Weed Science 2008 56:424–433

Response of Corn Genotypes to Weed Interference and Nitrogen in Nigeria

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The effects of nitrogen (N) rate and weed interference on the grain yield of four corn genotypes were investigated in 2002 and 2003 at Ikenne (7°38′N, 3°42′E), Shika (11°11′N, 7°38′E), and Samaru (10°24′N, 7°42′E) in Nigeria. Nitrogen (N) at 0, 30, 60, and 90 kg N ha^{-1} were the main plot treatments. Weed-free (weeded weekly), low (intrarow weeds only), and high (zero weeding) weed pressure were the subplot treatments. Four corn genotypes (ACR8328 BN C_7, Low-N-Pool C_2, Oba Super II, TZB-SR) were the sub-subplot treatments. Weed density was higher at Shika and Samaru than at Ikenne, and the order of average weed biomass 8 to 10 weeks after planting was Samaru (271 g m^{-2}) > Ikenne (236 g m^{-2}) > Shika (161 g m^{-2}). Corn genotype and N rate had no effect on weed biomass except at Samaru where fertilized treatments had higher weed biomass than the unfertilized treatments. Corn leaf area (LA) increased with increasing N rate at all locations regardless of weed pressure and genotype, except at Shika where ACR8328 BN C_7, Oba Super II, and TZB-SR did not show any clear N response; LA was highest in the weed-free and lowest in the unfertilized treatments for all genotypes and locations, and weed pressure treatments. Low-N-Pool C_2 had the highest LA, which was 1.3 times larger than in Oba Super II, which had the lowest LA. Nitrogen rate, weed pressure, and genotypes significantly affected corn leaf chlorophyll content. Chlorophyll content was higher in the fertilized treatments than the unfertilized treatments, and higher in the weed-free treatments than the low or high weed pressure treatments. ACR8328 BN C_7 and Oba Super II had significantly more chlorophyll than the other genotypes. Low-N-Pool C_2 showed a linear grain yield response with the increase in N rates. ACR8328 BN C_7 did not respond to N application. Compared with the results in the weed-free treatment, high weed pressure reduced grain yield in all genotypes by more than 65% at Samaru, 50% at Shika, and 35% at Ikenne.

Nomenclature: Corn, *Zea mays* L. 'ACR8328 BN C_7', 'Low-N-Pool C_2', 'Super Oba II', 'TZB-SR'.
Key words: Forest/savanna transition, Guinea savanna, soil fertility, weed pressure.

Corn is an important staple crop in West Africa where production has expanded from 3 million ha in 1990 to 8 million ha in 2001 (Badu-Apraku et al. 2001). Improved varieties with resistance to major biotic and abiotic stresses have been developed and tested for adaptability in several ecologies in West Africa (Kamara et al. 2004, 2005; Kim 1994; Kling et al. 1994). Kamara et al. (2004) reported that annual genetic gain in improved corn varieties in the savannas of West Africa was 0.41% from the 1970s to 1999. Despite grain yield increases as a result of improved germplasm, national per-hectare increase in corn productivity is low in Africa (< 1 ton ha^{-1}; Kumwenda et al. 1996).

Among other biotic and abiotic stresses, corn production is limited by low soil fertility and weed competition (Chikoye et al. 2004; Sanginga et al. 2003). Owing to reduced soil fertility and increasing weed pressure, resource-poor farmers have often abandoned land to prolonged fallow (> 10 years; Hobbs and Bellinder 2004). Currently, long fallows are no longer possible in many farming systems in West Africa because of the high human population density on limited arable land and the consequent demand for food (Chikoye and Ekeleme 2003). Low soil fertility, declining crop yields, and high weed pressure are among the major problems that have been associated with the intensification of cropping systems (Tian et al. 1995).

Soil nitrogen (N) is one of the most limiting nutrients in farming systems where there is little or no use of external inorganic or organic soil amendments. Continuous cultivation of corn without adequate measures to maintain fertility has contributed to the rapid depletion of native soil N (Logroño and Lothrop 2001). Although the use of fertilizer is a common solution to this problem, its high cost makes this option inaccessible to many farmers in West Africa. For example, in northern Nigeria, farmers use < 20 kg N ha^{-1} (Manyong et al. 2003) when the recommended rate for sustainable production is 90 to 120 kg N ha^{-1} (Usman et al. 2001). Settimi and Maranville (1998) reported that a reduction in the amount of N available to a corn plant affects the N-rich carbon dioxide assimilation enzymes, reduces productivity, and ultimately, grain yield. Evans et al. (2003) also reported that a reduction in N use can create the need for more intensive weed management because of reduced crop vigor and competitiveness against weeds. Corn response to N can vary with genotype. For example, Kamara et al. (2005) found that growth and grain yield varied among corn genotypes at three different N rates. Similarly, Sibale and Smith (2001) reported significant genotype by N interactions for grain yield and physiological characteristics of corn.

Besides low soil N, weeds seriously limit corn productivity in smallholder farms in the West African savannas. More than 32% of the total time devoted to corn production in Nigeria is used for weeding (Olaniyan and Lucas 2004). Weeds compete with corn for incident solar radiation, soil moisture, and nutrients, although little is known about the contribution of these factors to the total interference. Several researchers have reported that season-long weed interference reduces corn yield (Carey and Kells 1995; Chikoye et al. 2005; Lum et al. 2005). Weed competition in corn is strongly influenced by the availability of N, which is a major input in corn production (Di Tomaso 1995; Gonzalez and Salas 1995). Evans et al. (2003) reported that reductions in maximum corn leaf area (LA) and height due to weed competition were more severe at low N rates. The effect of weed interference on corn

DOI: 10.1614/WS-07-055.1
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grain yield was found to be more serious at low N rates than at high rates (Tollenaar et al. 1994), suggesting that increased N fertilization might enhance the competitiveness of corn over weeds. In contrast, Di Tomaso (1995) noted that weeds might be more competitive when fertility is enhanced with applied N because many weed species have superior uptake efficiency.

A potentially viable means of enhancing weed management in smallholder farms with limited access to inorganic fertilizers is the development and adoption of corn genotypes that are more efficient in N uptake, have a higher N-use efficiency, and have a competitive advantage over weeds. Breeders at the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria have developed corn genotypes that are adapted to suboptimal soil N levels (Meseka et al. 2006), but these have been bred and tested only under weed-free conditions. Information is lacking on their N-use efficiency under weed competition. Therefore, the objectives of this study were to (1) determine the response of low-N tolerant corn genotypes to weed pressure, (2) determine the response of low-N tolerant corn genotypes to N, and (3) quantify N uptake in corn and weeds.

Materials and Methods

Field experiments were conducted at Ikenne, Shika, and Samaru in Nigeria in 2002 and 2003. Ikenne (7°38′N, 3°42′E) is in the forest/savanna transition zone with a bimodal (two peaks: July and September to October) rainfall distribution pattern; Shika (11°11′N, 7°38′E) and Samaru (10°24′N, 7°42′E) are both in the Guinea savanna with a monomodal (one peak: August to September) rainfall distribution pattern (Figure 1). Physical and chemical soil characteristics of the study sites in 2002 and 2003 are shown in Table 1.

The experiment was set up as a split–split plot in a randomized complete block design with three replications at all locations. The main plot treatments were four rates of N (0, 30, 60, and 90 kg N ha^{-1}) applied as urea (46% N) in two equal splits, at seeding and at 4 wk after planting (WAP). Phosphorus (15 kg ha^{-1} of single superphosphate [46% P]), potassium (30 kg ha^{-1} of muriate of potash [60% K]), and the first half of urea were broadcast to the whole experimental plot prior to seeding. The second half of urea was applied by drilling. The subplot treatments were three levels of weed pressure: zero (weeded weekly), low (approximately 30 cm interrow hoed weekly), and high (not weeded throughout the growing season). The sub-subplot treatments were four corn genotypes: Oba Super II, Low-N-Pool C_2, ACR8328 BN C_7, and TZB-SR. Oba Super II is a commercial hybrid widely marketed in West Africa. Low-N-Pool C_2 and ACR8328 BN C_7 are open-pollinated varieties selected for suboptimal N conditions. TZB-SR is an improved, locally adapted variety which is susceptible to N stress but resistant to the maize streak virus.

In 2002, corn was sown on May 18 at Ikenne, June 30 at Shika, and July 14 at Samaru. In 2003, corn was sown on May 14 at Ikenne, July 4 at Shika, and July 2 at Samaru. Corn was sown at a population of 50,000 plants ha^{-1} at 76 by 25 cm spacing. Plot size was 8 by 3 m. Two seeds were sown per hill, approximately 5 cm deep, and thinned to one stand at 2 WAP. At silking, 8 to 10 WAP, data were collected on weed species composition, density, and biomass; corn leaf area (LA), photosynthetically active radiation (PAR), and chlorophyll content. At harvest 16 to 20 WAP, the data collected

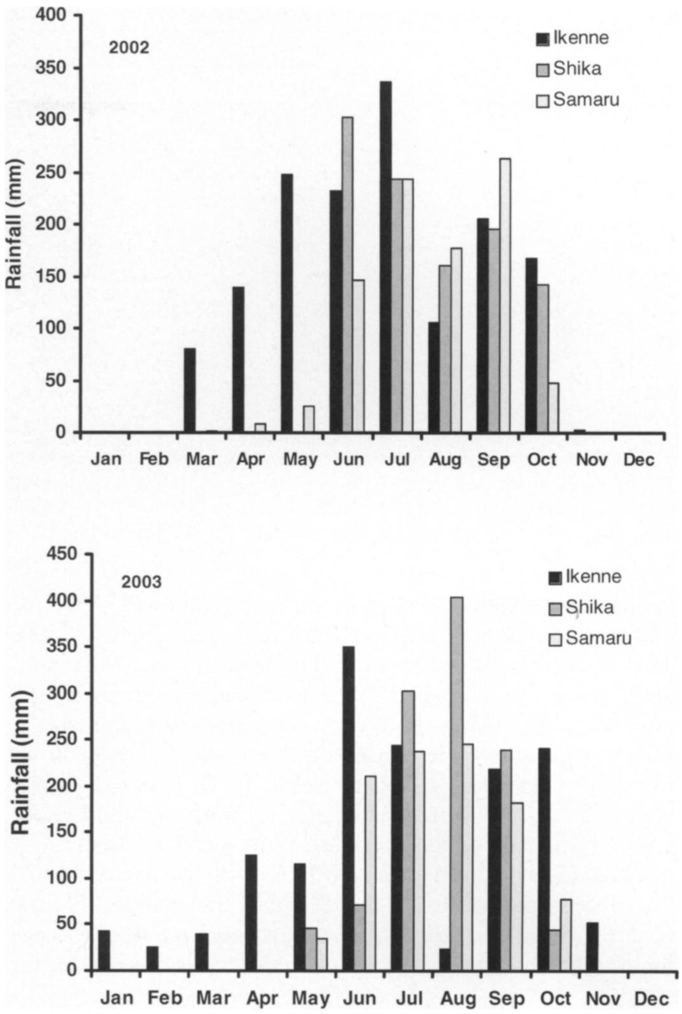

Figure 1. Rainfall distribution at Ikenne, Shika, and Samaru, Nigeria in 2002 and 2003.

included the corn stover weight (total aboveground biomass excluding grain weight or mass), grain yield, and N content of corn (leaf, stem, and grain) and weeds.

Corn LA $plant^{-1}$ was measured by harvesting four plants from each of the two center rows 0.5 m into the plots. Corn plants were separated into stems and leaves. The LA was determined using a benchtop LI-3100 meter.[1] The PAR of corn was measured between 10:30 A.M. and 2:30 P.M. with a SUNFLECK meter.[2] The average of four measurements per treatment was used to derive the treatment mean. Corn chlorophyll content was determined with a SPAD-502 meter.[3]

Weed species composition, density, and biomass were determined from two 0.25 m^2 quadrats placed on the two center rows of each plot. Within each quadrat, weed species were identified, counted, and harvested. The plant samples were dried to a constant mass in a forced-air oven at 80 C for 48 h. Samples from selected treatments (0, 30, and 90 kg N ha^{-1}) were ground for N content determination in the laboratory.[4]

In 2002, corn was harvested on September 5 at Ikenne, October 30 at Shika, and November 15 at Samaru. In 2003, corn was harvested on September 19 at Ikenne, November 19 at Shika, and November 14 at Samaru. A total of 16 plants were harvested from 3 m^2 in the two center rows of each plot

Table 1. Soil characteristics at Ikenne, Shika, and Samaru, Nigeria in 2002 and 2003.

	2002			2003		
Soil parameter[a]	Ikenne	Shika	Samaru	Ikenne	Shika	Samaru
% C	1.25	0.31	0.78	0.98	0.58	0.36
% N	0.19	0.03	0.10	0.10	0.06	0.04
P (mg kg^{-1})	4.45	2.25	3.40	15.2	3.20	11.90
Ca (cmol kg^{-1})	1.70	1.64	0.79	2.17	3.39	1.59
Mg (cmol kg^{-1})	0.35	0.45	0.12	0.83	1.00	0.53
K (cmol kg^{-1})	0.22	0.42	0.22	0.25	0.48	0.27
Na (cmol kg^{-1})	0.47	0.47	0.47	0.20	0.19	0.16
H^+	0.11	0.12	0.11	0.10	0.10	0.10
CEC (cmol kg^{-1})	2.85	3.10	1.71	3.55	5.16	2.65
pH	5.3	6.2	5.5	5.9	5.7	5.7
% Sand	84	64	54	74	42	48
% Clay	7	9	9	16	16	12
% Silt	9	27	37	10	42	40
Texture	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Loam	Loam

[a] Analytical procedures: Organic carbon by chromic acid digestion (Heanes 1984); nitrogen in soil by Kjeldahl digestion (Bremner and Mulvaney 1982); phosphorus and exchangeable cations in soil by Mehlich 3 extraction (Mehlich 1984); cation exchange capacity (CEC) by saturation with 1 N ammonium acetate and extraction of ammonium with 2 M potassium chloride (TSBF 1993); soil pH determined in water on 1:1 soil:water ratio (IITA 1982).

for the determination of corn stover and grain yield. After the bulk stover mass was obtained, the leaves and stems of two plants were oven-dried and ground to determine the N content. Grain yields were adjusted to 12% moisture content using a moisture tester.[5] After the corn grain yield was obtained, the grain was ground to determine the N content. Harvest index (HI) was calculated as grain yield · [grain yield + stover biomass]$^{-1}$, and N-uptake efficiency for both corn and weeds as total N uptake · total N applied^{-1} in each treatment.

All data were subjected to ANOVA using the Mixed Model Procedure in SAS (Littel et al. 1996). In the analyses, N rate, weed pressure, and genotypes were treated as fixed effects. Replicates and years were random effects. Treatment means were compared using the standard error of the difference at 5% level of probability.

Results and Discussion

Weed Species Composition, Density, and Biomass. The weed species composition and density varied with location (Table 2). Sedges and broadleaved weeds were widespread at all locations. At Ikenne, the major flora were sedges and broadleaved weeds in both the fertilized and unfertilized treatments. Grasses were more abundant at Shika and Samaru than at Ikenne. Previous studies have also reported more grasses in the northern Guinea savanna than in the derived

Table 2. Number of weeds in the fertilized and unfertilized treatments averaged over weed pressure and genotypes at Ikenne, Samaru, and Shika, Nigeria. Values are 2-yr means (2002 and 2003).

		Ikenne[a]		Samaru		Shika	
Common name	Weed Species	Unfertilized	Fertilized[b]	Unfertilized	Fertilized	Unfertilized	Fertilized
		(No. weeds m^{-2})					
Tropical ageratum	*Ageratum conyzoides* L.	39	19	36	170	146	159
Chinese violet	*Asystasia gangetica* (L.) T. Anders	57	69	–	–	2	6
Silver spinach	*Celosia laxa* Schumach. & Thonn.	9	2	27	36	10	7
Tropical spiderwort	*Commelina benghalensis* L.	8	8	10	11	8	7
Bermuda grass	*Cynodon dactylon* (L.) Pers.	–	–	1	5	4	6
Crowfoot-grass	*Dactyloctenium aegyptium* (L.) P. Beauv.	1	2	21	41	7	8
Wild paragrass	*Digitaria horizontalis* Willd.	5	4	44	20	14	13
Crabgrass	*Digitaria* sp.	–	–	25	14	8	6
False daisy	*Eclipta prostrata* L.	–	–	1	8	4	4
Goosegrass	*Eleusine indica* Gaertn.	7	5	4	2	10	10
Cobbler's pegs	*Ethulia conyzoides* L.	–	–	25	25	50	46
Wild poinsettia	*Euphorbia heterophylla* L.	19	17	–	–	1	1
Morning glory	*Ipomoea* sp.	–	–	32	24	10	12
Leucas	*Leucas martinicensis* (Jacq.) Ait. f	–	–	45	31	22	22
Wingleaf primrose willow	*Ludwigia decurrens* Walt.	–	–	18	28	16	17
Tropical girdle pod	*Mitracarpus villosus* (Sw.) DC	–	–	35	18	31	30
Diamond flower	*Oldenlandia corymbosa* L.	5	5	32	38	17	23
Common purslane	*Portulaca oleracea* L.	–	–	14	20	5	4
Itchgrass	*Rottboellia cochinchinensis* (Lour.) Clayton	–	–	0	30	10	7
Slender button weed	*Spermacoce ocymoides* Burm. f	27	31	24	11	4	4
Coat button	*Tridax procumbens* L.	12	2	–	–	3	3
Sedges		77	60	75	129	36	27
Others[c]		156	198	183	293	233	247

[a] Ikenne is in the forest/savanna transition zone while Samaru and Shika are in the Guinea savanna zone.
[b] Fertilized treatment (average of 30, 60, and 90 kg N ha^{-1}).
[c] Unidentified weed species were grouped as others.

Table 3. Weed biomass response to fertilizer rate, weed pressure, and corn genotype 8 to 10 WAP at Ikenne, Shika, and Samaru, Nigeria in 2002 and 2003.

Treatment	Ikenne	Shika			Samaru		
		2002	2003	Mean	2002	2003	Mean
	(g m^{-2})						
Nitrogen rate (kg ha^{-1})							
0	219.1	138	177.7	157.8	190.4	193.8	192.1
30	239.4	135.4	181.7	158.6	358.4	327.3	342.9
60	241.5	140.3	178	159.2	289.1	201.5	245.3
90	245.8	147.5	191	169.2	408.1	195.3	301.7
s.e.d.[a]	13.18	12.36	19.55	11.83	34	36.82	20.87
Weed pressure							
Low	215.7	133	171.8	152.4	302.5	236.7	269.6
High	257.1	147.6	192.4	170	320.5	222.2	271.4
s.e.d.	9.29	8.74	13.81	8.39	24.04	14.41	14.75
Genotype							
ACR8328 BN C_7	231.3	145.5	162	153.7	321.3	223.4	272.3
Low-N-Pool C_2	233.6	127.3	206.9	167.1	295.6	229.9	262.8
Oba Super II	241.6	145.8	172.7	159.2	292	229.2	260.6
TZB-SR	239.2	142.6	186.8	164.7	337.1	235.4	286.3
s.e.d.	13.1	12.36	19.37	11.83	34	20.38	20.38
	P value						
Nitrogen (N)	NS[b]	NS	NS	NS	0.0001	0.0168	0.0001
Weed (W)	0.0001	NS	NS	0.0375	NS	NS	NS
Genotype (G)	NS	NS	NS	NS	NS	NS	NS
N × W	0.0201	NS	NS	NS	NS	NS	NS
G × W	NS	0.0461	NS	NS	NS	NS	NS

[a] s.e.d., Standard error of difference between two treatment means.
[b] NS, not significant.

savanna (Ekeleme and Chikoye 2004). Differences in agronomic practices, solar radiation, and the amount and pattern of rainfall in the zones could have contributed to the observed trend. Factors such as current and previous crop, tillage practice, and planting date have also been reported to influence weed distribution (Chikoye and Ekeleme 2001).

The overall average total weed density was higher at Shika and Samaru than at Ikenne; this possibly could be due to the higher number of grasses that might have increased the weed seed bank. Grasses have been reported to produce more seeds than broadleaved weeds (Ekeleme et al. 2000). The densities of six weed species (tropical ageratum [*Ageratum conyzoides* L.], Chinese violet [*Asystasia gangetica* (L.) T. Anders], bermuda grass [*Cynodon dactylon* (L.) Pers.], crowfoot-grass [*Dactyloctenium aegyptium* (L.) P. Beauv.], wingleaf primrose willow (*Ludwigia decurrens* Walt.), and diamond flower [*Oldenlandia corymbosa* L.]) were higher in the fertilized than the unfertilized treatments at all locations, except for tropical ageratum and diamond flower at Ikenne (Table 2). In contrast, the density of wild paragrass (*Digitaria horizontalis* Willd.), goosegrass [*Eleusine indica* (L.) Gaertn.], and leucas [*Leucas martinicensis* (Jacq.) Ait. f.] was lower in the fertilized than unfertilized treatments. Silver spinach (*Celosia laxa* Schumach. & Thonn.), false daisy (*Eclipta prostrata* L.), and cobbler's pegs (*Ethulia conyzoides* L.) did not show any clear pattern of response to N fertilizer. Several studies have noted different patterns of weed response to N application (Blackshaw et al. 2002; Evans et al. 2003; Jørnsgård et al. 1996; Swanton et al. 1999). For example, Jørnsgård et al. (1996) found that in barley (*Hordeum vulgare* L.) increasing N rates enhanced weed germination but the total biomass of individual weed species decreased. Blackshaw et al. (2002) reported a positive response by green foxtail [*Setaria viridis* (L.) Beauv.] to an increased rate of soil N. In contrast, Van Delden et al. (2002) noted that in cropping systems with relatively high soil-N content, an increased N supply decreased weed density. Jørnsgård et al. (1996) found a significant interaction between weed species and N rate on weed biomass in wheat (*Triticum aestivum* L.) and barley. These observations suggest that factors other than N, such as species type and the associated crop, might confound the response of weeds to N application. In this study, weed biomass was not influenced significantly by N rate ($P > 0.05$), except at Samaru ($P = 0.0001$) where weed biomass was higher in the fertilized (297 g m^{-2}) than the unfertilized treatments (192 g m^{-2}; $P = 0.0129$). The significant influence of N application observed at Samaru on weed growth could not be explained based on available data. This observation is of interest for future investigations. Weed biomass in the high weed pressure treatment was higher by 10 to 20% at Ikenne and at Shika than in the low weed pressure treatment (Table 3). At Samaru, weed biomass in the two weedy treatments was similar ($P > 0.05$).

Weed biomass differed with location and was greater at Samaru (271 ± 9.24 g m^{-2}) than at Shika (161 ± 4.52 g m^{-2}) and Ikenne (236 ± 6.44 g m^{-2}). Weed biomass was affected by year except at Ikenne and by weed pressure treatment except at Samaru ($P < 0.05$; Table 3). Genotypes and all two-way interactions did not affect the weed biomass at all locations, except N by weed pressure interaction at Ikenne, and year by N at Samaru. The mean weed biomass in each genotype was 219 g m^{-2} in ACR8328 BN C_7, 221 g m^{-2} in Low-N-Pool C_2, 221 g m^{-2} in Oba Super II, and 230 g m^{-2} in TZB-SR.

Weed biomass was greater in 2003 (182 g m^{-2}) than in 2002 (140 g m^{-2}) at Shika, but greater in 2002 (316 g m^{-2}) than in 2003 (230 g m^{-2}) at Samaru ($P < 0.0001$). The differences in weed biomass between years might be attributable to differences in environmental factors, such as precipitation that promoted better corn growth, resulting in

Table 4. Corn leaf area (LA) and % photosynthetically active radiation (PAR) response to fertilizer rate and weed pressure 8 to 10 WAP at Ikenne, Shika, and Samaru, Nigeria in 2002 and 2003.

	Ikenne		Shika		Samaru	
Treatment	LA (m^2)	PAR (%)	LA (m^2)	PAR (%)	LA (m^2)	PAR (%)
Year						
2002	0.38	66	0.44	63	0.17	66
2003	0.38	77	0.37	77	0.19	62
s.e.d.[a]	0.023	1.149	0.030	4.057	0.001	1.809
Weed pressure						
Zero	0.46	73	0.49	82	0.26	75
Low	0.34	72	0.38	69	0.16	71
High	0.34	70	0.34	60	0.11	45
s.e.d.	0.012	1.412	0.022	1.362	0.011	1.630
Genotype						
ACR8328 BN C_7	0.39	74	0.40	69	0.18	64
Low-N-Pool C_2	0.42	72	0.40	70	0.18	64
Oba Super II	0.33	71	0.41	71	0.18	63
TZB-SR	0.38	69	0.40	70	0.18	64
s.e.d.	0.014	1.633	0.026	1.564	0.013	1.882
			P value			
Year (Yr)	NS[b]	0.0001	NS	NS	0.0014	NS
Nitrogen (N)	0.0001	0.0001	0.0406	0.0294	0.0001	0.0001
Weed (W)	0.0001	NS	0.0001	0.0001	0.0001	0.0001
Genotype (G)	0.0001	0.0330	NS	NS	NS	NS
Yr × N	NS	NS	NS	NS	0.0001	0.0001
Yr × W	NS	0.0021	NS	0.0001	NS	0.0001
G × N	NS	NS	0.0514	NS	NS	NS
N × W	NS	NS	NS	NS	0.0009	0.0001

[a] s.e.d., Standard error of difference between two treatment means.
[b] NS, not significant.

different levels of competitiveness by corn. Weed biomass was negatively correlated with corn LA at all locations (Ikenne: $r = -0.26$; $P = 0.0002$; Shika: $r = -0.22$, $P = 0.0028$; Samaru: $r = -0.30$, $P = < 0.0001$). At Shika, rainfall commenced early in May in 2003 and peaked in August after corn had been sown; in 2002, the highest precipitation was recorded in June before corn was planted. The higher precipitation in 2003 at Shika might have resulted in more weed emergence. Climate, among other environmental factors, has been found to influence the periodicity of weed emergence, which often results in increased weed density and biomass (Baskin and Baskin 1989; Ekeleme et al. 2004; Grundy and Mead 2000). At Samaru, corn was sown 2 wk earlier in 2003 than in 2002. The difference in planting time in the 2 yr possibly might have resulted in the lower weed density in 2003. Bullied et al. (2003) noted that the timing of crop management operations in relation to the periodicity of weed emergence could affect weed density.

Corn Leaf Area (LA). Corn LA per plant was affected by location and year at Samaru only ($P = 0.0014$), by N and weed pressure at all locations ($P < 0.05$), and by genotype at Ikenne only ($P < 0.0001$; Table 4). All two-way interactions were nonsignificant except year by N and N by weed pressure at Samaru, and genotype by N at Shika (Table 4). The corn LA was higher at Ikenne (0.38 ± 0.006 m^2) and Shika (0.40 ± 0.010 m^2) than at Samaru (0.18 ± 0.009 m^2). The lower LA at Samaru might have been caused by the reduction in the number of leaves as a result of poor plant growth from severe competition from weeds because weed biomass was highest at this location. At Samaru, LA in 2003 (0.19 m^2) was 11% higher than in 2002.

Corn LA was higher in the fertilized than unfertilized treatments (Figure 2a). For instance, corn LA in treatments that received 90 kg N ha^{-1} was greater than in the unfertilized plots by 27% at Ikenne, 20% at Shika, and 440% at Samaru, indicating a higher N response at Samaru. Corn LA was lower at Samaru than at other locations, especially in the unfertilized treatments and those with 30 kg N ha^{-1}. Corn LA was higher in the weed-free treatment than in the low and high weed pressure treatments at all locations (Table 4). For example, at Shika, LA of corn when weed-free was 1.3 times higher than under low weed pressure and 1.4 times higher than under high weed pressure. At Samaru, corn LA in the weed-free treatment was 1.6 times higher than in the low weed pressure treatment, and 2.4 times higher than in the high weed pressure treatment. At Ikenne, corn LA in the weed-free treatment was 1.4 times higher than in the two weedy treatments. For both years, corn LA was similar ($P > 0.05$) at Ikenne where the LA of Low-N-Pool C_2 was significantly higher than that of other corn genotypes and 1.3 times greater than that of Oba Super II, which had the lowest LA among the genotypes. Genotype by N interaction was significant at Shika. The LA of Low-N-Pool C_2 increased linearly with increase in N rate, whereas other genotypes did not show any clear N response.

Nitrogen rate by weed pressure interaction was significant only at Samaru ($P = 0.0009$). The treatments with 0 and 30 kg N ha^{-1} under low or high weed pressure had lower corn LA than at higher N rates (60 and 90 kg N ha^{-1}) under similar weed competition (Figure 3). At 60 and 90 kg N ha^{-1}, corn LA was higher when weed-free than in the low or high weed pressure treatments. This suggests that N availability was an important factor in the competition between corn and weeds. Our result is consistent with that of Tollenaar et al. (1994) who reported that corn LA was affected more by weed interference at low N than at high N rates.

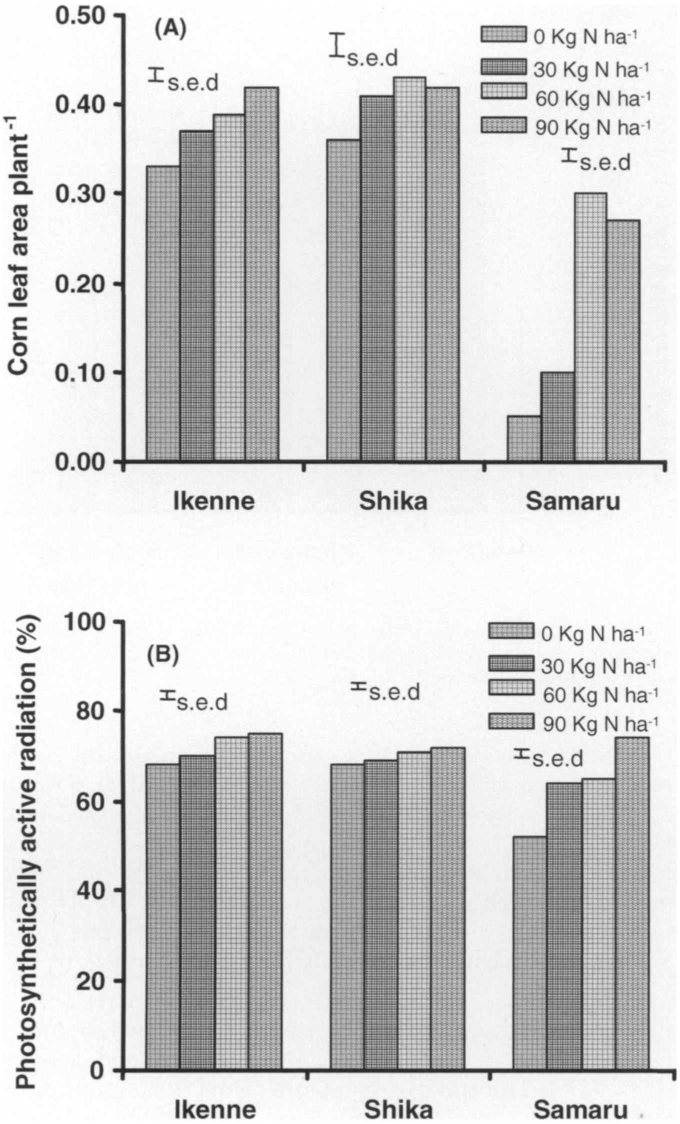

Figure 2. Effect of nitrogen rate (0, 30, 60, 90 kg N ha^{-1}) on corn leaf area per plant and percentage intercepted photosynthetically active radiation (PAR) at Ikenne, Shika, and Samaru, Nigeria. Means represent average of weed pressure treatments across corn genotypes. Bars represent interaction standard error of the difference.

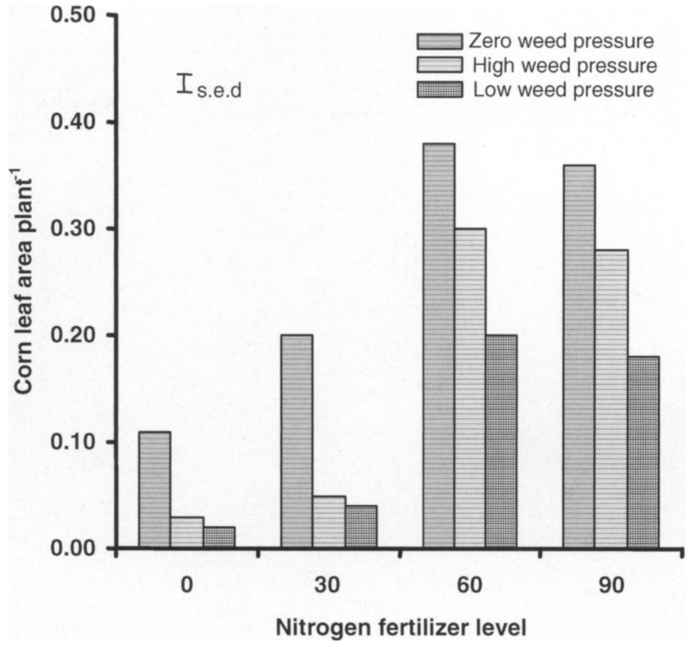

Figure 3. Effect of nitrogen rates (0, 30, 60, 90 kg N ha^{-1}) and weed interference on corn leaf area at Samaru, Nigeria. Bar represents interaction standard error of the difference.

Percentage Intercepted Photosynthetically Active Radiation (PAR). Percentage PAR was affected by location and year except at Samaru, by N and weed pressure at all locations, and by genotype at Ikenne only (Table 4). All two-way interactions were nonsignificant except year by weed pressure at all locations, and N by weed pressure at Samaru. Percentage PAR interception was not different among genotypes at Shika and Samaru but varied significantly at Ikenne ($P = 0.0330$). The mean PAR intercepted at Samaru (64%) was lower than at Shika (70%) and Ikenne (72%). This is a reflection of differences in the corn LA at each location. More radiation was transmitted through the corn canopy to the weed communities at Samaru; this is likely the cause of weed biomass being higher there in all treatments than in the other locations. Weed biomass was positively correlated with % PAR transmitted to the weeds at Samaru ($r = 0.63$, $P = < 0.0001$). The genotype effect on % PAR interception was significant only at Ikenne. ACR8328 BN C_7 intercepted 3 to 8% more PAR than the other genotypes, including Low-N-Pool C_2 which had 1.1 times more LA than ACR8328 BN C_7, indicating possible differences in leaf orientation. ACR8328 BN C_7 intercepted more PAR than TZB-SR (6%) and Oba Super II (3%).

Application of N increased the LA of corn, resulting in more radiation capture at all locations. Corn LA was positively correlated with % PAR intercepted at all locations (Ikenne: $r = 0.72$, $P = 0.0088$; Shika: $r = 0.64$, $P = 0.0249$; Samaru: $r = 0.68$, $P = 0.0142$). All the genotypes intercepted more % PAR in the weed-free treatment than in the high weed pressure treatment and this was greater in the fertilized than the unfertilized treatments (Figure 2b). The difference in % PAR intercepted by the corn canopy between the high weed pressure and the weed-free treatments was 4.1% at Ikenne and 27% at Shika.

Chlorophyll Content of Corn. Corn chlorophyll content was higher at Ikenne (46.4 ± 0.54 μmol m^{-2}) than at Shika (28.9 ± 0.70 μmol m^{-2}) and Samaru (26.1 ± 1.14 μmol m^{-2}; $P < 0.05$). Corn leaf chlorophyll content was affected by N rate, weed pressure, and genotype at all locations ($P < 0.05$, Table 5). All 2-way interactions were nonsignificant, except N rate by weed pressure at Samaru ($P < 0.0001$). At all locations, corn leaf chlorophyll content increased with the increase in N rate; corn in the unfertilized treatment had the lowest chlorophyll content. Corn leaf chlorophyll content was lower in all high and low weed pressure treatments than when weed-free. A similar observation on corn was reported by Tollenaar et al. (1997). The effect of weed pressure on corn leaf chlorophyll content was greater at Samaru than elsewhere (Figure 4). When weed-free, corn chlorophyll increased with N rate ($0 < 30 < 60 < 90$ kg N ha^{-1}). In the low weed pressure treatment, there were no differences in corn leaf chlorophyll between the rates of 0 and 30 kg N ha^{-1}, and the content was lower than at 60 kg N

Table 5. Effect of weed pressure and nitrogen rate on corn leaf chlorophyll content at Ikenne, Shika, and Samaru, Nigeria in 2003.

Treatment	Ikenne	Shika	Samaru
		(μmol m^{-2})	
Nitrogen rate (kg ha^{-1})			
0	42.07	26.20	12.56
30	45.04	29.86	16.16
60	47.64	28.85	34.44
90	50.72	30.77	41.20
s.e.d.[a]	1.485	1.328	1.127
Weed pressure			
Zero	50.27	36.40	33.48
Low	42.88	26.69	22.55
High	45.96	23.68	22.24
s.e.d.	0.793	1.154	0.630
Genotype			
ACR8328 BN C_7	48.21	30.54	26.84
Low-N-Pool C_2	46.85	27.76	26.25
Oba Super II	48.04	32.06	27.78
TZB-SR	42.36	25.32	23.49
s.e.d.	0.922	1.322	0.727
		P value	
Nitrogen (N)	0.0022	0.0059	0.0001
Weed (W)	0.0001	0.0001	0.0001
Genotype	0.0001	0.0001	0.0001
N × W	NS[b]	NS	0.0001

[a] s.e.d., Standard error of difference between two treatment means.
[b] NS, not significant.

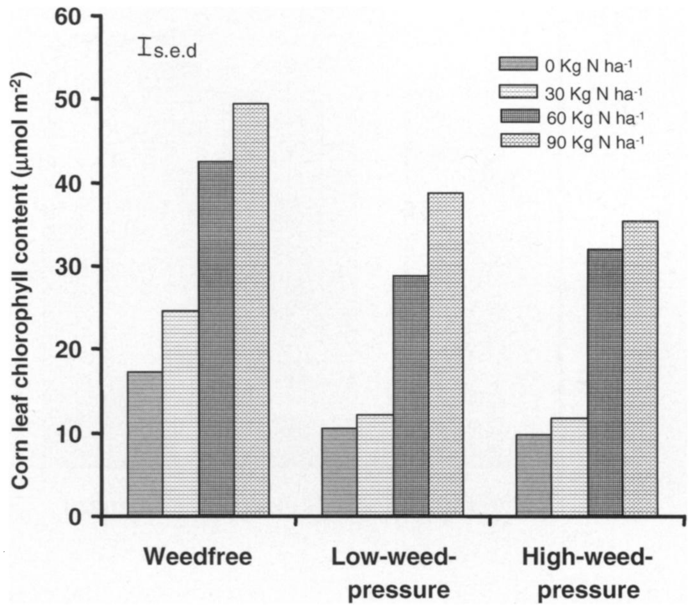

Figure 4. Effect of nitrogen rates (0, 30, 60, 90 kg N ha^{-1}) and weed interference on corn leaf chlorophyll content at Samaru, Nigeria. Bar represents interaction standard error of the difference.

ha^{-1}. The highest N rate had the highest chlorophyll content. Under high weed pressure, N at 0 and 30 kg ha^{-1} had similar corn chlorophyll, which was lower than that at higher N rates. At all locations, chlorophyll content was higher in ACR8328 BN C_7 and Oba Super II than in the other genotypes; TZB-SR had the lowest, suggesting that it absorbed less radiation than the other genotypes (Table 5).

Corn Grain Yield. Corn grain yield was influenced by year, N rate, and genotype at Ikenne and Samaru ($P < 0.05$). At Shika, grain yields were similar in both years of the study (3.6 t ha^{-1}). Corn grain yield was higher in 2003 than in 2002 at Ikenne (5.9 vs. 4.4 t ha^{-1}) and Samaru (2.7 vs. 1.9 t ha^{-1}). Corn grain yield averaged across year, N rate, and genotype in each location was 5.18 t ha^{-1} at Ikenne, 3.59 t ha^{-1} at Shika, and 2.29 t ha^{-1} at Samaru. At all locations, corn yield in fertilized treatments was higher than in unfertilized treatments (Figure 5). The response to N was greater at Samaru than at Ikenne and Shika. For example, at Samaru, compared with the unfertilized treatments, the response of corn grain yield to N was 91% for 30 kg N ha^{-1}, 600% for 60 kg N ha^{-1}, and 598% for 90 kg N ha^{-1}. At Shika, it was 16% for 30 kg N ha^{-1}, 15% for 60 kg N ha^{-1}, and 20% for 90 kg N ha^{-1}. At Ikenne, the application of 90 kg N ha^{-1} increased grain yield by 13% compared with the unfertilized treatment. Genotype by N interaction was significant at Ikenne and Shika, but not at Samaru where the grain yield increased linearly with the increase in N rate for all genotypes (Figure 6). In contrast, grain yield response to N rates at Ikenne and Shika was inconsistent for all genotypes except Low-N-Pool C_2, which showed a linear grain yield response with the increase in N rates. ACR8328 BN C_7 did not respond to N application at Ikenne and Shika. At all locations, weed interference reduced corn grain yield ($P = 0.0001$). All the genotypes gave higher grain yield when weed-free than in the weedy treatments. Compared with the weed-free treatment, high weed pressure reduced grain yield in all genotypes by more than 65% at Samaru, 50% at Shika, and 35% at Ikenne. Averaged over locations, the reduction in grain yield due to weed interference was 43% more in the low pressure and 59% more in the high weed pressure treatment for TZB-SR than for the other genotypes. These observations suggest that TZB-SR is less competitive with weeds than the other genotypes.

Corn Harvest Index (HI). There were significant year and N rate effects on harvest index (HI) at Ikenne and Samaru ($P < 0.05$). The effect of genotypes on HI was significant at all locations ($P < 0.05$). All 2-way interactions were not significant ($P > 0.05$) except genotype by year and genotype by N at Ikenne (Table 6). Weed interference had a significant effect on HI at Shika ($P < 0.0001$) and Samaru ($P = 0.001$). At all locations, TZB-SR had the lowest HI. Averaged over locations, the HI for ACR8328 BN C_7 was similar to that of Oba Super II (0.32). High weed pressure reduced HI by 41% at Shika and by 213% at Samaru compared with the weed-free treatment. The HI was greater at 90 kg N ha^{-1} for all genotypes and increased linearly with increases in N rate at all locations. At Ikenne, 90 kg N ha^{-1} increased HI by 14% and at Shika by 12% compared with the unfertilized treatment. These observations could explain the low grain yield at low N levels and high weed pressure. Similar observations have been reported by Tollenaar et al. (1994).

Nitrogen Uptake by Corn and Weeds. The amounts of N uptake in 2002 and 2003 were similar ($P > 0.05$), therefore, results were summarized over years for each location. At all locations, N uptake by corn was significantly affected by N rate, genotype, and weed pressure ($P < 0.05$). At all locations, N uptake increased with increasing rates of N in the weed-free and high weed pressure treatments, and was significantly higher in the weed-free treatment ($P < 0.0001$; Table 7). The N by weed pressure interaction was significant

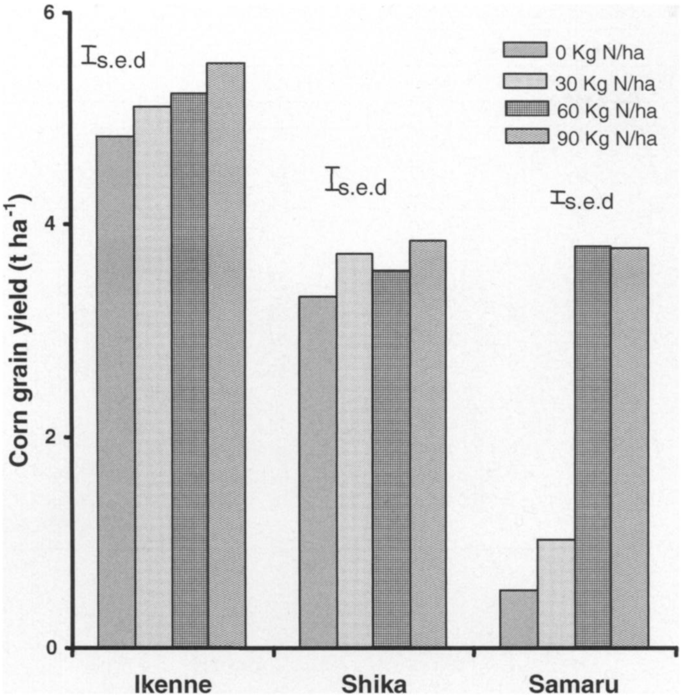

Figure 5. Response of genotypes to nitrogen fertilizer rates (0, 30, 60, 90 kg N ha^{-1}) at Ikenne, Shika, and Samaru, Nigeria. Data represent a 2-yr mean across weed pressure treatments and corn genotypes. Bars represent interaction standard error of the difference.

at Shika and Samaru. At Shika, the genotypes with the lowest N uptake were TZB-SR when weed-free and Low N Pool C_2 under high weed pressure. At Samaru, TZB-SR had a lower N uptake in both weed-free and high weed pressure treatments than the other genotypes. Nitrogen uptake by weeds was affected by N rate at Samaru, where the lowest uptake was observed in plots receiving 90 kg N ha^{-1}. Irrespective of treatment, N uptake by corn was 66% higher than by weeds; N uptake by weeds at 30 kg N ha^{-1} was higher than at other rates. N uptake by weeds in ACR8328 BN C_7 and Low-N-Pool C_2 treatments was lower than in Oba Super II and TZB-SR. The amounts of N taken by weeds and the crop in the weedy treatment was equal to the N uptake by corn in the weed-free treatment, suggesting competition for N.

This study has shown that corn grain yield was higher in fertilized than unfertilized treatments and in weed-free than weedy treatments. Weed-free conditions and the application of N resulted in high HI, chlorophyll content, % PAR intercepted by the corn canopy, and corn LA, which could explain the superior grain yield. Nitrogen uptake by corn increased with increasing N rate in both weed-free and high weed pressure treatments, suggesting that corn was more competitive than weeds. Increased N fertilization possibly enhanced the relative competitiveness of the corn genotypes. Corn genotype response to N application was influenced by location but not weed interference. Corn genotypes developed for suboptimal N conditions were more efficient in N uptake than TZB-SR at all locations. Nitrogen uptake by weeds in ACR8328 BN C_7 and Low-N-Pool C_2 treatments was lower than in Oba Super II and TZB-SR, suggesting that these open-pollinated genotypes bred under suboptimal N conditions were more competitive for N than weeds and could be an important component of integrated weed management in smallholder agriculture.

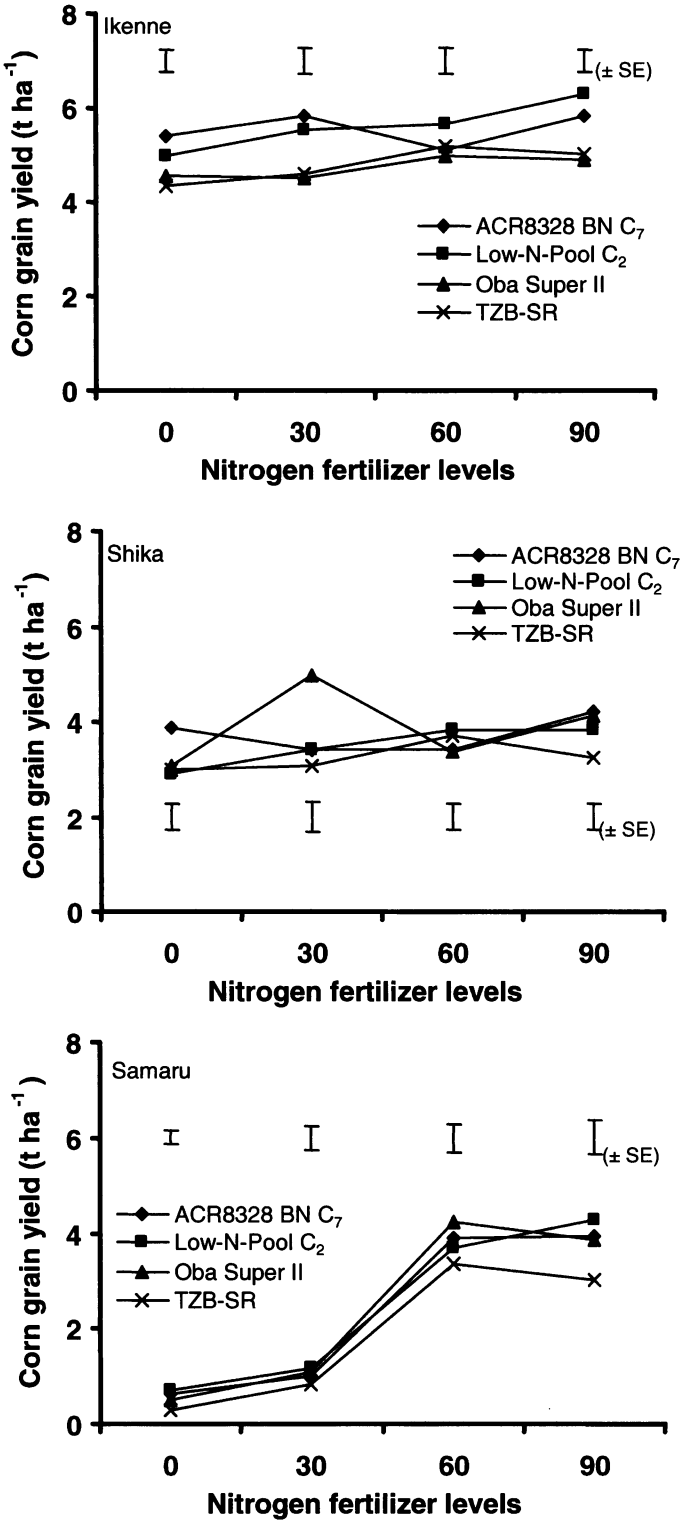

Figure 6. Effect of nitrogen rate (0, 30, 60, 90 kg N ha^{-1}) on corn grain yield at Samaru, Ikenne, and Shika, Nigeria. Data represent a 2-yr mean across weed pressure treatments. Bars represent interaction standard error of the difference.

Sources of Materials

[1] Benchtop LI-3100 meter, LI-COR, Inc., Lincoln, NE 68504.

[2] SUNFLECK meter, Decagon, Pullman, WA, 99163.

[3] SPAD-502 meter, Minolta Camera Co., Ltd., Osaka, Japan.

Table 6. Effect of weed pressure and nitrogen fertilizer on corn harvest index at Ikenne, Shika, and Samaru, Nigeria in 2002 and 2003.

Treatment	Ikenne					Shika					Samaru				
	ACR[a]	LOW	OBA	TZB	Mean	ACR	LOW	OBA	TZB	Mean	ACR	LOW	OBA	TZB	Mean
	Harvest index														
Year															
2002	0.43	0.35	0.45	0.33	0.39	0.29	0.28	0.3	0.27	0.29	0.23	0.22	0.25	0.17	0.22
2003	0.37	0.34	0.36	0.33	0.35	0.25	0.23	0.26	0.23	0.24	0.34	0.34	0.33	0.3	0.35
s.e.d.[b]					0.015					0.021					0.013
Nitrogen (kg ha^{-1})															
0	0.39	0.33	0.4	0.31	0.36	0.23	0.24	0.26	0.23	0.24	0.2	0.25	0.2	0.17	0.2
30	0.37	0.34	0.41	0.32	0.36	0.28	0.25	0.31	0.25	0.27	0.28	0.26	0.24	0.24	0.26
60	0.4	0.32	0.37	0.34	0.36	0.28	0.26	0.27	0.26	0.27	0.33	0.29	0.39	0.3	0.33
90	0.44	0.4	0.43	0.35	0.41	0.29	0.27	0.29	0.25	0.28	0.33	0.31	0.32	0.24	0.3
s.e.d.					0.013					0.011					0.02
Weed pressure															
Zero	0.4	0.35	0.4	0.32	0.37	0.32	0.29	0.33	0.3	0.31	0.49	0.48	0.49	0.41	0.47
Low	0.41	0.34	0.39	0.35	0.37	0.27	0.27	0.26	0.26	0.26	0.18	0.19	0.22	0.19	0.2
High	0.39	0.36	0.42	0.32	0.37	0.22	0.21	0.26	0.19	0.22	0.18	0.16	0.15	0.11	0.15
s.e.d.					0.011					0.009					0.017
	P value														
Year (Yr)			0.0500					NS[c]					0.0001		
Nitrogen (N)			0.0122					NS					0.0001		
Weed (W)			NS					0.0001					0.0001		
Genotype (G)			0.0001					0.0091					0.0439		
G × Yr			0.0023					NS					NS		
G × N			0.0332					NS					NS		

[a] Genotype abbreviations: ACR, ACR8328 BN C_7; LOW, Low-N-Pool C_2; OBA, Oba Super II; TZB, TZB-SR.
[b] s.e.d., Standard error of difference between two treatment means.
[c] NS, not significant.

Table 7. Nitrogen uptake by corn genotypes and weeds under zero and high weed pressure conditions at different nitrogen (N) rates at Ikenne, Shika, and Samaru, Nigeria in 2003.

Treatment	Ikenne				Shika				Samaru			
	Corn			Weed	Corn			Weed	Corn			Weed
	NWP[a]	HWP	Mean	HWP	NWP	HWP	Mean	HWP	NWP	HWP	Mean	HWP
	(kg ha^{-1})											
Nitrogen (kg ha^{-1})												
0	117.8	78.5	98.1	35.4	82.2	32.9	57.6	22.3	31.2	0.6	15.9	8.5
30	142.7	87.1	114.9	35.3	74.1	51.9	63	18.7	61.7	2.5	32.1	13.2
90	156	91.8	123.9	42	93.1	48.9	71	23.8	118.8	38.3	78.5	6.1
s.e.d.[b]			7.01	5.63			5.34	4.26			3.69	1
Genotypes												
ACR8328 BN C_7	153.7	94.7	124.2	36.4	95.2	51.5	73.3	22	72.3	13.2	42.8	7.5
Low-N-Pool C_2	143.2	103.5	123.4	42.5	81	37	59	23.5	81.2	13.7	47.4	8.8
Oba Super II	123.5	74.5	99	34.9	85.5	47.8	66.6	20.6	67.4	15.7	41.5	10.6
TZB-SR	134.9	70.5	102.7	36.4	71	41.9	56.4	20.3	61.4	12.5	37	10.1
s.e.d.			8.09	6.5			6.16	4.92			3.29	1.1
	P value											
Nitrogen (N)		0.0023		NS[c]		0.0495		NS		0.0001		0.0011
Genotype (G)		0.0028		NS		0.0364		NS		0.0257		0.050
Weed (W)		0.0001		N/A[d]		0.0001		N/A		0.001		N/A
N × G		NS		N/A		NS		NS		NS		0.0413
G × W		NS		N/A		NS		N/A		0.0328		N/A
N × W		NS		N/A		0.034		N/A		0.0001		N/A

[a] Weed pressure abbreviations: NWP, Zero weed pressure; HWP, High weed pressure.
[b] s.e.d., Standard error of difference between two treatment means.
[c] NS, not significant
[d] N/A, not applicable.

[4] Analytical Services Laboratory, IITA, Ibadan, PMB 5320, Oyo State, Nigeria.

[5] Moisture tester, Model 14998, Dickey-John Corporation, 5200 Dickey-John Road, Auburn, IL 62615.

Acknowledgment

This manuscript is published with the approval of the International Institute of Tropical Agriculture as contribution number IITA/06/JA/21.

Literature Cited

Badu-Apraku, B., M.A.B. Fakorede, and S. O. Ajala. 2001. Promoting maize technology transfer in West and Central Africa: a networking approach. Pages 45–65 *in* B. Badu-Apraku, M.A.B. Fakorede, M. Ouedraogo, R. J. Carsky, and A. Menkir, eds. Maize Revolution in West and Central Africa. Ibadan, Nigeria: IITA.

Baskin, J. M. and C. C. Baskin. 1989. Role of temperature in regulating timing of germination in soil seed reserve of *Thlaspi arvense* L. Weed Res. 29:317–326.

Blackshaw, R. E., G. Semach, and H. H. Janzen. 2002. Fertilizer application method affects nitrogen uptake in weeds and wheat. Weed Sci. 50:634–641.

Bremner, J. M. and C. S. Mulvaney. 1982. Nitrogen—total. Pp. 595–624 *in* A. L. Page, R. H. Miller, and D. R. Keeney, eds. Methods of Soil Analysis. Part 2. Agronomy 9. Madison, WI: ASA/ASSA.

Bullied, E. J., A. M. Marginet, and R. C. Van Acker. 2003. Conventional- and conservation-tillage systems influence emergence periodicity of annual weed species in canola. Weed Sci. 51:886–897.

Carey, J. B. and J. J. Kells. 1995. Timing of total post-emergence herbicide application to maximize weed control and corn (*Zea mays*) yield. Weed Technol. 9:356–361.

Chikoye, D. and F. Ekeleme. 2001. Weed flora and soil seed bank in fields dominated by *Imperata cylindrica* in the moist savannah of West Africa. Weed Res. 41:475–490.

Chikoye, D. and F. Ekeleme. 2003. Cover crops for cogongrass (*Imperata cylindrica*) management and effects on subsequent corn yield. Weed Sci. 51:792–797.

Chikoye, D., S. Schulz, and F. Ekeleme. 2004. Evaluation of integrated weed management practices in maize in northern Nigeria. Crop Prot. 23:895–900.

Chikoye, D., U. E. Udensi, and A. F. Lum. 2005. Evaluation of a new formulation of atrazine and metolachlor mixture for weed control in maize in Nigeria. Crop Prot. 24:1016–1020.

Di Tomaso, J. 1995. Approaches for improving corn competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491–497.

Ekeleme, F., I. O. Akobundu, A. O. Isichei, and D. Chikoye. 2000. Influence of fallow type and land use intensity on weed seed rain in a forest/savanna transition zone. Weed Sci. 48:604–612.

Ekeleme, F. and D. Chikoye. 2004. A survey of weed flora of arable fields in the moist savanna zone of Nigeria. J. Sust. Agric. Environ. 5:228–240.

Ekeleme, F., D. Chikoye, and I. O. Akobundu. 2004. Impact of natural, planted (*Pueraria phaseoloides, Leucaena leucocephala*) fallow and land-use intensity on weed seedling emergence pattern and density in cassava intercropped with corn. Agric. Ecosyst. Environ. 103:581–593.

Evans, S. P., S. Z. Knezevic, J. L. Lindquist, and C. A. Shapiro. 2003. Influence of nitrogen and duration of weed interference on corn growth and development. Weed Sci. 51:546–556.

Gonzalez, P. R. and M. L. Salas. 1995. Improvement of the growth, grain yield, and nitrogen, phosphorus, and potassium nutrition of grain corn through weed control. J. Plant Nutr. 18:2313–2324.

Grundy, A. C. and A. Mead. 2000. Modeling weed emergence as a function of meteorological records. Weed Sci. 48:594–603.

Heanes, D. L. 1984. Determination of total organic carbon in soils by an improved chromic acid digestion and spectrophotometric procedure. Commun. Soil Sci. Plant Anal. 15:1191–1213.

Hobbs, P. R. and R. R. Bellinder. 2004. Weed Management in Less Developed Countries. Encyclopedia of Plant and Crop Science. P. 1295. http://www.css.cornell.edu/faculty/hobbs/Papers/Wed%20magt%20developing%20coutries.pdf. Accessed: February 16, 2006.

[IITA] International Institute of Tropical Agriculture. 1982. IITA manual series no. 7. Ibadan, Nigeria: IITA Nigeria 33 p.

Jørnsgård, B., K. Rasmussen, J. Hill, and J. L. Christiansen. 1996. Influence of nitrogen on competition between cereals and their natural weed populations. Weed Res. 36:461–470.

Kamara, A. Y., A. Menkir, M.A.B. Fakorede, S. O. Ajala, B. Badu-Apraku, and I. Kureh. 2004. Agronomic performance of maize cultivars representing three decades of breeding in the Guinea savannas of West and Central Africa. J. Agric. Sci. 142:567–575.

Kamara, A. Y., A. Menkir, M.A.B. Fakorede, S. O. Ajala, B. Badu-Apraku, and I. Kureh. 2005. Performance of diverse maize genotypes under nitrogen deficiency in the northern Guinea savanna of Nigeria. Exp. Agric. 41:199–212.

Kim, S. K. 1994. Genetics of maize tolerance of *Striga hermonthica*. Crop Sci. 34:900–907.

Kling, J. G., K. F. Cardwell, and S. K. Kim. 1994. Advances in screening methods and breeding for downy mildew (*Peronoscleropora sorghi*) resistance of maize. Pp. 164–164 *in* D. C. Jewell, S. R. Waddington, J. K. Ransom, and K. V. Pixley, eds. Proceedings of the 4th Eastern and Southern African Regional Maize Conference. Mexico, D.F.: CIMMYT.

Kumwenda, J. D., T.S.R. Waddington, S. S. Snapp, R. B. Jones, and M. J. Blackie. 1996. Soil fertility management research for the maize cropping systems of smallholders in Southern Africa: A Review. NRG Paper 96–02. Mexico, D.F: CIMMYT, 36 p.

Littel, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS Systems for Mixed Models. Cary, NC: Statistical Analysis Systems, Inc., 633 p.

Logroño, M. L. and J. E. Lothrop. 2001. Impact of drought and low nitrogen on maize production in South Asia. http://www.cimmyt.org/Research/Maize/DLNCA/htm/DLNCo-2.htm. Accessed: January 2, 2007.

Lum, A. F., D. Chikoye, and S. O. Adesiyan. 2005. Effect of nicosulfuron dosages and timing on the post-emergence control of cogongrass (*Imperata cylindrica*) in corn. Weed Technol. 19:122–127.

Manyong, V. M., J. G. King, K. O. Makinde, S. O. Ajala, and A. Menkir. 2003. Impact of IITA germplasm improvement on maize production in West and Central Africa. Pp. 30–45 *in* R. E. Evenson and D. Gollin, eds. Crop Variety Improvement and Its Effects on Productivity: the Impact of International Agricultural Research. Wallingford, UK: CABI Publishing.

Mehlich, A. 1984. Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409–1416.

Meseka, S. K., A. Menkir, A.E.S. Ibrahim, and S. O. Ajala. 2006. Genetic analysis of the performance of maize inbred lines selected for tolerance to drought under low nitrogen. Maydica 51:487–495.

Olaniyan, A. B. and E. O. Lucas. 2004. Maize hybrids cultivation in Nigeria: a review. J. Food, Agric. Environ. 2:177–181.

Sanginga, N., K. E. Dashiel, J. Diels, B. Vanlauwe, O. Lyasse, R. J. Carsky, S. Tarawali, B. Asafo-Adjei, A. Menkir, S. Schulz, B. B. Singh, D. Chikoye, D. Keatinge, and R. Ortiz. 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. Agric., Ecosyst. Environ. 100:305–314.

Settimi, J. R. and J. W. Maranville. 1998. Carbon dioxide assimilation efficiency of corn leaves under nitrogen stress at different stages of plant development. Commun. Soil Sci. Plant Anal. 29:777–792.

Sibale, E. M. and M. E. Smith. 2001. Relationship Between Secondary Traits and Grain Yield of Maize Grown in Low Nitrogen Soils in Malawi. http://www.cimmyt.org/Research/Maize/DLNCA/htm/DLNCo-2.htm. Accessed: January 2, 2007.

Swanton, C. J., A. Shrestha, R. C. Roy, B. R. Ball-Coelho, and S. Z. Knezevic. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Sci. 47:454–461.

Tian, G., B. T. Kang, and V. M. Manyong. 1995. Food production in the moist savanna of West and Central Africa. Pp. 107–127 *in* B. T. Kang, I. O. Akobundu, V. M. Manyong,, R. J. Carsky, and N. Sanginga, eds. Proceedings of an International Workshop on Moist Savannas of Africa: Potentials and Constraints for Crop Production. September 19–23; Cotonou, Republic of Benin. Ibadan, Nigeria: IITA and Rome, Italy: FAO.

Tollenaar, M., A. Aguilera, and S. P. Nissanka. 1997. Grain yield is reduced more by weed interference in an old than in a new corn hybrid. Agron. J. 89:239–246.

Tollenaar, M., S. P. Nissanka, A. Aguilera, S. F. Weise, and C. J. Swanton. 1994. Effect of weed interference and soil nitrogen on four maize hybrids. Agron J. 86:596–601.

[TSBF] Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture 1993. . A Handbook of Methods. 221 p.

Usman, A., K. A. Elemo, A. Bala, and A. Umar. 2001. Effect of weed interference and nitrogen on yields of maize/rice intercrop. Int. J. Pest Manag. 47(4):241–246.

Van Delden, A., L.A.P. Lotz, L. Bastiaans, A. C. Franke, H. G. Smid, R. M. Groeneveld, and M. J. Kropff. 2002. The influence of nitrogen supply on the ability of wheat and potato to suppress *Stellaria media* growth and reproduction. Weed Res. 42:429–445.

Received March 19, 2007, and approved November 19, 2007.