

Assessment of Nitrogen Uptake and Utilization in Low-N Tolerant Maize Varieties (*zeay mays L.*) in Rain Forest-Zone of Nigeria

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Abstract:

The concerted efforts in combatting the yield quality and other physiological traits in maize production in tropical zone, especially in N-poor soils has been driving force by most researchers. To this effort, International Institute of Tropical Agriculture (IITA) has contributed to developing maize varieties which could strive adequately well in tropics and nitrogen deficiency zones. This study aimed at evaluating five selected improved maize varieties for their vegetative growth, grain yield and yield components, nitrogen uptake and use efficiencies. The research was conducted from 2019 to 2020 crop seasons at the experimental farm of the Department of Crop Sciences of the University of Benin, Nigeria. The experimental design adopted for this study was randomized completed block design with a split-plot factorial (3x5) arrangement, and with three replications. The main plots consisted of three nitrogen fertilizer rates (0 kg ha⁻¹, 60 kg ha⁻¹, and 120 kg ha⁻¹) whereas the sub-plots consisted of five (5) improved maize varieties, namely: Acr 97 TZL COMP 1-W LN C1, BR9928-DMRSR LN C1, LA POSTA SEQUIA C6, Sint Marzoca Larga, TZL COMP 1 C6 LN C1, and a check. Other agronomic best practices were duly observed throughout the two cropping seasons. The analyzed data based on traits under study showed high influence of N-application on phenology parameters, grain yield and yield components. The Nitrogen uptake and use efficiency was significantly high in both maize stover and grains at N optimal application but decreased with increase in N-application rates. However, the nitrogen rates did not influence the percentage of N concentration in both stover and maize grains. The highest grain yield was obtained in response to applying 60 kg ha⁻¹ N with split application of half dose of N two weeks after sowing and the other half dose at mid-vegetative stage of growth. The variety BR9928-DMRSR LN C1 was particularly outstanding for both growth and yield and may be recommended for large-scale demonstration and release to maize farmers in tropical rain forest zone.

Keywords:

Low-N Tolerant Maize, Fertilizer, N-Poor Soils, N Use Efficiency, And Rain-Forest

1. Introduction

Maize (*Zea mays* L.) is the most important cereal in the world after wheat and rice with regard to cultivation area, the global maize area (for dry grain) amounts to 197 M ha, including substantive areas in sub-Saharan Africa (SSA), Asia and Latin America [17]. Maize is an important staple food for more than 1.2 billion people in SSA and Latin America. Global production has increased over years and its increase is and estimated to be about 785 million tons per year. In 2021, the Americas were the top producing region for maize, with the United States of America and Brazil accounting together for 39 percent of the world production. China was the second largest producer, with a share of almost 23 percent and Africa 7 percent [17]. Nigeria became the second most important maize producer in Africa after South Africa, contributing about 13% of the continent's total production [16]. The Maize belt in Nigeria presents the highest potential [5], and accounts for nearly 80% of the total maize produce in Nigeria [14]. Despite the potential of this region, the increase has not been sufficiently large enough in relation to human population growth. There is an increasing demand for the crop for food, livestock feed and raw materials for industrial purposes.

The production of adequate food in SSA is threatened by a number of factors which include low and variable soil fertility [6], which is compounded by improper management strategies to sustain soil nutrient stocks, and improve yield response to nutrients [33] are considered the most critical factors limiting maize productivity in Nigeria's maize belt region. In addition to this, high cost of inorganic fertilizer and unsustainable farming activities in the rainforest have severely depleted soil nutrients throughout much of south western Nigeria [31]. The ultisols which constitute the main agricultural lands of southern Nigeria are deficient in essential plant nutrient and high in soil acidity due to torrential rainfall and constant deforestation [38]. Yields of agricultural crops like maize have been found to decline from 5 t ha⁻¹ immediately after forest clearing to 0.5 t ha⁻¹ after four years of cropping as result of extremely poor soils which are acidic and low in minerals and nutrients [23,7]. The cleared area supports vigorous growth for a few years, after which the nutrient stock is depleted and large amounts of fertilizer are required to keep the operation viable. A similar depletion of nutrients few years after opening up a secondary forest planted to maize has also been reported in Nigeria by [24].

Nitrogen deficiency in West Africa (WA) is caused by several factors including the leaching of soil N below the root zone due to torrential rainfall [12], poor weed control in farmers' fields [19], the application of sub-optimal levels of inorganic fertilizer due to high prices [33,19] and poor organic matter and available nutrients in the humid tropics as they are often been subjected to continuous cropping, bringing about great reduction in their productivity and sustainability.

Maize needs fertile soil to attain its yield potential because it is a heavy feeder of nutrients. Therefore, its productivity is largely dependent on effective nutrient management. Good nutrient management is a potential way to improve maize yields and this include proper fertilizer application and ready nutrients availability. Other

ways to effectively manage soil nutrients is in the use of low nitrogen-tolerant maize. Low N-tolerant maize has the capacity of utilizing small amount of nitrogen and maximizing the output and it has been of great benefit to farmers in SSA whose soil is highly depleted of nutrients [12].

The objective of this study was to evaluate the agronomic performance of low N-tolerant maize varieties under low soil fertility and N fertilized soil environments; and determine the amount of nitrogen uptake and use efficiency of low N-tolerant maize varieties under native soil fertility and N fertilized soil environments.

2. Materials and Methods

2.1. Experimental site

Field experiments were conducted at the experimental farm (Latitude 6° 20' N and Longitude 5° 40' E, at elevation of 152 m above the sea level) of the Department of Crop Science, University of Benin, Benin City during 2019 and 2020 cropping seasons. The experimental site is characterized by a humid tropical climate with a mean annual rainfall of 1762 mm and daily temperature of 26.4 °C; and lies within the rainforest agro-ecological zone of Nigeria. The site has been degraded to a secondary forest due to continuous cropping.

2.2. Maize varieties, nitrogen rates and experimental design

Six maize varieties and three nitrogen rates were compared in a split-plot factorial experiment laid out in randomized complete block design and replicated three times. The main plot treatments consisted of three N fertilizer rates (0, 60, and 120 kg N ha⁻¹), while subplot consisted of the six maize varieties (Acr 97 TZL COMP 1-W LN C1, BR 9928- DMRSR LN C1, LA POSTA SEQUIA C6, TZL COMP 1 C6 LN C1, Sint Marzoca Larga and Check). The subplots were 1.5 x 3 m² and seed were sown at 0.75 m between rows and 0.25 m within rows. The maize varieties were obtained from the maize breeding unit at International Institute of Tropical Agriculture (IITA), Ibadan, Oyo state Nigeria, while the control was obtained from oliji village in Edo State. In exception to the check, all the five maize varieties were open pollinated and low nitrogen tolerant varieties.

2.3. Cultural practices

About 300 ml of glyphosate was mixed in 15L of water and sprayed to the existing vegetation. Slashing, clearing and parking were done at the experimental site 10 days after glyphosate application. Land leveling was carried out with the use of hoe and cutlass. Planting was done on plain ground without ridging. Two seeds of the maize varieties were planted at a depth of 2 to 4 cm on 25th August 2019 and 3rd September, 2020 respectively. In each year, plots received basal application of Single Superphosphate (SSP) at a rate of 50 kg ha⁻¹ and Muriate of Potash (MOP) at the rate of 30 kg ha⁻¹. Urea was applied at the rate of 60 and 120 kg ha⁻¹ as source of nitrogen for the nitrogen treatments. One half of each rate was applied one week after planting (WAP) and the other half at five WAP. Seedlings were thinned to one plant per stand, 2 WAP to give a final population of 53,333 plants per ha. Manual or traditional weeds control was carried out at 3 and 5 WAP.

2.4. Measurements

Data were collected from the two middle rows leaving the outside rows to serve as borders at 50 cm of distance from each end based on the following parameters:

Days to 50% anthesis: Days to Anthesis (anthesis date) was calculated as the number of days from planting to when 50% of the plants shed pollen.

Anthesis-silking interval: Anthesis-silking interval (ASI): Anthesis-silking interval was calculated as the difference between days to anthesis and days to silking.

Days to 95% maturity: Number of days from planting to when 95% of the plants in the net plot reached physiological maturity (turn brown) was taken and recorded.

Data from (6 plants plot⁻¹) were taken, all the six plants plot⁻¹ within two middle rows were harvested for dry matter determination. The samples were separated into leaves, stem, cobs, and grain. They were left on the ground to dry for about 2-3 weeks, and later taken to laboratory for weighing using sensitive scales. The maize ears were de-husked and sun-dried for one week and shelled. Grains yield per split-plot was measured using electronic balance and final grain yield was expressed in kg ha⁻¹, adjusted to 12% moisture content using Farmex MT-16 grain moisture tester. N-uptake was determined by multiplying the dry weight of plant parts by N concentration. The percentage of total N in stover and grain was determined at (IITA) using Colorimethor auto analyzer. The valued obtained was used to calculate N use efficiency and N uptake. Efficiencies of N uptake, and N utilization, in stover and maize grain were calculated according to the formulae developed by Molle, *et al.*, [29] who defined use efficiency as grain production per unit of N available in the soil.

Stover N Uptake: This was determined based on (dry stem leaves + dry leaves + husk) and N concentration on dry weight basis as:

$$\text{SNY (kg ha}^{-1}\text{)} = \text{SNC (\%)} \times \text{SDW}$$

Where;

SNY = Stover N yield

SNC = Stover N concentration

SDW = Stover dry weight.

Grain N Uptake: It was computed based on grain yield and grain N nitrogen concentration as;

$$\text{GNY (kg ha}^{-1}\text{)} = \text{GNC (\%)} \times \text{GY (kg ha}^{-1}\text{)}$$

Where, GNY = grain N yield, GNC = Grain N concentration, GY = Grain yield

$$\text{N Use Efficiency for grain yield (kg kg}^{-1}\text{ N)} = (\text{U}_n \text{ kg ha}^{-1} - \text{U}_{n0} \text{ kg ha}^{-1}) \div \text{Na kg ha}^{-1} \times 100$$

Where;

U_n = nitrogen uptake in treatment with fertilizer

U_{n0} = nitrogen uptake in treatment without fertilizer

Na = applied nitrogen rate kg ha⁻¹

$$\text{N Use Efficiency for Stover yield (Kg kg}^{-1}\text{ N)} = (\text{U}_n \text{ kg ha}^{-1} - \text{U}_{n0} \text{ kg ha}^{-1}) \div \text{Na kg ha}^{-1} \times 100$$

Where U_n = nitrogen uptake in treatment with fertilizer

U_{n0} = nitrogen uptake in treatment without fertilizer

N_a = applied nitrogen rate kg ha^{-1}

There are two primary components of N use efficiency: (1) the efficiency of absorption (uptake), and (2) the efficiency with which the N absorbed is utilized to produce grain. These are expressed as follows:

N-uptake efficiency (NUPE) = Total N in aboveground biomass/amount of N applied

N-utilization efficiency (NUTE) = Grain Weight (g/plant)/total N in aboveground biomass

Nutrient use efficiency (NUE) = Grain yield (g/plant) at N rate applied/N applied (g Nf)

2.5. Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) using the split-plot model. Significant means were separated using the Fisher's protected least significant difference at 5% level of probability.

3. Results

3.1. Nutrient status of experimental site

The physicochemical properties of the soil prior to cropping and fertilizer application are presented in Figure:1. The pH of the soil is as low 4.8 (very acidic). The percentage of soil nitrogen was less than 1.50 g kg^{-1} which is below the critical level for performance of maize crops. Generally, maize as a crop does not tolerate pH conditions of less than 5.5; it grows best at a soil pH between 5.5 and 7.3 with pH 6.0 - 6.5 being optimum. The low level of N in the soil could be as a result of leaching, denitrification, volatilization, crop removal, soil erosion and water runoff that constantly occur in the rain forest [10]. The percentage organic carbon that is important in determining responses to N and P fertilization was equally lower than the critical level of 3%. The percentage of available phosphorous in the soils of the experimental sites falls within average level for most crops. The essential plant nutrients were low due to low soil nutrients in the experimental site as seen in Table 1. The soils were acidic sand with low level of nutrient which is a typical characteristic of an ultisol soil. The soil physio characteristics of this study is in accordance with the findings reported by [9] that ultisols constitute the main agricultural lands of Southern Nigeria and are deficient in essential plant nutrients and high in acidity. The observation is also in harmony with the findings of Akinmutimi [4] who observed that the ultisols of Southern Nigeria are low in exchangeable calcium, magnesium and potassium. The deficient levels of the major nutrients in the soil of the experimental site were compensated for in those sub-plots treated with inorganic fertilizer during the two cropping seasons.

The effect of interactions among years, nitrogen rates and variety on days to flowering, anthesis silking interval and 95% days to maturity in low N-tolerant maize for 2019 and 2020 cropping seasons are presented in Table 2. In 2019, days to 50% anthesis were similar in all the varieties at the application of 120 kg ha^{-1} N but not at the rates of 0 kg ha^{-1} and 60 kg ha^{-1} N respectively. In the former rate (0 kg ha^{-1}), days to anthesis was earliest in Acr 97 TZL COMP 1-W LN C1 and delayed most in TZL

COMP 1 C6 LN C1 while the corresponding varieties for the earliness and delayed anthesis at 60 kg ha⁻¹ N were TZL COMP 1 C6 LN C1 and BR 9928- DMRSR LN C1, and the varietal differences were significant. In 2020, at the application rate 0 kg ha⁻¹ N Acr 97 TZL COMP 1-W LN C1, BR 9928- DMRSR LN C1, LA POSTA SEQUIA C6, and check varieties had similar days to anthesis which were delayed significantly compared to the earliness in LA POSTA SEQUIA C6 and Sint Marzoca Larga varieties. At the application rate 60 kg ha⁻¹ N days to anthesis was earliest in BR 9928- DMRSR LN C1 and delayed significantly mostly in Sint Marzoca Larga while these two respective trends occurred in BR 9928- DMRSR LN C1 and TZL COMP 1 C6 LN C1 when 120 kg ha⁻¹ N was applied in 2020. The anthesis-silking interval in 2019 and 2020 significantly differed at all levels of nitrogen applications and they were delayed mostly by the check variety except at the application rate of 120 kg ha⁻¹ N in 2020; where it was delayed mostly by the variety BR 9928- DMRSR LN C1. In 2019, the interval was least in variety Sint Marzoca Larga at 60 kg ha⁻¹ and 120 kg ha⁻¹ N respectively while the corresponding varieties for the least interval for these rates were TZL COMP 1 C6 LN C1 and LA POSTA SEQUIA C6 in 2020. The varietal differences for anthesis-silking interval were not significant in 2019 at N level and in 2020 at 0 kg ha⁻¹ N and 60 kg ha⁻¹ N. Days to 95% maturity were earliest significantly in the check variety in 2019 and in the Acr 97 TZL COMP 1-W LN C1 variety in 2020, when 0 kg ha⁻¹ N was applied. Similar values occurred for this character for all the varieties when 120 kg ha⁻¹ N was applied in 2019, and, also, in 2020.

The application of 60 kg ha⁻¹ N led to similar days to 95% maturity in all the varieties in 2020 but not in 2019, where TZL COMP 1 C6 LN C1 was earliest but the check variety significantly delayed it.

Table 1. Physical and chemical properties of the experimental site prior to field experimentation.

Characteristics	Values
pH in (H ₂ O) 1:1 ratio	4.8
Organic Carbon (g kg ⁻¹)	1.21
Nitrogen (g kg ⁻¹)	0.76
Available P (mg kg ⁻¹)	7.72
Sand (g kg ⁻¹)	81.0
Silt (g kg ⁻¹)	4.0
Clay (g kg ⁻¹)	15.0
Calcium (cmol kg ⁻¹)	1.93
Magnesium (cmol kg ⁻¹)	0.59
Potassium cmol kg ⁻¹)	0.28
Sodium (cmol kg ⁻¹)	0.06
Zinc (m kg ⁻¹)	8.09
Copper (m kg ⁻¹)	4.26
Maganese (m kg ⁻¹)	8.0
Iron (m kg ⁻¹)	135
Textural class	Sandy loam

Table 2. Interactive effects of year, nitrogen rate and variety on days to anthesis, anthesis-silking intervals and days to 95% maturity in low-N maize varieties in Benin City the Nigerian Rainforest.

Variety (V)	Nitrogen rate (N)					
	2019			2020		
	0 kg ha ⁻¹	60 kg ha ⁻¹	120 kg ha ⁻¹	0 kg ha ⁻¹	60 kg ha ⁻¹	120 kg ha ⁻¹
Days to 50% anthesis						
Acr 97 TZL COMP 1-WLN	53.0b	68.3bc	58.0a	64.0a	59.0ab	60.0b

C1						
BR 9928- DMRSR LN C1	57.3b	71.7a	58.7a	65.0a	56.0ab	58.0b
LA POSTA SEQUIA C6	58.3b	67.3ab	58.7a	55.0b	59.5ab	68.0b
TZL COMP 1 C6 LN C1	69.0a	58.3d	57.3a	66.6a	61.0ab	73.5a
Sint Marcoza Larga	66.7a	69.7bc	59.7a	57.0b	72.10a	64.0b
Check	58.0b	60.0d	62.0a	64.5a	60.0ab	65.5b
LSD ($P \leq 0.05$) $Y \times N \times V$	5.878					
Anthesis-silking interval						
Acr 97 TZL COMP 1-WLN C1	5.8b	5.0b	6.0b	5.5b	3.5b	5.0b
BR 9928- DMRSR LN C1	5.7b	4.7b	6.7a	5.5b	4.0b	6.9a
LA POSTA SEQUIA C6	6.6b	4.1b	5.7b	5.0b	4.0b	3.0b
TZL COMP 1 C6 LN C1	6.6b	4.3b	5.7b	4.5b	3.1b	3.5b
Sint Marcoza Larga	6.5b	4.0b	3.7b	5.5b	3.5b	3.5b
Check	9.5a	8.0a	7.3a	10.5a	8.5a	4.0b
LSD ($P \leq 0.05$) $Y \times N \times V$	2.6					
Days to 95% maturity						
Acr 97 TZL COMP 1-WLN C1	88.5b	91.0ab	91.3a	93.5a	93.0a	93.0a
BR 9928- DMRSR LN C1	93.0ab	91.3ab	92.0a	93.0a	89.0a	87.8a
LA POSTA SEQUIA C6	90.0ab	95.7a	91.0a	89.0a	89.0a	93.0a
TZL COMP 1 C6 LN C1	96.7a	88.3c	93.3a	94.5a	91.0a	92.5a
Sint Marcoza Larga	95.0ab	89.7b	92.0a	93.5a	91.5a	90.0a
Check	80.0c	82.0ab	90.2a	92.0a	91.5a	92.0a
LSD ($P \leq 0.05$) $Y \times N \times V$	6.706					
In a column and for a given character, means having similar letter(s) are not significantly different.						

The effect of interaction among years, nitrogen rates, and variety on grain weights, cob lengths and number of grains in low-N tolerant maize for 2019 and 2020 cropping seasons are presented in Table: 3. There was a significant difference in number of grains per cob in responses to nitrogen level of 0 and 60 kg ha⁻¹ respectively in 2019 and 60 kg ha⁻¹ in 2020. Maize variety BR9928- DMRSR LN C1 had the most grains/cob, and the check variety the least grains/cob in response to 0 kg ha⁻¹ N in 2019; the corresponding varieties for these at 60 kg ha⁻¹ N in 2019 were Acr 97 TZL COMP 1-W LN C1 and check respectively. In 2020, most grains/cob were obtained at BR9928- DMRSR LN C1 and the least at Sint Marzoca Larga when 60 kg ha⁻¹ N was applied. In each year, the highest number of grains/cobs occurred at the N level of 60 kg ha⁻¹ and the least was at 0 kg ha⁻¹ N. In each year, the number of grains/cobs were similar among the varieties. Cob length increased significantly among the varieties at nitrogen application rate of 60 kg ha⁻¹ each year while the least value in 2020 was among the varieties that had 0 kg ha⁻¹ N. In each year variety BR9928- DMRSR LN C1 had the highest cob length at 60 kg ha⁻¹ N while the check variety had the least value. Cob length was similar among the varieties for 120 kg ha⁻¹ N in 2019 and 2020 respectively. In each year, grain weight was similar in the six varieties at N rate of 0 kg ha⁻¹. The varieties performed best each year for grain weight at N application of 60 kg ha⁻¹ with BR9928- DMRSR LN C1 having the highest value each year while TZL COMP 1 C6 LN C1 had the lowest values in 2019 and check variety in 2020. Grain weight was least in each variety in 2019 and 2020 when N application rate was 0 kg ha⁻¹.

The effect of interaction among years, nitrogen rates, and variety on stover yield and grain yield in low-N tolerant maize for 2019 and 2020 cropping seasons are presented in Figure 1. Stover yields of the varieties were not significant in each year at 0 kg ha⁻¹ N but significantly differed at 60 kg ha⁻¹ and 120 kg ha⁻¹ in both seasons

respectively. Each year stover yields were highest generally for the varieties at N levels of 60 kg ha⁻¹ and least at 0 kg ha⁻¹. Also, in each year, stover yields were highest at BR9928- DMRSR LN C1 and least at the check variety when 60 kg ha⁻¹ was applied.

Grain yield/ha among the varieties was not significantly different when 0 kg ha⁻¹ N was applied in 2019 but not in 2020 where LA POSTA SEQUIA C6 and Acr 97 TZL COMP 1-W LN C1 had similar values that out yielded other varieties. N application rates of 60 kg ha⁻¹ resulted in the highest grain yield/ha in the varieties, next was 120 kg ha⁻¹ whereas 0 kg ha⁻¹ had the least beneficial effect on the varieties for grain yield/ha. Apart from 0 kg ha⁻¹ N in 2019, the other varying N levels in 2019 and 2020 respectively resulted in significantly different grain yield/ha. In both years, at 60 kg ha⁻¹ N BR9928- DMRSR LN C1 had the highest grain yields among the varieties, and the least was TZL COMP 1 C6 LN C1 in 2019 and the check variety in 2020. The check variety also had the least grain yield/ha at application of 120 kg ha⁻¹ N in 2019, and 0, 60 and 120 kg ha⁻¹ N respectively in 2020.

Table 3. Effects of interaction among year, nitrogen and varieties on number of grains per cob, cob length, grain weight in low-N tolerant maize varieties in Benin forest-zone of Nigeria.

Variety (V)	Nitrogen rate (N)					
	2019			2020		
	0 kg ha ⁻¹	60 kg ha ⁻¹	120 kg ha ⁻¹	0 kg ha ⁻¹	60 kg ha ⁻¹	120 kg ha ⁻¹
Number of grain/cobs						
Acr 97 TZL COMP 1-W LN C1	150.3b	350.6ab	247.9a	255.4a	531.4b	305.2a
BR9928- DMRSR LN C1	259.3a	378.7a	249.5a	262.0a	560.6a	313.3a
LA POSTA SEQUIA C6	201.6ab	374.7a	253.8a	245.8a	490.8c	292.6a
TZL COMP 1 C6 LN C1	155.1b	331.5abc	261.5a	260.7a	496.8c	264.7a
Sint Marzoca Larga	171.1ab	268.0bc	250.2a	258.0a	432.2d	327.6a
Check	150.2b	255.0bc	247.2a	248.0a	472.4d	303.0a
LSD ($P \leq 0.05$) Y × N × V	16.9					
Cob Length						
Acr 97 TZL COMP 1-W LN C1	10.3c	16.3bc	14.3a	11.1c	17.7a	12.7a
BR9928- DMRSR LN C1	11.5b	18.9a	13.7a	12.2ab	18.8a	13.1a
LA POSTA SEQUIA C6	12.8a	17.4ab	15.1a	10.9c	15.3b	11.5a
TZL COMP 1 C6 LN C1	12.9a	14.4c	15.5a	12.1ab	14.7b	12.2a
Sint Marzoca Larga	12.1a	15.1c	14.6a	13.9a	14.5b	12.5a
Check	10.8b	12.7d	14.1a	10.1c	14.4b	11.3a
LSD ($P \leq 0.05$) Y × N × V	1.975					
Grain weight (g)						
Acr 97 TZL COMP 1-W LN C1	27.1a	50.2b	35.8b	23.2a	73.8b	37.7a
BR9928- DMRSR LN C1	25.4a	55.5a	22.0d	25.3a	102.5a	18.0bc
LA POSTA SEQUIA C6	23.9a	48.6b	53.3a	24.3a	63.3b	24.6ab
TZL COMP 1 C6 LN C1	26.5a	28.6b	32.0b	26.1a	45.8c	18.8bc
Sint Marzoca Larga	27.5a	34.9b	44.4a	27.3a	38.3cd	30.3ab
Check	27.1a	46.4b	26.5c	23.3a	27.8d	17.3bc
LSD ($P \leq 0.05$) Y × N × V	8.9					
In a column and for a given character, means having similar letter(s) are not significantly different.						

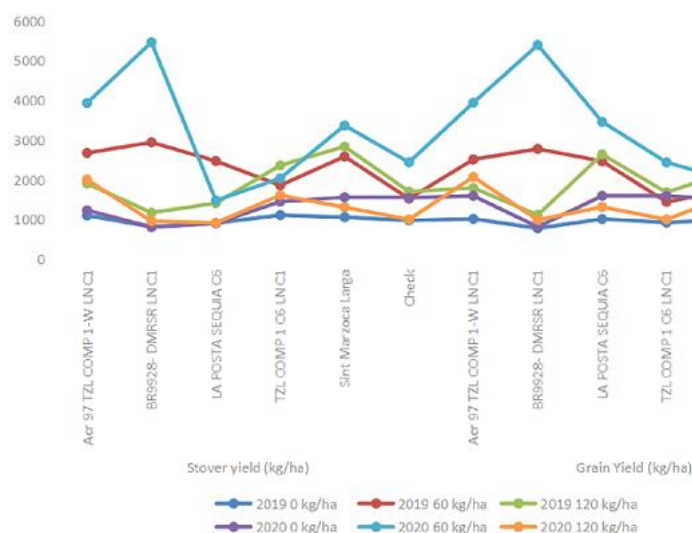


Figure 1. Effects of interaction among year, nitrogen rate and variety on stover yield and grain yield in low-N tolerant maize at Benin City in the Nigerian rainforest in 2019 and 2020 cropping seasons.

The effect of nitrogen rates and maize varieties on nitrogen uptake in stover and grains, and Nitrogen use efficiency are presented in Figure 2 and Figure 3 respectively. Nitrogen uptake in stover and grain was influenced by N rates in 2019 and 2020 cropping seasons. At 0 kg ha⁻¹ N application, the amount of nitrogen uptake in stover for BR9928-DMRSR LN C1, LA POSTA SEQUIA C6, Sint Marzoca Larga and Check were similar in 2019 and significantly lower than the respective values for the other varieties. The trend for uptake of N by stover in 2020 was almost similar to that of 2019 excepting that the values for Sint Marzoca Larga was much higher in 2020. The varieties that resulted in the highest stover N uptake at 0 kg ha⁻¹ N in 2019 also produced a similar trend in grain N uptake. In 2020, grain N uptake was highest in LA POSTA SEQUIA C6 and least in BR9928-DMRSR LN C1 among the low-N tolerant varieties, while the least grain uptake at this 0 kg ha⁻¹ N application was in the check variety and treatment differences were significant.

The amount of N taken up by maize grain and stover (N accumulation) increased at 60 kg ha⁻¹ N compared to 0 kg ha⁻¹ N. There were significant differences in N uptake in stover and grain respectively in 2019 and 2020, with variety BR9928-DMRSR LN C1 having the highest in each maize component while check variety had the least value. Among the low-N tolerant varieties, TZL COMP 1-W LN C1 had the least N uptake for both stover and grain in 2019 while the corresponding varieties for these in 2020 were LA POSTA SEQUIA C6 and Sint Marzoca Larga. The application at 120 kg ha⁻¹ N, a significant difference occurred between the varieties for N uptake in stover and grain components respectively in both years. The highest uptake in the stover component in 2019 was in Sint Marzoca Larga while the least was in BR9928-DMRSR LN C1, and the corresponding varieties for this trend in the grain component were LA POSTA SEQUIA C6 and the check variety respectively. For 2020, the corresponding varieties for this trend in the stover component were TZL COMP 1-W LN C1 and LA POSTA SEQUIA C6 respectively, and, for grain component, LA POSTA SEQUIA C6 and check respectively.

There was significant difference in N use efficiency between the varieties at 60 kg ha⁻¹ and 120 kg ha⁻¹ of nitrogen rate respectively in both stover and grain. The N use efficiency at 60 kg/ha N was much higher in both stover and grains compared to 120

kg ha⁻¹ of N. At 60 kg ha⁻¹, the N use efficiency in both the stover and grain components were highest in BR9928- DMRSR LN C1 in both years whereas the least value was obtained in the TZL COMP 1 C6 LN C1 for the stover component in 2019, and in the check variety for the grain component in 2019, and in the check variety for both components in 2019. Among the low-N tolerant varieties, nitrogen use efficiency for both components was significantly higher in BR9928- DMRSR LN C1 than other varieties each year, whereas the least values for both components occurred in TZL COMP 1 C6 LN C1 in 2019 and, also, stover component in 2020 and in Sint Marzoca Larga in 2020 for the grain components.

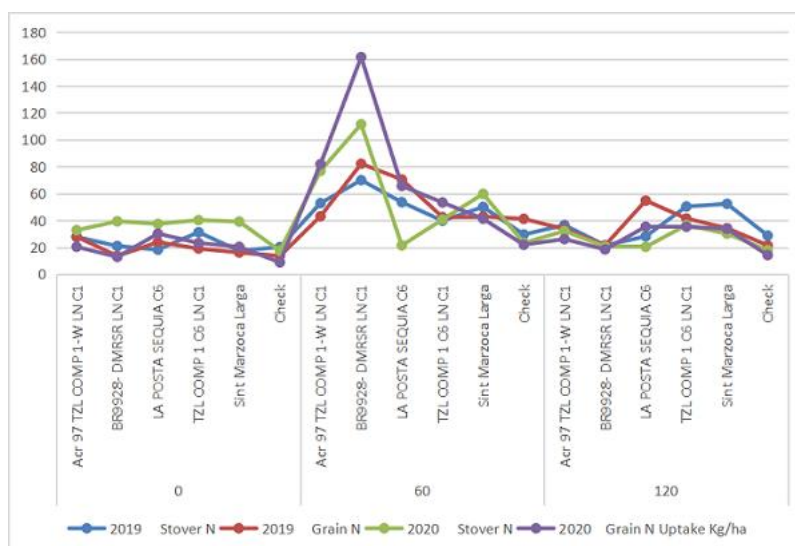


Figure 2. Effects of Nitrogen rate and maize varieties on nitrogen up take in Stover and grains of low-N tolerant maize varieties in Benin city, rainforest-zone of Nigeria.

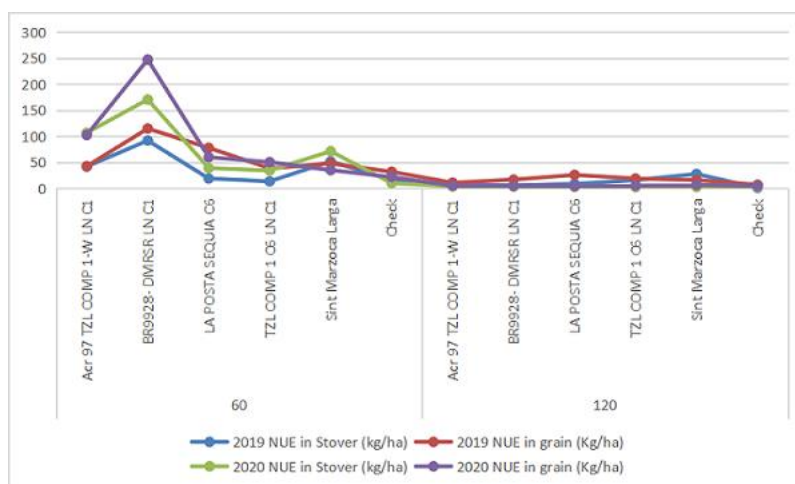


Figure 3. Effects of Nitrogen rate and maize varieties on nitrogen use efficiency in Stover and grain of low-N tolerant maize varieties.

4. Discussion

4.1. Nutrient status of experimental site

The experimental soil was characterized by high acidity and low rate of exchangeable cations that cannot support optimal crop production without the use of soil amendment. The percentage of soil nitrogen was less than 1.50 g kg⁻¹ which is below the critical level for performance of maize crops.

The percentage organic carbon that is important in determining responses to N and P fertilization was equally lower than the critical level of 3%. The percentage of available phosphorous in the soils of the experimental sites falls within average level for most crops; which could explain the reason of low level or poor in essential plant nutrients. The soils were acidic sand with low level of nutrient which is a typical characteristic of an ultisol soil. The findings of this study about the soils agree with [10] who reported that ultisols constitute the main agricultural lands of Southern Nigeria and are deficient in essential plant nutrients and high in acidity. The observation is also in harmony with the findings of Akinmutimi [4], who observed that the ultisols of Southern Nigeria are low in exchangeable calcium, magnesium and potassium. The deficient levels of the major nutrients in the soil of the experimental site were compensated for in those sub-plots treated with inorganic fertilizer during the two cropping seasons.

4.2. Effects of N rates on the flowering of maize varieties and physiological maturity

Anthesis is period during which a flower is fully open and functional, this study showed that the interaction of years, nitrogen rates and varieties ($Y \times N \times V$) significantly affected number of days to 50% anthesis, TZL COMP 1 C6 LN C1 took more days to 50% anthesis (61 days and 66.6 days) at 0 kg ha⁻¹ of nitrogen rates than other varieties in the two cropping seasons. However, when N was added, TZL COMP 1 C6 LN C1 and BR 9928- DMRSR LN C1 recorded lower number of days to 50% anthesis than other varieties in 2019 and 2020 respectively at all N rates. Seyed. *et al.*, [32] also reported that maize crop accumulated 51 days for 50% anthesis when N was applied at the rate of 225 kg N ha⁻¹. In a similar study, Ogundare *et al.*, 2012 conducted an experiment on organic amendment of an ultisol and found that agricultural wastes and mineral fertilizer applications significantly reduced days to 50% anthesis in maize plots treated with poultry manure combined with NPK fertilizer compared with unfertilized plots. Our findings also shows that varieties that took maximum days to attain anthesis attained both silking and physiological maturity later compared to varieties that attained anthesis earlier.

The N stress affected ASI at 0 kg N ha⁻¹ and was reduced with increasing N rates. At 0 kg N ha⁻¹ all cultivars recorded statistically similar ASI except control (check) which recorded longer ASI than the other varieties in both cropping seasons. Varieties that were not treated with fertilizer had longer ASI, especially the control (check) treatment. The shortening of ASI, with increase N application may be due to fertilizer induced early and rapid growth. Golla *et al.*, [21], reported that there will be more synchrony in flowering with higher nitrogen, which was confirmed by a shorter ASI observed in this study. Close synchrony between male and female inflorescence is desirable to improve grain yield and yield components. This study also indicated that the least ASI of 3.7 and 3.0 days were obtained with varieties Sint Marzoca Larga and LA POSTA SEQUIA C6 with the application of 120 kg ha⁻¹ of nitrogen in 2019 and 2020. This aligns with the findings of Gokmen *et al.*, [22], who reported that decrease in ASI occurs with increase in N levels. The higher ASI at 0 kg ha⁻¹ N in this study was evidence of stress as Lafitte and Edmeades [27] and Baenziger *et al.*, found that severe N stress increases ASI in maize.

Days to physiological maturity was delayed at 0 kg ha⁻¹ of N, with TZL COMP 1 C6 LN C1 having more days to physiological maturity in both cropping seasons. The result is in line with 0 kg ha⁻¹ N application rate delaying anthesis longer in this

variety. The prolonged stages of days to maturity are also not in line with Namvar and Seyed Sharifi [32] who reported that increase in N rate significantly delays the duration of vegetative and productive period. However, it agrees at 60 kg ha⁻¹ of N in 2019 and 120 kg ha⁻¹ of N in 2020, where control had higher days to physiological maturity.

4.3. Yield components and grain yield

Yield components are interrelated, have compensatory effects, and develop sequentially at different stages. The first order yield components of maize consist of number of ears/plants, kernels/ear, and 1000-seed weight, while the second order are, number of rows per cob, cob length, ear circumference, number of grains per cob [25]. Number of grain/cobs, grain weight, and cob length were high in this study with the application rate of 60 kg ha⁻¹ N. High values obtained for yield components at application of 60 kg ha⁻¹N resulted in increase in grain yield of maize for those cultivars involved, and BR9928-DMRSR LN C1 consistently recorded the highest value for all yield components which resulted attainment of the highest grain yield in this variety.

The increasing rates of fertilizer in this study did not increase yield of maize varieties in a sequential order, this agreed with the report of Agegnehu *et al.*, [3] who reported that *higher rates of fertilizer* application have not led to *higher crop yields* in both fertile and degraded non-responsive soil. The author found no increase in grain yield of maize with an increase in N levels. However, when N was applied at 60 and 120 kg ha⁻¹ had a significant influence on grain yield and its component during the two cropping seasons compared to plots where fertilizer was not applied. The highest grain yield in each year was obtained with variety BR9928- DMRSR LN C1 from application of 60 kg ha⁻¹ of N and the lowest yield was obtained from application of 0 kg ha⁻¹ of N. The slight decline in yield observed at 120 kg ha⁻¹ may be due to basal application of 60 kg ha⁻¹ of phosphorous to the existing moderate phosphorous in the experimental field. High rate of phosphorous has been reported to cause nutrient imbalance and subsequently depressing crop yield [8]. Reduction in grain yield at 120 kg ha⁻¹ of N could have also been attributed to genotype variations among the cultivars [28] because plant genotypes differ in their response to changing soil fertility and environmental conditions. Similarly, reduction of grain yield at 120 kg ha⁻¹ of N agreed with the findings of Zerihun [37] who reported that nitrogen application greatly affected dry matter production and amount partitioned to the kernels, but there were no additional benefits in application of N above 60 kg ha⁻¹ on grain yield.

4.4. Effects of N rates on N uptake efficiency and N use efficiency of maize varieties

Nitrogen uptake efficiency (NUpE) is the ratio of total N in the plant at maturity over the total N supply to the plant and acts as a measure of how well the plant absorbs available N, including applied N fertilizer. The decrease of N uptake with increasing N application rates in stover and maize grains in both cropping seasons was also reported by Flynn *et al.*, [18] who obtained decreasing nitrogen uptake efficiency with increasing fertilizer N rate per unit area. However, contrary to the result in this study increase in N uptake in maize with increasing N rates has been reported by Abbasi *et al.*, [1]. N uptake was greater at application of 60 kg ha⁻¹ N, and this produced better yield per land area.

NUE has been defined in several ways although most of them denote the ability of a system to convert nitrogen inputs into outputs. It can be also defined as the maximum

economic yield produced per unit of N applied, absorbed, or utilized by the plant to produce grain and straw yields [2]. The results in this study showed that N use efficiency decreased with increasing N application rates. Worku [35] also observed similar result in his study where the N level increases from the minimum rate to high rates, N use efficiency goes up to a point and then declines. Similarly, the results are in agrees with the report of Gheith *et al.*, [20] who also reported that N use efficiency was higher at lower rates of N application but drastically decreased with further increases in N application rate of 336 kg ha⁻¹. Similarly, these results are also in agreement with YONG Tai-wen *et al.*, [36] who reported that Lower N input with an optimized fertilization location for maize-soybean intercropping system (IMS) increased N fixation and N use efficiency without decreasing grain yield. Nitrogen was better utilized at the lower rate 60 kg ha⁻¹ N compared to high rate of 120 kg ha⁻¹ N. This agrees with Shiferaw *et al.*, [34] who also reported that application of high nitrogen rate may result in low nitrogen use efficiency due to excessive N losses and decreased N utilization efficiency. Reduction in N use efficiency may be due genetic variability that is attributed to two multi-factorial components. Genotypes may either differ in the efficiency with which the nutrients in the plant are utilized to produce yield, which is called N utilization efficiency, or they may differ in their effectiveness in absorbing nutrients from the soil, which is called N uptake efficiency.

The five open pollinated varieties performed well with regards to N uptake efficiency at 60 kg ha⁻¹ N compared to zero and 120 kg ha⁻¹ N in both cropping seasons. However, at 60 kg ha⁻¹ N, BR9928-DMRSR LN C1 performed better than any other varieties. Similarly, with regards to N use efficiency at 60 kg ha⁻¹ N the five open pollinated varieties performed well compared to 120 kg ha⁻¹ N in both cropping seasons.

5. Conclusion and Recommendation

The study was carried out to evaluate the agronomic performance of low N-tolerant maize varieties under low soil fertility and N fertilized soil environments; and determine the amount of nitrogen uptake and use efficiency of low N-tolerant maize varieties under native soil fertility and N fertilized soil environments. It was carried out in a Randomized Complete Block Design with a split-plot factorial (3x5) arrangement, and with three replications. Ten parameters were assessed to achieve the objectives of the study- Day to 50% anthesis, anthesis silking interval, 95% days to maturity, number of grains per cob, cob length, grains weight, stover yields, grain yields while Efficiencies of N uptake, and N utilization, in stover and maize grain were calculated according to the formulae developed by Moll *et al* [29]. The results showed high influence of N-application on phenology, grain yield, yield components, N uptake and N use efficiency. The five open pollinated varieties performed well with regards to N uptake efficiency and N use efficiency at 60 kg/ha N compared to zero and 120 kg ha⁻¹ N in both cropping seasons. However, the variety BR9928-DMRSR LN C1 was particularly outstanding for both growth and yields at 60 kg ha⁻¹ N and may be recommended for large-scale demonstration and release to maize farmers in tropical rain forest zone.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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