# Nitrogen Use Efficiency of Maize Genotypes Improved for Tolerance to Low Nitrogen and Drought Stress

***Alpha Yaya Kamara, Abebe Menkir, and Nteranya Sanginga***

International Institute of Tropical Agriculture, Ibadan, Nigeria
E-mail: A.Kamara@cgiar.org

## Introduction

In the past two decades, maize has spread rapidly into the savannas, replacing traditional cereal crops such as sorghum and millet; particularly in areas with good access to fertilizer inputs and markets (CIMMYT, 1996). In the West African moist savannas, higher radiation levels, lower night temperatures, and reduced incidence of disease and insect pests have helped to increase maize yield potentials in comparison with the traditional area for maize cultivation (Kassam et al., 1975). Soils in the savanna are mainly kaolinitic Alfisols that are low in organic matter and cation exchange capacity (Carsky and Iwuafor, 1995). Nitrogen is the most limiting nutrient in maize production in the savannas of West and Central Africa (Carsky and Iwuafor, 1995). Originally, resource-poor farmers relied on shifting cultivation or bush fallow for soil fertility maintenance. However, because of increasing population pressure, there is an intensification of land use. As a result, nutrients and organic matter in the soil are depleted and crop yields steadily decrease. Land-use intensification is only feasible if the nutrients depleted during cultivation are replenished.

Due to high cost and scarcity of supply, inorganic fertilizer use in sub-saharan Africa is generally limited. Average rates of fertilizer use in Nigeria are about 12 kg nutrients/ha of arable land and figures for other West African countries are lower (FAO, 1992). Farmers in the savanna zone of northern Nigeria often apply greater amounts of nitrogen fertilizer and organic manure because they recognise that they cannot grow maize without organic and inorganic nutrient inputs (Kling et al., 1996). However, in addition to cost, poor transportation and marketing infrastructure have often made fertilizer unavailable to the farmers. Also, heavy long term use will aggravate the acidifying effects of these fertilizers (Juo and Mano, 1996).

Two basic approaches can be taken to improve maize productivity in a sustainable fashion in areas with low nitrogen fertility. First, innovative agronomic practices can be developed to make better use of nitrogen from organic matter and nitrogen inputs from biological fixation and atmospheric deposition. The second approach would be to lower crop demand for nitrogen through breeding (Smith et al., 1994). This approach could help address productivity limitations in nitrogen-poor areas, and may help reduce reliance on synthetic nitrogen fertilizers. One strategy for improving the productivity of maize under suboptimal N fertility is to use the second approach of selecting for low N tolerance. In combination with the first approach, this will lead to high maize yields in the savanna. Cultivars have been identified that are less responsive to applied N and these sometimes perform better at low N than do N-responsive hybrids or cultivars (Pollmer et al., 1979). The low N tolerant cultivars are superior in the utilization of available N, either due to enhanced uptake capacity or because of more efficient use of absorbed N in grain production (Laffitte and Edmeades, 1994). N-use efficiency (NUE) is defined as grain production per unit of N available in the soil (Moll et al., 1982). There are two primary components of NUE, the efficiency of absorption (uptake) and the efficiency with which the N absorbed is utilized to produce grain. Efficiency in uptake and utilization of N in the production of grain requires that those processes associated with absorption, translocation, assimilation, and redistribution of N operate effectively (Moll et al., 1982). The relative contributions of these processes to genotypic differences in NUE vary among genetic populations and among environments.

Studies have been conducted at IITA to:

1. Determine the potential for breeding maize with greater NUE,
2. Characterize the N response of elite populations, inbred lines and hybrids.
3. Identify secondary traits associated with tolerance to low-N stress.

This paper presents the results of one of the experiments in which elite maize cultivars and hybrids were evaluated for tolerance to low-N stress and to identify mechanisms for low N tolerance.

## Materials and methods

Field studies were conducted during the 2000 and 2001 growing season at Samaru ($11^{o}$ 11'N latitude, $7^{o}$ $38^{'}$ E, longitude) representing the northern Guinea savanna agro-ecological zones of West Africa. The site had a mean annual rainfall of 1055 mm and the soils can be described as Alfisols..

Ten open-pollinated improved varieties (OPV) and one hybrid were used in the experiments. The 11 maize genotypes were grown at three N levels. Three separate experiments representing each N level were conducted. All experiments were arranged as randomized complete block designs with three replications. Tillage consisted of plowing, harrowing and ridging with spacing between ridges of 0.75 m. Each plot consisted of four 5 m long rows with 25 cm between plants to give a plant density of 53,333 plants $ha^{-1}$. Two maize seeds were sown per hole and later thinned to one at 2 weeks after sowing (WAS).

One-half of the nitrogen as calcium ammonium nitrate (26%) was applied at sowing, while the remaining half was top-dressed 4 weeks later. The N rates were 0, 30, and 90 kg N $ha^{-1}$. Phosphorus and potassium were applied basally at the rate of 60 kg $ha^{-1}$ of each nutrient. At maturity, four representative plants were harvested. The samples were separated into leaves, stem, and grain and dried for 48 h at $75^{o}$ C in a force-draft oven to constant weight. The samples were analyzed for total N content using the autoanalyzer. N-uptake was determined by multiplying dry weight of plant parts by N concentration and summing over parts for total plant uptake. Efficiencies of N-uptake, N utilization and N-use were calculated according to Moll *et al.,* (1982) as follows.

$$\text{N-uptake efficiency} = \frac{\text{N (g } N_t\text{) at N rate applied - N (g } N_t\text{) at 0 kg N ha}^{-1}}{\text{N applied (g } N_f\text{)}}$$

$$\text{N-utilization efficiency} = \frac{\text{Grain yield (g/plant) at N rate applied – grain yield at 0 kg N ha}^{-1}}{\text{N (g } N_t\text{) at N rate applied - N (g } N_t\text{) at 0 kg N ha}^{-1}}$$

$$\text{NUE} = \frac{\text{Grain yield (g/plant) at N rate applied – grain yield at 0 kg N ha}^{-1}}{\text{N applied (g } N_f\text{)}}$$

Where g Nt = total N in above ground biomass

g Nf = Amount of N applied.

Statistical analysis were performed using SAS for Windows Release 6.12 (SAS Institute, 1997). The SAS procedures used for the ANOVA and normalitys were GLM (general linear model) and UNIVARIATE, respectively. Protected ANOVA LSD tests were used to assess the differences between means (Steel and Torrie, 1980).

## Results and discussions

Significant differences occurred among cultivars for grain yield and N accumulation parameters. Figure 1 illustrates the mean grain yield at each N level. Yield reduction under 0 kg N ha$^{-1}$ in comparison to 90-kg N ha$^{-1}$ treatment ranged from 77 to 96%. Only TZUT recorded lower maize yield than the others. However, significant differences were observed at sub-optimal N levels. At 0 kg N ha$^{-1}$, most genotypes recorded yield lower than 1 Mg ha$^{-1}$ except AC8328C7, DTSR-WC0, LNPC2, and STREV-IWD which recorded yields between 1and 1.5 Mg. At 30 kg N ha$^{-1}$, there were significant increases in grain yield of some genotypes relative to that of 0 kg N ha$^{-1}$. Grain yield of some genotypes which were N-efficient ranged from 2.5 to 3.5 Mg ha$^{-1}$. DTSR-WC0, AC8328C7, DTSR-Y, LNPC2, LNCP3, LNTP, Oba Super 2, and STREV-IWD recorded higher grain yields at this N level. The lowest grain yield was recorded by TZB-SR.

Differences among cultivars were observed at each N level for NUE, N-uptake efficiency, and N-utilization efficiency. While N-uptake efficiency was higher at 90 kg N ha$^{-1}$, NUE and N-utilization efficiency for most genotypes were higher at 30 kg N ha$^{-1}$. Among all the cultivars, DTSR-WC0 was the most efficient in terms of N uptake at 30 kg N ha$^{-1}$. This genotype also had N utilization efficiency comparable to the most efficient lines at this N level. Two genotypes (LNPC3, LNTP) had high N-uptake efficiency at 90 kg N ha$^{-1}$ and high N-utilization efficiency at 30 kg N ha$^{-1}$. Two other genotypes (ACR8382C7 and STR-EV-IWD) had high N-uptake and utilization efficiency at 30 kg N ha$^{-1}$. TZB-SR performed well only at 90 kg N ha$^{-1}$. At 30 kg N ha$^{-1}$, this genotype recorded lower values for all N component parameters.

In this study, the response of the genotypes to low N stress could be divided into three. The first group showed high N-uptake efficiency, the second showed high Nutlization efficiency while one genotype recorded low N-uptake efficiency, low N-utilization efficiency and low NUE. The hybrid Oba super 2 recorded yield simliar to N-efficient OPV under suboptimal N levels. This is in contrast with findings from Akintoye et al. (1999), where N uptake and utilization in hybrids were higher than in OPV. DTSR-WC0 had the highest yield advantage under low-N stress. This conclusion is based on yield calculations at 0 and 30 kg N ha$^{-1}$. However, because of the very low yields of LNTP and LNPC3 at 0 kg N ha$^{-1}$, NUE in these genotypes was higher than that of DTSR-WC0. Some genotypes performed well under low-N conditions because of high N-uptake efficiency while others were more efficient in utilizing the N taken up to produce grain. The differences in N-uptake, N utilization efficiency and NUE of the genotypes studied may be due to several factors. According to Jackson *et al.* (1986), these factors may include root morphology and extension and biochemical and physiological mechanisms in nitrate assimilation and use. Laffitte and Edmeades, (1994); Kling et al., (1996) also 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. Efficiency of N uptake and N utilization in the production of grain requires that those processes associated with absorption, translocation, assimilation and redistribution of N operate efficiently (Moll *et al.,* 1982). Significant and consistent differences have been reported in the accumulation and distribution of N to various plant parts among maize lines (Chevalier and Schrader, 1977; Pollmer *et al*., 1979, Muruli and Paulsen, 1981). Our results also indicated that the drought tolerant genotypes DTSR-WC0 and STREV-IWD were as tolerant to low-N as those maize genotypes (ACR8328C7, LNPC2, LNPC3 and LNTP) that have been improved for low N-tolerance. Baenzinger et al. (1999) reported similar results where they showed that drought-tolerant selections of maize genotypes, increased biomass and N accumulation at maturity, the changes being largest under severe N stress. Additionally, drought-tolerant selection cycles were associated with delayed leaf senescence and an increased or unchanged N harvest index, indicating that leaf N was used more efficiently for grain production. Selection for tolerance to midseason drought stress appeared to increase grain yield across a range of N-stress levels and may lead to morphological and physiological changes that are of particular advantage under N stress. This may mean that selecting for tolerance to drought may simultaneously confer tolerance to low-N stress. Also, because both N-uptake efficiency (Laffitte and Edmeades, 1994) and N-utilization efficiency (Moll et al., 1982) are important in improving the tolerance of maize genotypes to low N stress, these traits should be considered while breeding for tolerance to low-N stress.

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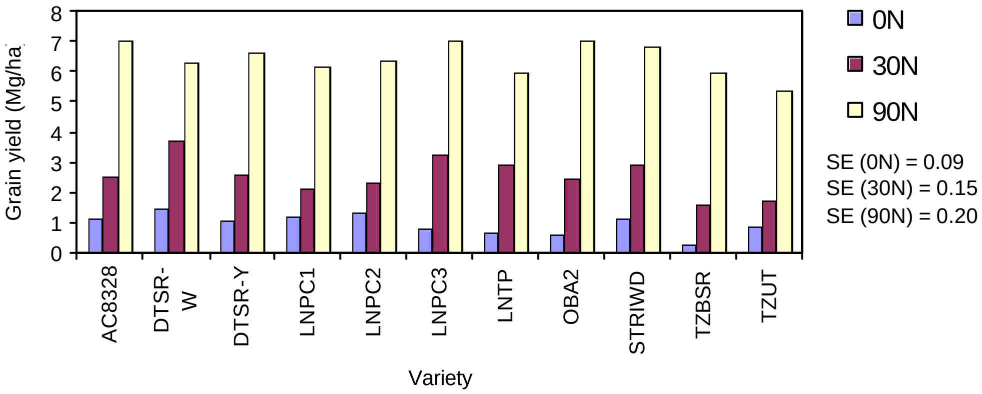

Figure 1 Grain yield of maize genotypes at 3 nitrogen levels

**Table 1. Nitrogen use efficiency and component traits as affected by nitrogen rates and maize genotypes.**

| Variety | N-Uptake Efficiency | | N-Utilization Efficiency | | N-Use Efficiency | |
|---|---|---|---|---|---|---|
| | 30 kg N ha$^{-1}$ | 90 kg N ha$^{-1}$ | 30 kg N ha$^{-1}$ | 90 kg N ha$^{-1}$ | 30 kg N ha$^{-1}$ | 90 kg N ha$^{-1}$ |
| ACR8328C7 | 0.75 | 1.55 | 77.54 | 47.77 | 73.40 | 62.85 |
| DTSRW-CO | 1.06 | 1.31 | 96.00 | 49.31 | 73.65 | 51.75 |
| LNPC1 | 0.33 | 1.33 | 139.94 | 49.38 | 43.25 | 58.60 |
| LNPC2 | 0.40 | 1.37 | 78.48 | 43.60 | 44.50 | 63.70 |
| LNPC3 | 0.94 | 1.92 | 98.78 | 42.49 | 88.50 | 71.55 |
| LNTP | 0.86 | 1.55 | 87.71 | 44.05 | 74.90 | 52.30 |
| STREV-IWD | 0.78 | 1.31 | 100.17 | 49.53 | 65.95 | 66.30 |
| TZB | 0.68 | 1.35 | 69.09 | 50.53 | 43.70 | 64.35 |
| **SE** | **0.09** | **0.07** | **7.73** | **1.13** | **6.16** | **2.42** |