Nitrogen Fertilizer Management Effects on Maize Grain Quality in the West African Moist Savanna

S. O. Oikeh, J. G. Kling,* and A. E. Okoruwa

ABSTRACT

Until recently, breeding programs in Africa placed little emphasis on grain quality improvement. Consequently, some farmers have not adopted improved high yielding varieties because they lacked desired quality characteristics for processing and other end uses. We conducted this study to determine the effects of N application on some maize (*Zea mays* L.) grain quality parameters. In 1993 and 1994, five maize cultivars under four N levels (0, 30, 60, and 120 kg ha^{-1}) were evaluated at Zaria (11° 11′ N), northern Nigeria, on a Plinthustalf (fine-loamy isohyperthermic). Increasing N levels increased grain yield, kernel weight, and grain protein quadratically for all the cultivars. The hybrid 8644-27 had the highest grain yield and kernel weight of 5.3 Mg ha^{-1} and 26.62 mg kernel^{-1}, respectively. Average grain protein yield per unit area was not significantly different among cultivars in both years. At 30 to 60 kg N ha^{-1}, the cultivars 8644-27 and TZPB-SR had a greater percentage of floaters, than the other cultivars in both years, reflecting a greater proportion of floury endosperm, indicating that they would be best for traditional dry milling, where the whole grain is ground to produce flour. Also, at 30 to 60 kg N ha^{-1}, SPL and TZB-SR had a relatively low percentage of floaters and high test weights of over 811 kg m^{-3} in 1993 and 778 kg m^{-3} in 1994, and should give high yields of grits when processed. Thus, both cultivars have high value for industrial dry milling. Results showed that the choice of cultivar and N level may affect grain quality and they should be considered in producing maize for dry milling purposes.

In Africa, maize is a major staple food crop. It is eaten fresh on the cob or the grains are processed into different products for a wide variety of traditional and industrial end uses. It is also valued as feed for livestock.

Yield potential is high (7–8 Mg ha^{-1}) in the moist savanna because of favorable environmental conditions (Kassam et al., 1975). Maize has become the most important cereal crop grown in this zone. Breeding efforts to develop high yielding, disease and pest resistant varieties of maize have encouraged wide adoption of maize by farmers, resulting in substantial increases in maize production and productivity (Badu-Apraku et al., 1995).

Until recently, however, breeding programs in Africa have placed little emphasis on grain quality improvement in terms of processing and nutritional properties. In some cases, improved high yielding varieties have not been adopted by farmers because they lack the desired quality characteristics for processing and some end uses (Thé et al., 1989; Badu-Apraku et al., 1995).

The quality of traditional or commercial maize products depends on certain endosperm characteristics. These include chemical properties such as protein, oil, sugars, and starch content, and physical properties, including test weight, percentage of floaters, dry milling yield (% grits), and kernel size. Large varietal differences have been observed in some of these quality characteristics (Sabata and Mason, 1992; Kling and Okoruwa, 1994; Okoruwa, 1997).

Nitrogen fertilization is an important agronomic practice for maize production in the West African moist savanna. Maize cultivars differ in grain yield response

Maize Improvement Program, International Institute of Tropical Agriculture (IITA), c/o L.W. Lambourn & Co., 26 Dingwall Rd., Croydon CR9 3EE, England. *Corresponding author (j.kling@cgnet.com).
Received 18 July 1997.

Published in Crop Sci. 38:1056–1061 (1998).

Abbreviations: GPC, grain protein concentration.

Table 1. Characteristics of cultivars used for study in 1993 and 1994.†

Cultivar	Type	Color	Texture
TZB-SR	Open-pollinated	White	Semi flint
EV8728-SR	Open-pollinated	Yellow	Semi dent
87TZPB-SR	Open-pollinated	White	Dent
SPL	Open-pollinated	White	Dent
8644-27	Single-cross hybrid	Yellow	Flint

to N fertilization (Kling et al., 1997; Oikeh et al., 1997). Studies conducted in the USA have shown that increased soil N levels increased kernel density and grain protein content of corn and decreased kernel breakage susceptibility (dry milling parameters) (Bauer and Carter, 1986; Sabata and Mason, 1992). Little information is available on the influence of N fertilizer application on maize grain quality in developing countries where maize is used primarily for human consumption.

The objective of this study was to determine the effects of N fertilizer application on quality parameters of five maize cultivars grown in the West African moist savanna.

MATERIALS AND METHODS

A field study was conducted at the experimental farm of the Institute for Agricultural Research (IAR), Zaria Nigeria (11° 11′ N, altitude of 686 m), in the 1993 and 1994 growing seasons. Four improved, late maturing (120-d) maize cultivars, EV8728-SR, Mokwa 87TZPB-SR, SPL (semiprolific, from CIMMYT, Mexico), 8644-27 (hybrid), and TZB-SR, a widely grown open- pollinated, late maturing cultivar developed at IITA were grown with N application levels of 0, 30, 60, and 120 kg ha^{-1}. Cultivars are described in Table 1. The study was conducted on a well drained and moderately acid (pH in water 5.2) loamy soil, classified as fine loamy, isohyperthermic Plinthustalf with organic matter content of 5.1 g kg^{-1} and total N of 0.54 g kg^{-1}. Meteorological data were collected during the study period.

The treatments were arranged as a split-plot in a randomized complete block design, with four replications in the first year and five in the second year. Nitrogen levels were the main plots (31.5 by 6 m) and cultivars were the subplots (6 by 5.25 m). Each subplot consisted of seven maize ridges 6 m in length and 0.75 m apart.

Table 3. Grain yield, kernel weight, and grain protein of five maize cultivars, 1993 and 1994.

Cultivar	Grain yield	Kernel weight	Grain protein	
			Concentration	Yield
	Mg ha^{-1}	mg/kernel	g kg^{-1}	kg ha^{-1}
TZB-SR	4.7	22.54	79.1	390
EV8728-SR	5.1	26.52	82.1	429
87TZPB-SR	4.8	26.91	79.6	395
SPL	4.9	24.53	82.6	423
8644-27	5.3	26.62	75.6	415
SE	0.19	0.53	1.53	21.1

† Averaged across N levels and years.

The cultivars were planted early in the season on 28 May 1993 and 16 June 1994. Plant population was 53 333 plants ha^{-1}. Basal application of 26 kg P ha^{-1}, 50 kg K ha^{-1}, and 1 kg Zn ha^{-1} was applied based on standard soil test values. Nitrogen was applied at 2 wk after planting as calcium ammonium nitrate containing 27% N. The highest N level of 120 kg ha^{-1} was applied in two equal splits at 2 and 5 wk after planting to minimize potential leaching losses (Enwezor et al., 1989). Weed control was done by hand.

Two interior rows were hand harvested for grain yield. Samples from each plot were collected for determination of grain yield, yield components, grain moisture content, grain protein content, test weight, and percentage of floaters. Grain moisture was determined using a Dickey-John grain moisture meter (Dickey-John Co., Auburn, IL). Grain yields were corrected to a 150 g kg^{-1} moisture basis. Kernel weight was determined by counting and weighing 1000 kernels, and expressed as grams per 100 kernels.

Grain N content was determined by using an autoanalyzer (Technicon Auto Analyzer II). Grain protein concentration (GPC) was reported as N × 6.25 on dry weight basis. Grain protein yield per unit area was obtained as a product of GPC and grain yield per unit area.

Test weight, a measure of kernel bulk density, was obtained by weighing 110 cm^3 of grain with moisture content among samples ranging from 140 to 150 g kg^{-1} (Kikuchi et al., 1982). Floatation test, a measure of kernel hardness (an indirect estimate of horny/floury endosperm ratio), was done by placing 50 randomly selected kernels in a 200 mL solution of $NaNO_3$ of specific gravity of 1.275 (Wischer, 1961). The number of kernels that float was calculated as a percentage of the total.

Table 2. Significance of year, N-fertilization level, cultivar, and interactions on test weight, percent floaters, grain protein, 100-kernel weight, and grain yield of maize in 1993 and 1994.†

Source of variation‡	NDF	DDF	Probability level of F					
			Test weight	Percent floaters	Grain protein		Kernel weight	Grain yield
					Concentration	Yield		
Year	1	7	<0.01	<0.01	0.01	0.01	<0.01	0.02
Nitrogen (N)	3	21	0.27	<0.01	<0.01	<0.01	<0.01	<0.01
N_L	(1)	(21)	0.26	<0.01	<0.01	<0.01	<0.01	<0.01
N_Q	(1)	(21)	0.58	0.53	<0.01	<0.01	<0.01	<0.01
N × Year	3	21	0.37	0.61	0.56	0.24	0.42	0.50
Cultivar (C)	4	111	<0.01	<0.01	<0.01	0.16	<0.01	0.05
N × C	12	111	0.40	0.16	0.62	0.88	0.30	0.72
C × Year	4	111	0.06	<0.01	0.09	0.42	0.12	0.25
N × C × Year	12	111	0.02	<0.01	0.79	0.72	0.21	0.43
Mineral N (kg ha^{-1}) in 0 to 90 cm soil depth (covariate)	1	111	0.58	0.21	0.42	<0.01	<0.01	<0.01
−2 Res Log Likelihood value			1215	1086	1010	1715	704	2356
CV (%)			1.7	11.9	8.4	19.5	8.4	15.9

† 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.
‡ Subscript L, linear, and subscript Q, quadratic.

Statistical analyses were conducted using the mixed model procedure with the restricted maximum likelihood method (REML) for variance components estimates (SAS Institute, 1992). 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 cultivar effects and interactions. Effect of N fertilizer level was partitioned into linear and quadratic components and regressions were calculated for effects significant at the 0.05 level of probability. Responses of higher-degree polynomials were not considered to have much practical value. Nitrogen level for maximum grain yield was calculated with $-b/2c$, from differentiation of the regression equation. The initial mineral N level in the 0- to 90-cm soil profile of the plots was used as a covariate.

RESULTS AND DISCUSSION

Weather

Long-term mean annual rainfall for the Zaria area is 1100 mm. Less than normal rainfall occurred in 1993 (1050 mm) and in 1994 (910 mm). In 1993, 1038 mm of rain occurred during the growing season, with 132, 156, 269, 301, and 180 mm in May, June, July, August, and September, respectively. In 1994, the rainfall during the growing season was 769 mm, with 232, 169, 216, 83, and 69 mm in May, June, July, August, and September, respectively. The monthly air temperatures during the growing season were similar in both years, dropping slightly from 28°C in May to 25°C in October.

Grain Yield

Grain yield averaged across cultivars and N levels was 5.4 Mg ha^{-1} in 1993 and 4.5 Mg ha^{-1} in 1994. The lower yield in 1994 may be associated with low rainfall during the grain filling period. This could have influenced kernel endosperm starch and protein assimilation (Hardter et al., 1982; Bauer and Carter, 1986), resulting in low response to N, particularly under N stress in 1994. No treatment interactions were found for grain yield (Table 2). Other studies for N fertilizer conducted in West African soils have also shown no cultivar × N interaction on grain yield (Kling et al., 1997). The reasons for this are not known.

Averaged across years and N, TZB-SR, a widely grown cultivar in the savanna of Nigeria, had the lowest grain yield of 4.7 Mg ha^{-1}, which may be attributed to its low kernel weight of 22.54 mg kernel^{-1} (Table 3). Increased kernel weight has been associated with decreased kernel breakage susceptibility, the potential for kernel fragmentation during milling (Bauer and Carter, 1986).

Grain yield increased quadratically as N fertilizer levels increased, with yield peaking (6.6 Mg ha^{-1}) at 109 kg N ha^{-1} (Fig. 1a). Kernel weight gave a response pattern similar to grain yield (Fig. 1b). Grain yield response to N was dependent on the initial mineral N in the soil profile (Table 2).

Grain Protein

Cultivar × N interactions were not observed for grain protein yield and concentration (data not presented).

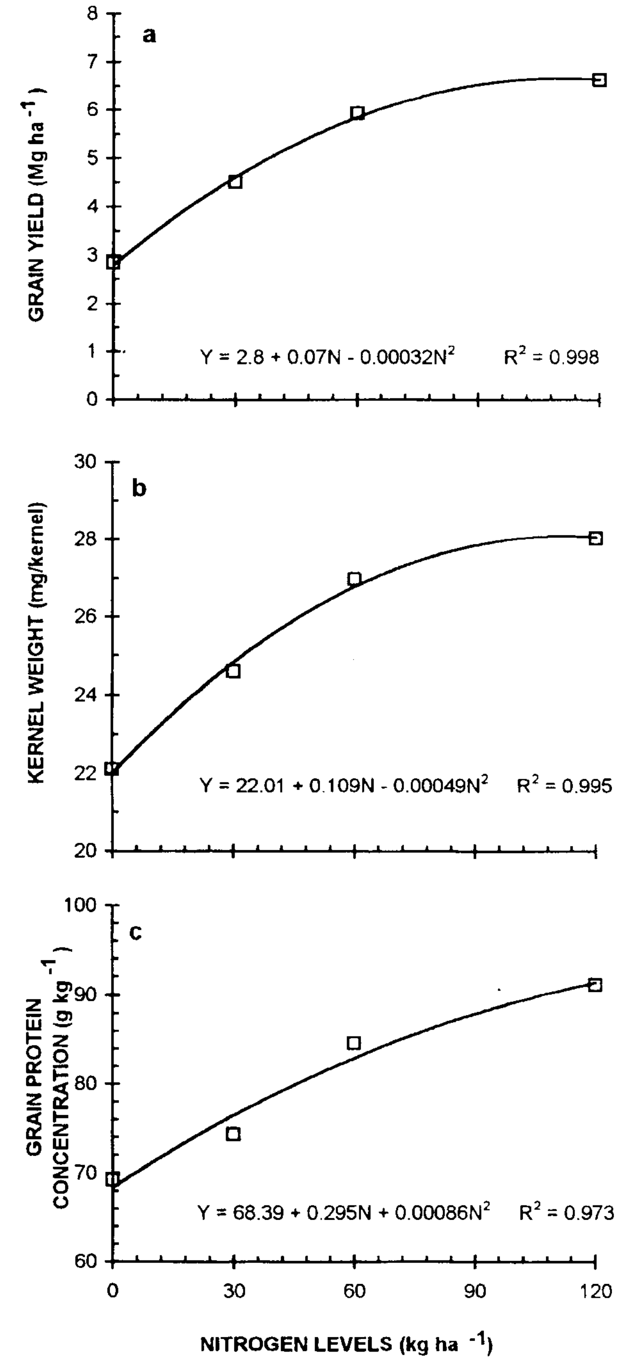

Fig. 1. Influence of N level on (a) grain yield, (b) kernel weight, and (c) grain protein concentration in 1993 and 1994. Each value is averaged across cultivars and years.

Averaged across cultivars and years, GPC responses to N were quadratic (Fig. 1c). Grain protein yield followed the same trend as GPC (data not presented). The increase in GPC with increase in N levels was consistent with the findings of Pierre et al. (1977), Kniep and Mason (1991), and Sabata and Mason (1992, 1995). Kniep and Mason (1991), and Sabata and Mason (1992) reported cultivar × N interactions for grain protein in one season only, indicating seasonal differences in grain protein response to N. In our study, the GPC of the cultivars was 10% lower in 1994, when less rainfall occurred during the grain filling period, than in 1993.

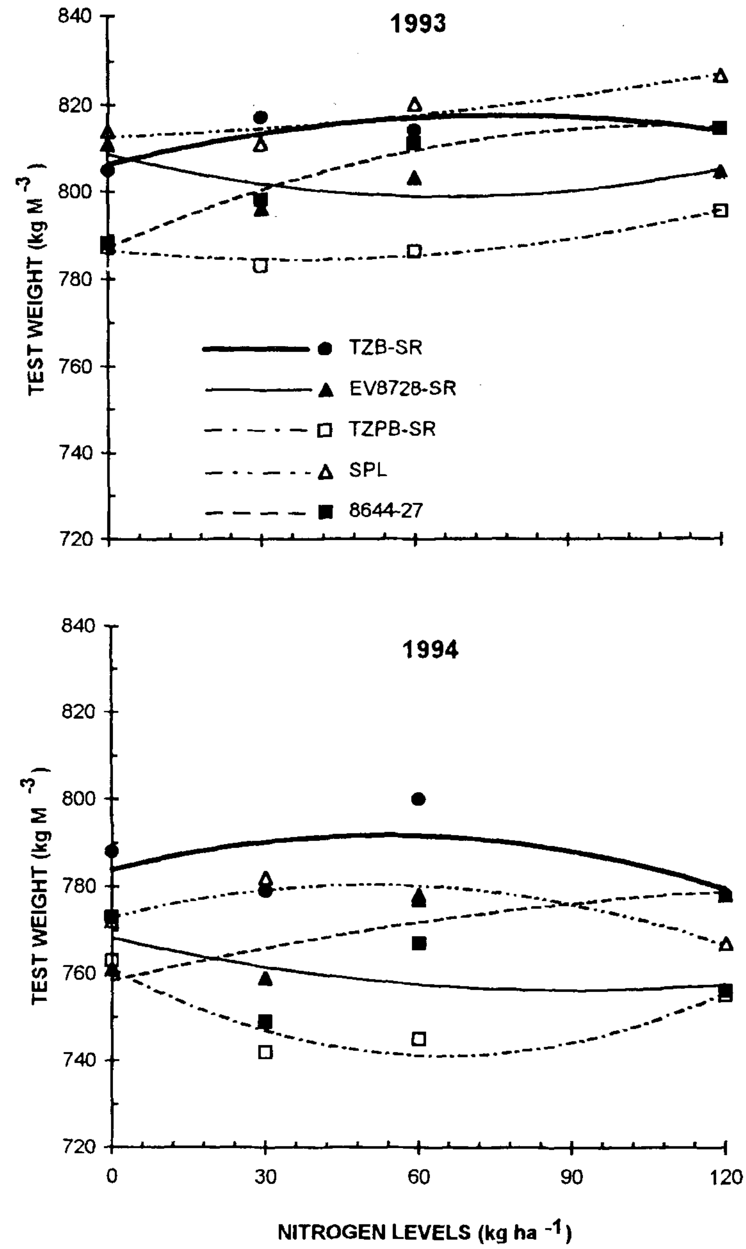

Fig. 2. Influence of N level on test weights among five cultivars in 1993 and 1994. Predicted regression equations are, for 1993: TZB-SR, $Y = 806.4 + 0.29N - 0.0019N^2$, $R^2 = 0.71$; EV8728-SR, $Y = 808.9 - 0.3N + 0.0022N^2$, $R^2 = 0.50$; TZPB-SR, $Y = 786.5 - 0.12N + 0.0016N^2$, $R^2 = 0.96$; SPL, $Y = 812.7 + 0.04N + 0.0006N^2$, $R^2 = 0.84$; 8644-27, $Y = 787 + 0.51N - 0.0024N^2$, $R^2 = 0.98$, and for 1994: TZB-SR, $Y = 783.8 + 0.30N - 0.0028N^2$, $R^2 = 0.31$; EV8728-SR, $Y = 758.4 + 0.28N - 0.0088N^2$, $R^2 = 0.73$; TZPB-SR, $Y = 761.2 - 0.62N - 0.0047N^2$, $R^2 = 0.85$; SPL, $Y = 773.1 + 0.29N - 0.0029N^2$, $R^2 = 0.89$; 8644-27, $Y = 768.3 - 0.27N + 0.0015N^2$, $R^2 = 0.22$.

Averaged across N levels and years, GPC was highest in SPL (Table 3). The hybrid 8644-27 had the lowest GPC, although it had the highest grain yield, supporting the findings of Kniep and Mason (1991) that GPC was negatively associated with grain yield. The grain protein yield per unit area however, was not significantly different among cultivars, ranging from 390 to 429 kg ha^{-1} in both years (Table 3). Thus, the cultivars translocated similar quantities of N to the grain, and differences in grain N concentration may be attributed to differences in starch production among cultivars.

Grain protein content would influence the amount of protein supplement needed for livestock rations. In the present study, any of the cultivars would be suitable for inclusion in livestock feed, since the grain protein yield per unit area did not vary among cultivars.

Dry Milling Quality Parameters

Analyses of test weights and percentage of floaters across years indicated occurrence of a cultivar × N × year interaction (Table 2). Under N stress (zero-N control), TZPB-SR and 8644-27 gave significantly lower test weights than the other cultivars only in 1993 (Fig. 2). Test weight for most cultivars was highest at 120 kg N ha^{-1} in 1993, but in 1994 this trend was not consistent, and the highest test weight of 800 kg m^{-3} was obtained by TZB-SR at 60 kg N ha^{-1}. The hybrid 8644-27 showed

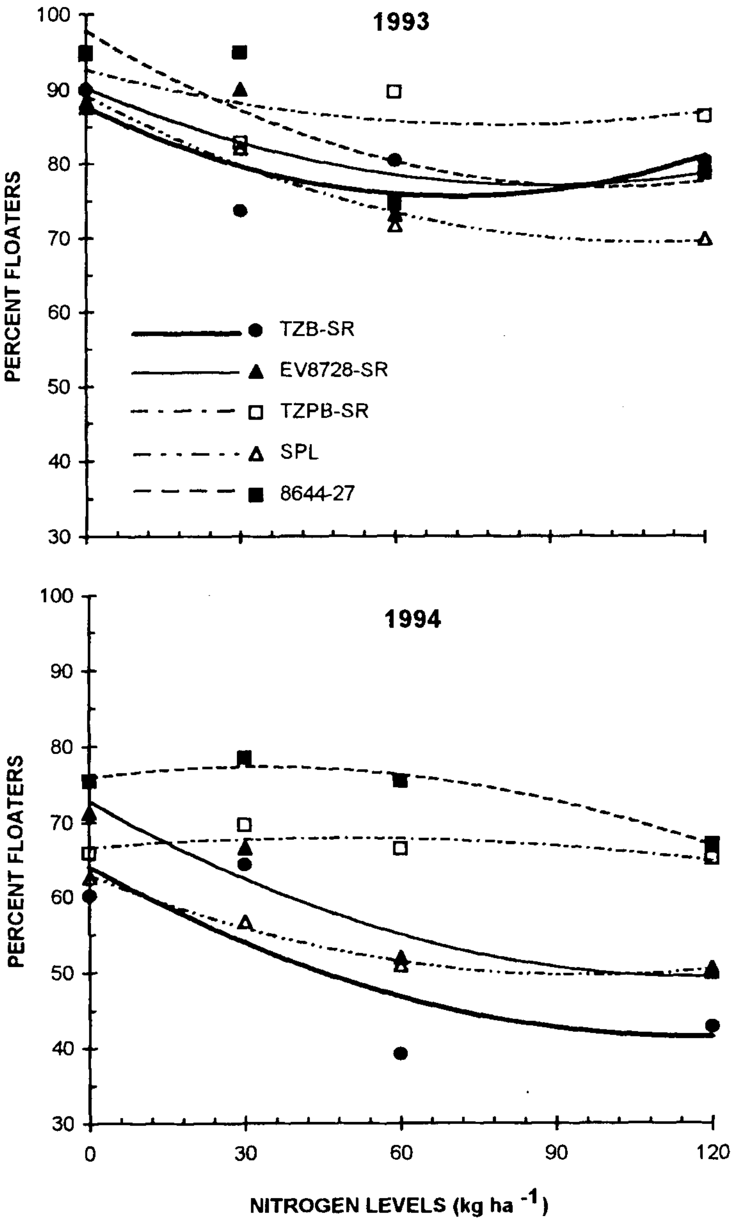

Fig. 3. Influence of N level on the percentage of floaters among five cultivars in 1993 and 1994. Predicted regression equations are, for 1993: TZB-SR, $Y = 87.75 - 0.34N + 0.0023N^2$, $R^2 = 0.54$; EV8728-SR, $Y = 90.28 - 0.3N + 0.0017N^2$, $R^2 = 0.51$; TZPB-SR, $Y = 92.7 - 0.19N + 0.0015N^2$, $R^2 = 0.37$; SPL, $Y = 89.3 - 0.36N + 0.0017N^2$, $R^2 = 0.96$; 8644-27, $Y = 97.9 - 0.42N - 0.0021N^2$, $R^2 = 0.71$, and for 1994: TZB-SR, $Y = 64.1 - 0.38N + 0.0016N^2$, $R^2 = 0.61$; EV8728-SR, $Y = 72.86 - 0.4N + 0.0017N^2$, $R^2 = 0.91$; TZPB-SR, $Y = 66.6 + 5.46N - 0.058N^2$, $R^2 = 0.48$; SPL, $Y = 62.9 - 0.27N + 0.0014N^2$, $R^2 = 0.99$; 8644-27, $Y = 75.9 + 8.9N - 0.0014N^2$, $R^2 = 0.97$.

an increased test weight with increased N in both years. TZPB-SR had relatively low test weights, with a minimum at intermediate N levels, while TZB-SR had high test weight with maximum at intermediate N levels in both years.

In 1993, the percentage of floaters of most cultivars decreased with increased N levels from 0 to 60 kg N ha^{-1}, with little change with further increases in N. The percentage of floaters of TZPB-SR was relatively high at all N levels. In 1994, 8644-27 and TZPB-SR maintained a relatively high percentage of floaters with increased N levels. In contrast, all other cultivars showed marked decrease in the percentage of floaters with increased N levels (Fig. 3). Based on these results, it is not possible to make a general recommendation of the N level to achieve a desired dry milling quality, because results may be specific for each variety and growing environment.

Our results support those of Hamilton et al. (1951), and Bauer and Carter (1986) that maize produced under high fertility gave higher corneous (horny)/floury kernel endosperm ratio (i.e., lower percentage of floaters and higher test weights) than that grown under low soil fertility. Differences among cultivars were observed for both parameters as previously reported by Kling and Okoruwa (1994) and Okoruwa (1997).

High test weights of SPL and TZB-SR indicate that a smaller volume of the grain is required for transportation per unit weight, and that a higher yield of grits can be obtained compared to cultivars with low test weights and a high percentage of floaters. When grown at 30 to 60 kg N ha^{-1}, SPL and TZB-SR should therefore, have high value for industrial dry milling. But, for the traditional dry milling process where the whole grain is ground to produce flour, cultivars with a high percentage of floaters such as 8644-27 (hybrid) and TZPB-SR grown at 30 to 60 kg N ha^{-1}, will be preferred.

Low test weights could reflect a low proportion of horny endosperm (softer grain type) or poor starch deposition during grain filling due to unfavorable environmental conditions. This might explain the quadratic response of test weight to N for some cultivars.

The SPL was among the lowest in percentage of floaters although it ranked highest in GPC in both years. Negative correlations between these traits have been reported previously (Monokarkumar et al., 1978; IITA, 1991). This implies that selecting for flintier cultivars, with increased horny endosperm relative to floury endosperm (low percentage of floaters) could increase the grain protein content, because the horny endosperm has a thick protein matrix (Watson, 1984).

CONCLUSIONS

This study indicates the significant role of N fertilization in improving maize grain yield and quality in the moist savanna. In both years, increasing N levels increased grain yield and GPC quadratically for all the cultivars. Among the improved cultivars, 8644-27 (hybrid) had the highest grain yield of 5.3 Mg ha^{-1}. Average grain protein yield per unit area was not significantly different among cultivars. SPL and TZB-SR grown at 30 to 60 kg N ha^{-1} have high value for industrial dry milling, whereas the softer cultivars 8644-27 and TZPB-SR grown at 30 to 60 kg N ha^{-1} may be preferred for traditional dry milling. Interactions of cultivars and N for grain quality parameters should be considered by maize producers and processors in Africa.

REFERENCES

Badu-Apraku, B., A.E. Okoruwa, J.G. Kling, and S.K. Kim. 1995. Improvement of maize genotypes with appropriate quality characteristics for industrial processing and use. p. 247–272. *In* J.M. Menyonga et al. (ed.) Processing and industrial utilization of sorghum and related cereals in Africa. OAU/STRC-SAFGRAD, Semi-Arid Food Grain Res. and Dev., Ouagadougou, Bukina Faso.

Bauer, P.J., and P. Carter. 1986. Effect of seeding date, plant density, moisture availability, and soil fertility on maize kernel breakage susceptibility. Crop Sci. 26:1220–1226.

Enwezor, W.O., E.J. Udo, N.J. Usoroh, K.A. Ayotade, J.A. Adepeju, V.O. Chude, and C.I. Udegbe. 1989. Fertilizer use and management practices for crops in Nigeria. Series no. 2. Fertilizer Procurement and Distribution Division, Federal Ministry of Agric., Water Resources, and Rural Development, Lagos, Nigeria.

Hamilton, T.S., B.C. Hamilton, B.C. Johnson, and H.H. Mitchell. 1951. The dependence of the physical and chemical composition of corn kernel on soil fertility and cropping system. Cereal Chem. 28:163–176.

Hardter, H.J., R.E. Carlson, and R.H. Shaw. 1982. Yield, yield components, and nutrient content of corn grain as influenced by post silking moisture stress. Agron. J 74:275–278.

IITA. 1991. Maize quality utilization project. 1991. Annual Report. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Kassam, A.H., J. Kowal, M. Dagg, and M.N. Harrison. 1975. Maize in West Africa and its potential in the savanna area. World Crops 27(1):73–78.

Kikuchi, K., L. Takatsuji, M. Todudo, and K. Miyake. 1982. Properties and uses of horny and floury endosperm corn. J. Food Sci. 47:1687.

Kling, J.G., and A.E. Okoruwa. 1994. Influence of variety and environment on maize grain quality for food uses in Africa. p. 119. *In* Agronomy abstracts. ASA, Madison, WI.

Kling, J.G., S.O. Oikeh, H.A. Akintoye, H.T. Heuberger, and W.J. Horst. (1997). Potential for developing N use efficient maize for low input agricultural systems in the moist savannas of Africa. p. 490–501. *In* G.O. Edmeades et al. (ed.). Developing drought- and low-nitrogen tolerant maize. Proc. Symp. CIMMYT. El Batán, Texcoco, Mexico. 25–29 Mar. 1996. CIMMYT, Mexico, D.F.

Kniep, K.R., and S.C. Mason. 1991. Lysine and protein content of normal and *opaque*-2 maize grain as influenced by irrigation and nitrogen. Crop Sci. 31:177–181.

Monokarkumar, B., P. Gerstenkorn, H. Zwingelgerg, and H. Bolling. 1978. On some correlations between grain composition and physical characteristics to the dry milling performance for maize. J. Food. Sci. Technol. 15(1):1–6.

Okoruwa, A.E. 1997. Enhancing maize processing and utilization in West and Central Africa. p. 108–119. *In* B. Badu-Apraku et al. (ed.) Contributing to food self-sufficiency: maize research and development in West and Central Africa. Proc. Regional Maize Workshop. IITA. Cotonou, Benin Republic. 29 May–2 June 1995. WECAMAN/IITA, Nigeria.

Oikeh, S.O., J.G. Kling, V.O. Chude, and W.J. Horst. 1997. Yield and N-use efficiency of five tropical maize genotypes under N levels in the moist savanna of Nigeria. p. 163–167. *In* J.K. Ransom et al. (ed.). Maize productivity gains through research and technology dissemination: Proc. 5th Eastern and Southern Africa Regional Maize Conf. Arusha, Tanzania. 3–7 June 1996. CIMMYT, Addis Ababa, Ethiopia.

Pierre, W.H., L. Dumenil, V.D. Jolley, J.R. Webb, and W.D. Shrader. 1977. Relationship of corn yield, expressed as percentage of maximum and the N percentage in the grain: I. Various nitrogen rates experiments. Agron. J. 69:215–220.

Sabata, R.J., and S.C. Mason. 1992. Corn hybrid interactions with soil nitrogen level and water regime. J. Prod. Agric. 5:137–142.

Sabata, R.J., and S.C. Mason. 1995. Water regime and N impact on maize grain yield, grain quality, and soil nitrate. Agron. (Trends in Agric. Sci.) 3:5–10.

SAS Institute, Inc. 1992. SAS Technical Report P-229. SAS/STAT software: Changes and enhancement, Release 6.07. SAS Inst., Cary, NC.

Thé, C., J.A. Ayu-Takem, and M. Nkoa. 1989. The contribution of introduced maize varieties to the improvement of Cameroon local maize accessions. p. 29–36. *In* Towards production technologies for maize and cowpea in semi-arid West and Central Africa. SAFGRAD-IITA, Bukina Faso.

Watson, S.A. 1984. Corn and sorghum starches: Production. p. 418–468. *In* R.L. Whistler et al. (ed.) Starch: Chemistry and technology. Academic Press, Orlando, FL.

Wischer, W.R. 1961. The world of corn processing. Am. Miller & Process. 89(1):29–31.