher LAI observed in the late season was driven by increased leaf number and area, confirming that LAI is a function of canopy structure and nitrogen-induced vegetative vigor.

Yield and Yield Components

Grain Yield and Cob Production

Yield and most yield components—except ear height—were significantly higher during the early cropping season. This observation partially aligns with Saddiq et al. (2014) and Adekunle et al. (2019), who reported superior grain yield in early-planted maize (4.32 t ha^{-1}) compared to late-planted maize (2.56 t ha^{-1}). The 120 kg N ha^{-1} treatment produced the highest grain yield across both seasons, consistent with Gotosa et al. (2019), who emphasized the importance of region-specific nitrogen recommendations.

Ear Height and Cob Length

Ear height was significantly greater in the late cropping season, likely due to increased plant height and favorable environmental conditions. This finding supports Khan et al. (2011), who reported a positive correlation between plant height and ear placement. However, the 160 kg N ha^{-1} treatment, despite producing the tallest plants, did not yield the highest ear height—suggesting complex interactions between nitrogen rate and assimilate partitioning. Cob height was also higher in the late season, consistent with Adekunle et al. (2019) and Oladimeji et al. (2017).

100-Grain Weight and Rows per Cob

The 120 kg N ha^{-1} treatment produced the highest 100-grain weight and number of rows per cob in both seasons. These results align with Kolawole and Olayinka (2023), who reported significant improvements in grain quality and cob structure under optimal nitrogen application. Grain yield was higher in the early season (1886.48 kg ha^{-1}) than in the late season (1538.55 kg ha^{-1}), consistent with Oladimeji et al. (2017), who observed early-season yields of 4.5 t ha^{-1} compared to 3.2 t ha^{-1} in late-planted maize. The reduced yield in the late season may be attributed to climatic factors affecting nitrogen uptake and utilization (Gu et al., 2023).

Agronomic Efficiency of Nitrogen Fertilizer

Agronomic efficiency (AE) declined with increasing nitrogen rates, indicating diminishing returns beyond optimal levels. The highest AE was recorded at 120 kg N ha^{-1}, while the lowest was observed at 160 kg N ha^{-1}

in the late season. These findings suggest that moderate nitrogen application is more efficient and cost-effective, supporting Girei and Dire (2020), who emphasized that excessive nitrogen does not proportionally enhance yield and may be economically disadvantageous.

CONCLUSION

This study demonstrates that nitrogen fertilization significantly enhances both vegetative and reproductive traits of maize, thereby improving overall crop performance. Nitrogen application positively influenced key yield components, including plant height, leaf area, cob number, and grain weight, across both cropping seasons. Notably, early-season planting in May resulted in superior grain yield compared to late-season planting, highlighting the importance of planting time in optimizing maize productivity under the agroecological conditions of the study area. Among the nitrogen rates tested, 120 kg N ha^{-1} consistently produced the highest grain yield and agronomic efficiency, indicating it as the most effective and economically viable rate for maize cultivation in this environment. Excessive nitrogen application beyond this threshold did not proportionally enhance yield and may compromise nutrient use efficiency and sustainability. Based on the findings of this study, it is recommended that farmers apply nitrogen fertilizer at an optimal rate of 120 kg N ha^{-1} to enhance vegetative growth, reproductive development, and grain yield in maize. Early-season planting in May is advised, as it aligns with favorable environmental conditions that support efficient nutrient uptake and crop performance. Furthermore, site-specific nitrogen management should be adopted in regions with variable soil fertility to ensure balanced nutrient application, minimize wastage, and promote sustainable maize production.

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AUTHORS CONTRIBUTIONS

This article was written and research carried out by Ajiboye, T.G. and Oroka, F.O.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Not applicable.

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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