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RESEARCH ARTICLE

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Effects of Different Doses of Nitrogen on Growth and Nitrogen Use Efficiency of Maize (*Zea mays* L.) in Berekum Municipality of Ghana

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ABSTRACT

Background: Adequate and balanced use of plant nutrients could increase crop performance and reduce adverse environmental effects. Farmers in Berekum have little information on the specific rate of nutrient, especially nitrogen application for hybrid and open pollinated maize varieties.

Methods: A field experiment was carried out in Berekum Municipality of Ghana to determine the effects of different doses of N fertilizer (0, 90, 120 and 150 kg N ha^{-1}) on growth and nitrogen use efficiency (NUE) of Pannar 12 (hybrid) and Omankwa (open-pollinated) maize varieties. The experiment was conducted in a factorial randomized block design and replicated thrice.

Result: Experimental results revealed that incremental doses of nitrogen significantly impacted vegetative growth and NUE of maize. The studies indicated that the growth response in terms of plant height, number of leaves per plant and stem diameter of Omankwa was better than that of Pannar 12. It was found that in the main cropping period of 2019, the maximum NUE of 14.58 kg/kg was gained when Pannar 12 was grown with 150 kg N ha^{-1}, while the highest NUE (15.91 kg/kg) was recorded when Omankwa was grown with 90 kg N ha^{-1}. In the minor season of 2019, NUE was highest (13.54 kg/kg) when Pannar 12 was grown with 150 kg N ha^{-1}, while application of 120 kg N ha^{-1} to Omankwa resulted in the highest NUE (10.85 kg/kg). The studies indicated that application of nitrogen at 90, 120 and 150 kg N ha^{-1} improved NUE in maize. However, NUE was optimized in Pannar 12 due to application of 150 kg N ha^{-1}, while application of 90 kg N ha^{-1} was enough to optimize NUE in Omankwa.

Key words: Growth, Maize, Nitrogen use efficiency, Variety.

INTRODUCTION

Maize, a member of the grass family, is a vital crop with several uses such as food for humans, animal feed and raw materials for industries (Gul *et al*., 2021). It is grown in different kinds of agro-ecologies and has the ability to remove huge quantities of mineral elements from the soil (FAOSTAT, 2020).

Nitrogen plays a key role in maize dry matter production by affecting the development and maintenance of leaf area and enhancing photosynthetic efficiency (Shah *et al*., 2021a). Moreover, nitrogen is pivotal in enhancing soil productivity and crop efficiency (Shivay *et al*., 2019; Shah *et al*., 2022). Increased nitrogen application to maize has been shown to lead to higher seedling emergence, improved plant growth and ultimately increased yield (Shah *et al*., 2021b; Karki *et al*., 2020). Additionally, nitrogen fertilizer has been observed to boost maize grain production by 43-68% and biomass by 25-42%, according to Ogola *et al*. (2002). Nitrogen also plays a vital role in various physiological and metabolic functions (Anas *et al*., 2020).

Plant genotype (Dong and Lin, 2020), soil characteristics such as increased soil compactness and wet conditions (Chattha *et al*., 2022), N source and rate (Zhang *et al*., 2023), climatic conditions such as rainfall, solar radiation and temperature (Shahadha *et al*., 2021; Rowlings *et al*., 2022) and N application method and time (Qiang *et al*., 2022; Liu *et al*., 2019b) affect N uptake. Environmental factors, principally higher temperature and wind speed, could increase the risk of NH_3 volatilization (Chattha *et al*., 2022). Chattha *et al*. (2022) reported that increased soil compactness and wet conditions encouraged denitrification, while no-till and coarse-textured soils resulted in maximum N losses due to leaching or volatilization. In coarse soils, NH_4NO_3 fertilizer is prone to severe leaching and denitrification losses. Enhancing plant NUE could reduce nutrient mining and largely increase output of crops (Xiong *et al*., 2018).

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Nutrient uptake in crops is impaired by poor maintenance of soil fertility, which could reduce NUE in crops. This research was, therefore, undertaken to assess the impact of various rates of N fertilizer on growth and NUE of hybrid and open pollinated maize varieties.

MATERIALS AND METHODS

Two field experiments (March - November, 2019) were conducted at Nsapor in the Berekum (latitudes 7° 27' 12.24" N and longitudes -2°35′2.54″W) municipality of the Bono Region of Ghana. The area has a semi-deciduous woodland agroecology, bimodal rainfall regime and well-drained forest Ochrosols type of soil (GSS, 2012).

A soil auger was used to take samples of soil from four different points in every experimental unit at 0-30 cm deep before sowing. A composite soil sample was formed and characterized using the ordinary procedures defined by Motsara and Roy (2008) (Tables 1 and 2). The rainfall and temperature data of the experimental location are presented in Fig 1.

The experiments were conducted in a factorial randomized block design and replicated thrice. The treatments comprised Omankwa (OM) and Pannar 12 (P-12) as one factor and four levels of nitrogen *viz* 0 (control), 90, 120 and 150 kg Nha^{-1} as another factor.

In each of the experiments, the zero-tilled land (using a systemic herbicide at 150 ml per 15 litres of water) was divided into plots of 2.4 m × 3.2 m, with 1 metre between plots and 1 metre between blocks for a total land area of 61.44 m^2. Certified seeds of maize were sown at a spacing of 80 cm × 40 cm on 4th April and 15th July, 2019 in experiments one and two, respectively.

Replanting and thinning were carried out two weeks after sowing. Weeding was done by manual hoeing at the second and fifth weeks after sowing. The maize plants were treated against fall armyworms (*Spodoptera frugiperda*) using Emamectin Benzoate at 10 ml per 1.5 litres of water using a knapsack sprayer at 2, 4 and 6 weeks after sowing. Fertilizers were applied to crops according to the treatments executed in both seasons of the trial. In both trials, fertilizers were applied using the side band placement method at the 2nd and 4th weeks after planting at their half rates per each application. Cobs were harvested at physiological maturity on 10th July, 2019 and 20th November, 2019 for the first and second experiments, respectively.

Data were taken on height, leaves and stem diameter of plants at 6 weeks after planting. Four crops were chosen and tagged from each plot's middle rows. The agronomic efficiency (AE) index was used to determine the nitrogen use efficiency (Dobermann, 2007).

$$AE = \frac{Y - Y_0}{F}$$

Where,

F = The quantity of fertilizer applied (kgha^{-1}).

Y = Crop yield with applied nutrients (kgha^{-1}).

Y_0 = Crop yield without applied nutrients.

Using the GenStat statistical package (Numerical Algorithms Group, Oxford, England), data collected were subjected to ANOVA (Payne *et al*., 2009). The Least Significant Difference (LSD) was used to separate treatment means at a confidence level of 95% (Torrie, 1996).

RESULTS AND DISCUSSION

Vegetative growth parameters

Response of plant height to variety in both cropping periods of 2019 was significant (P<0.05) with Omankwa being taller than Pannar 12 (Table 3). However, levels of N application did not significantly (P>0.05) influence plant height. The combined effects of maize variety and fertilizer on plant height in the main and minor cropping periods of 2019 were significant (P<0.05) (Table 4). In the main cropping period of 2019, the tallest maize plants (63.83 cm) were associated with application of N at 120 kgha^{-1} to Omankwa plants, while the Pannar 12 plants, which were not treated with fertilizer were the shortest (44.67 cm) (Table 3). Omankwa was generally taller than Pannar 12 under both nutrient-applied conditions and non-nutrient-applied conditions (Table 4). In the minor cropping period of 2019, Omankwa crops grown with 120 kgNha^{-1} were the tallest (62.9 cm), whereas Pannar 12 crops grown with no fertilizer were the shortest (44.40 cm).

Table 1: Preliminary physical characteristics of soil at the study site.

Soil particles	% Composition
Sandy soil	82
Silty soil	8
Clayey soil	10
Texture	Sandy loam

KNUST Soil Science Laboratory (2019).

Table 2: Preliminary chemical characteristics of soil at the study site.

Parameter	Value
pH (1:2.5 H_2O)	5.61
Carbon (%)	1.64
N (%)	0.15
O M (%)	2.83
Ca^{2+} (me/100g)	8.31
Mg^{2+} (me/100g)	1.70
K^+ (me/100g)	0.45
Na^+ (me/100g)	0.16
P (ppm)	2.63
Total exchangeable base (me/100 g)	10.61
Exchangeable acidity (me/100 g)	0.55
Effective cation exch. capacity (me/100 g)	11.16
% Base saturation	95.07

KNUST Soil Science Laboratory (2019).

Plant height increased in Omankwa relative to Pannar 12 in both seasons of the trial (Tables 3 and 4) probably because the former may be more efficient in dry matter distribution in support of plant height than the latter. Overall, application of nutrients did better than the no fertilizer treatment in terms of plant height probably because sufficient N application increases division and elongation of cells, nucleus formation and green leaves. This helps to increase the chlorophyll composition of leaves to speed up the photosynthetic rate and extension of stem, culminating in tallness in plants. Gul *et al*. (2021) and Anjum *et al*. (2018) reported that plant height increased due to application of huge quantities of nitrogen. Similarly, findings of Namvar and Sharifi (2016) indicated that, increasing the rate of N fertilizer increased internodal extension, plant height and good vegetative development. In a similar study, Adhikari *et al*. (2016) found that N increased the number and length of internodes, which increased height of the maize plant.

Both variety and different rates of N application significantly ($P<0.05$) affected mean number of leaves in the main cropping period of 2019 (Table 3). Omankwa had more leaves than Pannar 12. Mean number of leaves was highest (8) as a result of application of N at 90 kgha^{-1}. The lowest treatment effect of 6.75 was observed in the control treatment. All the fertilizer-applied treatments were similar in effect, but differed significantly from the control. In the minor cropping period of 2019, mean number of leaves was not significantly ($P>0.05$) affected by variety, but different N rates application significantly ($P<0.05$) affected it (Table 3). Mean number of leaves was highest (13.64) due to application of N at 90 kg ha^{-1}, with the control treatment producing the least value of 10.40. All the fertilizer-applied treatments were similar in effect, but differed significantly from the control treatment (Table 3). The combined effects of maize variety and fertilizer on mean number of leaves in the main and minor cropping periods of 2019 were significant ($P<0.05$) (Table 4). In the main cropping period of 2019, mean number of leaves was highest in Omankwa (8.42) following application of 90 kg N ha^{-1}, while crops of Pannar 12 which were not fertilized recorded the least mean number of leaves (6.50). In the minor cropping period of 2019, mean number of leaves was highest in Omankwa grown with 90 kg N ha^{-1}, while Pannar 12 crops which were

Table 3: Main effects of variety and fertilizer N on plant height, number of leaves per plant and stem diameter of two maize varieties at 6 WAP in both main and minor cropping periods of 2019.

Treatments	2019 Main cropping period			2019 Minor cropping period		
	Plant height (cm)	No. of leaves	Stem diameter (cm)	Plant height (cm)	No. of leaves	Stem diameter (cm)
Pannar (P-12)	46.90	7.00	0.66	48.6	10.95	0.73
Omankwa (OM)	59.92	7.92	0.75	57.80	12.18	0.64
LSD (5%)	3.91	0.53	0.05	5.97	NS	0.03
Control	50.21	6.75	0.63	49.70	10.40	0.62
90 kg ha^{-1}	54.88	8.00	0.74	51.60	13.64	0.70
120 kg ha^{-1}	54.71	7.46	0.72	58.00	10.99	0.71
150 kg ha^{-1}	53.83	7.62	0.75	53.60	11.24	0.72
LSD (5%)	NS	0.75	0.07	8.38	3.59	0.04
CV (%)	8.40	8.10	8.30	12.70	54.00	5.20

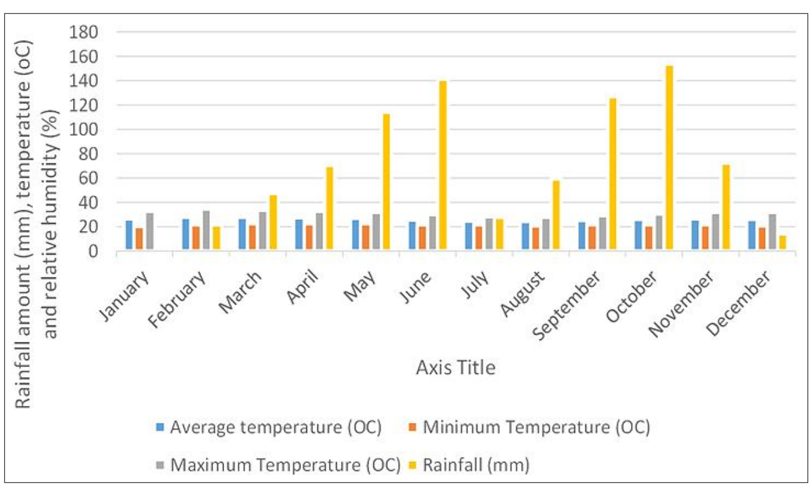

Fig 1: Climatic data at the study site in 2019 (Sunyani Meteorological Station, 2019).

not fertilized recorded the least mean number of leaves (Table 4).

The increase in number of leaves due to fertilizer application could be due to the involvement of N in leaf formation, growth and development as ever reported by Gharge *et al*. (2020). Plants of Pannar 12 may be more efficient in dry matter partitioning than those of Omankwa following nitrogen application and this may have led to an increased stem diameter in the former (Tables 3 and 4).

Both variety and rates of N application significantly (P<0.05) influenced stem diameter (Table 3). Stems of Panner 12 were significantly larger in diameter than those of Omankwa. Application of N fertilizer increased stem diameter in both varieties of maize throughout the study. In the main cropping period of 2019, stem diameter was highest due to application of N at 150 kg ha^{-1} and was lowest under the control. The combined effects of maize variety and fertilizer on stem diameter in the main and minor cropping periods of 2019 were significant (P<0.05) (Table 4). Generally, application of fertilizer increased stem diameter in Omankwa over Pannar 12 in the main cropping period of 2019. Plants of Pannar 12, which received no fertilizer had the lowest stem diameter of 0.59 cm (Table 4). In the minor cropping period of 2019, stem diameter was biggest (0.79 cm) when 120 kg N ha^{-1} was applied to Pannar 12 and was smallest (0.60 cm) when Omankwa was grown with no fertilizer (Table 4). The availability of sufficient N could have increased photosynthesis and dry matter partitioning in support of vegetative growth leading to an increase in stem diameter (Shah *et al*., 2021b; Karki *et al*., 2020).

Nitrogen use efficiency

Results of NUE in the major season of 2019 depicted no significant (P>0.05) differences between the two varieties, but fertilizer N applied significantly influenced it (Table 5). The application rate of 150 kg ha^{-1} gave NUE of 11.37 kg/kg, but did not differ significantly from the rest of the fertilizer N rates. Again, the application rate of 120 kg ha^{-1} gave NUE of 7.17 kg/kg, which varied significantly from that of 90 kg ha^{-1}, which had the highest NUE of 12.73 kg/kg. In the minor season of 2019, results of nitrogen use efficiency depicted significant (P<0.05) differences between the two varieties of maize, but the fertilizer N applied had no significant (P>0.05) effects on it (Table 5). Pannar 12 was more efficient in nitrogen use than Omankwa. The combined effects of maize variety and fertilizer on nitrogen use efficiency in the main and minor cropping periods of 2019 were significant (P<0.05) (Table 6). In the main cropping period of 2019, the greatest treatment interaction effects (15.91 kg/kg) were observed in Omankwa grown with 90 kg N ha^{-1}, while the lowest (6.52 kg/kg) was noticed in Pannar 12 grown with 120 kg N ha^{-1}. In the minor season of 2019, Pannar 12 plants treated with 150 kg N/ha had the highest NUE (13.54 kg/kg), while Omankwa plants treated with 150 kg N/ha had the lowest NUE (4.69 kg/kg) (Table 6).

Table 4: Variety × fertilizer N interactions on plant height, number of leaves and stem diameter of maize at 6 WAP in main and minor cropping periods of 2019.

Treatments	2019 Main cropping period						2019 Minor cropping period					
	Plant height (cm)		No. of leaves		Stem diameter (cm)		Plant height (cm)		No. of leaves		Stem diameter (cm)	
	P-12	O M	P-12	O M	P-12	O M	P-12	O M	P-12	O M	P-12	O M
Control	44.67	55.75	6.50	7.00	0.59	0.68	44.40	59.40	10.44	10.35	0.63	0.60
90 kg N ha^{-1}	49.58	55.75	7.58	8.42	0.67	0.80	49.10	54.10	11.31	15.96	0.74	0.66
120 kg N ha^{-1}	45.58	63.83	6.67	8.25	0.70	0.73	53.2	62.9	10.83	11.15	0.79	0.63
150 kg N ha^{-1}	47.75	59.92	7.25	8.00	0.69	0.80	47.10	59.40	11.23	11.25	0.75	0.68
LSD (5%)	7.82		1.06		0.10		11.85		5.07		0.06	
CV (%)	8.40		8.10		8.30		12.70		54.0		5.20	

LSD: Least significant difference, CV: Coefficient of variation, WAP: Weeks after planting.

The greatest NUE recorded following application of 90 kg N ha^{-1} to Omankwa could probably be due to the fact that, the rate of N application was sufficient enough to optimize NUE in Omankwa. However, these results were not translated into grain yield as Omankwa grown with 90 kg N ha^{-1} gave a seed yield of 4036 kg ha^{-1}, which was significantly lower than the seed yield of 6146 kg ha^{-1} recorded by Pannar 12 grown with 150 kg N ha^{-1} (Fig 2). Generally, it was noticed in the present study that increasing levels of N application in both seasons of 2019 decreased NUE in Omankwa, but increased NUE in Pannar 12, especially in the minor cropping period, where Pannar 12 grown with 150 kgNha^{-1} had the maximum NUE of 13.54 kg/kg (Table 6). The results could be due to the genetic differences between the two genotypes of maize grown. The application of 150 kg N ha^{-1} increased NUE in Pannar 12 in the minor cropping period of 2019 (Table 6) probably because the amount of N was sufficient to improve uptake and utilization of N in Pannar 12, meaning that augmenting rates of N application in the minor cropping period could increase NUE of hybrid maize varieties. These results were reflected in the maximum seed yield of 6095 kgha^{-1} gained in the minor cropping period of 2019 (Fig 2) as reported by Ansu *et al*. (2023). The increased levels of NPK application could have reduced losses of N through leaching and that roots of crop plants could have grown copiously to absorb sufficient mineral elements from a large area of soil. Zada *et al*. (2000) stated that NUE of crops maximized with high levels of nutrient application up to a certain point and then began to decrease and this is corroborated by the findings of this study.

Table 5: Main effects of variety and fertilizer N on nitrogen use efficiency of maize at harvest in both main and minor cropping periods of 2019.

	2019 Main cropping period	2019 Minor cropping period
Treatments	NUE (kg/kg)	NUE (kg/ka)
Pannar 12 (P-12)	10.21	11.25
Omankwa (OM)	10.63	8.46
LSD (5%)	NS	2.70
Control	10.21	9.85
90 kg ha^{-1}	12.73	9.30
120 kg ha^{-1}	7.17	11.20
150 kg ha^{-1}	11.37	9.12
LSD (5%)	5.40	NS
CV (%)	80.0	60.2

For the NUE indices, Fixen *et al*. (2015) gave a standard value of 15-30 kg kg^{-1} for AE. Values obtained in this study were below this range, except the value (15.91 kg/kg) obtained when Omankwa was grown with 90 kg N ha^{-1} (Tables 5 and 6).

Table 6: Variety × fertilizer N interactions on nitrogen use efficiency of maize at harvest in main and minor cropping periods of 2019.

Treatments	2019 Main cropping period		2019 Minor cropping period	
	NUE (kg/kg)		NUE (kg/kg)	
	P-12	OM	P-12	OM
Control	10.21	10.63	11.25	8.46
90 kg Nha^{-1}	9.55	15.91	8.69	9.84
120 kg Nha^{-1}	6.52	7.82	11.51	10.85
150 kg Nha^{-1}	14.58	8.16	13.54	4.69
LSD (5%)		7.60		5.4
CV (%)		80.0		60.2

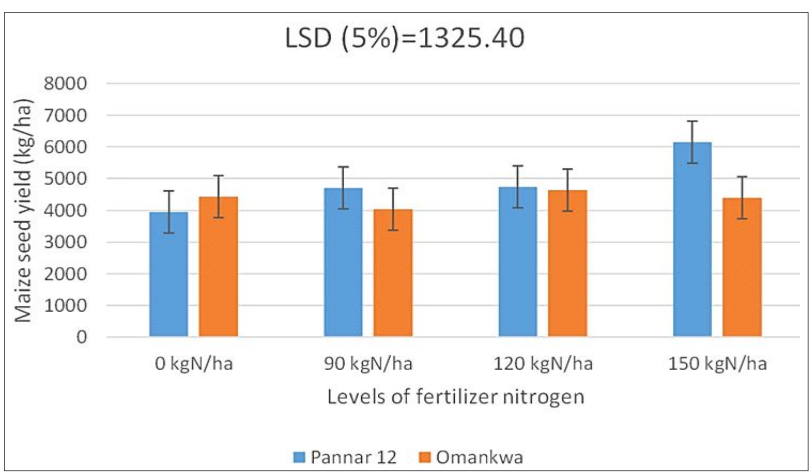

Fig 2: Variety × fertilizer N interactions on seed yield of maize at harvest in main cropping period of 2019.

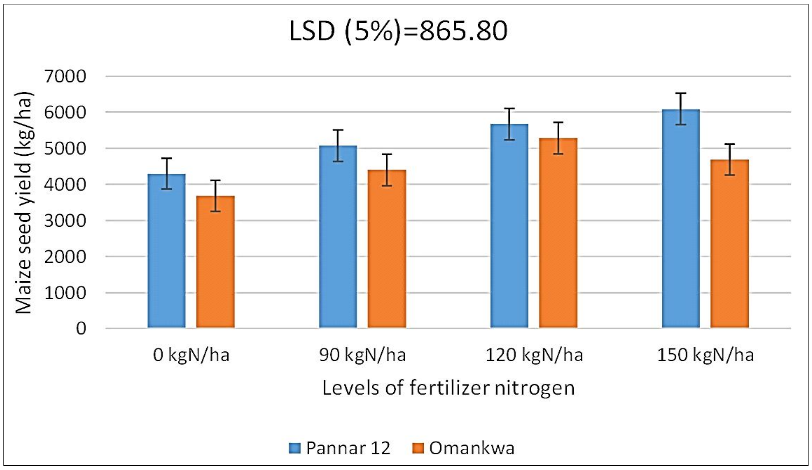

Fig 3: Variety × fertilizer N interactions on seed yield of maize at harvest in minor cropping period of 2019.

Seed yield

The combined effects of maize variety and fertilizer on seed yield of maize in the main and minor cropping periods of 2019 were significant ($P<0.05$) (Fig 2 and 3). In the main cropping period of 2019, Pannar 12 raised with 150 kg N ha^{-1} gave the highest seed yield of 6146 kg ha^{-1}, while Pannar 12 raised with no fertilizer gave the least seed yield of 3958 kg ha^{-1} (Fig 2). In the minor cropping period of 2019, Pannar 12 grown with 150 kgNha^{-1} recorded the greatest seed yield of 6095 kgha^{-1}, while Omankwa grown with no nutrient gave the least grain yield of 3684 kg ha^{-1} (Fig 3).

CONCLUSION

Application of fertilizer nitrogen significantly affected growth and nitrogen use efficiency of Omankwa and Pannar 12. The studies indicated that application of fertilizer nitrogen irrespective of application rate, improved plant height, number of leaves per plant and stem diameter in Omankwa over Pannar 12. Nitrogen use efficiency was increased in Omankwa and Pannar 12 grown with 90 kg N ha^{-1} and 150 kg N ha^{-1}, respectively. The studies indicated that application of nitrogen at 90, 120 and 150 kg N ha^{-1} improved NUE in maize. However, NUE was optimized in Pannar 12 due to application of 150 kg N ha^{-1}, while application of 90 kg N ha^{-1} was enough to optimize NUE in Omankwa.

Conflict of interest

All authors declare that they have no conflict of interest.

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