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MAIZE YIELD DETERMINANTS IN FARMER-MANAGED TRIALS IN THE NIGERIAN NORTHERN GUINEA SAVANNA

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SUMMARY

Farmer-managed tests of *Striga hermonthica*-resistant maize varieties were conducted in 1994 in a moderately intensified zone in the northern Guinea savanna of Nigeria. Field history, soil properties, current season fertility management, and crop management observations were recorded for 37 farmer-managed trials. Site averages for maize grain yield varied from 300 to 4000 kg grain ha^{-1}. In spite of the tremendous variability observed, the grain yield was significantly higher for the striga-resistant hybrid 8321-18 compared with an improved open-pollinated variety, STR Syn-W, and the farmers' current variety. Correlation analysis and stepwise regression analysis of grain yield on measured variables suggested that maize yield was a function of plant density for all three varieties. The rate of nitrogen fertilizer application was an important variable only for the hybrid, while the day of first weeding was most important for the improved varieties. The yield of the local varieties and STR Syn-W was related to the number of emerged striga at harvest in the stepwise regression, and the yield of the local varieties was highly correlated with the striga-damage score on maize. The striga-damage score was significantly lower on 8321-18 than on the other varieties, suggesting some degree of resistance in the hybrid. The number of emerged striga was lower for the hybrid but not significantly different. Farmers were almost unanimous in ranking the hybrid as least damaged by striga and highest yielding. Besides being related to maize variety, striga-damage score was lower if crop residue was observed on the field at the time of site confirmation. Highest yields (approximately 4 t ha^{-1}) were recorded on fields near the homestead (compound fields) where soil organic carbon values were 2.0–2.5%. Realization of maize yield potential in the absence of manure or fertilizer will only be possible on long-term compound fields. Striga-resistant maize can maintain high yields under *S. hermonthica* infestation.

INTRODUCTION

The northern Guinea savanna (NGS) is a high potential area for maize (*Zea mays*) production because of high solar radiation and low night temperatures (Kassam *et al*., 1975). Length of the growing period is 150–180 d and the rainfall pattern is mono-modal with low likelihood of drought during late June to late September. Most of the NGS is very suitable for maize; based on climate it is possible to attain

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80% of maximum yield (Jagtap, 1995). As a result, maize has been adopted extensively in the NGS as documented by Smith *et al.* (1994).

Two major constraints on the achievement of high maize yields in the NGS are low nitrogen (N) supply and *Striga hermonthica* parasitism. Maize has a high N requirement and so N deficiency is a major cause of low maize yields. In a previous survey in the NGS, grain yield of maize was closely associated with nitrate in the soil (Weber *et al.*, 1995a). Nitrogen fertilizer is generally used to provide much of the N required for high maize yield. Although fertilizer use in sub-Saharan Africa is very low (Bationo *et al.*, 1986), it is moderately high in some areas where fertilizer purchases are subsidized and where maize productivity compensates for the high input (Smith *et al.*, 1994). Fertilizer subsidies are being reduced in Nigeria and other African countries.

S. hermonthica parasitism is a very important determinant of maize yield in the NGS as shown by surveys in Nigeria (Weber *et al.*, 1995b), Togo (Vogt *et al.*, 1991), and Ghana (Albert and Runge-Metzger, 1995), especially as human population density increases (Vogt *et al.*, 1991). Maize yields are much more closely related to striga-damage symptoms than to striga plant numbers (Kim, 1991). A striga-damage scoring system was proposed by Kim (1994).

Several *S. hermonthica*-resistant hybrids and open-pollinated varieties (OPVs) have been developed at the International Institute of Tropical Agriculture (IITA) as reported by Kim *et al.* (1995). Hybrids initially showed better levels of resistance than the OPVs (Kim *et al.*, 1995) but progress in OPVs is encouraging (Berner *et al.*, 1995). On-farm testing with these striga-resistant varieties has been insufficient. Most results are from researcher-managed trials on research stations.

An area in southern Bauchi State of northern Nigeria was selected as a pilot research area for the development of sustainable maize-based cropping systems in the moderately intensified NGS, an area with a moderately high population density of approximately 25–75 inhabitants km^{-2} and poor to moderate market access. In this area land-use intensification is driven by increasing population more than by market opportunities and this is typical of 60% of the land area in West Africa (Manyong *et al.*, 1996). Smith and Weber (1994) argue that soil fertility will be a serious problem in areas where land use is intensifying due to population pressure. Access to fertilizer is difficult because of limited access to markets, and population pressure limits access to fallow land.

In preparatory meetings to discuss cereal production problems with farmers, low soil fertility (lack of fertilizer) and *S. hermonthica* parasitism were mentioned most often as the constraints on maize and sorghum production. Farmers in three villages volunteered to test the *S. hermonthica*-resistant varieties, developed by IITA, along with their own. This paper synthesizes the results of these farmer-managed trials to improve the understanding of determinants of maize yield in farmers' fields under farmer management.

MATERIALS AND METHODS

Three maize varieties were grown with farmer management on 37 farmers' fields in three villages in southern Bauchi State (northern Nigeria) in 1994. The varieties included a hybrid developed by IITA (8321-18), commercially available in Nigeria as Oba Super 1, and STR Syn-W (1993 version), a synthetic population used in IITA's hybrid breeding programme for striga resistance. These were compared with each farmer's choice of control variety, usually TZB or TZPB, introduced into the area in the mid to late 1970s (Fakorede *et al*., 1993; Smith *et al*., 1994). Soils were generally shallow, sandy, and infertile Alfisols with associated Inceptisols and Lithosols. The villages varied in terms of market access (poor to moderate) and population density (25–75 km^{-2}). Rainfall in the villages was approximately 960–1050 mm during May to October.

At the time of site confirmation, distance from the homestead to the trial field was estimated by the research staff to the nearest 10 m for compound fields, 100 m for village fields, and 500 m for distant fields. Field history was recorded wherever possible for the last 10 years, including crops grown, fallow years and whether animal manure was applied. At the time of plot layout, the presence of crop or other organic residues and the presence of trees on the plots was recorded. On each farmer's field, three contiguous plots measuring 10 m × 10 m were marked by the research staff. Soils were sampled to a depth of 10 cm at planting. Twelve subsamples from each experimental field were combined for analysis of selected chemical properties (organic carbon (C) and phosphorus (Bray-I P)), particle size distribution and *S. hermonthica* seed density. Depth of soil was estimated at six points at each trial site by inserting an iron rod 5 mm in diameter during August when the soil profile was moist throughout.

Dates of major operations (planting, weeding and harvest), as well as amounts and types of nutrient amendments applied, were recorded from farmers' recall. Farmers stated the number of 'mudus' (1.2 kg) of NPK fertilizer (generally 15:15:15) or urea applied per 300-m^2 plot. One mudu of 15:15:15 applied to 300 m^2 was equivalent to approximately 6 kg N ha^{-1} and one mudu of urea supplied 18 kg N ha^{-1}. Some farmers estimated the number of headpans of manure applied to the experimental area. One headpan of dry manure weighed approximately 5 kg and with a N concentration of 2% was equivalent to 3 kg N ha^{-1}. In a few cases the quantity of manure on the field was estimated in tonnes; 1 t dry manure ha^{-1} was equivalent to 6–19 kg N ha^{-1} (Powell, 1986) and was assumed to be equivalent to 10 kg N ha^{-1}.

Maize and *S. hermonthica* plant densities and the yields of maize were measured in the four central maize rows of each plot at the time of maize flowering. Symptoms of *S. hermonthica* damage were mainly stunting and yellow blotching of leaves leading to leaf firing. *S. hermonthica* damage on maize was scored on a 1 (no symptoms) to 9 (extreme symptoms resulting in death of plant) scale according to the system proposed by Kim (1991). Emerged *S. hermonthica* density and reaction score were determined again immediately before maize harvest, and flower-bearing and capsule-bearing striga were counted at the same time. All striga density data were divided by maize density data to calculate the number of emerged striga per maize host plant. After weighing all ears from the four central rows at maturity, a subsample of 10 ears was used to estimate shelling percentage and dry matter.

S. hermonthica seed analysis was undertaken as described by Berner *et al.* (1993). A soil subsample weighing 170 g was sieved over a 250-μ screen and seed was separated from trash using potassium dichromate solution with a specific gravity of 1.4. Routine soil analyses were performed by the IITA analytical services laboratory using standard techniques (Analytical Services Laboratory, IITA, Laboratory Methods Manual, in preparation). Organic C was determined using dry combustion in a LECO CHN analyser, plant-available P was extracted using Bray-I solution and determined colorimetrically and the hydrometer method was used for particle size analysis. Some soil samples were lost and others were too small so the number of observations was reduced to 34 for soil chemical properties and 31 samples for particle size.

Each farmer was asked about the performance of the varieties in his own trial both at flowering and immediately after harvest. In the mid-season survey farmers were asked to rank their varieties for density of *S. hermonthica* growing on the maize and for damage to maize caused by *S. hermonthica*. After harvest they were asked to rank their varieties in terms of *S. hermonthica* damage, grain yield, drought resistance and earliness.

Maize yield data were subjected to mixed model analysis of variance, using the restricted maximum likelihood method (REML) for the estimation of the random variance components. The general form of the model was:

$$\mathrm{Y} = \mu + \mathrm{Variety} + \mathrm{Village} + \mathrm{Variety}{*}\mathrm{Village} + \mathrm{Field(Village)} + \mathrm{Cov} + \mathrm{Error}$$

where Field(Village) and Error terms were considered as the random components. Covariates (Cov), where relevant, included DENSITY (density of plants at flowering), NHA (amount of N applied as fertilizer and manure in 1994). WEEDAY (number of days between planting and first weeding), SCORE (striga-damage score), TREE (binary variable indicating the presence or absence of trees on the plot), CLAY (% clay) and others. These covariates had been identified in a preliminary regression analysis with grain yield as the dependent variable separately for each of the three varieties. Emerged striga-count data were analysed without covariates. The mean response function (of the ordinal striga-damage scores) was fitted using the CATMOD (categorical modelling) procedure in SAS (SAS, 1989). The relationship between grain yield and striga-damage score was explored further using the conventional regression approach for the trends alone. Using MATMODEL (Gauch, 1993), biplot analysis was performed on the Field by Variety interaction; in this way high-yielding and stable varieties and

Table 1. Correlations of maize grain yield (by variety) with selected variables.

	8321-18		STR syn-W		Local varieties	
Variable	*r*	*p*	*r*	*p*	*r*	*p*
Years of fallow	−0.35	0.04	−0.29	0.08	−0.33	0.05
Organic carbon (%)	0.15	0.98	−0.05	0.79	0.33	0.06
Bray-I P (mg kg^{-1})	0.02	0.91	0.03	0.85	0.26	0.13
Clay (%)	0.33	0.07	−0.05	0.76	0.43	0.01
Sand (%)	−0.31	0.09	−0.10	0.59	−0.24	0.20
Silt (%)	0.21	0.23	0.18	0.32	0.04	0.82
Soil depth estimate (cm)	0.34	0.04	−0.19	0.27	0.03	0.85
Striga seeds per 170 g soil	−0.06	0.75	—	—	−0.09	0.58
Emerged striga per host plant at harvest	0.00	0.99	0.21	0.22	−0.21	0.21
Striga-damage score (1–9)	−0.28	0.10	0.31	0.08	−0.40	0.01
Nitrogen application (kg ha^{-1})	0.32	0.05	0.21	0.23	−0.04	0.80
Plant density at flowering (plants ha^{-1})	0.45	0.01	−0.33	0.06	0.37	0.02
Maize ears per plant	0.48	0.00	0.41	0.01	0.77	0.00

fields could be identified readily. Correlation analyses of key variables were also determined.

RESULTS AND DISCUSSION

A total of 52 variables were observed or derived. Correlations of grain yield with some selected variables are given in Table 1 for each of the three varieties. Correlations were generally low and varied from variety to variety. For on-farm trials this diversity was expected. Over all the fields the striga-damage scores were weakly related to maize grain yield; though significant, this might not necessarily indicate causal relationships. Striga plant numbers were highly variable but were not significantly correlated with mean maize yield over the 37 fields studied. Many farmers chose fields which apparently did not have a serious striga problem. Twenty-three of the 37 fields had less than 0.5 emerged striga per maize plant and 14 of the 37 fields had less than 0.1 emerged striga. Maize grain yield on fields with low numbers of emerged striga per host plant was highly variable and clearly related to other factors.

Maize yield was not related to *S. hermonthica* seed density, a result similar to that reported by Weber *et al.* (1995c) for a more intensified maize growing area in northern Nigeria. In this study there was no correlation between soil depth and maize grain yield even though depth ranged from less than 10 cm to more than 70 cm. This may have been because the rainfall during the vegetative and reproductive growth stages was adequate for maize, especially at the relatively low yields observed. Soil depth was not significantly related to yield in a field-monitoring study by Weber *et al.* (1995c). Maize grain yield was significantly

Table 2. Stepwise regression analysis of grain yield (kg ha^{-1}) on observed independent variables for three varieties separately

	8321-18		STR Syn-W		Local varieties	
	Estimate	Prob > F	Estimate	Prob > F	Estimate	Prob > F
Intercept	−253.6	0.7876	21.88	0.9715	243.57	0.6291
DENSITY	0.042	0.0053	0.037	0.0029	0.039	0.0126
NHA	12.58	0.0546	—	—	—	—
TREE	761.89	0.0890	713.48	0.0261	—	—
WEEDAY	−49.58	0.0585	−44.15	0.0156	—	—
CAPSH†	—	—	−1966.60	0.0947	−2037.4	0.0672
Adjusted R^2		36.18		41.45		17.28
Root mean square error		1207.2		878.7		1048.9

†CAPSH = emerged capsule-bearing striga plants per host plant at maize harvest.

correlated with plant density. This was also observed by Weber *et al.* (1995d) in a survey of farmers' fields in an area of more intensified production. Farmers tend to reduce planting density as soil fertility decreases so that they obtain ears of a reasonable size. Results of a preliminary regression analysis relating grain yield to the observed and derived variables gave an indication of the variables which might be used as covariates in formal analysis of variance (Table 2).

Improved maize varieties grown under well managed conditions can produce an average of 4–7 t grain ha^{-1} in the NGS zone (Elemo, 1993; Tian *et al.*, 1995), but average yields on farmers' fields fall well below this potential (Tian *et al.*, 1995). In this trial the mean site yield (average of the three varieties) ranged from 300 to 4000 kg grain ha^{-1}. Examination of the Box and Whiskers plots (Fig. 1) indicated considerable variability in yields of the hybrid variety, 8321-18, while those of the other two varieties were skewed with lower mean yields.

Two approaches were used to study the differences among the variables. Assuming that the local varieties varied considerably among villages and fields, two new variables measuring the performance of the two introduced varieties (8321-18 or HYB and old STR Syn-W or simply STR) were derived as HYB-LOC (the difference between the yield of the hybrid and the local varieties for a particular field) and STR-LOC. Analysis of variance (Table 3) indicated that the STR Syn-W variety was not significantly different from the local varieties since the least square mean (LSMEAN) of STR-LOC was not significantly different from zero. On the other hand, the hybrid 8321-18 was significantly higher than the others. The output from the alternative analysis (treating the local varieties as identical, and hence three varieties, and incorporating significant covariates) (Table 4), confirmed the results given in Table 3. In general, average grain yield of the hybrid was 2.1 t ha^{-1} with the local varieties yielding only 1.4 t ha^{-1}.

Maize plant density, the time of weeding after planting and striga-damage score contributed to differences in yields of the maize varieties. Significant differences were observed among varieties with respect to maize plant density at harvest and

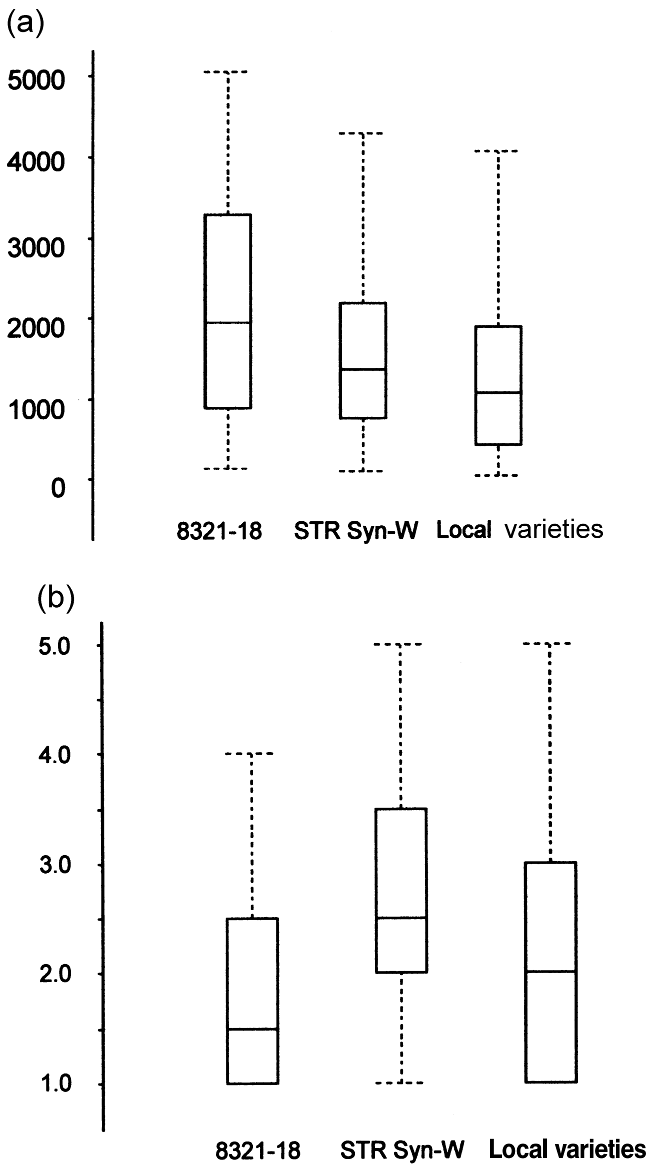

Fig. 1. Box and Whiskers plot of (a) grain yield (kg ha^{-1}) and (b) striga-damage score (1–9) in farmer-managed maize trials, 1994.

the number of ears per plant, but no such differences were observed among varieties for ear weight (Table 4).

Striga-damage score was significantly lower for the hybrid than for the OPVs. The analysis of the mean response scores using the CATMOD procedure and the RESPONSE statement in SAS (SAS, 1989) provided useful insights. The results indicated that the additive model including VARIETY, MANURE and RESIDUE fitted adequately since the residual chi-square was not significant

Table 3. Analysis of yield performance of introduced varieties over the local varieties. ANOVA of fixed effects and LSMeans.

ANOVA of fixed effects Source	NDF	DDF	Prob > F
Variety	1	34	0.0033
Village	2	34	0.3624
Village × Variety	2	34	0.6471
LSMeans (Test of null hypothesis H0: LSMEAN = 0)			
Comparison	LSMEAN	s.e.	Prob > t
HYB-LOC	760.3	167	0.0001
STR-LOC	186.3	167	0.2731
s.e.d.		182	

NDF = degree of freedom of numerator; DDF = degree of freedom of denominator; s.e. = standard error of means; s.e.d = standard error of difference between means; HYB-LOC = yield difference between hybrid (8321-18) and local varieties; STR-LOC = yield difference between STR Syn-W and local varieties.

Table 4. Mixed model covariance parameter estimates and tests of fixed effects and selected contrasts.

Dependent variable	Grain yield (kg ha^{-1})	Density (plants ha^{-1})	Ears per plant	Ear weight (g)
Covariance ($\times 10^5$)				
Field (Village)	6.49	433.3	0.031	145
Residual	5.18	567.6	0.065	133
Fixed effects probability				
Village	0.3404	0.0002	0.2174	0.4337
Variety	0.0206	0.0211	0.0019	0.4971
Village × Variety	0.7949	0.4031	0.5510	0.3577
Covariates Probability				
DENSITY	0.0045	—	—	—
WEEDAY	0.0127	—	—	—
SCORE	0.0631	—	—	0.0016
CLAY	—	0.0226	—	—
NHA	—	—	—	0.0421
Contrasts Probability				
Local *vs.* others	0.0505	0.0057	0.0033	—
HYB *vs.* STR	0.0312	0.9487	0.1186	—
Least square means (s.e.)				
8321-18 (HYB)	2061 (190)	36 443 (1832)	0.89 (0.05)	145 (9.5)
STR Syn-W (STR)	1625 (187)	36 317 (1832)	0.76 (0.05)	133 (9.4)
Local varieties	1529 (185)	31 513 (1832)	0.67 (0.05)	137 (9.2)
Standard error of the difference between means				
HYB *vs.* STR	203	1951	0.0596	—
HYB *vs.* Local	189	1951	0.0596	—
STR *vs.* Local	177	1951	0.0596	—

Table 5. Analysis of mean response function of ordinal striga-damage scores using CATMO.D (a) analysis of variance table and (b) analysis of weighted least squares estimates.

(a) Analysis of variance table

Source	d.f.	Chi-square	Probability
Intercept	1	436.45	0.0000
VARIETY	2	12.52	0.0019
MANURE†	1	2.26	0.1332
RESIDUE‡	1	14.13	0.0002
Residual	7	2.98	0.8869

(b) Analysis of weighted-least squares estimates

Effect	Parameter	Estimate	s.e.	Probability
Intercept		2.2910	0.1097	0.0000
VARIETY	8321-18	−0.3931	0.1173	0.0008
	STR Syn-W	0.3497	0.1366	0.0105
MANURE†	Yes	0.1442	0.0960	0.1332
RESIDUE‡	Yes	−0.3943	0.1049	0.0002

†MANURE = 'Yes' if manure was applied at some time during recalled field history (up to 10 years), otherwise MANURE = 'No'; ‡RESIDUE = 'Yes' if crop residues observed in the field at the time of site confirmation, otherwise RESIDUE = 'No' if crop residues not observed.

(Table 5a). It also showed that variety (at three levels) and crop residue (at two levels – residue not observed and residue observed) effects were significant, but manure (at two levels) was not. Further interpretation of the output, by the analysis of weighted least squares estimates (Table 5b), confirmed that the hybrid variety (8321-18) had the least mean score (lower than the response function), while variety STR Syn-W had the highest. The local variety (varieties) had a mean score just above the response mean since the estimate (x) was only 0.0434 $[-0.3931+0.3497+x = 0]$. The implication was that 8321-18 was very much more resistant to striga than STR Syn-W. Furthermore, at maize harvest, the numbers of emerged striga, flower-bearing striga and capsule-bearing striga were lowest on the hybrid although not significantly lower than on the other varieties (Table 6).

The biplot analysis of the fields × variety interaction (Fig. 2), which was executed using MATMODEL (Gauch, 1993), identified fields likely to be stable or specific to certain varieties and vice versa. The analysis confirmed high positive interaction principal components axis 1 (IPC1) scores for the hybrid and high negative IPC1 scores for the OPVs. Fields and varieties with mean grain yield greater than the overall mean are on the right of the mean line, marked 'M' in Fig. 2. As the graph accounted for 92% of the interaction sum of squares, reasonable inferences could be drawn from the plots. For instance, field 1 with highest mean grain yield was not necessarily suited for the hybrid, while several fields along the zero IPC1 axis (dotted lines) were 'stable' or relatively non-specific to the varieties.

Table 6. Analysis of least squares means of emerged striga per host maize plant†.

Variety	SHFLOW	SHHARV	FLOWSH	CAPSH
8321-18	0.30	0.53	0.19	0.03‡
STR Syn-W	0.31	0.80	0.31	0.06
Local varieties	0.42	0.78	0.30	0.07
s.e.d.	0.09	0.16	0.06	0.021

†Variety by Village interaction was not significant; SHFLOW = striga per host at maize flowering; SHHARV = striga per host at maize harvest; FLOWSH = flowering striga per host at harvest; CAPSH = capsule bearing striga per host at harvest; ‡not significantly different from zero (p = 0.1383).

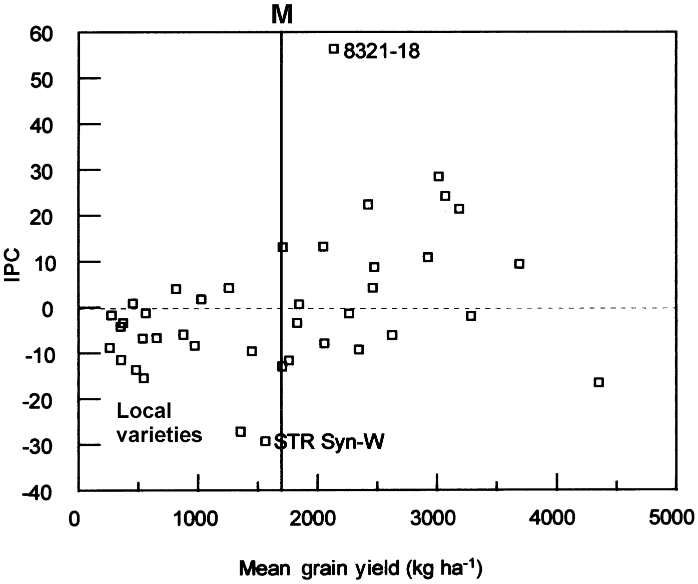

Fig. 2. Plot of maize grain yield and interaction principal component (IPC) axis 1 for three varieties and 37 environments (from AMMI analysis). Fields and varieties with mean grain yield greater than the overall mean are on the right of the mean line marked M.

Partitioning of the IPC1 versus IPC2 plot (Fig. 3) through the (0,0) co-ordinates leads to separation of varieties and fields. The hybrid was strongly positive for IPC1 while the other varieties were negative. In addition, the local varieties were negative for IPC2 but STR Syn-W was positive. The data for the outermost fields in the clusters were re-examined to identify distinguishing characteristics of the fields or trial management. The summary in Table 7 suggests that the fields with positive IPC1 received substantially more fertilizer (including inorganic and organic sources) than the fields with negative IPC1 values. Thus, good performance of the hybrid was observed on the fields with higher nutrient amendments. This compared well with the regression analysis (Table 2) in which only the hybrid yield was related to N inputs.

Conventional regression analysis for the trend of yield on striga-damage score

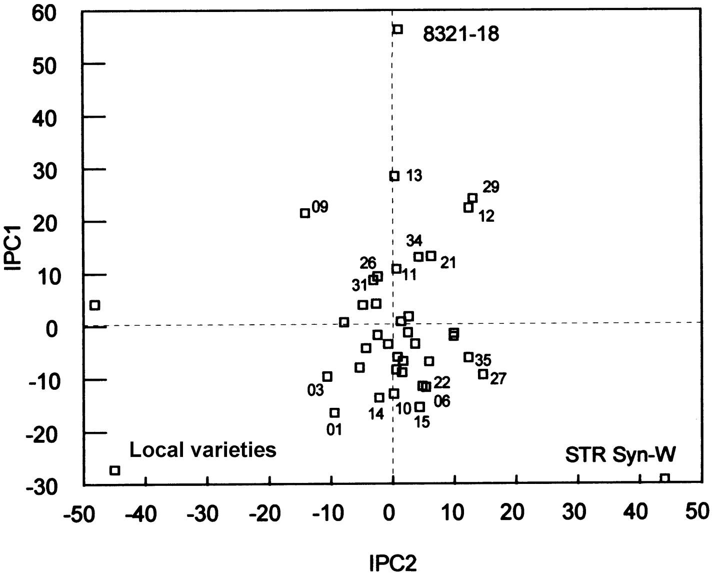

Fig. 3. Plot of interaction principal components (IPC) axes 1 and 2 for three varieties and 37 environments (from AMMI analysis).

Table 7. Mean grain yields (t ha^{-1}) and nutrient amendments applied to trials giving high and low interaction principal component axes 1 (IPC1) from AMMI analysis (see Fig. 3).

Field	Mean yield	Nutrient amendments
IPC1 ⩾ 0		
29	3.0	5 NPK + manure (++)
12	3.4	5 NPK + 5 urea
21	2.0	6 NPK + 5 urea
34	1.7	4 NPK + manure (?)
13	0.8	5 urea
09	3.2	5 NPK
11	2.9	4 NPK
26	2.5	8 NPK + manure (++)
31	3.7	manure (?) + house waste (?)
IPC1 ⩽ 0		
27	2.4	manure (?)
37	2.4	4 NPK
15	0.5	4 NPK
06	1.8	4 NPK
22	0.3	2 NPK
10	1.8	5 NPK
14	0.5	none
01	4.3	manure (?)
03	1.4	manure (?)

Fertilizer application is number of 'mudus' of N:P:K (usually 15:15:15) or urea and manure or household waste which was generally not quantified (?) except in some cases where it was substantial (++).

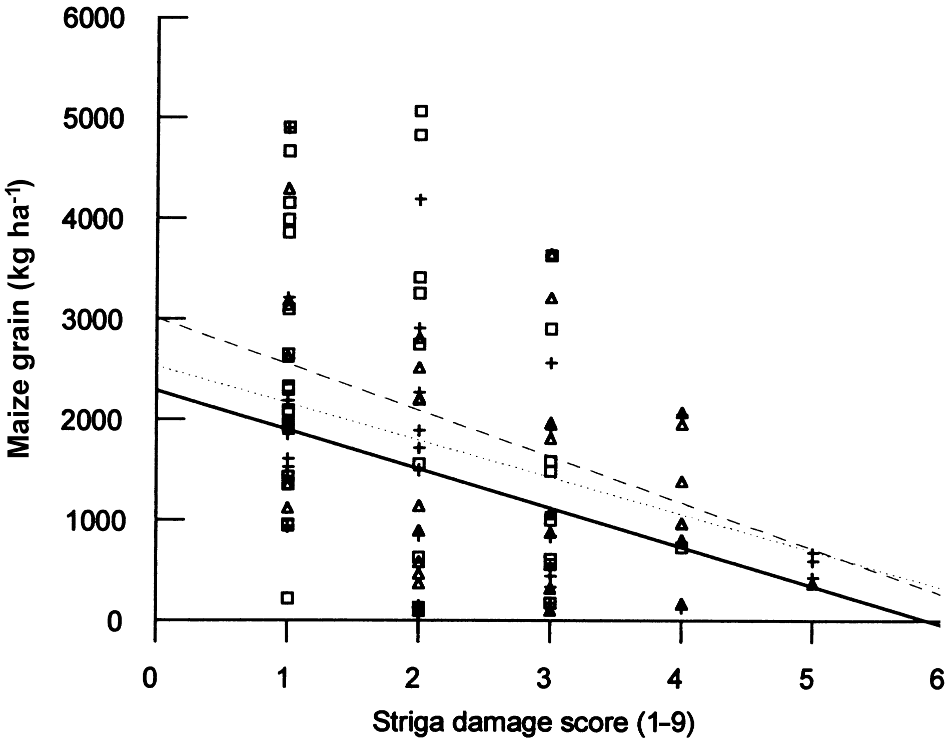

Fig. 4. Response of grain yield of three maize varieties (8321-18, -□- ; STR Syn-W, ·△·; local varieties, -+-) to *Striga hermonthica* damage score in 37 farmer-managed trials at Bauchi, 1994.

for all the fields and varieties indicated similarity in trend (Fig. 4). The fitted model ($p < 0.001$, with only 15% variance accounted for) was obtained as:

$$\begin{aligned}\text{Grain yield } &= 3005 - 459(\text{SCORE}) - 479(\text{HYBCODE}) - 721(\text{LOCODE})\\ &\quad + 91\text{SCORE} * \text{HYBCODE}) + 69(\text{SCORE} * \text{LOCODE})\end{aligned}$$

where HYBCODE and LOCODE were dummy variables taking on values of 1 if the variable is the hybrid or the local variety, and zero if otherwise. Hence a code value of zero for both HYBCODE and LOCODE was equivalent to a predicted model for STR Syn-W. The relationship between the varieties with respect to grain yield and striga damage could be visualized through the Box and Whisker plots given in Fig. 1. While differences in grain yields were clear, the same was not the case with the distribution of the striga-damage scores. However, the fact that large yield responses were more variable than small ones (heteroscedastic) implied that less emphasis should be placed on the predictive ability of the model. At best, the models (and plots) demonstrated the similarity in patterns in yield loss for increasing striga-damage score.

At the time of flowering, 13 of the 16 farmers with a definite opinion felt that the

Table 8. Number of collaborating farmers (out of maximum 37) choosing maize varieties for selected characteristics in Bauchi, 1994.

Characteristic	8321-18	STR Syn-W	Local varieties
At maize flowering			
Striga density lowest	13	0	3
Striga damage least	23	0	0
Post harvest			
Striga damage least	36	1	0
Maize ear yield best	36	1	0
Maize most drought resistant	12	3	10
Maize maturity appropriate	2	0	8

hybrid supported the lowest density of emerged striga (Table 8). Their perception regarding striga damage favoured the hybrid even more. All farmers with a definite opinion found the hybrid to be less affected by striga symptoms. At harvest, farmers were almost unanimous in ranking 8321-18 as the least damaged by striga and giving the best grain yield. Farmers were less convinced of its resistance to drought. Of the farmers who felt they could distinguish between the varieties in terms of drought resistance, approximately equal numbers found the hybrid and the local varieties to be most resistant. Very few farmers had an opinion on the maturity of the varieties. Of those who felt they could distinguish between the varieties, most preferred their own variety. Most of the farmers (32 of the 35) felt that their trial was a fair comparison of the varieties. Collaborating farmers were very pleased with the performance of the hybrid but were concerned about its availability and the cost of seed on a yearly basis.

The relative importance of constraints can be estimated using a combination of informal surveys, monitoring of farmers' fields, and controlled experiments. This study took advantage of the substantial variability encountered on farmers' fields to elucidate major determinants of maize yield. On-farm variability has been used to analyse constraints in maize production (Scopel and Louette, 1992) and in sorghum (De Steenhuijsen Piters, 1995) mostly using stratification techniques in addition to regression. Collateral data allowed analysis of the variability encountered in farmers' maize yields using a combination of analysis of variance, regression, and multi-variate methods.

Since maize requires good nutrient and water availability, relationships between soil organic matter and maize yield might be hypothesized. In a study on 57 farmers' fields (mean soil organic C 0.49% (s.e. 0.02) at a depth of 0–15 cm) in an intensified zone of the Nigerian NGS, maize yield was not associated with soil organic C (Weber *et al.*, 1995a). However, in another study on millet conducted in the Sahelian zone of Niger (Bationo *et al.*, 1986) soil organic matter (mean 0.4%, s.d. 0.1%) was significantly related to yield. Relationships between yield and soil organic C might have been expected because of the substantial range of C values. Onyeanuforo (1994) showed in one of our study villages that average NO_3^--N content at a depth of 0–15 cm during the first eight weeks after planting was 65 kg ha^{-1} for a continuously cropped compound field with 1.8% organic C, and 19 kg ha^{-1} for a continuously cropped distant field with 0.5% organic C. However, relationships between yield and soil organic C were not strong in the farmer-managed trials reported here because the correlations for varietal grain yield were extremely low (Table 1). Higher grain yields (3–4 t ha^{-1}) did tend to be produced on fields which had higher soil organic C (1–2.5%), although some high yields came from fields with low C, which received substantial fertilizer rates. Furthermore, some low yields were produced on fields with moderate to high soil organic C because the crop was poorly managed (late weeding, late planting) or suffered from relatively severe *S. hermonthica* damage.

Late weeding, late planting and high striga-damage score were observed in many of the fields with grain yields below 1 t ha^{-1}. Late first weeding (more than 40 d after planting) occurred on three fields. Average grain yields were below 400 kg ha^{-1} on each of these fields. Late planting (after 1 July) put the crop at risk of not reaching maturity by the end of the growing period. Four fields were planted late but poor fertility management was only evident on one field where the average grain yield was 240 kg ha^{-1}. Other grain yields on late-planted fields were 1–2 t ha^{-1}. Striga-damage scores greater than 3.5 occurred in four trials and average grain yields were below 900 kg ha^{-1} on those fields.

Farmers know that soil fertility is very important for maize production. Their solutions for inadequate soil nutrient supply include switching to a less demanding crop (such as sorghum, millet, grain legume or cassava), applying mineral fertilizer or animal manure, or letting the field rest. Although farmers complained about the lack of fertilizer, most managed to procure substantial amounts for their maize plots. The range of N application was 0–120 kg N ha^{-1} averaging slightly less than 50 kg N ha^{-1}.

Maize grain yield for each variety was significantly correlated with plant density. This was also observed by Weber *et al.* (1995d) in a survey of farmers' fields in the more intensified production area. Farmers tend to reduce planting density as soil fertility decreases so that they can obtain ears of a reasonable size. However, plant population was not correlated with soil organic C (data not shown). Although plant density of STR Syn-W was higher than for the local varieties, yield and yield components were not.

Maize yield per hectare and yield per plant decreased with increasing distance from the compound, but plant density did not. The strongest relationship with distance was maize planting date because planting was more likely to be delayed in distant fields. Weak negative correlations were consequently observed between distance and plant-available soil P and nutrient amendments applied.

CONCLUSIONS

Farmers' preliminary diagnosis of soil fertility and *S. hermonthica* parasitism as major constraints on maize production was accurate. About half of the collaborating farmers chose a moderately or severely striga-infested field for the maize variety trial. Based on the higher yield of the hybrid and its lower damage score, striga resistance appears to be capable of making a contribution to increased maize yield in the Guinea savanna zone. This characteristic should be incorporated into open pollinated maize varieties.

This study shows the importance of nutrient supply especially for the hybrid variety with higher yield potential. Soil organic C was not related to maize yield because collaborating farmers applied variable amounts of fertilizer and manure and managed the maize crop in diverse ways. Without fertilizer, especially N application, farmers will have to restrict maize production to their compound fields which have higher fertility.

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