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AGRONOMIC PERFORMANCE OF MAIZE OF CONTRASTING MATURITIES AT VARYING RATES OF NITROGEN FERTILIZER APPLICATION IN A TROPICAL RAINFOREST AGROECOLOGY

[*1]Aigbe U.D., [1]Ewansiha S.U., [1]Osaigbovo A.U. and [2]Meseka S.

[1]Department of Crop Science, University of Benin, PMB 1154, Benin City, Nigeria
[2]Maize Improvement Program, International Institute of Tropical Agriculture, Ibadan, Nigeria

[*]Corresponding author's email: uyiosaaigbe@yahoo.com

ABSTRACT

The agronomic response of maize (Zea mays L.) to nitrogen (N) fertilizer depends on the cultivation conditions. However, there is a knowledge gap on the optimal rates of N fertilizer application for cultivars with different days to maturities in the tropical rainforest agroecology. Field trials were conducted at the Teaching and Research Farm, University of Benin, Benin City, which lies in the tropical rainforest of Nigeria in 2019 and 2020, to evaluate the agronomic performance of maize of contrasting maturities at varying rates of nitrogen fertilizer application. The experiment was arranged in a split-plot fitted into a randomized complete block design having three replications. The main plot treatment was N rate (0, 30, 60, 90 and 120 kg N ha^{-1}) and sub plot treatment was maize variety (extra-early maturing (TZEE-Y POP STR C4); early maturing (2008 DTMA-Y STR); intermediate maturing (BR. 9928 DWRSR) and late maturing (TZL COMP.4 C4). Results showed non-significant N rate × variety interactions for measured traits except 1000-seed weight. However, optimum grain yield was achieved at 60 kg N ha^{-1} beyond which rate, additional N did not cause any significant increase, suggesting that application of N above this optimum rate to maize plants may result in fertilizer wastage. The intermediate and late maturing varieties out-yielded the extra-early and early maturing varieties, indicating better utilization of available N. Therefore, in the rainforest agro-ecology, intermediate and late maturing maize varieties should be grown at 60 kg N ha^{-1} for optimum yield.

Key words: grain yield, maturity, nitrogen rate, rainforest agro-ecology

INTRODUCTION

Maize (*Zea mays* L.) is a major cereal crop cultivated in the rainforest and guinea savannah zones of Nigeria. Its cultivation has overtaken other major traditional cereal crops because it is high yielding, easy to process, readily digested and costs less than other cereals (Jaliya *et al.,* 2008; Olaniyi and Adewale, 2012). In 2020, Nigeria produced a total of 11.8 million metric tons of maize, making it the second largest maize producer in Africa after South Africa (FAO, 2021). However, maize productivity in the tropical rainforest agroecology is often limited by low soil fertility (Badu-Apraku and Akinwale, 2011; Kamara, 2017), particularly nitrogen (N) deficiency, a crucial limiting factor for crop growth and yield.

The N deficiency is very common in the tropical rainforest agroecology due to N losses via erratic rainfall, excessive runoffs and leaching. Maize requires adequate supply of N and other nutrients for good growth and high yields. Research has shown that N has greatly reduced yield in most developing countries of the world where maize is produced under conditions of low soil fertility (Oikeh and Horst, 2001). Application of N-fertilizers is widely recognized as an effective strategy to address N deficiency and enhance maize productivity (Ladha *et al*., 2016). The optimal rate of N-fertilizer application can differ depending on factors such as maize genotype, maturity group, and environmental conditions (Ciampitti and Vyn, 2011). Therefore, it is essential to determine the optimal combination of maize varieties and N-fertilizer application rates that will result improved yields in different agroecologies. Several studies have shown significant responses of maize varieties to N-fertilizers (Kamara *et al*., 2009; Garba *et al*., 2017; Ewansiha *et al*., 2020). However, a study by Ewansiha *et al*. (2019) reported that late maturing maize varieties had higher grain yield than early maturing maize varieties in the rainforest agroecology of Nigeria. Despite the existing research, there is limited understanding of the interaction between maize maturity classes and varied N rates in tropical rainforest agroecologies.

By investigating yield differences, physiological attributes, and N demand among maize varieties with contrasting maturities, this study sought to provide region-specific recommendations for N-fertilizer application rates for maize maturity classes. This study would address how maize varieties with contrasting maturities respond to

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variations in N-fertilizer application rates, and the implications for N management in tropical rainforest agroecologies. The findings will contribute to the development of sustainable nutrient management practices that would enhance the productivity of maize cultivation in the region. Therefore, the objective of this study was to determine the agronomic performance of contrasting maize varieties at varying rates of nitrogen application in a tropical rainforest agroecology.

MATERIALS AND METHODS

Experimental Site

The study was conducted during the rainy seasons (April-July) of 2019 and 2020 at the Teaching and Research Farm of the Faculty of Agriculture, University of Benin, Benin City (06º 20′ 50″ N, 5º 37′ 23″ E; 78 m asl) in the tropical rainforest of Nigeria. Benin City has an average annual rainfall of 2015 mm with a growing period of 211 to 270 days and a daily mean temperature of 20°C during the growing season (Ogeh and Ukodo, 2012; Climate-data.org, 2016). The soils in the experimental area are classified as Ultisols (Olatunji *et al.,* 2014; Umweni *et al*., 2014). The physical and chemical properties (pH, organic matter, total N, extractable P, exchangeable cations and total acidity) of the soil at the experimental site were determined at the beginning of the experimentation in 2019 according to procedures of IITA (1982). The chemical properties of the soils were compared with USDA soil degradation standards (USDA, 2001). The second year trial was repeated on the same piece of land used for the first year trial.

Varietal Description

Maize varieties evaluated in this study were (*i*) extra-early maturing maize variety (TZEE-Y POP STR C4, matures in 80-85 days), (*ii*) early maturing maize variety (2008 DTMA - Y STR, matures in 90-95 days), (*iii*) intermediate maturing maize variety (BR. 9928 DWRSR, matures in 105-110 days) and (*iv*) late maturing maize variety (TZL COMP.4 C4, matures in 115-120 days). These varieties were obtained from International Institute of Tropical Agriculture (IITA), Ibadan.

Experimental Design and Treatments

The experiment was arranged in a split-plot fitted into a randomized complete block design (RCBD) having three replications. Treatments were N rate (0, 30, 60, 90 and 120 kg N ha^{-1}) and four maize varieties. Nitrogen rate formed the main plot and maize varieties the sub plots. A sub plot measured 3.0 m × 5.0 m having four rows. Treatment plots and replications were separated by 0.75 m.

Agronomic Practices

At the beginning of the experiment, the land was cleared manually using cutlass and the debris were gathered and removed from the field. Three seeds of maize were sown per hole on 01 April in both years. The seeds were sown at a depth of ca. 2-5 cm at a plant spacing of 75 cm × 25 cm. Seedlings were thinned to one plant per stand, two weeks after sowing to obtain the desired maize population of 53,333 plants ha^{-1}. One week after sowing, basal P was applied as single super phosphate (SSP) at a rate of 60 kg ha^{-1} P_2O_5 and K as muriate of potash (MOP) at a rate of 60 kg ha^{-1} K_2O, to all plots. Urea was the source of N for the N treatments. Half of each N treatment rate was applied one week after sowing as basal application and the remaining half at three weeks after the first application as top-dress application to augment any form of N loss.

Immediately after sowing, a mixture of paraquat (1,1-dimenthyl-4,4-bipyridylum dichloride 24% w/w paraquat dichloride) and atrazine (atrazine 80% w/w WP), each at a rate of 250 ml and 500 g per 16 L of water, were applied using knapsack sprayer to control weeds. Further weeding was done manually using hoe, at six weeks after sowing. From two weeks after sowing until tasselling, armyworm (*Spodoptera frugiperda* J.E. Smith) was controlled using Sniper (1000EC DDVP, dimethyl 2,2-dichloro-vinyl phosphate) at a rate of 16 ml per 16 L of water using knapsack sprayer at a weekly interval.

Sampling and Measurement

Data were collected from the two middle rows per plot (net plot). At full tasselling, plant height was determined on five randomly selected plants, by measuring the height from ground level to the node where the last top leaf (flag leaf) attached itself to the stem just before the tassel using a measuring rule. The average plant height was recorded. At harvest maturity, plants in a net plot were harvested for the determination of grain yield and yield components. The number of ears harvested were determined and expressed in number per plant. Harvested ears were de-husked and air-dried for one week. Grains were threshed from the dried cobs and weighed using a digital toploading balance, pioneer PA4101 manufactured by Ohaus. Grain yield was expressed in kg ha^{-1}, adjusted to 15% moisture content (MC) using Farmex MT-16 grain moisture tester manufactured by AgroTronix, LCC. 1000-seed weight was determined by counting and weighing 1000 seeds per net plot.

$$\text{Grain yield} = \frac{\text{Sample grain yield} * ((100 - \text{MC})/85) * 10}{\text{Sample area}}$$

Data Analysis

Data obtained were subjected to analysis of variance using the general linear model (PROC GLM) procedure of SAS for Windows Release 9.2 (SAS Institute Inc., Cary, NC, USA). Treatment means were separated using Least Significant Difference (LSD) test at 5% level of probability.

RESULTS AND DISCUSSION

Growing Conditions

The soil of the experimental site had 886 g kg^{-1} sand; 56 g kg^{-1} silt; 58 g kg^{-1} clay, indicating that the soil texture is sandy (Table 1). It also contained organic carbon of 14.30 g kg^{-1}, total N content of 1.10 g kg^{-1}, available P of 2.11 mg kg^{-1}, K content of 0.21 cmol kg^{-1}, Ca content of 0.89 cmol kg^{-1}, Mg ccontent of 0.57 cmol kg^{-1} and pH-H_2O of 5.2 (Table 1). Sandy soils are often characterized by rapid water infiltration and drainage, low nutrient retention, and potentially low organic matter content (Umeugokwe *et al*., 2021; Oguike *et al*., 2023). The chemical properties of the soil were inherently low in their natural fertility in respect to N, P and K which could not support any meaningful maize yield without fertilizer application. The mean monthly rainfall and minimum and maximum temperature during the cropping seasons are shown in Table 2. Rainfall was higher in 2019 compared to 2020 except for the month of April. However, the climatic condition during the cropping period was adequate for maize cultivation.

Variance Analysis

Year of cultivation significantly ($p < 0.01$) influenced plant height and number of ears harvested (Table 3). Nitrogen rate influenced plant height and grain yield. Significant varietal differences occurred in plant height, 1000-seed weight and grain yield. There was significant interaction between year and variety for 1000-seed weight. The three-way interaction among year, nitrogen rate and variety for plant height was also significant ($p < 0.05$). This may be due to differences in environmental factors and is consistent with the finding sof Kamara *et al*. (2012) and Ewansiha *et al*. (2017) that year × cultivar interaction was significant for number of ears, number of grains, total dry matter, 1000-seed weight and grain yield. Such environmental factors as pest infestation, rainfall and temperature varied between the two years of study. For example, rainfall was higher in 2019 than in 2020. Sufficient amount of inherent and applied N that would have been available to the maize plants for growth may have been lost through runoffs and leaching due to heavy rainfall during the growing season. Indeed, Jamal *et al*. (2006) had reported that about 50% at higher doses of applied N remains unavailable to a crop due to N loss through leaching in areas receiving heavy rainfall amount and uneven distribution. The growth and yield of maize with high rainfall regimes is generally low due to poor nutrient use efficiency (Sitthaphanit *et al*., 2010). It is worthy to note that, significant year × variety interactions limit the breeder's desire for stable genetic progress (Ewansiha *et al.,* 2015). There was no significant interaction of nitrogen rate × variety for all attributes with exception of 1000-seed weight, suggesting that the maize varieties varied in their response to levels of N applied for seed weight. This was in corroboration with Worku *et al*. (2001) who reported that different genotypes performed differently across different soil fertility levels. Similarly, Anjorin (2013) reported varietal differences in response to varying soil fertility.

Table 1: Soil physical and chemical properties of the experimental site

Parameters	Soil sample before planting	USDA soil standard ranges
Physical composition		
Sand (g kg^{-1})	886.00	
Silt (g kg^{-1})	56.00	
Clay (g kg^{-1})	58.00	
Chemical composition		
pH (H_2O)	5.20	5.50-8.50
Organic matter (g kg^{-1})	14.30	10.00 > 20.00
Total N content (g kg^{-1})	1.10	2.00 > 10.00
Available P (mg kg^{-1})	2.11	8.00-20.00
Exchangeable base (cmol kg^{-1})		
Calcium	0.89	2.00-20.00
Magnesium	0.57	0.30-8.00
Potassium	0.21	0.20-2.00
Sodium	0.13	0.10-2.00

Table 2: Rainfall and temperatures at Benin City, Nigeria for 2019 and 2020

Months	2019			2020		
	Rainfall (mm)	Maximum (°C)	Minimum (°C)	Rainfall (mm)	Maximum (°C)	Minimum (°C)
April	119.40	35	26	157.10	34	25
May	378.50	32	25	281.60	33	24
June	503.30	28	23	285.90	30	23
July	615.40	27	23	513.20	27	23
Average	404.20	31	24	309.50	31	24

Source: Benin, Benin City weather data (http://worldweatheronline.com)

Table 3: Effect of year, N rate and variety on the performance of maize grown at varying rates of N fertilizer application

Effect	Plant height (cm)	Number of ears (number $plant^{-1}$)	1000-seed weight (g)	Grain yield (kg ha^{-1})
Year (*Y*)	0.0005	0.0026	0.6767	0.1020
N rate (N)	0.0081	0.3540	0.4754	0.0006
Y × N	0.9770	0.3455	0.2728	0.1262
Variety (*V*)	< 0.0001	0.2421	0.0092	0.0156
Y × *V*	0.7937	0.4401	0.0331	0.2730
N × *V*	0.3003	0.9772	0.0186	0.6649
Y × N × *V*	0.0492	0.8940	0.1178	0.6587

Plant Height

Maize plants responded to N application and variety for plant height (Table 4). Taller plants were observed with application of N rates, albeit with similar heights at varying N rates than under N deficiency. This highlights the importance of applied N to maize production. Brady and Weil (1990) indicated that nitrogen affects various physiological and biochemical processes in plant cells and ultimately, affects growth and development. Lack of N reduces cell division and growth of the plants. Haque *et al.* (2001) indicated that at sub-optimal level of N, growth is reduced. Plant height of the various varieties was in the following order: BR. 9928 DWRSR > TZL COMP.4 C4 > TZEE-Y POP STR. C4 > 2008 DTMA-Y STR. This shows that the intermediate maturing maize variety had the tallest plant followed by the late maturing maize variety. While the early maturing maize variety had the shortest plants. These differences may be due to the genetic constitution of the varieties. Bello *et al.* (2012) reported that most of the late or intermediate varieties evaluated were late to maturity, and higher in plant and ear heights compared to early maturing group. Ewansiha *et al.* (2020) reported that varietal differences in plant height were real to the point that even in the presence of high N-fertilizer, the extra-early and early maturing varieties remained shorter than the late maturing varieties.

Seed Weight

Maize variety influenced 1000-seed weight whereas N rate had no influence on this trait (Table 4). Varieties TZEE-Y POP STR C4, BR.9928 DWRSR and TZL COMP.4 C4 had heavier seed weight than 2008 DTMA-Y STR. The significant N rate × variety interaction for seed weight (Table 5) suggests that the maize varieties varied in their response to levels of applied N for seed weight. At 0 kg N ha^{-1}, seed weight differed between 2008 DTMA-Y STR and BR. 9928 DWRSR and between 2008 DTMA-Y STR and TZL COMP.4 C4. At 30 kg N ha^{-1}, differences among the varieties were not significant. At 60 kg N ha^{-1}, differences occurred only between 2008 DTMA-Y STR and BR. 9928 DWRSR. At 90 kg N ha^{-1}, the trend was similar to that obtained at 30 kg N ha^{-1}. At 120 kg N ha^{-1}, differences in seed weight occurred only between BR. 9928 DWRSR and TZL COMP.4 C4. However, 2008 DTMA-Y STR had low seed weight at 0 and 60 kg N ha^{-1}. This may be due to the fact that the variety is early to maturity, had shorter plants and probably have a narrow genetic potential for nutrient utilization for yielding. The extra early, intermediate and late maturing varieties produced heavier seeds even at low N and high N environments. This may be that, the varieties have better N utilization. Raun and Johnson (1999) and Halvorson *et al.* (2001) stated that N utilization may be affected by crop species and rate of N application.

Table 4: Main effect of year, N rate and variety on the performance of maize grown at varying rates of N fertilizer application

Effect (s)	Plant height (cm)	Number of ears (number plant^{-1})	1000-seed weight (g)	Grain yield (kg ha^{-1})
Year (*Y*)				
2019	141.30	1.00	239.90	2972.30
2020	125.90	1.03	237.20	3276.30
Mean	133.60	1.01	238.50	3124.30
$LSD_{0.05}$	7.66	0.023	ns	ns
Nitrogen rate (N)				
0 kg N ha^{-1}	118.00	1.00	227.10	2211.70
30 kg N ha^{-1}	135.50	1.00	236.60	2923.40
60 kg N ha^{-1}	140.40	1.03	243.70	3469.50
90 kg N ha^{-1}	137.90	1.02	242.90	3449.00
120 kg N ha^{-1}	136.20	1.02	242.40	3568.00
Mean	133.60	1.02	238.50	3124.30
$LSD_{0.05}$	12.12	ns	ns	586.06
Variety (*V*)				
TZEE-Y POP STR. C4	127.70	1.00	242.80	2882.70
2008 DTMA-Y STR	123.50	1.01	222.10	2861.60
BR.9928 DWRSR	149.50	1.02	239.40	3191.80
TZL COMP.4 C4	133.80	1.03	249.80	3561.10
Mean	133.60	1.02	238.50	3124.30
$LSD_{0.05}$	6.15	ns	16.24	479.49

TZEE-Y POP STR C4 - extra early maturing, 2008 DTMA-Y STR - early maturing, BR.9928 DWRSR - intermediate maturing, TZL COMP.4 C4 - late maturing, ns - not significant

Table 5: Interactive effects of N rate and variety on 1000-seed weight of maize grown at varying rates of N fertilizer application

Variety (*V*)	Nitrogen rate (kg N ha^{-1})				
	0 (g)	30 (g)	60 (g)	90 (g)	120 (g)
TZEE-YPOPSTRC4	222.80^{ab}	248.70^{a}	261.60^{ab}	240.00^{a}	241.10^{ab}
2008DTMA-YSTR	188.30^{b}	231.70^{a}	210.80^{b}	252.50^{a}	227.30^{ab}
BR.9928 DWRSR	242.10^{a}	225.80^{a}	262.70^{a}	242.70^{a}	223.70^{b}
TZLCOMP.4C4	255.10^{a}	240.20^{a}	239.60^{ab}	236.40^{a}	277.50^{a}
$LSD_{0.05}$ N × *V*	51.35				

TZEE-Y POP STR C4 - extra early maturing, 2008 DTMA-Y STR - early maturing, BR.9928 DWRSR - intermediate maturing, TZL COMP.4 C4 - late maturing. Means within a column with the same letter (s) are not significantly different at $p \leq 0.05$ using LSD.

Grain Yield

The N rate and maize maturity (variety) influenced grain yield (Table 4). Grain yield increased with increase in applied N. Grain yield was 32, 57, 56 and 61% higher at 30, 60, 90 and 120 kg N ha^{-1} respectively, compared to 0 kg N ha^{-1}. However, grain yield was optimum at 60 kg N ha^{-1} beyond which rate, increase in grain yield was minimal. This is in agreement with the finding of Ewansiha *et al*. (2020). This means that application of N above 60 kg N ha^{-1} to maize plants may result in fertilizer wastage and soil contamination. Excessive application of N fertilizer has negative effects on crops, greatly reduces N use efficiency and causes significant nitrate leaching losses (more than 50% N to the environment) and contamination of groundwater (Erisman *et al*., 2013; Wang *et al*., 2014; McBratney and Field, 2015; Ahmad *et al*., 2018; Suchy *et al*., 2018; Wang *et al*., 2019). Reduced grain yields at 0 and 30 kg N ha^{-1} might have resulted from nutrient insufficiency as little or no N was available. Kamara *et al*. (2005) and Kamara *et al*. (2009) reported severe yield losses in maize in Nigerian Savannas when no nitrogen was applied. Kamara *et al.* (2012) reported that N is a major limiting nutrient in the Nigerian Savannas as shown by the significant yield reduction under low N conditions. Ewansiha *et al*. (2017, 2019) suggested that farmers will need to add N to the soil as to improve yields of maize, whether extra-early, early or late maturing varieties. Varieties TZL COMP.4 C4 and BR.9928 DWRSR had comparable grain yields; similarly TZEE-Y POP STR C4 and 2008 DTMA-Y STR had comparable grain yields; but the former had higher yields than the later (Table 5). This may be due to their lateness to maturity and deeper roots to absorb more nutrients. Bello *et al*. (2012) reported that the late or intermediate maturing varieties are high yielding compared to early maturing groups. Similarly, Ewansiha *et al.* (2019) reported that the late maturing varieties had superior yield compared to the early maturing maize varieties because of better utilization of soil nutrient.

CONCLUSION

Maize performance was influenced by N rate and maize maturity. Plant height of maize increased with increase in N application rates. Mean grain yield was approximately 2.2, 2.9, 3.5, 3.4 and 3.6 t ha^{-1} at N rate of 0, 30, 60, 90 and 120 kg N ha^{-1}, respectively. Optimum performance was achieved for grain yield at 60 kg N ha^{-1} beyond which rate, additional N did not cause any significant increase in grain yield. Variety BR.9928 DWRSR grew taller than other varieties. Extra early maturing variety (TZEE-Y POP STR C4), intermediate maturing (BR.9928 DWRSR) and late maturing (TZL COMP.4 C4) had heavier seed weight than early maturing variety (2008 DTMA-Y STR). Varieties TZL COMP.4 C4 and BR.9928 DWRSR out-yielded varieties TZEE-Y POP STR C4 and 2008 DTMA-Y STR, indicating better utilization of available and applied N. Therefore, in the rainforest agro-ecology, variety TZL COMP.4 C4 and BR.9928 DWRSR should be grown with N fertilizer application at 60 kg N ha^{-1} for optimum yield. This will lead to reduction in fertilizer wastage.

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