Performance of tropical maize hybrids under conditions of low and optimum levels of nitrogen fertilizer application – grain yield, biomass production and nitrogen accumulation

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Abstract

Nitrogen (N) is the most limiting mineral nutrient in the soils of the major maize producing areas of West and Central Africa. Low soil N and sub-optimal application of N fertilizers lead to N deficiency and poor grain yield (GY) in maize. Maize varieties with improved grain yield under low soil N and increased performance under optimal N availability could be beneficial to low input agriculture. This study evaluated the performance of a selection of experimental and commercial hybrids under suboptimal and optimal N fertilizer applications. Significant differences were observed among the hybrids, as well as significant interactions between hybrid and N level for GY and other measured attributes, with the severity of variation increasing as the level of N decreases. Mean GY reductions across the years was 76.5% at no-N and 35.4% at low-N. Depending on N treatment, GY varied from 0.48 to 4.42 Mg ha^{-1}, grain N content from 0.17 to 1.26 g plant^{-1}, total N content at harvest from 0.33 to 2.00 g plant^{-1}, above ground biomass at silking from 30.6 to 91.2 g plant^{-1} and at maturity from 39.9 to 191.1 g plant^{-1}. Number of kernels was the GY component most severely reduced by N stress and had significant ($p \leq 0.001$) positive correlation with GY at all N levels. Six hybrids (4001/4008, KU1409/4008, KU1409/9613, 4008/1808, 4058/Fun 47-4, and 1824/9432) which showed consistent above average grain yields under no-N, low-N, high-N and across N levels were found and their use could further be investigated.

Keywords: maize hybrids, grain yield, number of kernels, low soil N, low input agriculture

Introduction

Maize, *Zea mays* L, is one of the cereals that have to meet increasing demand for food and feed in the developing world (Cassman et al, 2002). By the year 2020, the demand for maize in developing countries is expected to exceed the demand for wheat and rice (Pinstrup-Andersen et al, 1999). In sub-Saharan Africa, maize is the most widely cultivated crop and the most important food staple, accounting for up to 70% of the daily human calorie intake (Martin et al, 2000). Increased maize production is therefore needed in the developing countries of Africa to meet its demand within the limits of available land and environmental conditions (Pingali and Pandey, 2001). Decreasing arable land caused by intensified land use and the rapid decline in the length of fallow, as well as the extension of farming into marginal lands, have resulted in a rapid decline in soil fertility in sub-Saharan Africa (Bellon, 2001). Nitrogen (N) deficiency is therefore a common feature in maize production (Jones and Wild, 1975).

The release of hybrid maize varieties, use of artificial fertilizers and the adoption of improved agro-technical production systems have resulted in enhanced grain yields over the years (Carlone and Russel, 1987; Tollenaar, 1991). For optimum yields, hybrid maize requires high doses of fertilizer (Gardner et al, 1990; Killorn and Zourarakis, 1992) possibly because their development is usually under high N fertilizer applications (Purcino et al, 1998; Bertin and Gallais, 2000). Genetic selection of maize hybrids is usually conducted under optimum levels of N application which eliminates the effects of N as a restrictive variable during the selection process (Kamprath et al, 1982). This procedure could either lead to the release of genotypes that present luxury N consumption (Carlone and Russel, 1987) or require a high N input to accomplish their yield potential (Sangoi et al, 2001).

Fertilizer use in Africa is low, with an average of 8 kg nutrients/ha (Heisey et al, 2007). The limited local supply of N fertilizers in Africa and inadequate transportation and distribution infrastructure contribute to higher prices compared to global market prices (Mosier et al, 2005). These factors, when combined with the low purchasing power of the predominant resource-poor smallholder farmers in sub-Saharan Africa, perpetuate sub-optimal N fertilizer application in their farms (Bänziger et al, 1999; Crawford et al, 2005). Sub-optimal N fertilizer applications have been

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shown to result in lower yields of maize hybrids (Sallah et al, 1998; Worku et al, 2007). Studies (Tsai et al, 1984; Eghball and Maranville, 1991) have however revealed that cultivars less responsive to applied N could sometimes perform better than N-responsive hybrids or cultivars under low soil N conditions. The current low average maize grain yield of 1.78 Mg ha^{-1} across sub-Saharan Africa (FAO, 2009) is a reflection of the limited use of fertilizer and the inadequacy of other strategies employed to mitigate the effects of poor soil fertility in African agriculture.

One strategy for improving maize productivity and reducing the effects of low soil N on maize production is to select cultivars with superior grain yields under low soil N. This could be achieved by selecting cultivars with superior N-use efficiency either by possessing a high N-uptake efficiency or enhanced N-utilization efficiency (Lafitte and Edmeades, 1994a). Under low soil N, a maize plant with good performance should exhibit increased total biomass production, and plant height, leaf area and chlorophyll concentration little affected by N deficiency, as well as, an efficient partitioning of biomass and N to the grain (Lafitte and Edmeades, 1994a).

One of the goals of the International Institute of Tropical Agriculture (IITA) Maize Improvement Program is the development of maize varieties with improved stress tolerance and good grain yield under low soil N. Maize varieties with improved grain yield under low soil N and increased performance under optimal N could be beneficial to low input agriculture. The objective of our study was to evaluate the performance of experimental and commercial single cross maize hybrids developed at IITA Ibadan, Nigeria, under suboptimal and optimal levels of N fertilizer application.

Materials and Methods

Field experiments were carried out at the IITA experimental station in Mokwa (9°18'N, 5°04'E, and 457 masl) located in the southern guinea savanna agroecology of Nigeria in 2006, 2007 and 2008. The soil type is a lixisol with high sand content (FAO, 2003). The field had previously been depleted of nitrogen (N) by planting maize at high densities for two growing seasons without fertilizer application and removing the above ground biomass after each growing season. The experimental field was cleared, ploughed and harrowed. The physical and chemical properties of the field prior to land preparation in each cropping season, as well as precipitation during the growing season at the location are shown in Table 1.

Twelve single cross maize experimental hybrids along with two commercial hybrids were used in the present study. The twelve experimental hybrids were developed at the IITA station in Ibadan. The parental inbred lines of these hybrids, which were classified as either tolerant or susceptible to drought, had in a previous study (Meseka et al, 2006) been evaluated alongside other inbreds, for their performance under low N under condition. The two commercial hybrids included in this study, Oba Super I (9021-18, previously 8321-18) and Oba Super II (8644-27) have since 1984 been marketed in Nigeria, with the former being N-inefficient and the latter being N-efficient (Sanginga et al, 2003).

The experimental field was divided into three blocks viz: high-N, low-N and no-N. The high-N block received 90 kg N ha^{-1}, the low-N block received 30 kg N ha^{-1} and the no-N block received 0 kg N ha^{-1}. The three blocks were separated from one another by at least 5.0 m to minimize N movement from one treatment to the other. The hybrids were planted in

Table 1 - Physical and chemical properties of the soils prior to land preparation in each cropping season and precipitation at the experimental site.

Properties	2006†	2007‡			2008‡		
		no-N	low-N	high-N	no-N	low-N	high-N
pH (1:1 H_2O)	5.1	4.8	4.9	4.7	5.8	5.9	5.9
Organic Carbon (g kg^{-1})	3.8	2.6	4.1	4.2	4.2	5.0	5.6
Total N (g kg^{-1})	0.40	0.25	0.39	0.41	0.42	0.54	0.60
Available P (mg kg^{-1})	14.59	7.70	15.3	2.60	5.60	6.21	6.55
K (cmol kg^{-1})	0.23	0.18	0.25	0.16	0.23	0.18	0.17
CEC (molc kg^{-1})	4.13	3.77	3.15	3.42	2.97	1.75	1.31
Mechanical analyses							
Sand (g kg^{-1})	673	700	700	680	740	820	820
Silt (g kg^{-1})	150	140	130	150	120	60	60
Clay (g kg^{-1})	177	160	170	170	140	120	120
Textural class (USDA)*	SL	SL	SL	SL	SL	LS	LS
Total precipitation (mm) (May to October)							
2006	880						
2007	1222						
2008	1379						

†All the blocks were uniformly depleted at the beginning of 2006; therefore composite soil samples were used to determine physical and chemical properties. ‡ In 2007 and 2008, no-N, low-N and high-N refers to blocks to which 0, 30 and 90 kg N ha^{-1} fertilizer was applied respectively; * SL: sandy loam; LS: loamy sand.

Table 2 - Mean grain yields of 14 tropical maize hybrids at no-N (0), low-N (30) and high-N (90) kg N ha^{-1} fertilizer application at Mokwa, Nigeria between 2006 and 2008.

	Grain yield (Mg ha^{-1}) and Rank			
Hybrids (H)	no-N	low-N	high-N	across N
4001/4008	1.29 (2)	3.09 (2)	4.42 (1)	2.93 (1)
KU 1409/4008	1.53 (1)	2.93 (4)	4.21 (7)	2.89 (2)
9450/MOK Pion-Y-S4	0.48 (14)	2.29 (11)	3.68 (13)	2.15 (13)
KU 1409/9613	0.98 (7)	3.18 (1)	4.30 (2)	2.82 (3)
4008/1808	1.10 (4)	2.80 (5)	4.18 (8)	2.69 (5)
4008/9071	1.00 (6)	2.75 (6)	3.70 (12)	2.48 (8)
9613/9006	0.77 (11)	2.46 (9)	3.90 (10)	2.38 (11)
4058/Fun 47-4	1.04 (5)	2.73 (7)	4.25 (5)	2.67 (6)
1824/9432	0.89 (8)	2.95 (3)	4.24 (6)	2.69 (4)
4058/GH 24	0.68 (12)	2.33 (10)	3.83 (11)	2.28 (12)
9071/4058	0.83 (10)	2.23 (13)	4.28 (3)	2.45 (10)
9006/4058	0.86 (9)	2.27 (12)	4.27 (4)	2.47 (9)
OBA SUPER-1	0.63 (13)	2.02 (14)	3.34 (14)	2.00 (14)
OBA SUPER-2	1.17 (3)	2.47 (8)	3.90 (9)	2.51 (7)
Mean	0.95	2.61	4.03	2.53
CV (%)	17.2	13.2	11.4	13.6
LSD (0.05)	0.13	0.28	0.37	0.16
Range	0.48 - 1.53	2.02 - 3.18	3.34 - 4.42	2.00 - 2.93
H × N	***			

***: significant at 0.001 probability level; H × N: Hybrid by Nitrogen level interaction.

each block in a randomized complete block design with four replications. The hybrids in each block were planted in four rows of 5.0 m length spaced 0.75 m apart with 0.25 m spacing between plants within a row. Two seeds were hand planted per hill and later thinned to one to obtain a plant population density of 53,333 plants per hectare. The inner two rows in each plot were used for yield determination, whereas outer two rows were used for destructive sampling. At planting, P in the form of single super phosphate and K as muriate of potash were applied at the rate of 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} respectively. N fertilizer in the form of urea was applied in two equal split doses, the first half at 2 weeks after planting (WAP) and the second dose at 4 WAP. Herbicides complemented with hand weeding were used to achieve complete weed control.

All agronomic and yield data with the exception of days to anthesis and days to silking were collected on the rows reserved for grain yield in each plot. Days to anthesis and days to silking were expressed as number of days from planting to when 50% of plants in a plot shed pollen or show silk extrusion. Anthesis-silking interval was calculated as the difference in days between days to anthesis and days to silking. Plant and ear heights were measured in meters on five competitive plants as distance from the ground level to the collar of the upper most leaf and upper ear leaf respectively. Ear leaf chlorophyll concentration was measured at silking on the middle of the upper ear leaf of five competitive plants per plot using a portable Single-Photon Avalanche Diode (SPAD-502) chlorophyll meter (Minolta, 1989). Ears per plot was recorded as the number of ears harvested in a plot. Kernel rows was recorded as the average number of kernel rows measured on 5 top ears. Number of kernels was recorded as the number of kernels on ear per plant after shelling. Estimated indirectly through the relationship between the weight of 200 kernels, weight of total number of kernels and number of ears harvested per plot. Grain moisture at harvest was measured with a portable Dickey-John moisture tester (Model 14998, Dickey-John Corporation, Auburn USA) as the percent moisture content of shelled kernels. One thousand kernel weight was measured in g as the weight of 1,000 kernels adjusted to 15% moisture content. It was estimated by weighing a representative 200 kernels and multiplying by 5. For yield determination, all ears in the inner two rows of each plot were harvested and shelled, and the fresh weight, moisture content of shelled grains and number of plants per plot at harvest used to estimate grain yield. Grain yield was expressed in Mg/ha adjusted to 15% moisture content. Number of plants per plot was recorded as the number of plants on the inner two rows of each plot at harvest.

Data on N acquisitions were determined using whole shoots sampled at silking (when 50% of plants in a plot have visible silks) and at harvest. At each sampling, four representative plants were harvested from each plot by cutting near the soil surface. All plant stover at silking and stover (with ears removed) at maturity were chopped and dried in a forced-draft oven (600°C) for 72 hours. The harvested ears were also oven-dried at 600C for 72 hours. The dry weight of each sample was determined after drying to constant weight. At silking, plant biomass (g $plant^{-1}$) was calculated by dividing the dry weight of each sample by four, while at harvest, total plant biomass in (g $plant^{-1}$) was calculated from the average of the sum of ear and stover weights. Post-silking biomass accumulation (g plant^{-1}) was calculated by subtracting plant biomass at silking from total plant biomass at harvest. Individual samples were ground, passed through 20-mesh screen and stored for assay. Grain and stover sub-samples were analyzed for total N concentration (g kg^{-1}) using a combustion technique (NA2000 N-Protein, Fisons Instruments) at the University of Illinois, Urbana-Champaign. N content (g plant^{-1}) of stover at silking was calculated by multiplying the N concentration by the dry weight. Total N content (g plant^{-1}) at harvest was calculated by multiplying the N concentration for the stover and grain samples by their respective dry weights and summing both values. N-remobilization and post-silking N-accumulation were estimated adopting the balance method, by assuming that all N absorbed after silking was allocated to the grain. Therefore, N-remobilization was calculated as stover N content at silking minus stover N content at harvest. Post-silking N-accumulation which represents the quantity of total N at harvest absorbed after silking and was calculated as total N content at harvest minus N content at silking.

Analysis of variance (ANOVA) was carried out on all measured traits using the Proc GLM procedure from SAS statistical software (SAS Institute Inc, 2003). Analyses were performed for each N rate followed by analyses for the N rates combined. In both cases, all effects were considered fixed. Means were separated using Least Significant Difference (LSD). To assess the association between measured traits at different N input levels, correlation analysis was carried out between pairs of measured traits.

Results

Grain yield

There were significant ($p < 0.01$) differences among the hybrids studied for grain yield at the three N levels. In the analysis of variance combined across years and N levels, Hybrid × N interaction effect was also significant ($p < 0.001$) which reflects the differences observed in the relative ranking in grain yield under the different N levels (Table 2). Generally, grain yield increased with increasing level of N fertilizer. Mean grain yield averaged across years, was reduced by 35.2% at low-N and 76.4% at no-N. At high-N, the range in mean grain yield across the years among hybrids varied from 3.3 Mg ha^{-1} to 4.4 Mg ha^{-1} and from 2.0 Mg ha^{-1} to 3.2 Mg ha^{-1} at low-N. The range under no-N was 0.5 Mg ha^{-1} to 1.5 Mg ha^{-1}, which translates to a reduction of 64 - 87%. Six hybrids, namely 4001/4008, KU1409/4008, KU1409/9613, 4008/1808, 4058/Fun 47-4 and 1824/9432 showed consistent above average grain yields under no-N, low-N, and high-N as well as across N levels. Hybrids 9071/4058 and 9006/4058 on the other hand, had below average grain yields under no-N and low-N but comparable grain yields with the six top yielding hybrids under high-N. This suggests the two hybrids could have special adaptation to high soil N environment. Although the commercial hybrid Oba Super-2 ranked third in grain yield under no-N, suggesting tolerance to adverse N stress, it had below average grain yield under both low-N and high-N which could be a reflection of its not being N responsive. The hybrid Oba-Super-1 was the lowest yielding under low-N, high-N and across N levels (Table 2).

Yield components and flowering traits

All the grain yield components measured showed significant ($p < 0.01$) hybrid differences at the three N levels. In the combined analysis across the years and N levels, Hybrid × N interactions was significant ($p < 0.01$) for kernel rows, number of kernels, ears per plant, and one thousand kernel weight (Table 3). Differences among the hybrids for plant height and ear height, as well as flowering traits, except anthesis-silking interval (ASI), were also significant ($p < 0.01$) at high-N and low-N. Under no-N, significant ($p < 0.05$) differences among hybrids were observed for these traits, except for days to anthesis. In the combined analysis over the years and N levels, Hybrid × N interaction effect for these traits was not significant (Table 3). Of the grain yield components, number of kernels was the most affected by N stress showing a 21.5% and 60.3% reduction at low-N and no-N respectively. One thousand kernel weight was reduced by 2.4% at low-N and 16.7% at no-N. Number of ears per plant

Table 3 - Means of various agronomic traits of 14 tropical maize hybrids grown under 0 (no-N), 30 (low-N) and 90 (high-N) kg N ha^{-1} nitrogen fertilizer application at Mokwa, Nigeria between 2006 and 2008.

Traits	N-rate no-N (mean)	low-N (mean)	high-N (mean)	LSD (0.05)	H × N
Days to anthesis	60.5	57.2	55.3	0.39	NS
Days to silk	64.1	59.6	57.4	0.41	NS
Anthesis-silking interval (days)	3.6	2.5	2.1	0.21	NS
Plant height (m)	1.27	1.77	1.83	0.03	NS
Ear height (m)	0.55	0.82	0.86	0.02	NS
Kernel rows	12.1	13.6	14.3	0.19	**
Number of kernels	132.7	262.6	334.5	11.13	***
Ears per plant	0.64	0.85	0.95	0.03	***
One thousand kernel weight (g)	184.2	215.8	221.2	4.07	**

NS, **, ***: not significant at P = 0.05, significant at 0.01, 0.001 probability levels, respectively; H × N: Hybrid by Nitrogen level interaction.

Table 4 - Means of selected physiological traits of 14 tropical maize hybrids at 0, 30 and 90 kg N ha^{-1} fertilizer application in Mokwa, Nigeria from 2006 to 2008.

Hybrids (H)	Stover dry weight at silking (g plant^{-1})			Stover dry weight at maturity (g plant^{-1})			Grain weight			Total dry weight (g plant^{-1})			Harvest index (HI) at maturity (g plant^{-1})			Ear leaf chlorophyll concentration (SPAD)		
	0	30	90	0	30	90	0	30	90	0	30	90	0	30	90	0	30	90
4001/4008	30.6	81.0	81.1	42.6	82.4	98.0	24.0	54.4	77.5	66.6	136.8	175.6	0.36	0.40	0.45	21.8	34.5	41.1
KU 1409/4008	32.1	73.2	76.8	45.5	91.2	102.2	29.8	60.4	79.3	75.3	151.6	181.5	0.38	0.42	0.44	21.9	34.3	42.4
9450/MOK Pion-Y-S4	28.5	73.2	79.3	26.7	70.6	96.7	13.1	44.4	71.5	39.9	115.0	168.2	0.29	0.36	0.41	18.2	30.8	41.0
KU 1409/9613	35.0	86.9	79.3	34.2	79.2	94.2	23.1	45.5	78.8	57.2	124.6	173.0	0.40	0.35	0.45	20.3	33.1	42.2
4008/1808	35.0	80.1	79.5	38.7	77.5	93.4	21.3	52.1	76.0	59.9	129.7	169.4	0.34	0.41	0.45	20.2	33.2	41.4
4008/9071	44.5	73.6	91.2	37.2	79.8	86.0	20.0	42.7	59.4	57.2	122.5	145.4	0.33	0.35	0.40	20.5	30.6	38.9
9613/9006	36.4	78.7	78.9	31.8	71.8	95.5	16.3	46.5	73.6	48.1	118.4	169.2	0.32	0.38	0.42	17.6	31.5	38.4
4058/Fun 47-4	35.3	78.9	88.4	35.0	76.8	105.9	15.3	52.6	85.2	50.3	129.5	191.1	0.32	0.40	0.43	18.3	30.5	41.3
1824/9432	31.5	82.5	70.8	35.3	63.9	86.7	19.7	46.1	77.7	55.0	110.0	164.4	0.35	0.41	0.48	21.3	31.5	41.6
4058/GH 24	34.0	71.2	80.2	31.5	74.9	99.6	16.2	47.5	72.6	47.6	122.4	172.2	0.35	0.37	0.43	19.0	29.1	39.5
9071/4058	35.2	79.5	77.1	32.7	76.7	103.3	16.5	50.9	83.4	49.2	127.7	186.7	0.31	0.39	0.42	17.8	30.8	37.9
9006/4058	37.0	79.3	85.1	30.1	76.0	98.0	13.8	52.0	71.3	43.9	128.0	169.3	0.31	0.37	0.40	17.8	29.7	42.8
OBA SUPER-1	35.5	74.0	79.5	33.6	65.0	88.5	10.5	46.0	62.7	44.1	110.9	151.3	0.24	0.39	0.41	15.4	29.3	38.1
OBA SUPER-2	38.0	73.7	77.6	37.7	78.4	94.8	15.7	49.0	67.0	53.4	127.5	161.8	0.28	0.39	0.43	16.6	30.8	40.9
Mean	34.9	77.6	80.3	35.2	76.0	95.9	18.2	49.3	74.0	53.4	125.3	169.9	0.33	0.39	0.43	19.2	31.4	40.5
CV	20.5	10.4	11.9	23.7	9.7	10.5	31.2	16.0	14.5	21.3	9.4	9.6	23.9	14.0	11.2	15.2	13.3	9.7
LSD (0.05)	5.76	6.54	7.71	6.75	5.96	8.13	4.60	6.35	8.68	9.20	9.53	13.1	0.06	0.04	0.04	2.35	3.36	3.18
H × N		***			***			***			***			**			NS	

NS, **, ***: not significant at P = 0.05, significant at 0.01 and 0.001 probability levels, respectively; H × N: Hybrid by Nitrogen level interaction.

was less than one even under high-N (0.95) conditions. Kernel rows averaged 14.3 at high-N, 13.6 at low-N and 12.1 at no-N. Estimated from number of kernels and kernel rows, number of kernels per row was 11.0, 19.3 and 23.4 at no-N, low-N and high-N respectively. These values indicate 17.9% and 53.4% reduction in number of kernels per row at low-N and no-N, respectively. Under low-N, number of days to silking was delayed by 2.3 days while anthesis was delayed by 1.9 days. ASI was not adversely affected by N stress (2.1 days at high-N, 2.5 days at low-N and 3.5 days at no-N). Severe N stress at no-N reduced plant height and ear height by 30% and 36%, respectively. Under low-N, reductions in these traits were 3.3% and 4.7%, respectively (Table 3).

Biomass production and N accumulation traits

Differences among hybrids for ear leaf chlorophyll concentration (SPAD) and all traits associated with biomass production were significant ($p < 0.05$) at the three levels of N application. In the combined analysis, differences among hybrids for these traits were also significant ($p < 0.001$). Hybrid × N interaction effect was not significant for ear leaf chlorophyll concentration (SPAD) (Table 4). Ear leaf chlorophyll concentration showed more pronounced variation among hybrids at no-N than at low-N and high-N. N stress reduced Ear leaf chlorophyll concentration by 22.5% at low-N and 52.7% at no-N. Under low-N, stover dry weight was reduced by 3.5% at silking and 20.7% at harvest. Although N stress reduced grain weight per plant by 33.4% at low-N and 75.4% at no-N, the reduction in harvest index (HI) was 9.3% and 23.3% at low-N and no-N respectively. This indicates a relative stability in the proportion of percent reductions in grain weight to HI at low-N and no-N. Post-silking dry matter accumulation was reduced by 46.7% at low-N and it contributed 52.7%, 37.3% and 34.7% to the total dry weight at harvest under high-N, low-N and no-N, respectively. A 2% stover remobilization was observed under low-N (Table 4).

Total dry weight varied from 145.7 to 191.1 g plant^{-1} (mean = 169.9 g plant^{-1}) under high-N, from 110.0 to 151.6 g plant^{-1} (mean = 125.3 g plant^{-1}) under low-N and from 39.9 to 75.3 g/plant (mean = 53.4 g plant^{-1}) under no-N. The highest total above ground dry weight was produced by 4058/Fun 47-4 at high-N. The hybrid KU1409/4008 accumulated the highest total biomass post-silking and had the highest total dry weight at both low-N and no-N. Grain dry weight ranged from 59.4 to 85.2 g plant^{-1} (mean = 74.0 g plant^{-1}) under high-N, from 42.7 to 60.4 g plant^{-1} (mean = 49.3 g plant^{-1}) under low-N, and 10.5 to 29.8 g plant^{-1} (mean = 18.2 g plant^{-1}) at no-N. Despite the significant hybrid differences for HI, the range in values under each N level was moderate (Table 4).

For all the N content traits, both at silking and harvest, hybrid and hybrid × N interaction effects were significant ($p < 0.01$). Similar results were obtained for the post-silking N accumulation traits (Table 5). At low-N, the reduction in stover N content at silking was 34.5%. Reductions in total N at harvest compared with high-N were on average 45.4% at low-N and 76.0% under no-N. The reduction in total N content was higher than the corresponding reduction in grain yield at low-N and similar to its reduction at no-N. N stress under low-N reduced Grain N content by 42.1%. Corresponding reduction at no-N was 77.2%. At low-N, 72% of the total N content at harvest was accumulated at silking while 60.1% of the total N content at harvest was accumulated at silking under high-N. Post-silking stover N accumulation was 7.3% and 75.6% higher at low-N and no-N, respectively, than at high-N. Compared to high-N treatment, total N accumulation between silking and maturity was at low-N reduced by 61.6%. The stover N remobilized

Table 5 - Means of selected N related traits of 14 tropical maize hybrids at 0, 30 and 90 kg N ha^{-1} fertilizer application in Mokwa, Nigeria from 2006 to 2008.

Hybrids (H)	Stover N content at silking (g plant^{-1})			Grain N content (g plant^{-1})			Total N content at maturity (g plant^{-1})			Post-silking stover N accumulation (g plant^{-1})			Post-silking total N accumulation (g plant^{-1})			N remobilization (g plant^{-1})		
	0	30	90	0	30	90	0	30	90	0	30	90	0	30	90	0	30	90
4001/4008	0.23	0.70	1.05	0.32	0.69	1.17	0.53	1.06	1.95	-0.02	-0.33	-0.26	0.30	0.36	0.91	0.02	0.33	0.26
KU 1409/4008	0.24	0.69	1.01	0.41	0.85	1.21	0.63	1.28	2.00	-0.03	-0.26	-0.22	0.39	0.59	0.99	0.02	0.26	0.22
9450/MOK Pion-Y-S4	0.23	0.79	1.24	0.20	0.60	1.20	0.33	0.93	1.84	-0.01	-0.45	-0.60	0.10	0.15	0.60	0.10	0.45	0.60
KU 1409/9613	0.27	0.84	1.19	0.32	0.65	1.21	0.47	0.98	1.89	-0.12	-0.51	-0.50	0.20	0.13	0.71	0.12	0.51	0.50
4008/1808	0.29	0.76	1.13	0.31	0.67	1.15	0.49	1.06	1.78	-0.11	-0.38	-0.50	0.20	0.29	0.65	0.11	0.38	0.50
4008/9071	0.38	0.67	1.26	0.28	0.59	0.88	0.50	0.98	1.50	-0.16	-0.28	-0.64	0.13	0.31	0.24	0.16	0.28	0.64
9613/9006	0.28	0.67	1.04	0.26	0.64	1.26	0.44	0.95	1.93	-0.10	-0.37	-0.37	0.16	0.26	0.89	0.10	0.37	0.37
4058/Fun 47-4	0.28	0.72	1.12	0.22	0.70	1.25	0.40	1.06	1.97	-0.10	-0.36	-0.40	0.13	0.34	0.85	0.10	0.36	0.40
1824/9432	0.24	0.78	0.97	0.27	0.58	1.12	0.46	0.86	1.70	-0.05	-0.50	-0.39	0.22	0.08	0.73	0.05	0.50	0.39
4058/GH 24	0.27	0.63	1.05	0.24	0.61	1.11	0.38	0.89	1.83	-0.13	-0.34	-0.34	0.11	0.27	0.78	0.13	0.34	0.34
9071/4058	0.31	0.76	1.11	0.23	0.66	1.22	0.38	0.99	1.87	-0.16	-0.43	-0.45	0.07	0.23	0.77	0.16	0.43	0.45
9006/4058	0.29	0.77	1.07	0.20	0.70	1.16	0.33	1.02	1.88	-0.17	-0.45	-0.36	0.03	0.25	0.80	0.16	0.45	0.36
OBA SUPER-1	0.31	0.67	1.08	0.17	0.65	1.03	0.39	0.98	1.72	-0.10	-0.34	-0.39	0.08	0.31	0.64	0.09	0.34	0.39
OBA SUPER-2	0.29	0.62	1.08	0.24	0.62	1.01	0.46	0.96	1.76	-0.09	-0.28	-0.33	0.15	0.34	0.68	0.07	0.28	0.33
Mean	0.28	0.72	1.10	0.26	0.66	1.14	0.44	1.00	1.83	-0.10	-0.38	-0.41	0.16	0.28	0.73	0.10	0.38	0.41
CV	21.4	16.0	15.1	29.6	16.4	15.3	19.8	12.9	12.0	-106.7	-32.0	-39.6	58.4	54.1	30.4	67.9	32.0	39.6
LSD (0.05)	0.05	0.09	0.13	0.06	0.09	0.14	0.07	0.10	0.18	0.06	0.10	0.13	0.08	0.17	0.26	0.03	0.10	0.13
H × N		***			***			***			***			***			***	

***: significant at 0.001 probability level; H × N: Hybrid by Nitrogen level interaction.

to meet kernel demand was 52.8% at low-N and 37.3% at high-N (Table 5).

The differences in stover N content measured at silking were more pronounced at high-N than at both low-N and no-N. Post-silking stover N accumulation ranged from -0.64 to -0.22 g plant^{-1} (mean = -0.41 g plant^{-1}) under high-N and -0.51 to -0.26 g plant^{-1} (mean = -0.38 g plant^{-1}) under low-N. KU1409/4008 had the highest post-silking total N accumulation and total N content but remobilized the lowest N from stover to grain under the three N rates. The range in Grain N content was 0.88 to1.26 g/plant (mean = 1.14 g plant^{-1}) under high-N and 0.58 to 0.85 g plant^{-1} (mean = 0.66 g plant^{-1}) under low-N. KU1409/4008 had the highest Grain N content at low-N and no-N, which was significantly higher than that of all other hybrids. Although 9613/9006 had the highest Grain N content at high-N, the value was not significantly different from that of KU1409/4008 (Table 5).

Correlation of grain yield with other measured traits

Grain yield and its components were significantly ($p < 0.01$) correlated at the different levels of N. The correlation coefficient between one thousand kernel weight and grain yield at high-N was more than twice that at low-N. Among the yield components considered, number of kernels showed the highest level of association with grain yield at high-N and low-N. Plant height, ear height, days to anthesis and days to silking were positively related ($p < 0.01$) to grain yield at all the N levels. On the other hand, ASI was negatively correlated ($p < 0.01$) to grain yield at no-N and low-N, but the association was comparatively low and non-significant at high-N (Table 6).

The correlations of grain yield on the one hand, with ear leaf chlorophyll concentration (SPAD) and plant biomass recorded at silking and harvest on the other, were positive and significant ($p < 0.01$) at all the N levels. Grain yield also showed significant ($p < 0.05$) association with post-silking stover and total dry matter accumulation at high-N and no-N, but was associated only with post-silking total dry matter accumulation under low-N (Table 6).

A significant ($p < 0.01$) positive correlation was observed between grain yield on the one hand, and grain N content and stover N content at silking on the other, at all the N levels. At harvest, the association between grain yield and stover N content was positive at no-N and low-N, but was negative under high-N. Post-silking N accumulation (stover and total) were negatively correlated with grain yield at all the N levels (Table 6).

Discussion

The fourteen hybrids included in this study exhibited significant genetic differences in grain yield and its components. Hybrid × N rate interaction was significant for grain yield and its components, indicating that the hybrids differed in their response pattern to N. The result of the present study is contrary to that reported in other studies (Oikeh et al, 1998; Akintoye et al, 1999) for grain yield in tropical maize. However, the findings agrees with the results of Agrama et al (1999) and Worku et al (2007) in tropical maize, Bertin and Gallais (2000) in European maize, and O'Neill et al (2004) in temperate maize. The differences in grain yield among hybrids at the same level of N fertilizer application could be attributed to differences among the maize hybrids for N-uptake and utilization (Pollmer et al, 1979; Beauchamp et al, 1976). According to Huber et al (1994) four factors determine the response of maize grain yield to N availability and these are: root N uptake; vegetative storage capacity; efficiency of remobilization from vegetative tissues to developing kernels; dynamics and strength of the kernel sink. The six top yielding hybrids (4001/4008, KU1409/4008, KU1409/9613, 4008/1808, 4058/Fun 47-4, and 1824/9432) in the present study, showed

Table 6 - Simple phenotypic correlation (r) between grain yield and agro-physiological traits of 14 tropical maize hybrids at no-N (zero), low-N (30) and high-N (90) kg N ha^{-1} fertilizer application at Mokwa, Nigeria between 2006 and 2008.

Traits	N level no-N	 low-N	 high-N
At silking			
Days to anthesis	0.36**	0.38**	0.54**
Days to silk	0.21**	0.28**	0.50**
Anthesis-silking interval (days)	-0.43**	-0.28**	-0.15ns
Ear leaf chlorophyll concentration (SPAD)	0.55**	0.75**	0.85**
Stover dry weight (g plant^{-1})	0.61**	0.78**	0.80**
Stover N content (g plant^{-1})	0.63**	0.77**	0.77**
At harvest			
Plant height (m)	0.53**	0.66**	0.82**
Ear height (m)	0.58**	0.66**	0.83**
Kernel rows	0.43**	0.36**	0.25**
Number of kernels	0.62**	0.79**	0.81**
Ears per plant	0.48**	0.56**	0.56**
One thousand kernel weight (g)	0.68**	0.26**	0.62**
Stover dry weight (g plant^{-1})	0.73**	0.75**	0.84**
Grain weight (g plant^{-1})	0.58**	0.55**	0.79**
Total dry weight (g plant^{-1})	0.74**	0.74**	0.86**
Stover N content (g plant^{-1})	0.65**	0.47**	-0.34**
Grain N content (g plant^{-1})	0.52**	0.60**	0.68**
Total N content (g plant^{-1})	0.67**	0.63**	0.38**
Post-flowering changes			
Stover dry matter accumulation (g plant^{-1})	0.17*	-0.03ns	0.47**
Total dry matter accumulation (g plant^{-1})	0.47**	0.31**	0.76**
Stover N accumulation (g plant^{-1})	-0.35**	-0.68**	-0.80**
Total N accumulation (g plant^{-1})	0.26**	-0.33**	-0.50**

ns, *, **: not significant, significant at 0.05, and 0.01 probability levels, respectively.

variation in the processes used to achieve superior grain yields. The hybrids possessed either a strong capacity for N-uptake and storage or high N remobilization from vegetative source tissues to the kernels or a combination of these processes. Some varieties of maize have been reported to combine high dry-matter yield and high N content for grain production (Coque and Gallais, 2007b). For example, hybrids 4001/4008 and KU1409/4008 expressed a high capacity for N absorption and storage, as well as high biomass production and accumulation, whereas, hybrids KU1409/9613 and 4008/1808 had a larger ability for N remobilization from vegetative tissues to kernels after silking. The hybrids 9071/4058 and 9006/4058 which although showed susceptibility to N stress under no-N and low-N, had comparable yields with the best six hybrids under high-N. The performance of hybrids 9071/4058 and 9006/4058 therefore indicate that the two hybrids are inefficient but responsive to N and therefore require a high N input to accomplish their yield potential (Sangoi et al, 2001). The hybrid Oba Super-2 which had previously been reported to show tolerance to N-stress (Sanginga et al, 2003; Kamara et al, 2005) ranked third in grain yield under no-N but had below average grain yield under both low-N and high-N. This suggests that although it expressed tolerance to severe N stress under no-N, it was not responsive to N input. This finding is in consonance with the reports of Tsai et al (1984) and Eghball and Maranville (1991) that cultivars less responsive to applied N could sometimes perform better than N-responsive hybrids or cultivars under limiting soil N conditions.

The observed 35% reduction in grain yield under low-N is comparable with the results of Bänziger et al (1999) and Bertin and Gallais (2000) who reported 40% and 38% reduction in maize grain yield under low-N, respectively. Among yield components, number of kernels was the most severely affected by N-stress with a reduction by 21% at low-N and 60% at no-N, whereas corresponding reductions in kernel weight were 2% and 16% respectively. Bertin and Gallais (2000) reported a 32% and 9% reduction for number of kernel and kernel weight, respectively. Other previous studies also showed that the yield component that is most severely affected by N-stress in maize is number of kernels (Tollenaar, 1977; Uhart and Andrade, 1995). However, contradictory responses have been reported for the effect of N-stress on kernel weight. While Muchow (1994) reported a reduction in kernel weight due to N-stress, Purcino et al (2000) reported that kernel weight was not affected. Both genotypic differences (Smiciklas and Below, 1990) and the intensity of N-stress (Lemcoff and Loomis, 1986) have been suggested as possible causes of the contradictory reports. The result of the present study agrees with a previous report (Coque and Gallais, 2007a) that a stress resulting in grain yield reduction higher than 20% has a greater effect on number of kernels than on kernel weight. As the number of ovules initiated in maize is not limiting (Lemcoff and Loomis, 1986), the effect of N-stress on number of kernels results from embryo abortion occurring within the first two weeks of ovule fertilization (Weiland and Ta, 1992; Uhart and Andrade, 1995; Bertin and Gallais, 2000). As the carbon and N assimilate requirement of embryos immediately after ovule fertilization is high (Below et al, 2000), the abortion of ovules could be due to limitation in the source of photosynthetic products (Bertin and Gallais, 2000).

During grain filling, both current assimilation which is mobilized directly to kernels and remobilization of assimilates stored in the stover contribute to grain yield in grain crops (Gebbing et al, 1999). In the present study, N accumulation after silking was reduced by 62% under low-N. Remobilization of N to meet kernel demand is therefore required under N stress conditions (Ta and Weiland, 1992; Rajcan and Tollenaar, 1999). Studies by Gallais and Coque (2005) and Coque et al (2008) had previously indicated that the proportion of N remobilized vary from 30 to 70% depending on genotype and environment. Furthermore, results of the study reported by Coque and Gallais (2007b) showed that more N was remobilized under low-N. The high N transfer observed in the present study under low-N was only accompanied by a 2% (1.5 g plant^{-1}) dry matter transfer, a result consistent with the report of Gallais and Coque (2005) that such stover N transfer was barely accompanied by dry matter transfer.

Number of kernels was the grain yield component that showed the highest positive association with grain yield, a result in agreement with the results of Bänziger et al (2002) and O'Neill et al (2004). This indicates that the physiological mechanisms needed to maximize number of kernels are crucial for enhanced grain yields in maize hybrids. The positive correlations between number of kernels and stover N content at silking (r = 0.57, 0.68, and 0.63, respectively) under no-N, low-N and high-N levels could relate to the strong effect of assimilate supply during periods around flowering (Cantarero et al, 1999; Paponov et al, 2005). This is further supported by the strong positive correlations between number of kernels and ear leaf chlorophyll concentration (r = 0.53, 0.68, and 0.76, respectively) under no-N, low-N and high-N levels. In the present study, delayed flowering and grain yield were positively correlated at all levels of N. Zaidi et al (2003) reported a positive relationship between grain yield and days to anthesis as well days to silking only under optimal N, but negative under N stress. Similar to the results reported by Kamara et al (2005), ASI and grain yield were significantly and negatively correlated under no-N and low-N. When maize plants are grown under stresses such as N deficiency, drought and high plant density, there result an increase in ASI (Lafitte and Edmeades, 1995; Campos et al, 2004).

At silking, stover N content was significantly positively correlated grain yield under the three levels of N application, indicating that whatever the level of N, a high N accumulation before flowering was required for optimal performance in maize. Lafitte and Edmeades (1994b) reported the presence of a relationship between grain yield and N content at flowering only under high-N. The importance of pre-flowering N accumulation in determining grain yield has been shown in other studies (Pearson and Jacobs, 1987). At harvest however, stover N content was significantly and positively correlated with grain yield under no-N and low-N. At high-N, the correlation was significant but negative. A high N content in the stover at harvest could suggest that N remobilization was inefficient. This result shows that under high-N, efficient utilization of absorbed N was required for grain yield in maize.

Conclusions

The hybrids included in this study responded differently to N supply for the evaluated attributes. Six hybrids (4001/4008, KU1409/4008, KU1409/9613, 4008/1808, 4058/Fun 47-4, and 1824/9432) showed consistent above average grain yields under the three N levels and across N levels and their use could further be investigated. The hybrids however differed in their capacity for N absorption and storage, N remobilization from storage tissues, as well as biomass production and accumulation. The commercial hybrid Oba Super-2, which had previously been selected for tolerance to N-stress, ranked third in grain yield under no-N but recorded below average GY under low-N and high-N, an indication that it is not responsive to N. Two hybrids (9071/4058 and 9006/4058) had special adaptation to high-N conditions. Number of kernels was the grain yield component most severely reduced by N stress and had significant positive correlation with grain yield at the three N levels.

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