Full Length Research Paper

Comparative productivity of nitrogen-use efficient and nitrogen-inefficient maize cultivars and traditional grain sorghum in the moist Savanna of West Africa

S.O. Oikeh[*], V.O. Chude[1], G. J. Kling[2] and W. J. Horst[3]

[1]National Special Program on Food Security, Abuja, Nigeria.
[2]107 Crop Science Building, Oregon State University, Corvallis, OR 97331-3002, U.S.A.
[3]Institut für Pflanzenernährung, Universität Hannover, Herrenhäuser Str. 2, D 30419 Hannover, Germany. Africa Rice Center, (WARDA), 01 BP 2031, Cotonou, Benin Republic.

Strategies to cope with low fertilizer use in West Africa include choice of crop (that is., sorghum vs. maize) and the development of nitrogen-use efficient maize (*Zea mays* L.) varieties. A two-year field study was undertaken to compare the N response of an N-use efficient maize (hybrid, cv. 8644-27) and a nitrogen-inefficient maize (cv. TZB-SR), and to compare the productivity of the two cultivars with a traditional grain-sorghum (*Sorghum bicolor* [L.] Moench) in the moist savanna agroecosystem in Zaria, Nigeria. The two maize cultivars were evaluated under three N levels (0, 60, and 120 kg ha^{-1}). Sorghum (cv. 'mori') was evaluated under 0 and 120 kg N ha^{-1}. Mean grain yield was 0.5 Mg ha^{-1} greater for N-use efficient than for N-inefficient maize, mostly because of its larger harvest indices for dry biomass and for N, and a greater N-utilization efficiency. In both years, with 120 kg N ha^{-1} applied, grain yield and grain-N were 54 to 275% higher in maize than in grain sorghum. Under nitrogen stress (zero-N), grain yield of the N-efficient maize was similar to that of grain sorghum. But sorghum had 2 to 3 times greater total aboveground dry-matter yield and 165 to 230% higher total N-uptake than the maize cultivars, suggesting that sorghum was exhausting the soil of a greater amount of mineral-N than maize. Results showed that even under limiting nitrogen supply, a maize-based system with N-efficient maize was potentially more ecologically sustainable than a sorghum-based system involving traditional grain sorghum.

Key words: Cereal-based systems, grain sorghum, moist savanna, N-efficient maize, N-inefficient maize, N-utilization efficiency, West Africa.

INTRODUCTION

Nitrogen nutrition is a major constraint to maize production in the West African subregion because of high prices and inefficient fertilizer distribution. Strategies to cope with this situation include choice of crop (that is., sorghum vs. maize) and the development of nitrogen-efficient maize varieties. The development and adoption of nitrogen-use efficient maize cultivars could reduce the use of input nitrogen to levels below the recommended rate of 120 to 150 kg N ha^{-1} for the Nigerian savanna agroecoystems (Enwezor et al., 1989).

The cropping systems of the West African savanna are dominated by cereal crops, including maize, sorghum mi-

llet, and rice. The production of maize and sorghum is complementary and in most areas these crops are inter-cropped (Fusillier, 1994). It is common to see farmers partially substituting traditional grain-sorghum production for maize in seasons when fertilizers are not readily available (Weber and Oikeh, unpublished). Sorghum is recognized by farmers to be more adapted to low soil N. Reasons for this are, however, not clear. There are limited studies comparing maize and sorghum in the cropping system under the same conditions. Lemaire et al. (1996) compared both crops in the temperate zone and reported that with irrigation and high nitrogen fertilizer application, maize dry matter accumulation was higher than that of sorghum, due to earlier development of leaf area in maize, leading to a larger quantity of intercepted radiation. But when nitrogen was limiting, the capacity of sorghum to

fertilizer mixture was uniformly broad-cast onto the soil surface and rototilled prior to ridging. Nitrogen was applied at 2 weeks after sowing (WAS) as calcium

take up N from the soil was always higher than that of maize. Earlier studies in Australia under irrigation and a wide range of N applications showed no difference between both species (Muchow and Davis, 1988).

The traditional, photosensitive grain-sorghum commonly grown in the savanna has a longer growing period of 160 days that extends into the dry season compared to maize with a 120-day growing period. Soil nitrogen continues to be released during those additional 40 days, and is taken up by the sorghum plant. Sorghum may, therefore, have a greater nitrogen-uptake capacity and may be exhausting the soil of more mineral-nitrogen than maize in any growing season. It may not be true there-fore, that when nitrogen is limiting, it is better to grow grain-sorghum than maize. It is important to analyze the productivity of N-efficient and N-inefficient maize and the traditional grain-sorghum in the savanna agroecosystem and to contribute to smallholder farmers' decision-making on crop enterprises. The objectives of the study were to analyze the nitrogen responses of N-use efficient and N-inefficient maize cultivars; and to compare the productivity of the maize cultivars with a traditional grain-sorghum in the cropping system of the moist savanna agroecosystem.

MATERIALS AND METHODS

A field study was conducted for two years on a loamy soil (fine-loamy, isohyperthermic Plinthustalf or Plinthic Luvisol) at the experimental farm of the Institute for Agricultural Research, Zaria, Nigeria (11°11'N, 7 °38'E, 686 m asl). The field was well drained; the physicochemical characteristics and the weather conditions during the growing seasons were earlier described by Oikeh et al. (1999). There were dry spells in the second week of June in the first year and in July to September in the second year compared with long term average. Two maize cultivars, N-use efficient (hybrid 8644-27; [Oba Super 2]) and N-inefficient (cv. TZB-SR) earlier classified by Oikeh et al. (1997), and a tall, photosensitive, traditional grain-sorghum (cv. 'mori') were used for the experiment. Nitrogen application levels were 0, 60, and 120 kg ha^{-1}. Nitrogen use-efficient (low N-tolerant) maize cultivars are cultivars that can realize more than average grain yield under conditions of low N availability or suboptimal N supply, while cultivars that give below average grain yield are N-inefficient (Graham, 1984; Sattelmacher et al., 1994).

The treatments were arranged as split plots in a randomized complete block design, with four replications in year 1 and five in year 2. Nitrogen levels were the main plots (31.5 m × 6 m), and the crops were the subplots (6 m × 5.25 m). Each subplot consisted of seven maize/sorghum ridges 6 m in length and 0.75 m apart. The crops were seeded when rains were established in both years. Intra row spacing of hills was 0.5 m with two plants per hill, resulting in a density of 53 333 plants ha^{-1} for maize, but sorghum was established at 26 666 hills per hectare with an average of five plants per hill, as generally practiced by farmers in northern Nigeria. Sorghum was seeded only in subplots with 120 kg N ha^{-1} in year 1, and 0 and 120 kg N ha^{-1} in year 2, to compare the capacity of sorghum and the two maize cultivars for N uptake from the soil, and the utilization of the N taken up by the plant for grain production. A basal dressing of 26 kg P ha^{-1}, 50 kg K ha^{-1}, and 1 kg Zn ha^{-1} was made, based on standard soil test values and expected maize yield (Enwezor et al., 1989). The

ammonium nitrate with 27 % N. It was placed in a single band 5 cm deep made along the ridge 5-10 cm away from the plants and covered with soil. The highest N level of 120 kg N ha^{-1} was applied in two equal doses at 2 and 5 WAS to minimize potential leaching losses (Enwezor et al., 1989). Plots were kept weed-free by hand hoe throughout the growing season.

Two interior rows were used for measuring agronomic characteristics and grain yield. At harvest, samples were collected from a net plot of 7.5 m^2 for the determination of grain yield and yield components. After the ears/panicles had been removed, all the stalks and husks of maize and stalks of sorghum were weighed; cut into pieces, mixed, and sub-samples were taken for fresh weight. Dry weight of these sub-samples was measured after oven drying at 80°C for 72 h. Dry-matter yield for each plot was estimated from the sub-sample dry weight by simple proportion. Total aboveground dry-matter yield included dry weight of stalks, kernels, husks, and cobs (maize) and grain, stalks, and panicles (sorghum). Representative sub-samples of plant and grain samples were ground to pass through a 1 mm sieve for N analysis using an autoanalyzer (Technicon Auto Analyzer II). Nitrogen harvest index was calculated as the proportion of the total aboveground plant N found in the grain. Nitrogen utilization efficiency was calculated as the grain weight per unit of N in the plant at harvest.

Statistical analysis of maize data was conducted using the mixed model procedure with the restricted maximum likelihood (REML) method for variance components estimates (SAS Institute, 2001). The covariance parameter for block × year was used to test year effects, and block × N levels × year was used to test N fertilizer treatment effects and interactions of N levels with year. The pooled residual error term was used to test variety effects and interactions with N levels and years. Comparison of cultivar means was done only for the two maize cultivars. Sorghum data were analyzed separately.

RESULTS

Dry-matter yields in low N-tolerant and N-inefficient maize

Analysis of variance showed no significant interactions between nitrogen × year, nitrogen × variety, and year × nitrogen × variety (Table 1). Mean yields (grain and stover) across cultivars and N levels (Figure 1) were significantly (*p* < 0.01) lower by 28-47% in year 2 than in the first year. But the harvest index (grain yield per total aboveground dry-matter yield) was smaller in year 1 than in year 2. Therefore, even though a lower total amount of aboveground dry matter was produced in year 2, a greater proportion of this was partitioned to the kernels than in year 1. Grain yield, averaged across years and N levels, was 0.5 Mg ha^{-1} greater for the N-use efficient cultivar than for the N-inefficient cultivar (Figure 1). The N-inefficient maize, however, had a greater capacity to accumulate total amount of aboveground dry matter. Furthermore, mean grain yield was increased by 130% with N application (Figure 1). Increasing N levels beyond 60 kg ha^{-1} had little additional benefit on grain yield.

Nitrogen accumulation and N-utilization efficiency in N-

The effect of year on N uptake and partitioning within plant when averaged across cultivars and N levels followed a

Table 1. Analysis of variance for plant aboveground dry biomass at harvest for N-use efficient and N-inefficient maize cultivars as influenced by N levels in the moist savanna

Analysis of variance[a]	NDF	DDF	Aboveground dry biomass			HI
			Grain yield	Stover[b]	Total	
			Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	
Year	1	7	0.01	<0.01	<0.01	0.01
Nitrogen (N)	2	14	<0.01	<0.01	<0.01	<0.01
N × Year	2	14	0.26	0.16	0.30	0.22
Variety (V)	1	21	0.03	<0.01	0.01	<0.01
N × V	2	21	0.91	0.06	0.36	0.85
V × Year	1	21	0.57	0.01	0.04	0.32
N × V × Year	2	21	0.17	0.13	0.16	0.08
-2 Res Log likelihood Value			712	750	783	265
CV (%)			14.3	13.5	12.7	9.8

[a]Probability levels are for test of fixed effects. NDF = Numerator degrees of freedom for fixed effects. DDF = Denominator degrees of freedom of covariance parameter for block × year, block × N levels × year, and residuals. [b]Stover = stalk + husk + cob.

Table 2. Analysis of variance for plant nitrogen uptake parameters at harvest for N-use efficient and N-inefficient maize cultivar as influenced by N levels in the moist savanna

Analysis of variance[a]	NDF	DDF	Nitrogen					
			Grain	Stover[b]	Total	HI	Utilization efficiency	Uptake rate
			kg ha^{-1}	kg ha^{-1}	kg ha^{-1}		kg grain/kg plant-N	kg ha^{-1}d^{-1}
Year	1	7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (N)	2	14	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
N ×Year	2	14	0.53	0.39	0.26	0.11	0.44	0.01
Variety (V)	1	21	0.19	<0.01	0.09	<0.01	<0.01	0.17
N × V	2	21	0.78	0.55	0.72	0.63	0.12	0.86
V × Year	1	21	0.92	0.01	0.10	0.75	0.24	0.11
N × V × Year	2	21	0.13	0.41	0.22	0.19	0.29	0.22
- 2 Res Log Likelihood Value			358	345	398	281	276	353
CV (%)			14.3	22.9	15.7	8.9	11.3	15.1

[a]Probability levels are for test of fixed effects. *NDF* = Numerator degrees of freedom for fixed effects. *DDF* = Denominator degrees of freedom of covariance parameter for block × year, block × N levels × year, and residuals

pattern similar to dry-matter production (Figure 2 and Table 2). Both cultivars had similar grain N and total plant N, but the N-use efficient cultivar had a larger nitrogen harvest index of 0.63 (Figure 2) and a higher nitrogen-utilization efficiency of 52 kg grain per kg total plant N than the N-inefficient cultivar (Figure 3).

Averaged across years and cultivars, total plant N, nitrogen partitioned to kernels and stover (Figure 2), and nitrogen-uptake rates (Figure 3) were reduced by 34 to 63% due to nitrogen stress (zero-N). Nitrogen stress also reduced nitrogen harvest index by 20% (Figure 2). While nitrogen utilization efficiency declined by 8% at 120 kg N ha^{-1} over the zero-N treatment (Figure 3).

Performance of N-use efficient and N-inefficient maize and sorghum under high N

In the two years of the experiment, under high fertility (120 N kg ha^{-1}), grain yield (Figure 4) and grain-N (Figure 5) were 54 to 275% higher in maize than in sorghum. A greater proportion (85-91%) of total dry-matter produc-

tion in sorghum was partitioned to the stovers and panicles (Figure 5). The corresponding value for N-inefficient maize was 58 to 66% and for N-efficient maize was 50 to 57% (Figure 5)

In year 1, total N uptake for sorghum was 5 to 17% lower than for the maize cultivars, whereas in the second year when moisture was limiting, sorghum had 49% high-

Nitrogen-utilization efficiency was the lowest for sorghum, 12 to 19 kg grain per kg total plant-N, as against 36 to 46 kg for N-inefficient maize and 43 to 52 kg for N-use efficient maize (Figure 6). In year 1, the rate of N uptake per unit time was 35 to 42% lower for sorghum than for the maize cultivars, but values were similar for all three cultivars in year 2 (Figure 6).
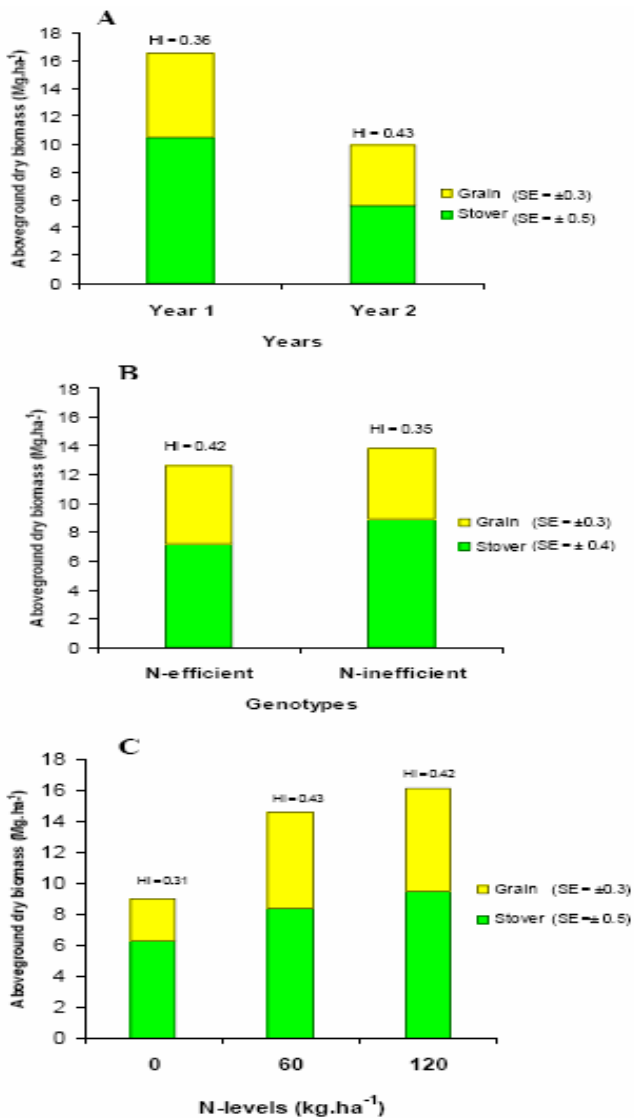
Figure 1. Mean aboveground dry biomass yield at harvest as influenced by year (A). genotypes (B) and N levels (C) in the moist savanna. Values above the bars are harvest indices (HI) for dry matter. Stovers = stalk + husk + cob. SE = Standard error mean.

er N uptake (Figure 5) and had more stable yield than the maize cultivars (Figure 4). The harvest index for dry matter in the N-use efficient maize was three times larger than that for sorghum, but 1.2 times larger than that for the N-inefficient maize (Figure 4). The N harvest index followed a similar trend (Figure 5).
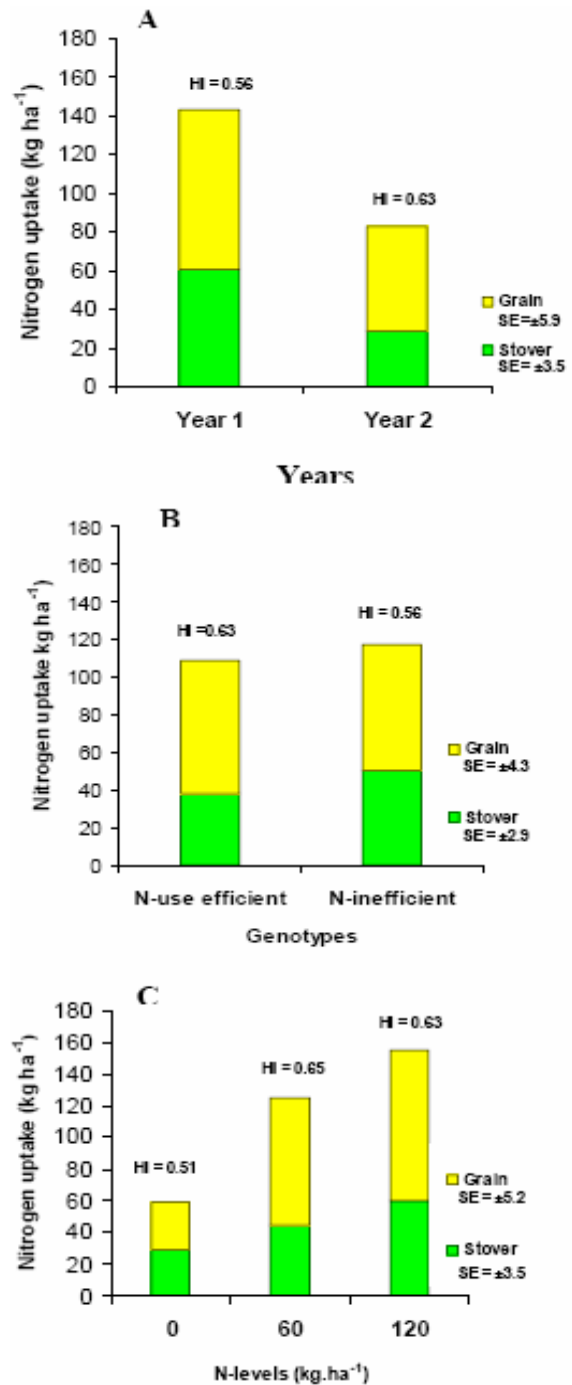

Figure 2. Mean nitrogen uptake at harvest as influenced by year (A). genotypes (B) and N levels (C) in the moist savanna. Values above the bars are harvest indices (HI) for nitrogen. Stovers = stalk + husk + cob. SE = Standard error mean.

Performance of N-use efficient and N-inefficient maize and sorghum under N stress

The grain yield of the N-use efficient maize was similar to that of the grain sorghum, but about 60% higher than that

of the N-inefficient maize (Figure 4). The traditional grain sorghum had 2 to 3 times greater total aboveground dry-matter yield than the maize cultivars (Figure 4). Furthermore, the grain-sorghum had the highest grain-N and 165 to 230% higher total aboveground N-uptake than the maize cultivars (Figure 5).

Figure 3. Mean N-Utilization efficiency and N uptake rate ¢UR] kg ha⁻¹ d⁻¹; values above the bars) at harvest as influenced by year (A), genotypes (B) AND N levels (C) in the moist savanna. SE = Standard error mean.

Figure 4. Mean aboveground dry biomass yield at harvest for N-efficient and N-inefficient maize cultivars and a traditional grain sorghum as influenced by N levels in Year 1 and Year 2. Values above the bars are harvest indices (HI) for dry matter. Stovers = stalk + husk + cob.

DISCUSSION

A comparative evaluation of productivity of N-efficient and N-inefficient maize and traditional grain sorghum in smallholder production systems can guide farmers' decision-making in crop enterprises. In this study, the depressed yield observed in the second year may have been due to the lower rainfall and insulation during the kernel filling period in year 2. A greater proportion of the total amount of

above-ground dry biomass produced in year 2 was partitioned to the kernels, hence the observed higher harvest index for dry-matter in year two than in the first year.

The greater yield obtained for the N-use efficient cultivar compared to the N-inefficient cultivar was mostly attributed to its larger harvest indices for dry-matter and for nitrogen.
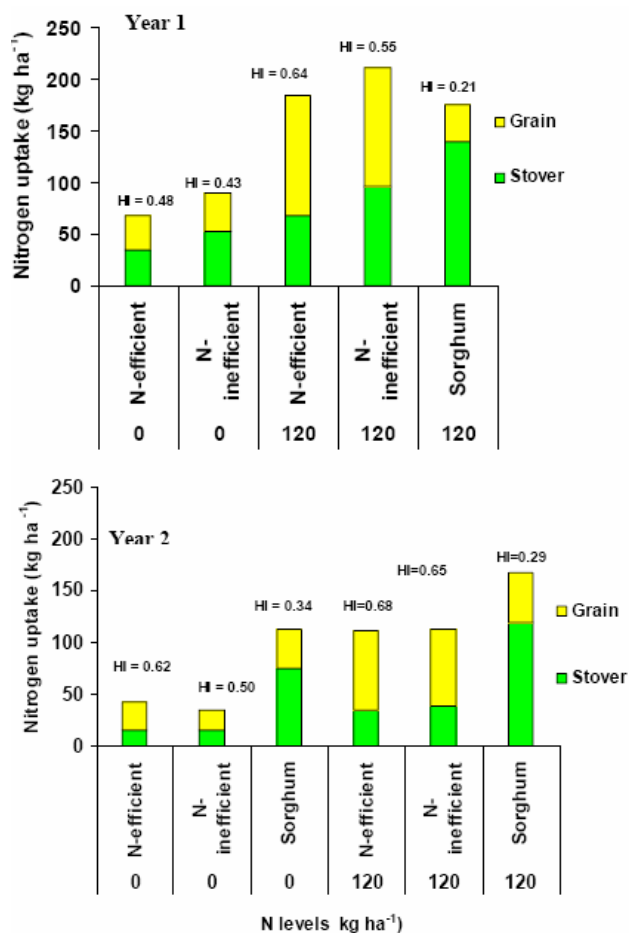
N ha^{-1}.

High nitrogen supply may have enhanced the production of more tillers in sorghum, and thus, more stalk dry-matter resulting in total aboveground dry-matter yield in sorghum than in maize. When moisture was not limited in the first year, total N uptake for sorghum was lower than that of the maize cultivars, whereas in year two when moisture was limiting, sorghum had higher N uptake and more stable grain yield than the maize cultivars. These results

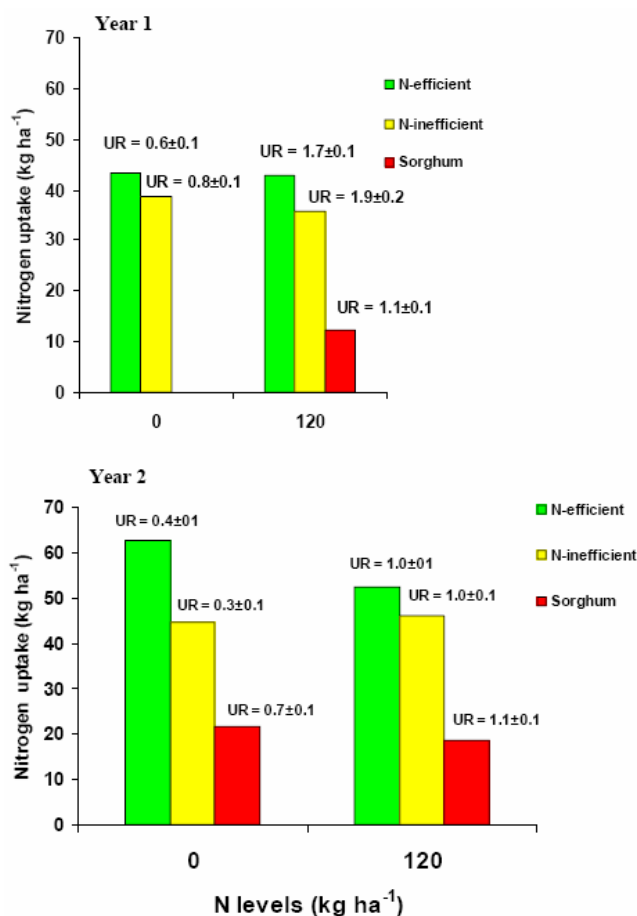**Figure 5.** Mean nitrogen uptake at harvest for N-efficient and N-inefficient maize cultivars and a traditional grain sorghum as influ-enced by N levels in Year 1 and Year 2. Values above the bars are harvest indices (HI) for nitrogen. Stovers = stalk + husk + cob.

Figure 6. Mean N-Utilization efficiency and N uptake rate ([UR]kg ha^{-1} d^{-1}; values above the bar) at harvest for N-efficient and N-inefficient maize cultivars and a traditional grain sorghum as influenced by N levels in Year 1 and Year 2 in the moist savanna

The low grain yield of the N-inefficient variety (TZB-SR) was attributed to its low harvest index for dry-matter and its small kernel size, that is., weight per kernel (Oikeh et al., 1999).

Nitrogen application greatly affected the aboveground dry matter production and the amount partitioned to the kernels, but there was no additional benefit in the application of N above 60 kg ha^{-1} on grain yield as previously reported by Kling et al. (1997). These authors observed that the maize cultivars used in their trials were able to resist barrenness under moderate N fertility of 60 kg

support a previous study reported by Lemaire et al. (1996) that when moisture and nitrogen were not limiting under temperate conditions, maize had a higher growth than sorghum, but when these factors where limiting, sorghum had a greater capacity to take up N from the soil than maize.

The observed low nitrogen-utilization efficiency in the grain sorghum compared with the maize cultivars supported the study of Muchow (1998) in Australia. This author reported a smaller N-utilization efficiency for sorghum than for maize (48 vs. 61 g grain per g N absorbed). However, N-utilization efficiency for the sorghum used in his study

was higher than in ours, possibly because improved sorghum used in that study had relatively short growth duration com-pared to the 160-d traditional grain sorghum used in our study.

The three cultivars responded differently under nitrogen stress (zero-N). The observed lower grain yield of the N-in-efficient maize (TZB-SR) compared to the N-efficient maize (hybrid Oba-Super 2) or grain-sorghum, was possibly due to the observed lower harvest index and N-utilization effci-

ency of TZB-SR as previously reported (Oikeh et al., 1997; Akintonye et al., 1999; Kamara et al., 2005). Since maize grain attracts a much higher price than sorghum, it will be more profitable to grow N-efficient maize even under limited N supply than to grow traditional grain sorghum, if the farmers' main interest is grain yield. Also, maize stover has greater nutritive value for use as animal feed than sorghum stover because of its higher crop residue quality in terms of crude protein and digestibility (Powell, 1986). However, if the major interest of the farmers is to have stalks for thatching their houses, in addition to some grain yield, the traditional grain sorghum with long, strong stalks will give a greater value to the farmer than maize.

Furthermore, the grain sorghum had the highest grain-N and higher total aboveground N-uptake than the maize cultivars, suggesting that even under N stress; sorghum exhausted (depleted) the soil of a greater amount of mineral-N than maize. This may be attributed to the longer duration, and a continuous absorption of mineral-N from the soil resulting from the production of a higher root density and a greater root absorption capacity in sorghum than in maize (Oikeh, 1996). Our results were in contrast with those reported by Muchow and Davis (1988) who indicated no difference in N uptake between maize and sorghum crops of similar growth duration for a large range of N applications, under subhumid subtropical conditions of Australia. Even though sorghum had a higher N uptake rate than maize, it was surprising that N deficiency was not obvious in sorghum as it was observed in maize under zero-N in year 2.

Conclusion

This study indicates the clear advantage of growing N-efficient maize over N-inefficient maize or traditional grain sorghum even under limited N supply. Increasing N levels beyond 60 kg ha^{-2} did not increase grain yield of either maize cultivars. Sorghum was potentially exhausting the soil of greater amounts of mineral-N than maize. Thus, under limited N supply, a sorghum-based cropping system comprising traditional grain sorghum is potentially less ecologically sustainable than a maize-based cropping system using an N-efficient cultivar, in contrast to the general perception of farmers.

REFERENCES

Akintonye HA, Kling JG, Lucas EO (1999). N-use efficiency of single, double and synthetic maize grown at four N levels in three ecological zones of West Africa. Field Crops Res. 60:189–199.

Enwezor WO, Udo EJ, Usoroh NJ, Ayotade KA, Adepetu JA, Chude VO, Udegbe CI (1989). Fertilizer Use and Management Practices for Crops in Nigeria (Series No.2). Fertilizer Procurement and Distribution Division, Federal Ministry of Agriculture, Water Resources and Rural Development, Lagos, Nigeria, p. 163.

Fusillier JL (1994). West Africa: maize or sorghum. Agriculture et Développement. Special issue –December 1994. pp. 12–20.

Graham RD (1984). Breeding for nutritional characteristics in cereals. In: Tinker PB, Lauchli A (eds). Adv. Plant Nutr. 1:57–102.

Kamara AY, Menkir A, Ajala SO, Kureh I (2005). Performance of diverse maize genotypes under nitrogen deficiency stress in the northern Guinea savanna of Nigeria. Exp. Agric. 41:199–212.

Kling JG, Oikeh SO, Akintoye HA, Heuberger HT, Horst WJ (1997). Potential for developing nitrogen-use efficient maize for low input agricultural systems in the moist savannas of Africa. In Edmeades GO, Bänziger MH, Mickelson R, Peña-Valdivia CB (eds) Proceedings of an International Symposium on Developing Drought- and N-efficient Maize, Mexico: CIMMYT, pp. 490–501.

Lemaire G, Charrier X, Hébert Y (1996). Nitrogen uptake capacities of maize and sorghum crops in different nitrogen and water supply conditions. Agronomie 16:231–246.

Muchow RC, Davis R (1988). Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semiarid tropical environment. II. Radiation interception and biomass accumulation. Field Crops Res. 18:17–30.

Muchow RC (1998). Nitrogen utilization efficiency in maize and grain sorghum. Field Crops Res. 56:209–216.

Oikeh SO (1996). Dynamics of soil nitrogen in cereal-based cropping systems in the Nigerian Savanna. PhD dissertation, Ahmadu Bello University, Zaria. Nigeria.

Oikeh SO, Kling JG, Horst WJ, Chude VO (1997). Yield and N-use efficiency of five tropical maize genotypes under N levels in the moist savanna of Nigeria. In: Ransom KJ, Palmer AFE, Zambezi BT, Mduruma ZO, Waddington SR, Pixley KV, Jewell DC (eds) Maize Productivity Gains Through Research and Technology Dissemination. Proceedings 5th Eastern and Southern Africa Regional Maize Conf. Arusha, Tanzania, 3-7 June 1996. CIMMYT, Addis Ababa, Ethiopia, pp. 163–167.

Oikeh SO, Kling JG, Horst WJ, Chude VO, Carsky RJ (1999). Growth and distribution of maize roots under nitrogen fertilization in plinthite soil. Field Crops Res. 62:1–13.

Powell JM (1986). Crop-livestock interactions in the subhumid zone of Nigeria. In von Kaufmann R, Chater S, Blench R (eds) Proceedings of the 2nd ILCA/NAPRI Symposium of Livestock Systems Research in Nigeria's Subhumid Zone, Addis Ababa: ILCA, pp. 268–303.

SAS Institute (2001). SAS Technical Report. SAS/STAT Software: Changes and Enhancements. Release 8.02. SAS Inst., Cary, NC, USA.

Sattelmacher B, Horst WJ, Becker HC (1994). Factors that contribute to genetic variation for nutrient efficiency of crop plants. Z. Pflanzenernahr. Bodenk., 157:215–224.