Nitrogen-use Efficiency of Maize Genotypes under Weed Pressure in a Tropical Alfisol in Northern Nigeria

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Key words: Nitrogen-use efficiency- Nitrogen-uptake- Nitrogen application- Tropical alfisol and low N tolerant maize- Nigeria

Summary

*A split - split plot experiment in a randomized complete block design with three replicates was established at Samaru (Typic Haplustalf) in 2002 and 2003 rainy seasons to investigate the response of four low nitrogen tolerant maize (*Zea mays *L.) cultivars (Oba super II, Low N pool C2, TZB-SR and ACR 8328 BN C7) to nitrogen fertilizer and weed pressure. Maize grain yield, nitrogen-uptake, utilization and use efficiency were significantly higher in Oba super II and Low N pool C2 followed by ACR 8328 BN C 7 and least in TZB -SR. At the application rate of 90 kg N.ha^{-1}, 68 kg N.ha^{-1} were recovered in maize shoot while weeds uptake of N was 15.98 kg.ha^{-1}. With the application of 30 kg N.ha^{1}, weed uptake was 28.38 while maize shoot uptake was 23.35 kg N.ha^{-1}. Generally, fertilizer addition enhanced the competitive ability of maize. The nitrogen-use efficiency of the maize genotypes was reduced due to weed interference while there were no differences in the residual soil nitrate among nitrogen rates and genotypes, partly due to the morphology of the site.*

Résumé

Efficacité d'utilisation de l'azote par des génotypes du maïs en présence de mauvaises herbes dans un alfisol tropical dans le nord du Nigeria

*Un essai visant à étudier le comportement de quatre cultivars de maïs (*Zea mays *L.), tolérants à une faible fertilisation azotée, lorsqu'ils sont semés en présence de mauvaises herbes avec différentes doses d'engrais azotés a été réalisé selon un dispositif expérimental en blocs aléatoires avec parcelles divisées et trois répétitions dans la région de Samaru (Typic Haplustalf) durant les saisons pluvieuses de 2002 et de 2003. Les cultivars de maïs testés étaient Oba super II, Low N pool C2, TZB-SR et ACR 8328 BN C7. Le rendement en grains; l'absorption, l'utilisation et l'efficacité de l'azote étaient significativement supérieurs (p< 0,01) pour les cultivars Oba super II et Low N pool C2. Pour les mêmes paramètres, le cultivar ACR 8328 BN C7 se classait après ceux-ci alors que la variété TZB-SR venait en dernière position. En cas d'application d'une dose de 90 kg N.ha^{-1}, on a observé un prélèvement de 68 kg N.ha^{-1} par les plantes de maïs et de 15,98 kg N. ha^{-1} par les adventices. Pour la dose de 30 kg N.ha^{-1}, la quantité d'N prélevée par les mauvaises herbes s'élevait à 23,38 kg. ha^{-1} tandis que le prélèvement des plantes de maïs en N atteignant 23,25 kg.ha^{-1}. En général, l'apport d'azote a amélioré la compétitivité du maïs. L'efficacité d'utilisation de l'azote par les génotypes de maïs a été réduite du fait de la concurrence des mauvaises herbes. Aucune différence significative n'a été observée pour la teneur résiduelle en nitrates dans le sol; sans doute partiellement à cause du relief du site d'essai.*

Introduction

West Africa soils are fragile, predominantly of kaolinitic clays with low effective cation exchange capacity (ECEC) and low plant nutrients (5, 11). Tropical climates are characterized by high rainfall and insolation. The attendant problems of nutrient leaching and low level of soil organic matter has made N the most limiting nutrient to maize production in Nigeria (1, 5). This has encouraged the excessive use of organic fertilizers above the amount recommended particularly in the savanna zone of Nigeria (12).

The prolonged and excessive use of nitrogen fertilizers on the other hand has led to the acidification of the soil (10) and is implied for nitrate leaching and environmental pollution (2).

Maize (*Zea mays* L.) is the dominant cereal crop grown in Nigeria. Despite the widespread cultivation and numerous scientific efforts geared towards increasing maize yields, production by farmers is still low. This is attributed to the low soil fertility, problems of soil fertility management and high cost of farm inputs like herbicides. Maize farmers in the tropics are mostly resource poor, practising subsistence farming. Weed management is a major component of maize production (23); it is labour intensive (19) and accomplished primarily by hand weeding. This takes a substantial part of their time (3) and sometimes costlier than they can afford (23).

One probable means of reducing herbicide use and high cost of maize production is by growing maize hybrids that

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compete more effectively against weeds for light, nutrients and water. This is aimed at preventing environmental contamination occasioned by herbicide use while increasing the crop yield. In a bid to alleviate the problem of soil fertility and its management in maize production, breeders have developed maize cultivars that are relatively more efficient in nitrogen-uptake from the soil or with high nitrogen use efficiency.

These potential competitive maize cultivars can prevent the occurrence or slow the increase of herbicides-resistant weed population in maize. It will also offer the opportunity of maximizing farmers profit while providing effective weed control at minimal cost. This is particularly important because farmers in developing countries are resource poor and hence need cheap weed control systems like the use of competitive cultivars. These cultivars have been bred and tested under weed-free conditions. Hence, before any reasonable conclusion could be drawn on their suitability to effectively adapt to low nitrogen soils and their ability to perform in a 'low input' production system like no herbicide application, the nitrogen use efficiency of these cultivars need to be tested under some levels of weed competition. This is to ascertain their superiority or otherwise in the uptake and utilization of nitrogen as compared to weeds.

The objectives of this study therefore are to quantify the amount of nitrogen-uptake by low nitrogen tolerant maize and weeds and to evaluate the nitrogen-use efficiency of maize genotypes under weed pressures.

Materials and methods

Field experiments were conducted in 2002 and in 2003 rainy seasons at Samaru (11^0 11' N, 07^0 38' E altitude of 686 m) which is representative of the northern Guinea savanna agro ecological zone of West Africa. The selected site at Samaru has been depleted of their fertility. The soil of the site is described as alfisol. Mean annual rainfall of 1055 mm. The land is prepared by ploughing, harrowing and ridging. The experimental design was a randomized complete block in a split-split plot arrangement with three replications. The treatments were:

Main plots - Two levels of weed pressure, which were: - No weed pressure, (weekly weeding), and high weed pressure (not weeded throughout the growing season).

The subplot was three nitrogen levels: 0, 30, and 90 kg N.ha$^{-1.}$ They were applied in two equal splits as urea (46% N) at two and six weeks after planting by side placement. Phosphorus and Potassium were applied at 15 kg P.ha^{-1} as triple – super phosphate (46% P_2O_5) and 30 kg K.ha^{-1} as muriate of potash (60% K_2O), respectively. Both were applied to the entire experimental plots. Four maize genotypes constituted the sub- sub plot, they included:

1) Oba Super II (Commercial nitrogen tolerant variety with high utilization efficiency).
2) Low N pool C2 (Open pollinated variety for low nitrogen conditions, both high nitrogen uptake and high utilization efficiency).
3) TZB-SR (Susceptible to nitrogen stress) and
4) ACR 8328 BN C7 (Variety improved at CIMMYT for low nitrogen tolerance and high utilization efficiency).

All cultivars were sourced from the International Institute of Tropical Agriculture (IITA) Ibadan. To each plot of dimension 3 m x 8 m, two maize seeds were sown per hole and later thinned to one at 2 weeks after planting (WAP) at a distance of 25 cm x 75 cm giving a plant population of 53,333 stands per hectare. At harvest, 16 plants, (2 m) were taken from each plot from two center rows, the cobs were weighed. They were latter shelled, the weight of the grains were taken with the corresponding moisture content measured using Dickey-John moisture meter (Dickey-John *Corporation Auburn, IL. 62615 USA).* The grain weight was then corrected to 12% moisture content. Stovers from the 16 plants were weighed with a hanging balance. A subset of 4 plants was also weighed and later separated into leaves and stem. The leaf and stem was oven dried for 48 hours at 70 °C in the laboratory. The dry weight was taken on a scale (Denver Instrument Company Model XD4k). Weed dry matter yield was taken by using a 1 m x 0.3 m quadrat from areas where maize cobs were harvested, cut at ground level, oven dried at 70 °C for 48 hours and weighed. Dried maize grains, leaf, stem and weed samples from the treatments were milled; the nitrogen was determined by Kjeldahl digestion, while the nitrogen content was determined with the use of Technicon auto-analyzer. Efficiencies of nitrogen-uptake, utilization and use were calculated according to Moll *et al.* (14) as follows:

$$\text{N-uptake efficiency} = \frac{\text{Total nitrogen in plant at maturity}}{\text{Quantity of nitrogen applied}}$$

$$\text{N-utilization efficiency} = \frac{\text{Grain dry matter}}{\text{Nitrogen in above ground part}}$$

$$\text{N-use efficiency} = \frac{\text{Grain yield}}{\text{N applied}}$$

The residual soil nitrate was taken at crop harvest. Soil samples were taken randomly at a depth of 0-20 cm in each plot. Composite samples were then extracted with 2 Normal KCl measured by steam distillation with MgO and Devarda's alloy (16) and determined with an autoanalyser. Data generated was analysed using the General Linear Model procedure (GLM); Statistical Analysis systems Package (SAS) (21). Differences between treatments and their interactions were compared using Standard Errors of the Means and LSD***.***

Results and discussion

Figure 1 shows that there were significant increases in grain yields of maize genotypes with increase in N rates. Low N pool C2 and Oba super II had higher yield compared to other genotypes at all the N levels.

TZB-SR-SR had the lowest grain yield. Generally, yield reduction under 0 kg N /ha in comparison to 90 kg N /ha ranged from 79% in Low N pool C2 to 83% in TZB-SR.

At 90 kg N/ha, the yield ranged from 2.80 tons /ha in ZB-SR to 3.93 tons /ha in Low N pool C2. Overall lowest yield of 0.48 tons /ha was observed in TZB-SR at the control plots (0 kg N /ha) while yield at 30 kg N /ha ranged from 0.99 tons/ ha in ACR 8328 BN C7 to 1.28 tons /ha in Low N pool C2. The positive response observed in maize yield due to N

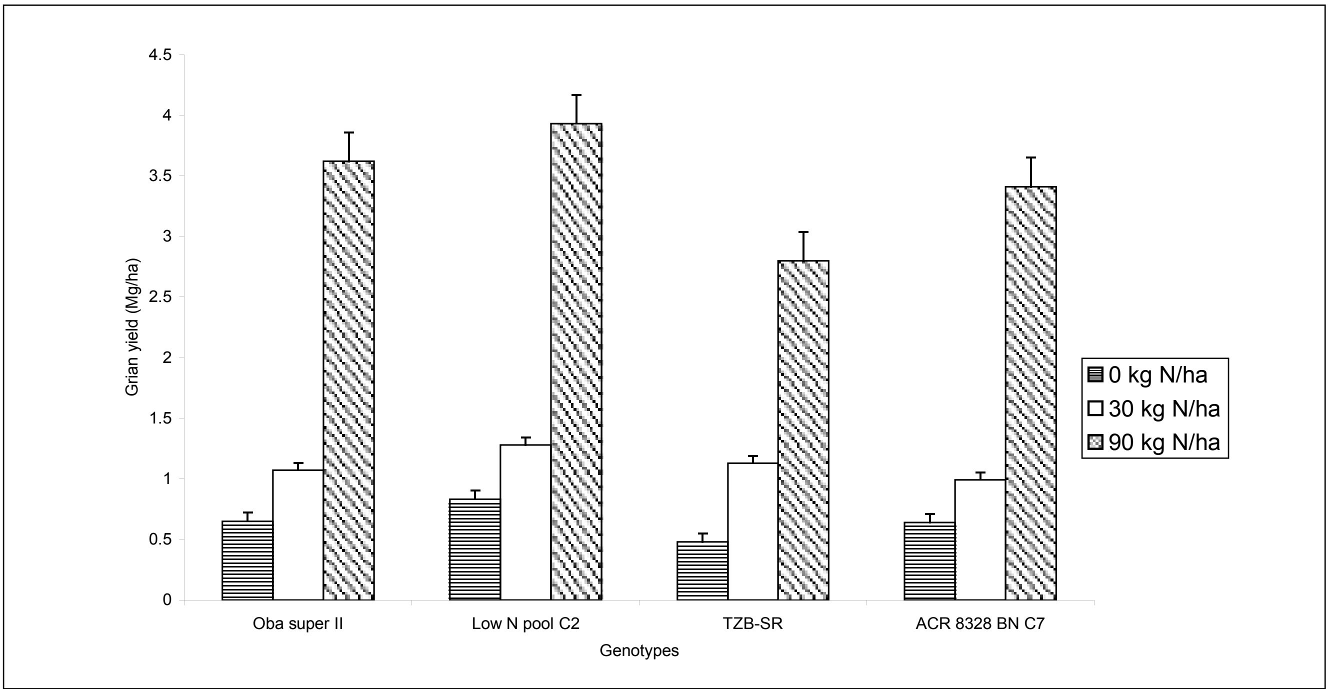

Figure 1: Grain yield of maize genotypes at 3 nitrogen levels; vertical bars represent standard error of the means.

application confirms the importance of N in maize nutrition. Adetunji (1) reported a strong dependence of maize yield on N content of some nigerian soils. Gallaher *et al.* (8) also reported increases in maize grain yield due to N-application rates.

Nitrogen-uptake values show that high soil N enhanced the relative competitiveness of the maize in these studies. Maize genotypes differed in their response to soil N, with a larger reduction in TZB-SR, a genotype susceptible to N stress. Oba super II and LOW N POOL C2 had superior grain yield partly due to their higher N-uptake and utilization efficiencies.

The effect of weeding pressure on N-uptake efficiency shown in table 1 revealed that there was a significant reduction in the N-uptake efficiency of the maize genotypes. The magnitude of the decrease was more with the application of 30 kg N/ha.

In a weed free environment N-uptake at 30 kg N/ha was higher than at 90 kg N/ha in all the genotypes. Oba Super II had the highest value while LOW N POOL C2 had the least uptake value. However, with increase in N rate to 90 kg N/ha, LOW N POOL C2 performed better than the other genotypes in a weed free environment; ACR8328 BN C7 had the least uptake efficiency. The reduction observed was more in 30 kg N/ha treatment for all the genotypes. It ranged from 86% in ACR8328 BN C7 to 41% in LOW N POOL C2. At the application rate of 90 kg N/ha, the resultant reduction in uptake efficiency due to weed interference were 50% in LOW N POOL C2, 55% in ACR8328 BN C7, 57% in TZB-SR and 92% in Oba super II. The effect of weed pressure in reducing the N- utilization efficiency was more pronounced at the application rate of 30 kg N/ha (Table 2).

N-utilization efficiency of TZB-SR was very low due to weed interference, LOW N POOL C2 was least affected. The reduction ranged from 96% in TZB-SR to 67% in LOW N POOL C2. At the application of 90 kg N/ha, weed pressure had reductions that varied among genotypes, 57% in Oba super II and ACR8328 BN C7; 62% in LOW N POOL C2 and 64% in TZB-SR. In a weed free condition the N-utilization efficiency of all the genotypes was higher at 30 kg N/ha rate than 90 kg N/ha. At the lower N rate, Oba super II performed best (95.67) though similar to LOW N POOL C2 (94.67) while TZB-SR was the poorest (72.00). With increase in N rates to 90 kg N/ha, LOW N POOL C2 and Oba super II still had the best utilization efficiencies (58.67 and 58.33 respectively) while TZB-SR had the lowest (48.78) N-utilization efficiency.

Table 3 shows that the nitrogen-use efficiency (NUE) of all the maize genotypes were reduced by weed interference both at 30 and 90 kg N/ha fertilization.

Table 1
Nitrogen-uptake efficiency* of maize genotypes (mean of two years)

	N uptake efficiency at 30 kg N/ha Weed free	N uptake efficiency at 30 kg N/ha High weed pressure	N uptake efficiency at 90 kg N/ha Weed free	N uptake efficiency at 90 kg N/ha High weed pressure
Oba super II	1.41	0.23	0.98	0.51
Low N pool C2	1.17	0.47	1.15	0.58
TZB-SR	1.20	0.18	1.01	0.43
ACR 8328BN C7	1.36	0.19	0.95	0.43
Average	1.29	0.27	1.02	0.49
SD (±)	0.12	0.14	0.09	0.07

*Calculated in reference to N-uptake in No-nitrogen treatment (0 kg N/ha).

Table 2
Nitrogen-utilization* efficiency of maize genotypes (mean of two years)

	N-utilization efficiency at 30 kg N/ha Weed free	N-utilization efficiency at 30 kg N/ha High weed pressure	N-utilization efficiency at 90 kg N/ha Weed free	N-utilization efficiency at 90 kg N/ha High weed pressure
Oba super II	95.67	5.00	58.33	25.22
Low N pool C2	94.67	31.33	58.67	30.44
TZB-SR	72.00	3.00	48.78	17.67
ACR 8328BN C7	85.67	7.33	54.44	23.44
Average	87.00	11.67	55.06	24.19
SD (±)	10.97	13.23	4.60	5.27

*Calculated in reference to N-utilization in No- nitrogen treatment (0 kg N/ha).

Nitrogen-use efficiency of all the maize genotypes was increased with increase in N rate (except TZB-SR) under a weed free condition. At lower N rate, the NUE of TZB-SR was higher (40) compared to other genotypes. Oba super II, LOW N POOL C2 and ACR8328 BN C7 had NUE values of 38, 28 and 25.67 respectively. Higher NUE recorded at 90 kg N/ha application rates ranged from 34.44 in ACR8328 BN C7 to 39.11 in Oba super II. LOW N POOL C2 and TZB-SR had similar NUE. At the application of 30 kg N/ha, the reduction due to weed interference in NUE were 82% in ACR8328 BN C7; 88% Oba super II, 93% in TZB-SR and 4% increase in LOW N POOL C2. The magnitude of the decrease was lower at the application of 90 kg N/ha. It ranged from 19% to 54% in TZB-SR.

Table 4 shows that the application of urea also increased the uptake of N. The highest uptake was recorded in the 90 kg N /ha treatment in maize. There was however, no significant difference in the uptake of N in the control plots and 30 kg N /ha. Weed uptake of nitrogen was generally found to decrease with increase in N rates.

The least uptake was recorded in the 90 kg N /ha treatment. With the application of 90 kg maize parts take only 76% of it while weeds took 18%. At the control plots (0 kg N/ha) 30.08 kg N/ha was taken by weeds while only 16.32 kg N/ha was found in maize parts with an increase in N application (30 kg N/ha), the uptake by weeds reduced to 28.38 kg/ha while maize uptake rose to 23.35 kg N/ha. There was however no significant difference in the weed uptake of N in the control plots and the 30 kg N /ha treatment.

Weed N-uptake was found to decrease with increases in N

Table 3
Nitrogen-use* efficiency of maize genotypes (mean of two years)

	N-use efficiency at 30 kg N/ha Weed free	N-use efficiency at 30 kg N/ha High weed pressure	N-use efficiency at 90 kg N/ha Weed free	N-use efficiency at 90 kg N/ha High weed pressure
Oba super II	38.00	4.67	39.11	25.11
Low N pool C2	28.33	29.33	36.56	29.78
TZB-SR	40.00	3.00	38.11	17.67
ACR 8328BN C7	25.67	4.63	34.44	22.56
Average	33.00	10.41	37.06	23.78
SD (±)	7.06	12.64	2.03	5.05

*Calculated in reference to N-use in No- nitrogen treatment (0 kg N/ha).

Table 4
Nitrogen-uptake by maize and weed (kg/ha) (mean of two years)

	Maize shoot	Weed	Soil nitrate
Nitrogen rates ($kg.ha^{-1}$) (N)			
0	16.32b	30.08a	1.10a
30	23.35b	28.38a	1.22a
90	68a	15.98b	1.62a
SE (±)	2.53	2.00	0.22
Genotypes (G)			
Oba super II	35.94ab	27.05a	1.04a
Low N pool C2	40.84a	24.72a	1.36a
TZB-SR	31.96b	26.19a	1.40a
ACR 8328 BN C7	34.81ab	21.30a	1.45a
SE (±)	2.93	2.31	0.26
N X G SE (±)	5.07ns	4.00ns	0.44ns

Mean values with the same alphabets are not statistically different at p= 0.05 ns: Not significant.

rates. There seems to be an inverse relationship between maize and weed N uptake with increase in N application. Variations observed among the genotypes indicated that LOW N POOL C2 had the highest shoot nitrogen uptake. This was similar to the values observed in Oba super II. Generally, shoot uptake of N is in the order LOW N POOL C2 >ACR 8328 BN C7 > Oba super II > TZB-SR-SR. Application of 90 kg N /ha resulted higher soil nitrate, this was not significantly higher than other N rates. Genotypes had no effect on the amount of soil nitrate. Total N content of plant is an indication of the plant's capacity to accumulate N (6). Maize lines have been shown to vary in their capacity to accumulate N and produce dry matter (15). This was observed in the present study. Differences occurred among genotypes for N accumulation and for efficiency in N- use, N- uptake and N-utilization. Total N that accumulated at maturity in the genotypes increased with N rates applied. Maize genotypes showed more competitiveness than weeds for N, particularly at 30 kg N/ha where more than 50% of the applied N was taken by maize. An inverse trend observed between maize N-uptake (high uptake values) and weed N uptake (low uptake values) with increased N rates shows that maize competitive ability was improved with increament in N applied. The greatest capacity to accumulate N in the shoot by LOW N POOL C2 and Oba super II may be related to the above ground dry matter at harvest and the percent N concentration that were high for both genotypes at maturity (18). The limited uptake capacity of TZB-SR might be due to its low N concentration and low stover yield. High above ground dry matter yield has been shown to correlate strongly with total aboveground N uptake among tropical maize populations, especially at low soil N rates (13). In contrast to the study of Wiesler and Horst (22) which showed that there was no difference in N uptake after silking among temperate maize cultivars, this study is consistent with the studies of Moll *et al.* (14) who observed significant differences among maize cultivars in N-uptake after silking.

Generally, the low soil nitrate of the study areas might be due to the high rate of run-off in the sites and the subsequent loss of applied N. Morphological description of the soil by Ogunwale *et al.* (17) have reported the occurrence of manganiferrous concretions in the 20 cm depth of Samaru soil due to the existence of an active zone of alternating wet and dry cycles. This formation hindered nutrient infiltration, encouraged run off losses and reduced subsequent uptake by maize crop. The attendant problems of accelerated runoff and water logging (anaerobiosis) had probably contributed to the great loss of unused soil N, coupled with the likely loss of N by NH_3 volatilisation at application. Several workers have reported loss of N applied to the soil due to different pathways. Fertilizer N losses through denitrification have been estimated to be more than 10% in maize (9). Losses due to surface run off ranged between 1- 13% (4), while losses due to NH_3 volatilisation is higher than 40% (7). Also, the high insolation of the study area and the consequent dry soil condition enhanced ammonium accumulation while the amount of nitrate decreases. Ammonium has been reported as the dominant form of N during the dry season while nitrate is the dominant form in the rainy season (20). In the present study, differences were observed in the uptake, utilisation and use efficiency of the genotypes evaluated. N-uptake and utilisation efficiency at lower N rates is higher than at higher N rate thus showing the probability of having large losses of N at higher rate of N application to soil even with weed competition. The N-uptake efficiency (gram of plant per gram of available soil N), nitrogen-use efficiency and N-utilisation efficiency is higher in LOW N POOL C2 and Oba super II at both rates of N due to their superior ability to absorb and utilize N more efficiently than other genotypes. ACR 8328 BN C7 was moderate while TZB-SR was poor in N-use, uptake and utilisation. The reduction observed in the N-use, N-uptake and N-utilisation due to weed interference was more at low N rates; this is an indication of the low competitive ability of the maize genotypes at suboptimal N levels. This is also hinged on the ability of the genotypes to utilize N, the N stress susceptible genotype, TZB-SR was mostly affected while LOW N POOL C2 and Oba super II performed better due to their superior inherent genetic qualities.

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