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# Agronomic response of drought-tolerant and Striga-resistant maize cultivars to nitrogen fertilization in the Nigerian Guinea savannahs

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## Abstract

In additon to drought and *Striga hermonthica* parasitism, nitrogen deficiency is a major constraint to maize production in the Guinea savannahs of Nigeria. The use of mineral fertilizers is limited because of unavailability and high costs. The use of maize cultivars that perform well under sub-optimal N conditons is therefore desirable. Breeders at IITA have selected maize cultivars that combine tolerance to drought and *Striga hermonthica* parasitism. This study evaluated six of these cultivars under a range of N application rates and compared these with a widely grown variety, TZB-SR. The study was conducted in Zaria and Samaru Kataf in Kaduna State of Nigeria. Results showed N application significantly reduced days to flowering and increased yield and yield components. Cultivars selected for combined tolerance to drought and Striga recorded lower number of days to flowering under N stress and higher dry matter, higher grain yield, higher number of grains $m^{-2}$ and higher 500-seed weight at all N rates. This confirms earlier reports that maize cultivars selected for tolerance to drought will perform well under N-limited conditions. Grain yield was significantly associated with dry matter, number of grains $m^{-2}$ and 500-seed weight at all N levels suggesting that these agronomic traits are significant determinants of maize yield at all N rates. Two cultivars (DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W) were particularly outstanding at all added N levels probably due to long term improvement for drought tolerance. These two cultivars can be recommended for large-scale demonstration and release to the farmers in the West African savannas.

**Keywords**: maize cultivars, N rates, grain yield

## Introduction

Nitrogen is the most limiting nutrient in maize production in the savannas of West Africa (WA) (Carsky and Iwuafor, 1995). It is estimated that annual loss of maize yield due to low-N stress varies from 10 to 50% (Wolfe et al, 1988). Nitrogen deficiency in WA is caused by several factors including the leaching of soil N below the root zone due to torrential rainfall (Bennett et al, 1989) poor weed control in farmers' fields (Lafitte and Edmeades, 1994) and the application of sub-optimal levels of inorganic fertilizer due to high prices (Smith et al, 1997) and non-availability of fertilizer. In most cases, less than 20 kg $ha^{-1}$ is applied to maize crops. Kamara et al (2005) and Kamara et al (2009) reported severe yield losses in maize in Nigerian savannas when no nitrogen was applied. In addition to poor soil fertility, intermittent drought during the cropping season and infestation with the parasitic weed *Striga hermonthica* pose severe threats to profitable maize production in the savannas. This means that maize fields in the West African savannas face a complex of biotic and abiotic constraints.

Annual maize yield loss due to drought is estimated to be 15% in West and Centra Africa (WCA) (Edmeades et al, 1995). Grain yield losses can be even greater if the stress coincides with flowering and grain filling period. NeSmith and Ritchie (1992) reported that maize yield can be reduced by as much as 90% if drought stress occurs between a few days before tassel emergence and the beginning of grain filling. Under induced moisture stress from about tassel emergence stage to the end of the crop cycle of maize, Badu-Apraku et al (2005) observed yield reduction of 62% relative to the well-watered treatment. Surveys in the northern Guinea savanna of Nigeria (NGS) showed that Striga has remained a serious problem, attacking millet, sorghum [*Sorghum bicolor* L Moench], maize [*Zea mays* L] and upland rice (Kim et al, 1997; Showemimo et al, 2002). In northern Nigeria, over 85% of fields planted to maize and sorghum were found to be infested with Striga (Dugje et al, 2006). Grain yield losses ranged from 10–100% for these crops as a result of Striga infestation (Lagoke et al, 1991; Oikeh et al, 1996).

The development of maize germplasm with tolerance to low-N is crucial for increased maize productivity (Betrán et al, 2003) and reduced input costs in WCA (Badu-Apraku et al, 2011). This is achieved by

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lowering crop demand for nitrogen through breeding (Smith et al, 1995). This may be done by enhancing the higher utilization of available N either by possessing high uptake efficiency or a more efficient use of absorbed N to produce grain (Lafitte and Edmeades, 1994; Muruli and Paulsen, 1981). The development of maize cultivars with high and stable yields under drought is important since access to drought-adapted genotypes may be the only alternative available to small-scale farmers (Tsai et al, 1984). This does not imply that agronomic interventions that aim to maximize water availability at key growth stages are not critically important, since genetic solutions are unlikely to close more than 30% of the gap between potential and realized yield under water stress (Edmeades et al, 2004). However, improved genetics can be conveniently packaged in a seed and therefore more easily and completely adopted than improved agronomic practices that depend more heavily on input availability, infrastructure, access to markets, and skills in crop and soil management. For any maize to be acceptable to the farmers of the Guinea and Sudan savannas of WCA, it should possess some level of tolerance to Striga. This is because farmers live with the scourge of Striga while drought occurs intermittently. Because of the difficulty in controlling Striga, researchers have recommended a range of component technologies that have been found to be effective in combating the parasite. For instance the use of resistant (reduced parasitism by Striga) or tolerant (reasonable crop yield even with high parasitism) maize varieties, maize–legume rotation using trap crops that stimulate suicidal germination and the application of nitrogen fertilizer can all be effective in reducing infestation and damage (Ellis-Jones et al, 2004; Franke et al, 2006).

Rather than select maize cultivars that are resistant or tolerant to only one of the stresses, researchers of the maize breeding program at IITA have shifted their focus to breeding maize cultivars that have combined tolerance or resistant to drought and Striga (A Menkir, personal communication; Badu-Apraku et al, 2011). Significant progress have been made in developing and disseminating maize cultivars that have combined tolerance to drought and Striga (Kamara et al, 2008; Kamara et al, 2009; Badu-Apraku et al, 2008; Badu-Apraku et al, 2011). There is however, no information on the agronomic performance of these varieties under low nitrogen conditions. The question we seek to answer is whether selection for combined resistance to drought and Striga indirectly confer tolerance of these cultivars to N-deficient conditions. This study had two objectives:

1) Evaluate under a range of N rates, the agronomic performance of some maize cultivars selected for tolerance to drought and Striga;

2) Identify agronomic traits that are associated with maize performance under varying N rates.

## Materials and Methods

### *Experimental site*

Field studies were conducted during the 2010 and 2011 growing season at Samaru-Kataf (9°45'N latitude, 8°22'E, longitude) in the southern Guinea savanna and Zaria (11°11'N latitude, 7°38'E, longitude) in the northern Guinea savanna of Nigeria. The soil in Samaru-Kataf, prior to trial establishment was sandy clay with organic matter of 5.8 g $kg^{-1}$, N 0.4 g $kg^{-1}$, P 17.26 mg $kg^{-1}$, K 0.13 Cmol $kg^{-1}$ and pH of 4.8. The soil at Zaria is sandy loam. Prior to establishment of the trial, the soil had organic matter of 6.7 g $kg^{-1}$, N 0.5 g $kg^{-1}$, P 14.51 mg $kg^{-1}$, K 0.13 Cmol $kg^{-1}$ and pH of 6.1. Rainfall in Samaru-Kataf was 1,904.0 in 2010 and 1,111.1 mm in 2011; rainfall in Zaria was 1,127.0 mm in 2010 and 930.6 mm in 2011.

### *Cultivars used*

A total of seven cultivars were obtained from the breeding program at IITA for use in the study: six cultivars; DT STR SYN-W, DT STR SYN-W/IWD C3 SYN, DT-SR-W C2, DT-SYN-1-W, IWD C3 SYN, IWD C3 SYN/DT-SYN-1-W) are drought and/or Striga tolerant; one (TZB-SR) is a widely grown N-inefficient cultivar. Cultivars DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-I-W derived 50% of their genome from IWD C3 SYN with the remaining 50% of their genome obtained from either DTSTR SYN-W or DT-SYN-I-W

### *Treatments and experimental design*

A split-plot factorial in a randomized complete block design with four replications was used in each location. The main plot treatments consisted of four N fertilization rates (0, 30, 60, and 120 kg N $ha^{-1}$). The subplot treatments were the seven maize cultivars. The subplots were 3 × 5 $m^2$ and consisted of four rows with 0.75 m spacing between rows and 0.25 m within row.

### *Agronomic practices*

The experimental field was disc-harrowed and ridged before planting. Three seeds of the maize cultivars were planted at a depth of 2 to 4 cm. Planting dates in 2010 were 14 June at Samaru-Kataf and 24 June at Zaria. In 2011, planting dates were 13 June at Samaru-Kataf and 25 June at Zaria. At planting, the experiments in the two locations over the two-year period received a basal application of Single Superphosphate SSP at a rate of 50 kg $ha^{-1}$ $P_2O_5$ and Muriate of Potash MOP at the rate of 30 kg $ha^{-1}$ $K_2O$. Urea was used 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, two weeks after planting (WAP). Weeds were controlled by hoe-weeding at three and five WAP.

### *Data collection*

Data were collected from the two middle rows leaving the outside rows and a distance of 50 cm at the ends of each middle row to serve as borders. Days

Table 1 - Probability of F values for agronomic response of drought-tolerant and Striga-resistant maize cultivars to nitrogen fertilization.

| Effect | Days to tasselling | Days to silking | Anthesis silking interval | Number of ears (no. $m^{-2}$) | Number of grains (no. $m^{-2}$) | Total dry matter (g $m^{-2}$) | 500-seed weight (g) | Grain yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Year (Y) | 0.0035 | <.0001 | <.0001 | <.0001 | 0.3155 | <.0001 | <.0001 | <.0001 |
| Location (L) | <.0001 | 0.0012 | <.0001 | 0.162 | <.0001 | <.0001 | <.0001 | <.0001 |
| Y x L | 0.028 | 0.0032 | 0.0257 | 0.1823 | 0.385 | <.0001 | 0.0019 | 0.0663 |
| Nitrogen rate (N) | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| Y x N | 0.4712 | 0.0319 | 0.0003 | 0.066 | <.0001 | <.0001 | 0.0048 | <.0001 |
| L x N | 0.0872 | 0.0038 | 0.0014 | 0.0073 | 0.0721 | 0.032 | 0.0564 | <.0001 |
| Y x L x N | 0.4666 | 0.5544 | 0.3444 | 0.0861 | 0.0111 | 0.0038 | 0.0048 | <.0001 |
| Variety (V) | <.0001 | <.0001 | 0.0012 | 0.0267 | 0.0058 | <.0001 | <.0001 | <.0001 |
| Y x V | 0.9447 | 0.6004 | 0.0723 | 0.8505 | <.0001 | <.0001 | <.0001 | <.0001 |
| L x V | 0.3632 | 0.0434 | 0.007 | 0.2913 | 0.9049 | <.0001 | 0.0038 | <.0001 |
| Y x L x V | 0.1602 | 0.1114 | 0.0215 | 0.7246 | 0.0175 | <.0001 | 0.0215 | 0.0006 |
| N x V | 0.0182 | 0.1582 | 0.2903 | 0.6114 | 0.0083 | 0.0003 | 0.0056 | <.0001 |
| Y x N x V | 0.0246 | 0.0878 | 0.0178 | 0.1906 | 0.0346 | 0.0486 | 0.0002 | 0.0014 |
| L x N x V | 0.3884 | 0.6961 | 0.6265 | 0.0089 | 0.0002 | 0.0021 | 0.1117 | 0.0008 |
| Y x L x N x V | 0.7989 | 0.2336 | 0.0142 | 0.1856 | 0.0351 | <.0001 | 0.0008 | 0.4741 |

from sowing to when 50% of the number of plants per net plot had tassels (anthesis date) and to 50% silk extrusion (silking date) were measured. Anthesis-silking interval (ASI) was calculated as the interval in days between 50% silking and 50% anthesis. At maturity, all the plants in a quadrat measuring 1.875 $m^2$ placed across the two middle rows were harvested for dry matter determination. The samples were separated into leaves, stem, cobs and grain and dried at 60°C for 76 h in a force-draft oven to constant weight. Leaf, stem, cob and grain weight were expressed in g $m^{-2}$. These were used to calculate total dry matter in g $m^{-2}$. The number of ears and number of grains $m^{-2}$ were also measured and calculated. For grain yield determination, plants from the two middle rows excepting the quadrat area were hand-cut at the soil surface. Maize ears were removed, sun-dried for one week and shelled. Grains were weighed and added to those from the quadrat area, and final grain yield was expressed in kg $ha^{-1}$, adjusted to 12% moisture content using Farmex MT-16 grain moisture tester. Mean 500-grain weight was recorded for each plot.

### *Data analysis*

Statistical analysis was performed using SAS for Windows Release 9.2 (SAS Institute, 2008). The SAS procedure used for the ANOVA was mixed model. Replication was treated as a random effect and nitrogen rate and cultivar as fixed effects in determining expected mean square and appropriate F-tests in the ANOVA. Differences between two treatment means were compared with Students't-test based on the standard error of the difference (SED) at 5% level of probability. Pearson's correlation coefficient was used to test for a correlation between grain yield and other variables at each N level using PROC CORR of SAS.

## Results and Discussion

### *Phenology*

Analysis of variance of the two year data showed significant differences among cultivars and N rates for days to tasseling, days to silking, and anthesis-silking interval (ASI) (Table 1). There were several significant interactions among N levels, cultivars, location and year for the phenological traits. For example, there were Y × N and Y × V interactions for some phenological traits but these were mainly due to changes in rankings of cultivars or N levels among the two years. Notable interaction was that of N × V for days to tasseling and dry matter accumulation suggesting that the cultivars responded differently to N application for these two traits. N application did not significantly affect days to tasseling. There were however, significant differences among cultivars at all N rates (Table 2). TZB-SR and DT-SYN-1-W recorded higher number of days to tasseling at 0 kg N $ha^{-1}$ than the other cultivars. When N was added, DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W consistently recorded lower number of days to tasseling at all N rates. Nitrogen stress significantly increased number of days to silking (Table 2). At 0 kg N ha-1, N stress delayed days to silking by 5 days. The cultivars TZB-SR, DT-SYN-1-W and DT STR SYN-W recorded days to silking that were significantly higher than the other cultivars. N stress negatively affected ASI and was reduced with increasing N rates (Table 2). At 0 kg N $ha^{-1}$, all cultivars recorded statistically similar ASI except IWD C3 SYN which recorded ASI higher than the other cultivars. ASI did not significantly differ among cultivars at moderate N rates of 30 and 60 kg N ha. At 120 kg N $ha^{-1}$, DT-SR-WC2 and DT-SYN-1-W recorded lower ASI than the other cultivars. The lack of difference among most cultivars under severe N stress suggests that ASI in these cultivars responded similarly to N stress. The higher mean ASI at 0 kg N $ha^{-1}$ corroborates findings by Baenziger et al (1999) and Lafitte and Edmeades (1994) that severe N stress

Table 2 - Days to tasselling, days to silking and anthesis silking interval in maize cultivars under varying N fertilization.

| | Days to tasselling | | | | | Days to silking | | | | | Anthesis silking interval | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen (kg ha$^{-1}$) | 0 | 30 | 60 | 120 | Mean | 0 | 30 | 60 | 120 | Mean | 0 | 30 | 60 | 120 | Mean |
| Variety | | | | | | | | | | | | | | | |
| DT STR SYN-W | 70.0 | 69.5 | 69.2 | 68.9 | 69.4 | 75.1 | 73.4 | 72.3 | 72.6 | 73.3 | 5.1 | 3.9 | 3.1 | 3.7 | 3.9 |
| DT STR SYN-W/IWD C3 SYN | 69.4 | 67.5 | 67.3 | 67.1 | 67.8 | 74.5 | 71.3 | 70.7 | 70.3 | 71.7 | 5.1 | 3.8 | 3.4 | 3.2 | 3.9 |
| DT-SR-W C2 | 69.6 | 68.1 | 67.1 | 67.7 | 68.1 | 74.6 | 71.6 | 69.9 | 69.3 | 71.4 | 5.0 | 3.5 | 2.8 | 1.7 | 3.3 |
| DT-SYN-1-W | 72.7 | 69.3 | 69.5 | 69.4 | 70.2 | 76.8 | 73.3 | 72.0 | 71.2 | 73.3 | 4.1 | 3.9 | 2.5 | 1.8 | 3.1 |
| IWD C3 SYN | 69.8 | 68.4 | 68.1 | 69.4 | 68.9 | 75.8 | 72.6 | 71.6 | 72.1 | 73.0 | 6.0 | 4.2 | 3.5 | 2.7 | 4.1 |
| IWD C3 SYN/DT-SYN-1-W | 69.3 | 67.1 | 67.2 | 66.6 | 67.5 | 74.6 | 71.3 | 70.5 | 69.2 | 71.4 | 5.3 | 4.3 | 3.3 | 2.6 | 3.9 |
| TZB-SR | 72.8 | 69.1 | 69.2 | 70.7 | 70.4 | 77.3 | 73.2 | 72.8 | 73.2 | 74.1 | 4.5 | 4.1 | 3.7 | 2.5 | 3.7 |
| Mean | 68.5 | 68.2 | 69.4 | 68.4 | | 75.5 | 72.4 | 71.4 | 71.1 | | 5.0 | 4.0 | 3.2 | 2.6 | |
| SED N | 0.35 | | | | | 0.47 | | | | | 0.30 | | | | |
| SED V | 0.32 | | | | | 0.34 | | | | | 0.27 | | | | |
| SED N x V | 0.64 | | | | | 0.67$^{ns}$ | | | | | 0.55$^{ns}$ | | | | |

ns: not significant

increases ASI in maize.

***Yield and yield components***

The ANOVA revealed highly significant differences in dry matter accumulation (DM), yield and yield components among the maize cultivars evaluated under a range of N rates (Table 1). There were significant differences between the two years for number of ears m$^{-2}$, 500-seed weight and grain yield with higher values produced in 2010 than in 2011 (Table 3). Total rainfall was lower in 2011 than in 2010 for both locations which affected crop performance. Crop performance was also better in Zaria than in Samaru-Kataf (Table 3) probably because of the higher soil organic carbon and N in Zaria. There were several interactions among year, location, N rates and cultivar suggesting the cutlvars responded to N application in each location and year. Notable interaction was that of N × V for DM, number of grains m$^{-2}$, 500-seed weight and grain yield.

Total DM m$^{-2}$ significantly increased with increasing rate of N application (Table 4). It ranged from 409 at 0 to 970 g m$^{-2}$ at 120 kg N ha$^{-1}$, an increase of 137%. This result is consistent with earlier findings of Kamara et al (2009) who reported increases in DM with increasing N rates even under Striga infestation. The cultivars TZB-SR and DT STR SYN-W consistently produced DM that was significantly lower than those of the other cultivars at all N rates. When N was added at moderate and higher rates, DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W produced similar and significantly higher DM than those produced by the other cultivars suggesting that they responded better to added N. Under severe stress at 0 kg N ha$^{-1}$, these two cultivars did not differ from most other drought-tolerant cultivars in their DM response but with added N even at 30 kg N ha$^{-1}$, they produced significantly higher DM.

Generally grain yield increased with increasing N rates (Table 5) for all maize cultivars. Averaged over locations, years and cultivars, grain yield was 76% higher at 30, 156% higher at 60, and 203% higher at 120 kg N ha$^{-1}$ than when no N was applied. This confirms that N is a major limiting nutrient in the Nigeria savannas as earlier reported (Kamara et al, 2009; Kamara et al, 2005; Oikeh et al, 2007). At 0 kg N ha$^{-1}$, all the improved drought-tolerant varieties produced grain yield that were significantly higher than the widely-grown TZB-SR. At moderate N rates (30 and 60 kg N ha$^{-1}$), TZB-SR and one drought/Striga tolerant cultivar produced lower grain yield than the other cultivars. At nitrogen rates of 60 and 120 kg N ha$^{-1}$, two cultivars that have combined tolerance to drought and Striga cultivars (DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W) produced grain yield that were higher than the other cultivars suggesting that they respond better to added N than the other cultivars. DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W share a common parent, which is tolerant to both drought and *S. hermonthica*. The second parent of each of these varieties was also formed from drought tolerant maize inbred lines.

The number of ears m$^{-2}$, number of grains m$^{-2}$ and 500-grain weight generally increased with increasing rate of nitrogen (Tables 4 and 5). Significant differ-

Table 3 - Year and location effects on agronomic response of maize cultivars to nitrogen fertilization.

| Effects | Days to tasselling | Days to silking | Anthesis silking interval | Number of ears (n° m$^{-2}$) | Number of grains (n° m$^{-2}$) | Total dry matter (g m$^{-2}$) | 500-seed weight (g) | Grain yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Year | | | | | | | | |
| 2010 | 68.5 | 71.7 | 3.1 | 4.9 | 1187.2 | 865.3 | 118.8 | 3693.4 |
| 2011 | 69.3 | 73.5 | 4.2 | 4.5 | 1141.2 | 574.7 | 90.1 | 2102.3 |
| SED | 0.25 | 0.33 | 0.21 | 0.09 | 45.06 | 10.92 | 1.19 | 79.54 |
| Location | | | | | | | | |
| Samaru-Kataf | 67.8 | 72.0 | 4.2 | 4.8 | 1051.2 | 597.5 | 101.0 | 2553.8 |
| Zaria | 70.0 | 73.2 | 3.2 | 4.6 | 1277.2 | 842.5 | 107.9 | 3242.0 |
| SED | 0.25 | 0.33 | 0.21 | 0.09 | 45.06 | 10.92 | 1.19 | 79.54 |

Table 4 - Days to tasselling, days to silking and anthesis silking interval in maize cultivars under varying N fertilization.

| | Total dry matter ($g\ m^{-2}$) | | | | | Number of ears ($n°\ m^{-2}$) | | | | | Number of grains ($n°\ m^{-2}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen ($kg\ ha^{-1}$) | 0 | 30 | 60 | 120 | Mean | 0 | 30 | 60 | 120 | Mean | 0 | 30 | 60 | 120 | Mean |
| Variety | | | | | | | | | | | | | | | |
| DT STR SYN-W | 378.9 | 565.5 | 716.1 | 851.2 | 627.9 | 3.5 | 4.5 | 4.8 | 4.9 | 4.4 | 824.6 | 971.1 | 1110.5 | 1455.8 | 1090.5 |
| DT STR SYN-W/IWD C3 SYN | 448.4 | 670.6 | 919.1 | 1114.5 | 788.2 | 3.9 | 4.2 | 5 | 5.1 | 4.5 | 758.4 | 1055 | 1338.8 | 1675.5 | 1206.9 |
| DT-SR-W C2 | 410.8 | 661.4 | 898.7 | 997.6 | 742.1 | 4.2 | 4.8 | 5.2 | 5.3 | 4.9 | 702.2 | 1138.3 | 1491.9 | 1667.3 | 1249.9 |
| DT-SYN-1-W | 420.9 | 650.1 | 890.5 | 958.2 | 730 | 4.1 | 4.8 | 5.5 | 5 | 4.9 | 579 | 1274.5 | 1359 | 1430.7 | 1160.8 |
| IWD C3 SYN | 477.6 | 671.1 | 861.7 | 922.1 | 733.1 | 4.3 | 4.8 | 4.9 | 5 | 4.8 | 846.2 | 1014.8 | 1388 | 1503.6 | 1188.1 |
| IWD C3 SYN/DT-SYN-1-W | 390.2 | 712.8 | 922.1 | 1052 | 769.3 | 3.9 | 5 | 5.4 | 5.1 | 4.9 | 547.2 | 1140.4 | 1503.1 | 1639.9 | 1207.6 |
| TZB-SR | 338.8 | 614.4 | 748.9 | 895.5 | 649.4 | 3.7 | 4.4 | 5.2 | 5.4 | 4.7 | 558.9 | 966.9 | 1277.8 | 1379.1 | 1045.7 |
| Mean | 409.4 | 649.4 | 851 | 970.2 | | 3.9 | 4.7 | 5.1 | 5.1 | | 688.1 | 1080.1 | 1352.7 | 1536 | |
| SED N | 15.45 | | | | | 0.13 | | | | | 63.72 | | | | |
| SED V | 18.39 | | | | | 0.16 | | | | | 57.41 | | | | |
| SED N x V | $0.32^{ns}$ | | | | | $0.32^{ns}$ | | | | | 114.82 | | | | |

ns: not significant

ences were detected among the cultivars for all the yield components at all N rates. Average number of ears $m^{-2}$ was lower for TZB-SR and DT STR SYN-W than the other cultivars. Number of grains per $m^{-2}$ increased by 20.5% at 30 kg N $ha^{-1}$ and doubled at 60 and 120 kg N $ha^{-1}$. At 0 kg N $ha^{-1}$, number of grains per $m^{-2}$ was not consistent among the cultivars. TZB-SR, one drought-tolerant cultivar (DT-SYN-1-W) and one that has combined tolerance to drought and Striga (IWD C3 SYN/DT-SYN-1-W) produced lower number of grains per $m^{-2}$. When N was added at 60 and 120 kg N $ha^{-1}$, the cultivars that have combined tolerance to drought and Striga produced higher number of grains per $m^{-2}$ except DT STR SYN-W. Averaged across N rates, DT STR SYN-W/IWD C3 SYN, IWD C3 SYN/DT-SYN-1-W, and DT-SR-W C2 produced higher number of grains per $m^{-2}$ than the other cultivars. N-application significantly increased the 500-seed weight. Wide differences were detected among the cultivars when no N was applied with TZB-SR producing the lowest 500-seed weight. When N was added, other cultivars only produced seed weight that were higher than TZB-SR at 120 kg N $ha^{-1}$ suggesting that the improved cultivars responded better to added N in the savannas. The study showed that all the drought-tolerant and cultivars that had combined tolerance to drought and Striga produced higher dry matter, grain yield and yield components except DT STR SYN-W. The better performance obtained for the drought-tolerant cultivars is consistent with findings of other workers (Lafitte and Edmeades, 1994; Baenziger et al, 1999; Kamara et al, 2005; Badu-Apraku et al, 2011) who reported that maize cultivars selected for tolerance to drought produced higher grain yield in N-deficient environments. They attributed this to the fact that the physiological mechanisms that confer tolerance to drought may be similar to those that confer tolerance to N-deficient conditions. The response of maize to drought is related to the root system development which influences water uptake (Aina and Fapohunda, 1986). Oikeh et al (1999) reported that the widely cultivated maize cultivar, TZB-SR has a poor root system and was therefore more prone to drought than cultivars that had a denser root system. For efficient N-uptake by maize cultivars, early proliferation of roots in the top soil would be required. Kamara et al (2005) reported lower performance of TZB-SR under N-stressed conditions as compared to drought-tolerant cultivars probably due to poor root system. Oikeh et al (2007) also found this cultivar to be N-inefficient. Laffitte and Edmeades (1994) and Kling et al (1996) suggested that cultivar traits such as maximum rooting depth and the capacity of the roots to absorb nutrients enable plants to take up N from different soil layers. Two cultivars, DT STR SYN-W/IWD C3 SYN and IWD C3 SYN/DT-SYN-1-W were particularly superior particularly at moderate to high N rates (30 to 120 kg N $ha^{-1}$) in terms of DM production, grain yield, number of grains $m^{-2}$, and 500-seed weight. These two cultivars have combined tolerance to drought and Striga. Although drought-tolerance is linked to tolerance to low-N conditions, it

Table 5 - Maize grain yield and 500-seed weight as affected by N-fertilization in the Nigerian Guinea savannas.

| | 500-seed weight (g) | | | | | Grain yield ($kg\ ha^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Nitrogen ($kg\ ha^{-1}$) | 0 | 30 | 60 | 120 | Mean | 0 | 30 | 60 | 120 | Mean |
| Variety | | | | | | | | | | |
| DT STR SYN-W | 93.8 | 98.3 | 106.2 | 108.4 | 101.7 | 1307.8 | 2039.6 | 3011.8 | 3146.2 | 2376.3 |
| DT STR SYN-W/IWD C3 SYN | 89.6 | 108.2 | 104.3 | 112.3 | 103.6 | 1568.6 | 2761.4 | 4013.7 | 4904.4 | 3312.0 |
| DT-SR-W C2 | 94.3 | 103.3 | 107.5 | 114.7 | 104.9 | 1405.6 | 2596.9 | 3805.0 | 4678.7 | 3121.6 |
| DT-SYN-1-W | 97.2 | 109.4 | 115.6 | 122.5 | 111.2 | 1360.5 | 2466.5 | 3492.4 | 3949.4 | 2817.2 |
| IWD C3 SYN | 98.8 | 110.3 | 107.8 | 113.5 | 107.6 | 1688.4 | 2560.3 | 3429.8 | 4409.6 | 3022.0 |
| IWD C3 SYN/DT-SYN-1-W | 91.5 | 103.4 | 117.3 | 114.5 | 106.7 | 1526.9 | 2759.7 | 4224.9 | 5031.7 | 3385.8 |
| TZB-SR | 83.6 | 90.1 | 102.6 | 104.9 | 95.3 | 849.4 | 1938.0 | 2893.9 | 3319.0 | 2250.1 |
| Mean | 92.7 | 103.3 | 108.8 | 113.0 | | 1386.7 | 2446.0 | 3553.1 | 4205.6 | |
| SED N | 1.68 | | | | | 112.48 | | | | |
| SED V | 1.70 | | | | | 96.10 | | | | |
| SED N x V | 3.57 | | | | | 192.20 | | | | |

Table 6 - Correlation of agronomic trait with grain yield at each nitrogen rate.

| Characters | Nitrogen rate (kg ha$^{-1}$) 0 | 30 | 60 | 120 |
|---|---|---|---|---|
| Days to tasselling | -0.74 | -0.83 | -0.84 | -0.81 |
| P value | 0.0587 | 0.0205 | 0.019 | 0.0276 |
| Days to silking | -0.65 | -0.83 | -0.88 | -0.87 |
| P value | 0.1137 | 0.021 | 0.0086 | 0.0109 |
| Anthesis silking interval | 0.66 | -0.06 | -0.17 | -0.27 |
| P value | 0.1054 | 0.8933 | 0.7154 | 0.5636 |
| Ear number (m$^{-2}$) | 0.57 | 0.35 | 0.36 | 0.06 |
| P value | 0.1836 | 0.4349 | 0.4238 | 0.9033 |
| Grain number (m$^{-2}$) | 0.50 | 0.53 | 0.77 | 0.88 |
| P value | 0.2578 | 0.2169 | 0.0444 | 0.0088 |
| 500-Grain-weight | 0.71 | 0.79 | 0.51 | 0.45 |
| P value | 0.0768 | 0.0353 | 0.2385 | 0.3091 |
| Total dry matter (g m$^{-2}$) | 0.87 | 0.88 | 0.91 | 0.88 |
| P value | 0.0101 | 0.0084 | 0.0041 | 0.0082 |

is not clear whether cultivars selected for tolerance/resistance only to Striga are tolerance to low-N conditions. Further studies on performance of Striga-tolerance maize cultivars to low-nitrogen conditions may therefore be recommended.

### *Correlation of all parameters with yield at each N rate*

Under severe N stress at 0 kg N ha$^{-1}$, days to tasseling (r = - 0.74), 500-seed weight (r = 0.71), and total DM (r = 0.87) were the only traits that were significantly associated with maize grain yield (Table 6). As would be expected, days to silking and ASI are important traits that influences maize yield under severe N stress (Edmeades et al, 2004; Baenziger et al, 1999) but in this study, these traits did not significantly influence grain yield. This is because there were no wide differences between the cultivars under this severe N level. When N was added, days to tasseling and days to silking were negatively correlated with grain yield. Total DM and 500-seed weight were positively correlated with grain yield at 30 kg N ha$^{-1}$. Days to tasseling, days to silking, grain number m$^{-2}$, and DM significantly influenced grain yield at 60 and 120 kg N ha$^{-1}$.

### *Conclusion*

The study revealed that N is a major limiting nutrient in the savannas as shown by the significant yield reduction under low N conditions. There was consistent yield increases with increasing application of N. Most of the cultivars selected for combined tolerance to drought and Striga performed better under low and high nitrogen conditions than the widely used TZB-SR. This confirmed earlier findings that drought-tolerant maize cultivars are also tolerant of low-N conditions. This is particular important for the West African savannas where soils are poor in N and access to fertilizer is limited. Two cultviars were particularly outstanding at all added N levels probably due to long term improvement for drought tolerance. These two cultivars can be recommended for large-scale demonstration and release to the farmers in the West African savannas. It is not clear whether cultivars selected for tolerance/resistance to only Striga are also tolerance to low-N conditions because all the Striga-resistant/tolerant cultivars evaluated in this study were also tolerant to drought. Further studies on the response of Striga-resistant/tolerant maize cultivars to N are therefore recommended.

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