ANALYSIS AND INTERPRETATION OF THE MAIZE COMPONENT OF MAIZE AND CASSAVA SYSTEM WITH NITROGEN IN A MULTILOCATION EXPERIMENT

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ABSTRACT

In Nigeria fertilizer recommendation for cassava and maize intercropping is based upon maize data, since cassava is less likely to demand a higher fertilizer level than maize. Recommended levels are the same across the major ecologies in which this crop association is important. Using a wide range of nitrogen levels and three maize varieties (one early and two late maturing), the response of a cassava and maize intercrop was studied at three locations within the three major ecozones in which this crop combination is important. Nitrogen levels for optimum maize grain yield varied with maize variety, ecozone and year (season). Analysis of variance based upon a linear model gave similar results to that based on Additive Main Effects and Multiplicative Interaction (AMMI). However with the AMMI biplot and its spatial configuration of treatment responses, visual clustering was facilitated and therefore locations and maize varieties which responded similarly were determined. Differences in maize yield were attributed to time to maturity in a given ecozone and to nitrogen rate.

Key Words and Phrases: Additive main effects and multiplicative interaction, Biological yield, Ecozone, Fertilizer rates, Intercropping, Linear models, Maize varieties.

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INTRODUCTION

In Nigeria, cassava is traditionally intercropped with maize. The other crops added to this root crop-cereal combination may be yams, *Discorea* spp., which is a major crop, particularly in the yam zone (Coursey, 1967) and vegetables such as okra, African spinach (*Amaranthus hybridus*), pole beans (*Sphenostylus stenocarpa*), and *Solanum macrocarpum* (Okigbo, 1980). Except in the yam zone, where yam is still retained, most of the other crops added to cassava and maize intercrop are being gradually dropped in larger farms far away from homesteads or compounds (Nwosu, 1973). The most commonly observed sequence after land clearing are those in which nutrient-demanding crops such as yams and maize are followed by less nutrient-demanding crops. Cassava may be added to yam and maize in the first year. The sequence is, therefore, cassava and maize, followed by (fb) cassava and maize, fb fallow. The second year, cassava is invariably harvested from a fallowed field (Ezumah and Okigbo, 1980). In the yam zone, the sequence is usually yam and maize (and cassava), fb cassava and maize and (vegetables), fb fallow. The performance of this sequence across the major West African agricultural zones has not been coordinated using improved maize grown with a wide range of nitrogen fertilization. Nitrogen has been described as a "key nutrient for sustaining or increasing food production in the tropics" (Kang, 1988). Yet it is the most readily deficient in the tropical humid environment, where it is readily lost by leaching and runoff in the highly erosive conditions caused by high rainfalls (Lal, 1989). The high temperature that prevails in the humid tropics also causes nitrogen losses by volatilization (Nnadi, 1980; Okigbo and Greenland, 1976). However, by some judicious choice of cropping system which includes legumes, some carry-over of nitrogen to following crops (Nnadi, 1980; Jones, 1971), or even direct transfer to associated crops in an intercrop system (Agboola and Fayemi, 1972; Eaglesham *et al.*, 1981) have been reported. Many farmers in the humid tropical zones of West Africa stick to systems that do not include grain legumes or legume fallow crops. Therefore, in order to derive maximum benefits from the improved maize varieties being released, information on the nitrogen to be applied should be provided. Perhaps this information may encourage policy makers to seek means of availing farmers with the required nitrogen fertilizer. It may also encourage extension efforts to incorporate legumes into cassava-based intercrop systems with maize, particularly since most farmers do not have the money to purchase inorganic fertilizers (Oputa, 1983). Note that previous reports have shown that hybrid maize responded significantly to nitrogen applications greater than 220 kg/ha, the highest level used in the study (Alofe, 1985, Personal Communication). The recommended economic level used in Nigeria is about 80 kg/ha. It has been observed that farmers who have access to nitrogen fertilizer in Southern Nigeria apply much lower levels (20-40 kg/ha) (Mutsaers and Walker, 1990). This experiment was designed to study the response of maize intercropped with improved TSM 30572 cassava, at various nitrogen levels ranging from very low to very high across the major cassava- and maize-growing ecologies in Nigeria. Three ecological zones were selected to represent similar zones across the West African region.

MATERIAL AND METHODS

Three sites, representing three major ecological zones in West Africa, were selected for the trial. They are Warri (perhumid; ultisol soil derived from coastal sediment; Oxic paleudult, pH 4.0, sandy – > 87% sand); Okolu (humid, alfisol soil, pH 6.1, loamy sand – sand 62%, clay 18%, loam 20%) and Mokwa (moist savanna; alfisol, clayey loam, pH 6.4 – sand 57%, clay 23%, loam 20%).

Three maize varieties, the early maturing (90-day) streak-resistant TZESRW; its late equivalent (110-120-day) TZSRW and a hybrid (8321 × 180, about 120 days to maturity) bred for suitability to wet, tropical environments, were intercropped with TMS 30572 cassava at five nitrogen rates at the three sites (Warri, Okolu and Mokwa). The nitrogen (N) rates were kg/ha: 20, 2×20, $2^2 \times 20$; $2^3 \times 20$ and $2^4 \times 20$. Phosphorus (P) and Potassium (K) were applied at a uniform rate of 60 kg/ha.

The three maize varieties and five nitrogen levels were arranged in a randomized complete block with four replications at Mokwa and Warri and three at Okolu. Plot size was 6 m × 8 m. Cassava and maize were planted in alternate rows. Cassava spacing was 1 m × 1 m, while the maize was spaced at 1 m × 0.25 m for 10,000 and 40,000 plants/ha, respectively. P and K were applied as seedbed fertilizers, while half the nitrogen was applied as seedbed and half scheduled at four weeks after planting – the recommended timing. Both crops were planted the same day. The experiment was repeated for a second year using the same randomization as the first. The planting date varied with inception of rains at the locations. First planting was at Warri on April 11, 1985 and April 29, 1986. The second location planted was Okolu on May 5, 1985 and May 17, 1986. The third location, Mokwa, was planted on June 13, 1985 and June 23, 1986.

Cassava stakes, about 30 cm, selected for uniformity of size and approximately similar ages, were used. Maize seeds were supplied by the Maize Improvement Program at IITA. Three maize seeds were planted per hole and later thinned to one plant at three weeks, just before the side dressing. The plots were hoe weeded to control weeds when necessary. The Okolu site was managed by IITA staff; the Warri site was by Shell and IITA; and the Mokwa site through an arrangement with a research extension program located on the site. Harvests at all locations were by IITA staff. Plot area harvested was 4 m × 6 m. The maize grain yield was reported at 14% moisture, while the cassava root yield was as fresh tuber harvested at about 12 months.

Soil samples (0-10 cm) were obtained prior to planting and at the end of the second year. The data were obtained at two locations from each plot and composited across replications. The pH, organic carbon, nitrogen and physical compositions were determined. The data was analyzed using an appropriate Analysis of Variance model. Further analysis of the same data set was done with the AMMI (Additive Main Effect and Multiplicative Interaction) Model.

The AMMI Analysis is essentially an analysis of variance followed by a singular value decomposition which with some changes results in the general model for the multivariate statistical methods for Principal Component Analysis (PCA) (Gauch, 1982; Zobel *et al.*, 1988). The AMMI analysis here was done by the Rhizostat program (Zobel, Personal Communication), derived from Matmodel (Gauch, 1990). The analysis is usually done on a 2-way factorial with and without replication having significant main effects and significant interaction effects. The main purpose of the AMMI analysis is to model or understand data with a biplot graph in which both the main effects and interactions for genotypes (treatments) and environments are factors and also to gain efficiency with few replications, particularly in experiments such as on-farm trials where restrictions to replicate may arise (Gauch, 1988; Gauch and Zobel, 1988).

RESULTS AND DISCUSSION

2a. Additive Model Analysis

A standard additive model for this experiment is:

$$Y_{fghij} = \mu + \lambda_f + \delta_g + \lambda\delta_{fg} + \rho_{fgh} + \tau_i + \eta_j + \tau\lambda_{fi} + \tau\delta_{gi} + \tau\eta_{ij} + \delta\eta_{gj} + \lambda\eta_{fj}$$
$$+ \tau\lambda\rho_{fgi} + \tau\delta\eta_{gij} + \tau\lambda\eta_{fij} + \lambda\delta\eta_{fgi} + \tau\lambda\delta\eta_{fgij} + \epsilon_{fghij} ,$$

where μ is a mean effect common to every observation, λ_f is the effect of year f(= 1,2), δ_g is the effect of site g (= 1,2,3), $\lambda\delta_{fg}$ is the interaction effect peculiar to site g in year f, ρ_{fgh} is the effect of block h (= 1,2,3, or 4) in year f and site g, τ_i is the effect of variety i (= 1,2,3), η_j is the effect of nitrogen level j (= 1,2,3,4,5), $\tau\lambda_{fi}$ is the interaction effect peculiar to the ith variety in year f, $\tau\delta_{gi}$ is the interaction effect of the ith variety at site g, $\tau\eta_{ij}$ is the interaction effect of variety i with nitrogen level j, $\lambda\eta_{fj}$ is the interaction effect of nitrogen level j with year f, $\delta\eta_{gj}$ is the interaction effect of nitrogen level j with site g, $\tau\delta\rho_{fgi}$ is a three-factor interaction effect of variety i, year f, and site g, $\tau\kappa\rho_{fij}$ is a three-factor interaction effect of variety i, year f, and nitrogen level j, $\tau\delta\eta_{gij}$ is a three-factor effect of variety i, site g, and nitrogen level j, $\lambda\delta\eta_{fgj}$ is a three-factor interaction effect of year f, site g, and nitrogen level j, $\tau\lambda\delta\eta$ is a four-factor interaction effect of variety i, year f, site g, and nitrogen level j, and ϵ_{fghij} is a random error effect with mean zero and variance σ^2_ϵ.

Since the two years were quite different climatically, it is more appropriate to analyze and interpret the results for each year separately. This amounts to eliminating all terms involving k from the model and then dropping the subscript f from the remaining terms. The means for the variety, nitrogen level, and variety-by-nitrogen level treatments are given in Table 1 by year and site. An analysis of variance for each site and year is given in Table 2. Since there is considerable structure in the treatment factorial design with three varieties and five levels of nitrogen, it was advisable to partition the 14 treatment degrees of freedom into orthogonal single degrees of freedom. The varietal contrasts were early maturing versus late maturing maize varieties. The nitrogen contrasts used were linear regression of yield on nitrogen level, quadratic eliminating linear regression of yield on the squares of nitrogen levels, and cubic eliminating linear and quadratic regression of yield on the cubes of nitrogen levels. The remaining term, quadratic after eliminating linear, quadratic, and cubic regression is, of course, the fourth orthogonal polynomial member of this set of contrasts among nitrogen levels. It is unlikely that this fourth degree polynomial is the correct response model for yield as a function of nitrogen levels. The orthogonal polynomial model used is only an approximation to the true and unknown model. Formulae for computing the coefficients for the various polynomial regression coefficients are given in Table 3 along with the coefficients for linear, quadratic after linear, cubic after linear and quadratic regressions. GENSTAT software was used to compute the analysis of variance (ANOVA), single degree of freedom sums of squares, and F ratios. Block by treatment mean squares at each site treatment mean squares at each site were used to compute F ratios at each site and year. F ratios were little affected by a logarithmic transformation of the yield data. Hence, it was decided to use the untransformed yield data in ANOVAs.

For nitrogen levels, large F ratios were found at Mokwa (the moist savannah with monomodal rainfall) in both years, at Okolu (humid forest, bimodal rainfall) in 1985/86, and at Warri (humid forest with monomodal rainfall, acid soil) in 1985/86 (Figures 1, 2 and 3). At Warri in 1986/87, the nitrogen level mean square was less than the residual mean square, and at Okolu in 1986/87, the F ratio was just above the tabulated F at the five percent level. The differential response of nitrogen levels over sites and years leads to nitrogen by site, nitrogen by year, and nitrogen by site by year interactions (Table 4).

The varietal contrast of early versus late maturity, C_2, has large F ratios only at Warri in both years and at Okolu in 1985/6 (Table 2). The remaining three are much below the tabulated F value at the five percent level. The interaction of C_2 with the linear effect of nitrogen on yield was associated with relatively large F ratios at Warri in 1985/6 and at Mokwa in 1986/7 (Table 2). The contrast interacting with the curvilinear (quadratic) effect to nitrogen level produced quite large F values at Mokwa in both years; the other four F values were smaller than the expected F ratio of one under the null hypothesis. The curvilinear effects of yield on nitrogen were quite apparent, large F ratios, in 1985/6 at all locations but absent in 1986/7. The cubic regressions were associated with large F ratios at Mokwa in both years and at Okolu in 1986/7. The two late varieties interaction moderately with cubic regression effects at Warri in 1986/7. Note that there was a fairly large cubic effect at Okolu in 1986/7 and at Mokwa in both years. Apparently this is attributable to the lower yields obtained from the 160 kg/ha application of nitrogen. A study of Figures 1-4 shows the drop in yield for the 160 kg N/ha, and less frequently for the 80 kg N/ha application of nitrogen at some of the sites in some of the years. The biological explanation for these responses is not apparent. It could be that the 80- and 160-pound applications of nitrogen started a lush growth of maize but weather conditions were such that toward the end of the crop inadequate moisture and nutrient level or balance were available to support such a lush growth and hence the yield suffered. One would expect a nice smooth curve such as in Figure 1 for 1985/6 data. As is apparent the shapes of the response curves varies widely.

From Figures 1-4, it can be observed that the response of yield to nitrogen level increases from zero to the 40-pound application. This is the level at which many farmers who have access to fertilizer nitrogen frequently reach. Note that beyond this level, large differences in response are observed depending upon maize variety, site and year.

Perhumid Site: Warri

The response of all the maize varieties to N application was generally low. Grain yield averaged 1799 kg/ha, which was about 72% of the average yield from Okolu (humid) and Mokwa (subhumid moist savanna) (Table 1). Lower yields were observed in 1986/87 compared with 1985/86. The sandy acid soil (pH about 4.2, Table 5) of Warri, combined with the very high mean rainfall (almost 2700 mm/year), and poor insolation due to overcasts of clouds are not usually favorable to maize growth and grain yield. In fact much of the maize grown in this area is harvested as green cobs, apparently because of the difficulty in drying maize grains. Note that only the hybrid maize responded positively to increasing N application up to 160 kg N/ha, and only in 1985/86 (Figure 1). The contrasts of the early versus the two later-maturing varieties is highly significant (Table 2). The mean yields of TZSRW and the hybrid compared with TZESRW were 1696:1314 in 1985/86 and 2310:1466 in 1986/87 (Table 1).

Humid Site: Okolu with bimodal rains

The maize varieties responded differently to nitrogen application at Okolu during both seasons. Okolu is typical of the bimodal rainfall sites of West Africa whose annual rainfall, though sometimes high, may be poorly distributed (Whyte, 1983). In 1985, the mean response slope of the two late varieties (TZSRW and hybrid) differed significantly from that of the early (Table 2, Figure 2). Note the different curvilinear relationships of the late and early maize. The N level giving the highest maize yield in 1985/86 was 160 kg N/ha irrespective of maize variety. Response to N in 1986/87 was cubic ($P = 2.45$, Table 2). Yield depression at 160 kg N/ha and a rise at 320 kg N/ha resulted in this unusual response (Figure 2). Another unusual observation was the poor distribution of rainfall in 1986 in which 40% of the total annual rainfall was received in June and July. Maize grain yield was lower in 1986 than in 1985. The average yield was only 44% of the 1985 yield.

Subhumid Site: Mokwa, a moist savanna area with monomodal rains

Varietal mean response was nonexistent at Mokwa in both years (Table 2). Some response to N application was observed only in 1985 (Table 1, Figure 3). The N level for highest biological yield varied with maize variety at this site in 1985. For the early maturing maize, TZESRW, the level is 160 kg N/ha; for TZSRW it is 40 kg N/ha and for the hybrid it is 80 kg N/ha. The second year variety-nitrogen relationship was so inconsistent that the relationship tended to cubic and quartic which, biologically, is hard to explain by normal known environment-growth relationships. Two possible explanations are, however, attempted. Firstly, after the side dressing with nitrogen in 1985 there was a ten-day period with no rain, which could lead to N losses by volatilization. Secondly, in 1986, an effort was made to correct for this problem by waiting until there was enough rain before side dressing with nitrogen. This led to a delay of two weeks in the timing of the side dressing with nitrogen at Mokwa. The delay to 42 days nearly corresponded with a very sensitive stage (tasseling: 48-52 days) in the late-maturing maize (TZSRW and hybrid). The early maize (TZESRW) seemed to use the first nitrogen (seedbed nitrogen) more effectively and grew normally, while the later-maturing maize suffered.

These observations do not seem to explain the higher maize yield at 320 kg N than at 160 kg N, unless it is assumed that a higher N level remained in the soil at the 320 kg/ha than at the 160 kg/ha application. Moreover, the volatilization effect should have been more at 320 kg N/ha. Note that the 0-10 cm soil nitrogen at the 160 kg N/ha rate, though lower than at the 320 kg N rate, was higher than at the 80 kg N rate (Table 5). Therefore N level in the soil does not seem to explain the yield decline at the 160 kg N rate. Leaching losses are not applicable at the Mokwa site, since a relatively dry weather prevailed. We can therefore assume that the cumulative effects of delay in side dressing, leaf shriveling by volatile ammonia gas, soil reaction, if any (note pH differences!) may have led to a development of an environmental condition not good enough for normal maize growth at Mokwa and resulted in unusual responses, especially at the high nitrogen application rate of 320 kg N/ha.

AMMI ANALYSIS OF THE MAIZE COMPONENTS OF THE TRIAL

Through the additive model, it was shown that the three maize varieties responded differentially to nitrogen rates during each of two years at each of the three sites, making interpretation site-specific.

The AMMI (Additive Main Effects and Multiplicative Interaction) Model, which incorporates multiplicative interactions into the additive main effects or linear model (Gauch and Zobel, 1988), was applied to the same data set across all three site-years. The data were displayed to conform with the Rhizostat format (Zobel, Personal Communication) derived from the Metmodel (Gauch, 1990). The three maize varieties, TZESRW, TZSRW and Hybrid, were the genotypes and the three sites × two years × five N levels were the environments in a two-way axis of 3 × [3 × 2 × 5]. The model was

$$Y_{ij} = \mu + g_i + \ell_j + \left[\sum_{k=1}^{n} \lambda_k \alpha_{ik} Y_{jk}\right] + E_{ij} ,$$

where Y_{ij} is the yield of the ith genotype in the jth environment, μ = the grand mean; g_i and ℓ_j are, respectively, the genotype and location deviations from the grand mean; λ_k = the eigenvalue of the principal component analysis axis, k; α_{ik} and Y_{jk} are the genotype and location principal component scores for axis k; n is the number of principal components in the model; E_{ij} is the error term. Gauch and Zobel (1988) noted that extensive iterative computations, especially for the complex eigenanalysis for the Principal Component Analysis (PCA), are required.

The AMMI analysis of variance in Table 6 comprises treatment with 89 df, which accounts for 87.5% of pattern-related variance and 240 df of residual (or noise), which accounts for only 12.5% variance. This result contrasts with the linear model (Table 4) which in 1985/6 captured 77.52% of the sum of squares (SS) with 44 decrees of freedom (df) and 61.07% in 1986/7. The combined AMMI analysis shows that maize variety, environment (i.e., site-year-nitrogen) and their interaction are highly significant (Table 6). The first interaction PCA captured most of the interaction SS. Note that the interaction SS is large (more than six times variety SS, and about $\frac{1}{4}$ treatment SS). The first interaction PCA captured most of the interaction SS. The second interaction axis was found to be noise by predictive assessment – Ems* treatment df (Gauch, 1990; Leftkovitch, 1990).

A useful graphical display of the AMMI results is the biplot from which the interrelationships of the main effects and interactions and environments are shown for both varieties. Positions along the abscissa (X-axis) show main effects and those about the ordinate (Y-axis) show the interaction patterns captured in the first interaction PCA (Figure 6). Note the generally low grain yields at Warri where the average yield at most N levels were below the overall mean yield. The biplot also shows that the highest average yields were obtained at the humid site (Okolu) when N levels were 160 and 320 kg/ha. The biplot also shows that maize grain yield at 160 kg N/ha at Mokwa was lower than those at 40 kg N/ha and 320 kg N/ha, showing us the unusual reactions reported earlier. This response is unusual and led to a reexamination of the Mokwa yield during the first year (Figure 7).

The average grain yields of the hybrid and TZSRW were not different. They were greater than that of TZESRW. These contrasts were illustrated in the linear model reported earlier. Higher levels of interaction were observed between TZESRW and the environments than those between TZSRW and the environments. The hybrid was shown to require higher inputs of nitrogen as attested by its highest level interactions for yield at the high N rates at Okolu and Mokwa (Figure 6).

The most complicated data was obtained from the Mokwa site. In order to obtain a two-way data structure for AMMI analysis, Mokwa data with the three maize varieties and two years were combined to give six variety-years and the five N levels were designated the environments. The models accounted for 90.78% (29 df) of the variance, while 9.22% (6 df) was attributed to residual (noise). The interactions were highly significant up to PCA 2.

At Mokwa, the biplot shows a highly significant negative interaction of the hybrid maize and TZSRW – the two later-maturing varieties – at 160 kg N/ha. This contrasts with a highly significant positive interaction with TZESRW at the 160 kg N level, particularly during the second year. Note the wide spread of Mokwa responses to nitrogen with no distinct pattern during the second year (Figure 7). During the first year, all the maize varieties yielded higher with increasing nitrogen to 80 kg/ha and tended to decline at 160 kg/ha. Between 160 kg/ha and 320 kg/ha their rates varied in unusual patterns, except TZESRW (Figure 8). These effects were also shown in the biplots (Figures 6 and 7).

GENERAL DISCUSSION

Fertilizer recommendations for maize in Nigeria are the same for all sites. Maize is grown in environments ranging from high rainfall humid forest to dry savannah. Different fertilizer recommendations may be required, especially since the soil conditions also vary from highly acidic, sandy ultisol, e.g., in coastal Warri with pH about 4.0 to mildly acid but dry savannah zones in the north with pH over 6.0. Results from this trial indicate some inconsistencies in response by maize to N. Some general inferences are, however, observed.

While maize yield averaged 2421 kg/ha in the moist savannah site at Mokwa and 2573 in the humid, bimodal rainfall site at Okolu, the grain yield at the perhumid site (Warri) averaged only 1799 kg/ha. Response to increasing nitrogen level from very low to levels far above the recommended rate of 80 kg/ha also varied with location, year and maize variety (Figures 4 and 5).

In the perhumid, high rainfall environment dominated by sandy soil (Warri), low nitrogen rates (20-80 kg/ha) may be adequate for all the maize varieties in a year such as 1986, when the organic matter mulch is less than the amount in the first year (Figure 4). Earlier studies at this site and similar sites show that soil organic matter is particularly important for crop yield in these sandy soils (Hulugalle *et al.*, 1987; Opara-Nadi *et al.*, 1989; IITA, 1985). In 1985, the first years's high residual mulch from fallow appears to respond to a higher N rate (160 kg/ha) at this site (Figure 5).

The hybrid maize responded similarly to the late-maturing composite (TZSRW) at Okolu, the humid site in 1986 (the relatively dry year) and in 1985 (Figure 5). There was therefore no difference in yield by replacing the composite TZSRW with the hybrid seed in this location. Since farmers will have to purchase seeds yearly for the hybrid-based system, they may not prefer the hybrid over TZSRW. The genetically lower-yielding, early-maturing TZSRW also peaked at 160 kg/ha at the Okolu site (Figure 2). It appears recommendations of nitrogen for maize intercropped with cassava vary more with site (Figure 5) than with variety and that the 80 kg/ha generally recommended for maize at all sites in Nigeria needs to be reexamined by more intensive verification trials across different ecological sites in Nigeria (Figure 4). Economic analysis will be needed in order to determine the profitable levels. This study also indicates that for some site-years, nitrogen fertilizer rates less than the 80 kg/ha generally recommended may be adequate while for others, higher rates may be preferred (Figure 4). Year-to-year variations, perhaps related to rainfall and soil type, as well as insolation, need to be documented over time to enable a better assessment of long-range effects of various sites on the performance of maize intercropped with cassava. Further analysis of these data by other methods will, perhaps, help explain the variations, particularly at the subhumid site at Mokwa.

Although the AMMI Model captured more of the variances as patterns than the linear model alone, similar conclusions were reached from both the analyses of variance. However, the AMMI Model presented the spatial relationships between individual main effects and their interactions (if present). Visual clustering effects which identified the interrelationships of treatments were deduced from the biplot. We see an important application of AMMI in on-farm research involving several sites. An aggregation of sites with similar responses will provide an estimation of locations for use in technology validation experiments. Further research will examine AMMI's ability to give more accurate yield estimates than raw means over replications (see Gauch, 1988; Gauch and Zobel, 1988). This could be very helpful for yield trials planted on many farms but with little or not replications.

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Table 1. Mean maize grain yield per hectare of variety by nitrogen level for each year and site.

Nitrogen yield	Variety	Mokwa 1985/6	Mokwa 1986/7	Okolu 1985/6	Okolu 1986/7	Warri 1985/6	Warri 1986/7
20 kg	TZESR-W	1318	413	1708	1129	672	1323
	TZSR-W	2071	735	2743	1433	752	2479
	Hybrid	1946	1136	2660	1358	635	1750
40 kg	TZESR-W	2076	2829	2584	1428	860	1677
	TZSR-W	2599	2861	3111	1326	900	2515
	Hybrid	1841	427	2877	1356	890	2385
80 kg	TZESR-W	3086	1256	2203	2063	1475	1453
	TZSR-W	2528	1917	3892	1879	1535	2161
	Hybrid	3626	3302	4451	2016	1840	3187
160 kg	TZESR-W	3972	3597	3181	1792	1768	1552
	TZSR-W	2451	886	4921	1689	2348	2041
	Hybrid	2721	1239	5181	1219	2495	2682
320 kg	TZESR-W	3700	2271	3149	1534	1798	1328
	TZSR-W	3496	4598	5435	1893	2264	1219
	Hybrid	3976	3746	5327	2171	3295	2682
	LSD 0.05	872	1082	1741	936	715	1174
20 kg		1778	762	2370	1307	687	1850
40 kg		2172	2039	2857	1370	883	2192
80 kg		3080	2158	3515	1986	1617	2267
160 kg		3048	1908	4428	1567	2203	2092
320 kg		3724	3538	4637	1866	2452	1743
	LSD 0.05	504	625	1005	542	413	678
	TZESR-W	2830	2073	2565	1589	1314	1466
	TZSR-W	2629	2200	4020	1644	1560	2083
	Hybrid	2822	1970	4099	1624	1831	2537
	LSD 0.05	1166	1437	2274	1161	948	1557
Overall mean		2760	2081	3562	1619	1568	2029
Location mean		2421		2591		1799	

Table 2. Analysis of variance and F-ratios by site and year for grain yield in kilograms per hectare.

Source of variation	Degrees of Freedom	1985/86 Mean square	1985/86 F-ratio	1986/87 Mean square	1986/87 F-ratio
		Warri: Perhumid, monomodal, sandy soil			
Block	3	2,079,955	8.31	6,896,661	10.23
Variety	2	1,334,988	5.33	5,776,003	8.57
c_1: Between late	1	735,766	2.94	2,062,068	3.06
c_2: Early vs. late	1	1,934,211	7.73	9,489,939	14.08
Nitrogen	4	7,299,409	29.16	603,522	0.90
Linear	1	23,744,690	94.86	713,424	1.06
Quadratic	1	5,178,597	20.69	941,169	1.40
Cubic	1	60,541	0.24	635,714	0.94
Quartic	1	213,809	0.85	123,782	0.18
Variety × Nitrogen	8	443,728	1.77	847,043	1.26
Linear × Linear	1	1,440,863	5.76	4,151,574	6.16
Quadratic × Linear	1	1,818,781	7.27	111,260	0.17
Linear × Quadratic	1	42,084	0.17	624,867	0.93
Quadratic × Quadratic	1	53,470	0.21	114,461	0.17
Linear × Cubic	1	149,378	0.60	1,375,989	2.04
Deviations	3	15,081	0.06	132,730	0.20
Residual	42	250,321		674,067	
		Okolu: Humid, bimodal			
Block	2	55,461	0.05	360,398	1.28
Variety	2	11,193,965	10.37	11,436	0.04
c_1: Between late	1	46,650	0.04	3,040	0.01
c_2: Early vs. late	1	22,341,280	20.69	19,832	0.07
Nitrogen	4	8,603,724	7.97	805,908	2.86
Linear	1	27,576,394	25.54	1,063,416	3.78
Quadratic	1	6,796,281	6.29	232,315	0.82
Cubic	1	24,138	0.02	1,416,022	5.03
Quartic	1	18,080	0.02	511,880	1.82
Variety × Nitrogen	8	663,389	0.61	171,370	0.61
c_1 × Linear	1	1,652	0.00	34,345	0.12
c_2 × Linear	1	2,640,044	2.45	164,867	0.59
c_1 × Quadratic	1	333,675	0.31	213,346	0.76
c_2 × Quadratic	1	586,217	0.54	670,646	2.38
c_1 × Cubic	1	85,627	0.08	229,499	0.81
Deviations	3	553,300	0.51	19,420	0.07
Residual	28	1,079,734		281,657	

c_1 = Between TZSRW and Hybrid.

c_2 = Between TZESRW and mean of (TZSRW and Hybrid).

Table 2. *Continued.*

Source of variation	Degrees of Freedom	1985/86 Mean square	1985/86 F-ratio	1986/87 Mean square	1986/87 F-ratio
		Mokwa: Moist Savannah			
Block	3	609,464	1.61	302,060	0.53
Variety (V)	2	260,053	0.69	264,240	0.46
c_1: Between late	1	373,456	0.99	526,704	0.92
c_2: Early vs. late	1	146,650	0.39	1,780	0.00
Nitrogen (N)	4	7,273,402	19.21	11,707,488	20.49
Linear	1	22,863,696	60.37	35,016,916	61.29
Quadratic	1	2,814,313	7.45	26,964	0.05
Cubic	1	3,051,753	8.06	9,301,344	16.28
Quartic	1	363,846	0.96	2,484,728	4.35
Variety × Nitrogen	8	1,267,176	3.35	6,662,460	11.66
c_1 × Linear	1	586,238	1.55	92,332	0.16
c_2 × Linear	1	715,276	1.89	3,191,296	5.59
c_1 × Quadratic	1	537,115	1.42	2,957,852	5.18
c_2 × Quadratic	1	4,960,354	13.10	13,033,040	22.81
c_1 × Cubic	1	636,294	1.68	352	0.00
Deviations	3	900,711	2.38	11,341,596	19.85
Residual	42	378,712		571,356	

c_1 = Between TZSRW and Hybrid.

c_2 = Between TZESRW and mean of (TZSRW and Hybrid).

$F_{.05}$ (1, 42) =	$F_{.01}$ (1, 42) =	$F_{.05}$ (1, 28) =	$F_{.01}$ (1, 28) =
$F_{.05}$ (2, 42) = 3.22	$F_{.01}$ (2, 42) = 5.15	$F_{.05}$ (2, 28) = 3.34	$F_{.01}$ (2, 28) = 5.45
$F_{.05}$ (4, 42) = 2.59	$F_{.01}$ (4, 42) = 3.80	$F_{.05}$ (4, 28) = 2.71	$F_{.01}$ (4, 28) = 4.07
$F_{.05}$ (8, 42) = 2.17	$F_{.01}$ (8, 42) = 2.96	$F_{.05}$ (8, 28) = 2.29	$F_{.01}$ (8, 28) = 3.23

Table 3a. Equations used to determine the value of contrasts in a maize variety by nitrogen trial in Nigeria.

$$X_i - SX_i/n = U_i$$

$$X_i^2 - \Sigma X_0^2 n - \frac{U_i \, \Sigma \, U_i X_i^2}{\Sigma U_i^2} = Z_i$$

$$X_i^3 - \frac{\Sigma X_0^3}{n} - \frac{U_i \, \Sigma \, U_i X_i^3}{\Sigma U_i^2} - \frac{Z_i \, \Sigma \, Z_i X_i^3}{\Sigma Z_i^2} = U_i$$

$$X_i^4 - \frac{U_i \, \Sigma \, U_i X_i^4}{\Sigma U_i^2} - \frac{Z_i \, \Sigma \, Z_i X_i^4}{\Sigma Z_i^2} - \frac{W_i \, \Sigma \, W_i X_i^4}{\Sigma W_i^2} =$$

Table 3b. Values of contrasts derived from equations in Table 3a.

b_{y1}	$b_{y2 \cdot 1}$	$b_{y3 \cdot 12}$
−26	30	−176
−21	11	76
−11	−19	252
9	−47	−181
49	25	29

Table 4. Analysis of variance and F-ratios for maize grain yield per hectare for each of two years.

Source of variation	Degrees of Freedom	1985/86		1986/87	
		Mean square	F-ratio	Mean square	F-ratio
Sites = S	2	53,256,880	105.29	3,150,484	5.86
Blocks within S	8	1,022,397	2.02	2,789,620	5.19
Variety = V	2	5,228,995	10.34	1,994,266	3.71
V × S	4	3,780,005	7.47	2,028,707	3.77
Nitrogen = N	4	22,337,391	44.16	5,690,548	10.59
N × S	8	419,572	0.83	3,713,185	6.91
N × V	8	864,850	1.71	3,321,595	6.18
N × V × S	16	754,722	1.49	2,179,638	4.06
Remainder	112	505,821		537,448	

$F_{.05}$ (1, 42) =	$F_{.01}$ (1, 42) =	$F_{.05}$ (1, 28) =	$F_{.01}$ (1, 28) =
$F_{.05}$ (2, 42) = 3.22	$F_{.01}$ (2, 42) = 5.15	$F_{.05}$ (2, 28) = 3.34	$F_{.01}$ (2, 28) = 5.45
$F_{.05}$ (4, 42) = 2.59	$F_{.01}$ (4, 42) = 3.80	$F_{.05}$ (4, 28) = 2.71	$F_{.01}$ (4, 28) = 4.07
$F_{.05}$ (8, 42) = 2.17	$F_{.01}$ (8, 42) = 2.96	$F_{.05}$ (8, 28) = 2.29	$F_{.01}$ (8, 28) = 3.23

Table 5. Soil pH, organic carbon and nitrogen at beginning of trial compared with the levels – in 1986 (the end).

	Location								
	Mokwa			Okolu			Warri		
N Rate	%N	%Org C	pH	%N	%Org C	pH	%N	%Org C	pH
20	1.66	2.11	6.5	1.40	1.01	6.3	0.73	1.13	4.4
40	0.93	1.86	6.4	1.38	0.88	6.4	0.86	1.39	4.3
80	2.18	2.05	6.0	2.61	1.11	6.2	0.97	1.86	4.2
160	2.63	1.97	6.0	1.98	1.86	6.0	1.11	1.55	4.1
320	3.35	1.93	5.3	2.82	2.06	5.7	1.92	1.38	3.8
Mean	2.03	1.92	6.0	2.04	1.38	6.1	1.12	1.46	4.2

* Levels at inception of trial of % Nitrogen, Organic Carbon and pH, respectively:

Mokwa, 1.18, 2.04 and 6.4;
Okolu, 2.04, 1.91 and 6.5;
Warri, 1.33, 1.53 and 4.2.

Table 6. AMMI analysis of variance of the maize yield of cassava and maize intercropping in six site years (three sites, two years).

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Probability
Total	329	608,029,343	1,848,114	–
Treatment	89	454,739,169	5,109,429	0.0000000***
Variety	2	17,394,797	8,697,399	0.0000025***
Environment	29	325,786,975	11,234,037	0.0000000***
Var. × Environ.	58	111,557,396	1,923,403	0.0000000***
IPCA 1	30	79,898,638	2,663,288	0.0000000***
IPCA 2	28	31,658,758	1,130,670	0.0123101*
Residual	28	31,658,758	1,130,670	0.0123101*
Error	240	153,290,174	638,709	

*** Significant at < 0.01 probability level.

* Significant at $P < 0.05$ probability level.

FIG.~~5~~ 1 YARRI MAIZE GRAIN YIELD/HA. AS AFFECTED BY VARIETY AND N.

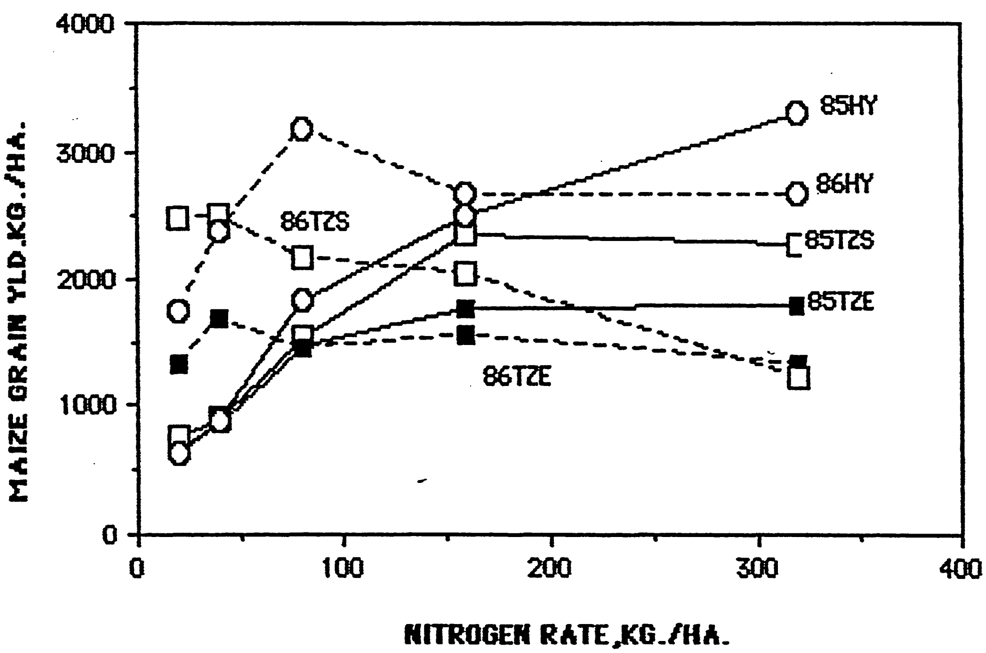
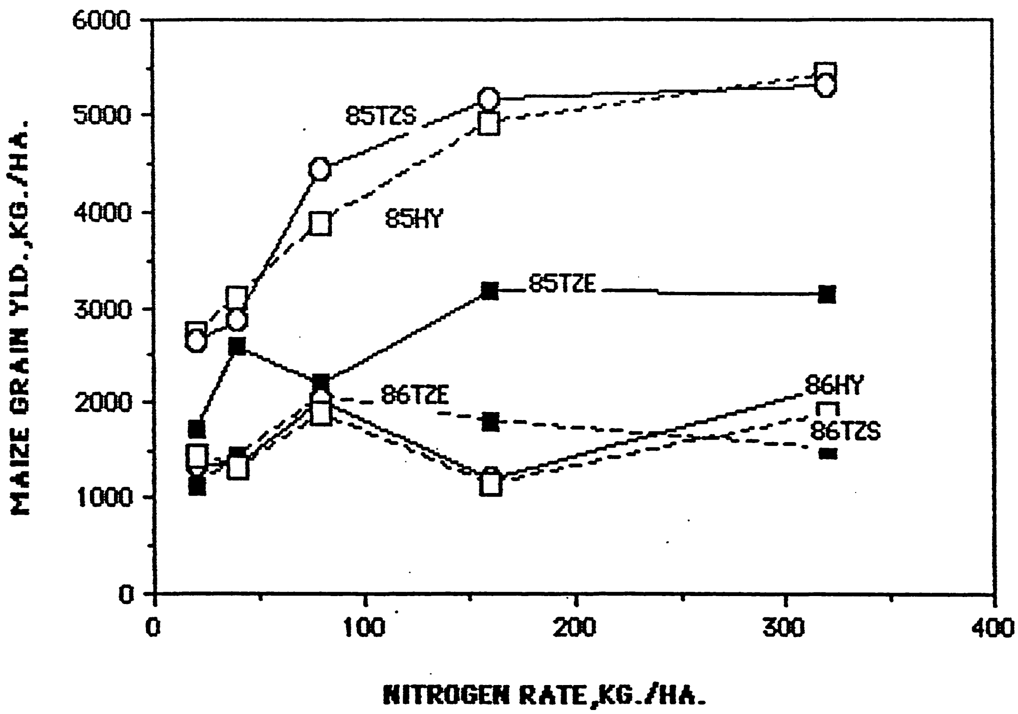


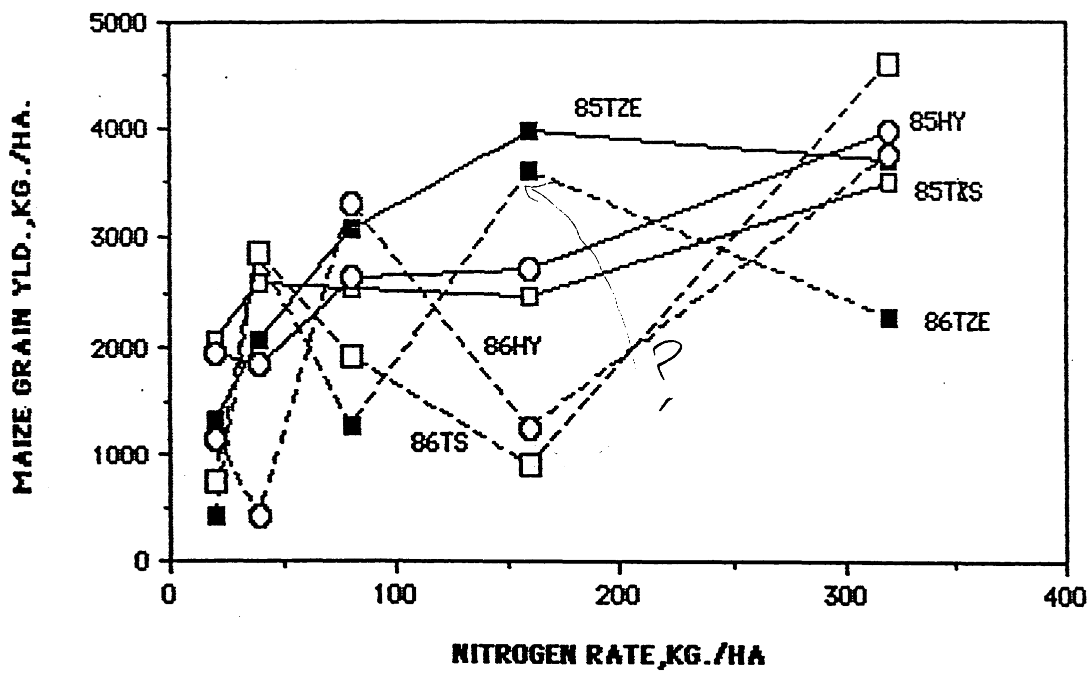
FIG.2.OKOLU MAIZE GRAIN YLD./HA. AS AFFECTED BY VARIETY AND N.



5Nit: 20 40 80 160 320

6 YG: 85TZE 86TZE 85HY 86HY 85TS 86TS

FIG.1 MOKWA MAIZE GRAIN YIELD/HA. AS AFFECTED BY VARIETY AND N.



$\boxed{5 \text{ Nit} \times 6 \text{ Env}}$

"(2Yr x 3Gen)"

AMMI $\hat{Y}_{ge} = \mu_g + \mu_e - \mu + (\gamma_g \times \delta_e)$

MF file MAIZE.DATS

Genotype — J. ID

Env — C. 3

Drop

3
FIG.1 MOKWA MAIZE GRAIN YIELD/HA. AS AFFECTED BY VARIETY AND N.

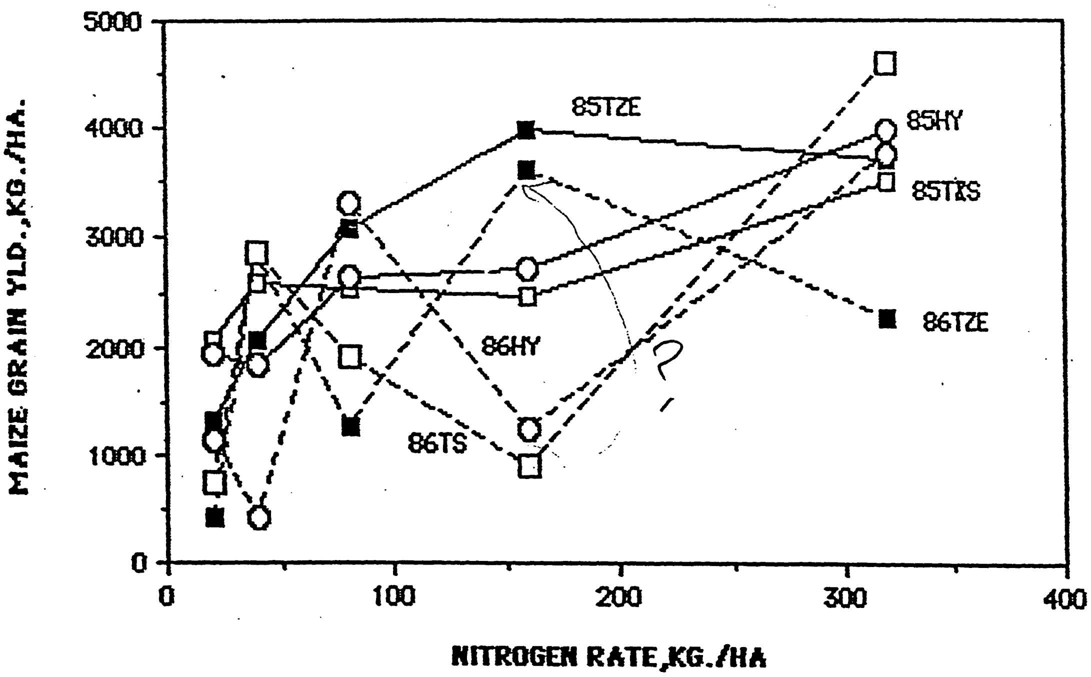


FIG.4. N EFFECT ON MEAN MAIZE GRAIN YLD. PER SITE.

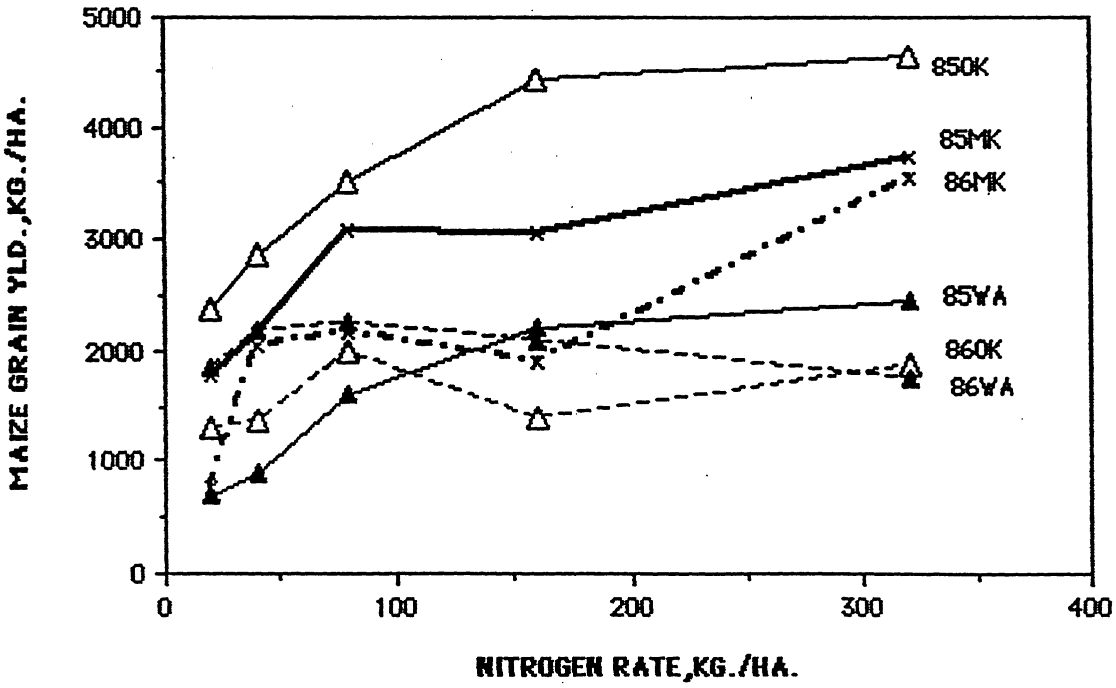
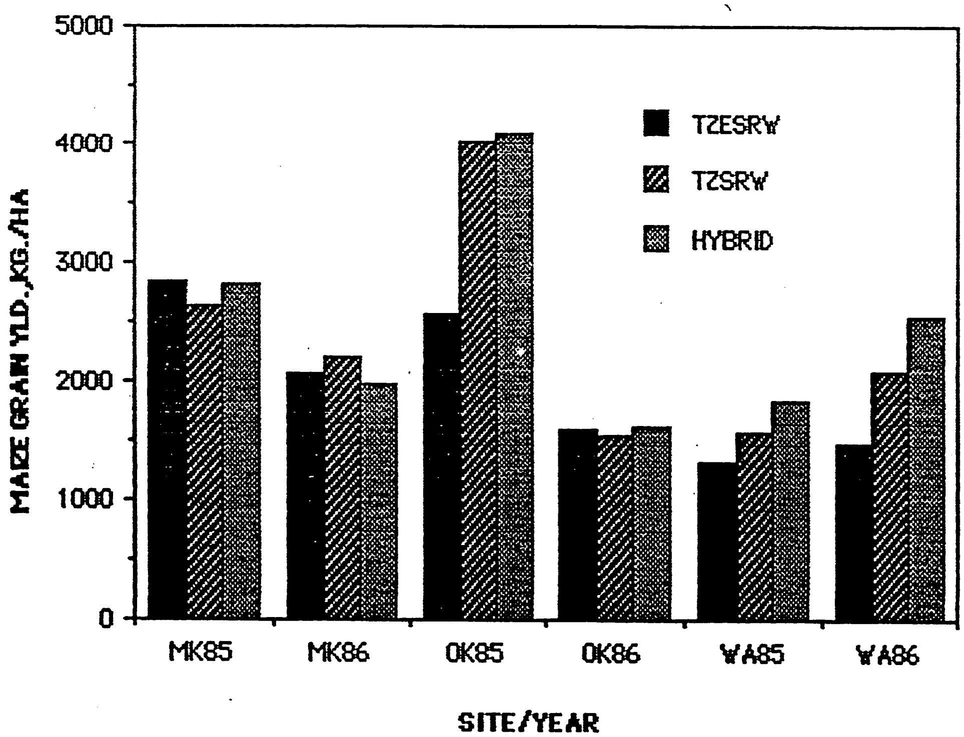


FIG.5 MEAN SITE AND YEAR EFFECTS ON MAIZE GRAIN YIELD.



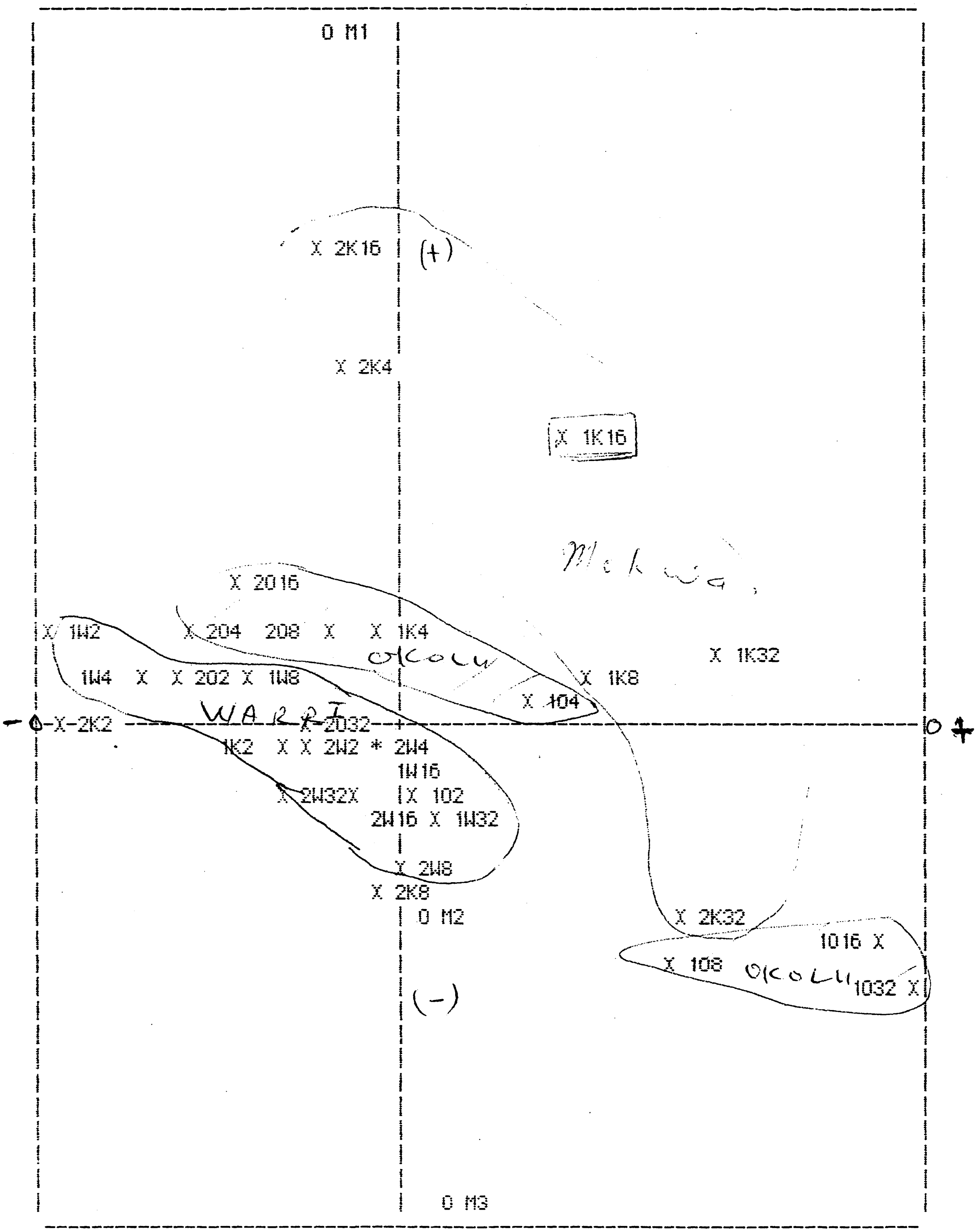


Figure 6: Biplot of unadjusted means in kg/ha and the first PCA axis for interaction of three maize genotypes (O) grown at three sites (O, W, K) during two years (1, 2) at five Nitrogen rates 20, 40, 80, 160 and 320 kg/ha (denoted by 2, 4, 8, 16, 32). The sites are shown as x in diagram. The grain mean of the experiment is represented by vertical line and PCA1 = 0 is the horizontal [illegible]

RHIZOSTAT: Graph of Means and IPCA Axis 1.

MAMKOUT.NORM 9:25- 6/ 5/91
This graph accounts for 82.42% of the TRT sum of squares.

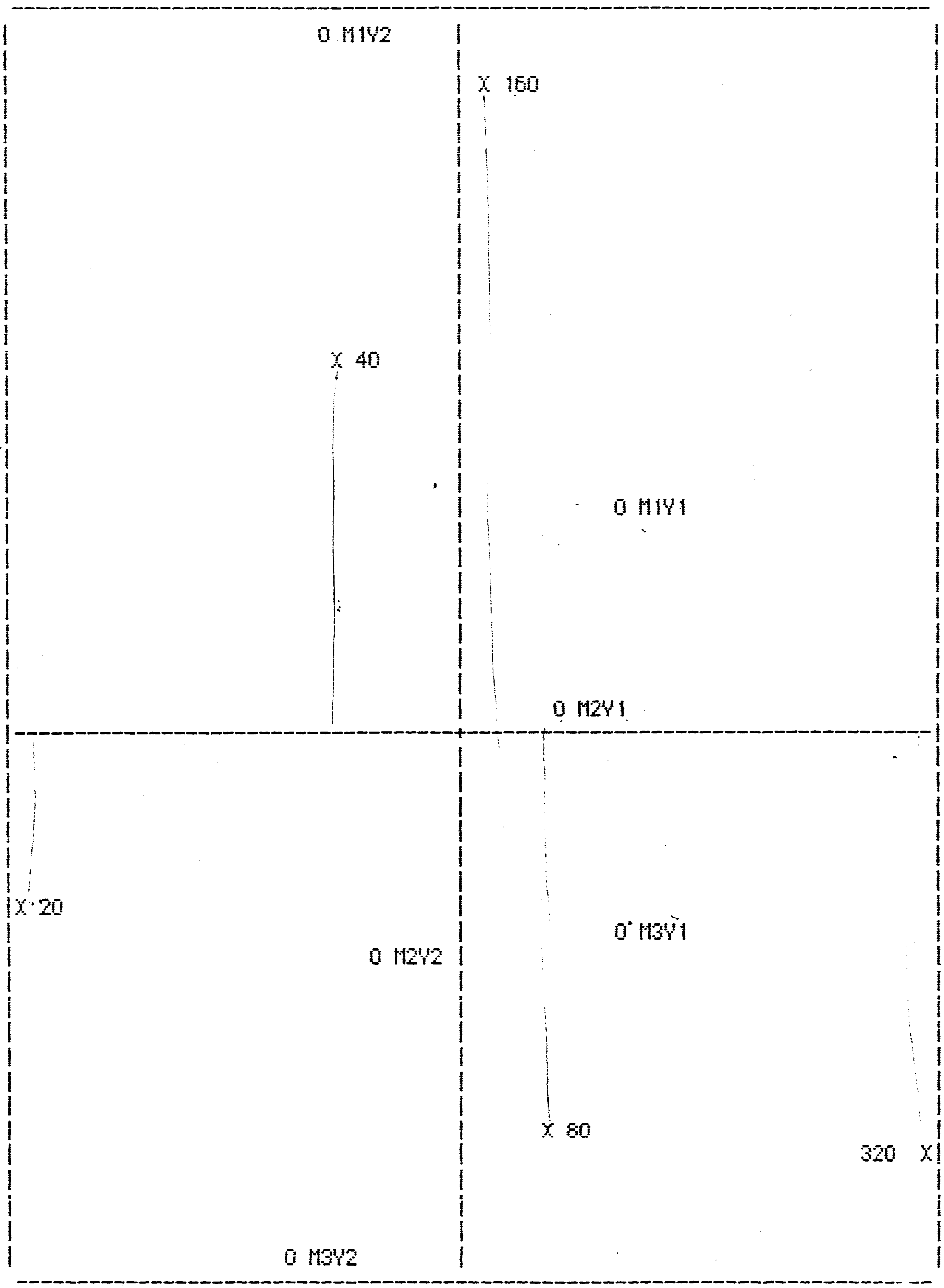


Figure 7. Biplot of unadjusted mean in kg/ha and the first PCA interaction of three maize varieties by two sites (0) grown at 5 Nitrogen rates (x). Other notations

Figure 8 PREDICTED AMMI MEAN EFFECTS OF VARIETY, YEAR AND NITROGEN EFFECTS ON MAIZE YLD. AT MOKWA

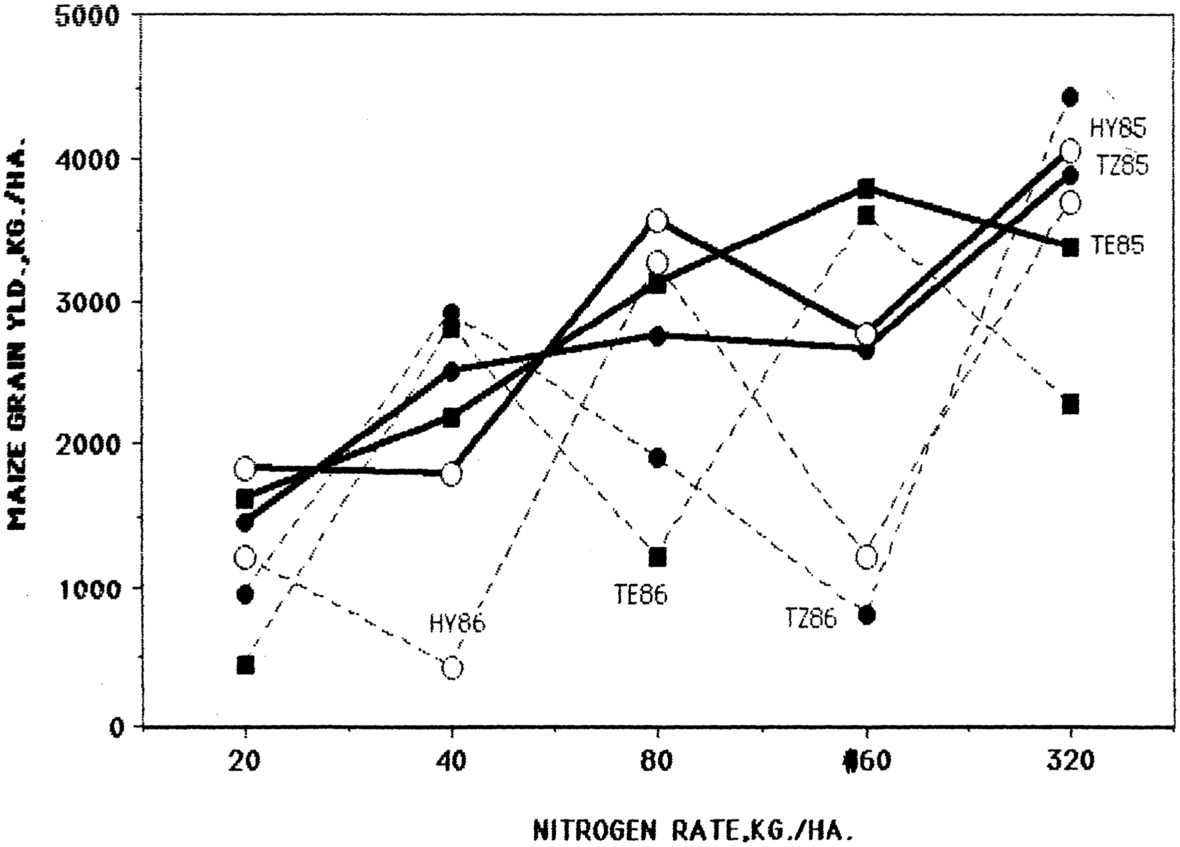


Figure : ~~Ammi estimates of~~