International Journal of

Plant Breeding and Genetics

ISSN 1819-3595

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS International Journal of Plant Breeding and Genetics

ISSN 1819-3595
DOI: 10.3923/ijpbg.2021.24.33

Research Article
Analysis of Grain Yield of Early-Maturing Yellow-Endosperm Maize Hybrids under Nitrogen Stress and Optimal Conditions Using AMMI Biplot

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Abstract
Background and Objectives: Additive main effects and multiplicative interaction (AMMI) model has been used to assess crop performance and stability. In this study, AMMI biplot was used to assess the responses of 34 maize hybrids and to identify those with broad or limited response to varied nitrogen (N) conditions. **Materials and Methods:** Twelve yellow maize inbred lines were crossed to generate 66 single-cross hybrids which were evaluated with four checks in three soil N conditions: 0, 30 and 90 kg N ha^{-1} denoting no N, low N and optimal N, respectively. The experiment was laid out in 10×7 lattice design with three replicates each year. Data collected on grain yield were subjected analysis of variance (ANOVA) for each year and across years. AMMI model was used to analyze the grain yield across N conditions and to investigate Genotype×environment (G×E). **Results:** ANOVA showed significant variation in genotypes under the three N conditions each year and significant differences ($p<0.0001$) attributable to genotypes, environment and interaction principal component axis. The AMMI biplot for the maize in varied N conditions explained 91.6% of the total sum of squares. Hybrids TZEI128×BD74161 and TZEI124×BD74222 had high yield under the three N conditions. TZEI13×TZEI10, TZEI11×TZEI16 and TZEI124×BD74165 interacted with N stress condition, while TZEI13×TZEI146, TZEI13×TZEI128, TZEI146×TZEI124, TZEI10×BD74165 and TZEI16×BD74165 responded to optimal condition. **Conclusion:** High yielding TZEI128×BD74161 and TZEI124×BD74222 are stable. They can be recommended for cultivation under both deficient and optimal N conditions. The other hybrids are suitable for cultivation under N stress and optimal conditions based on their interactions.

Key words: Diallel analysis, G×E analysis, single cross, stability analysis, *Zea mays*

Citation: Ogunniyan, D.J., O.O. Olakojo, S.T. Akinyosoye and S.A. Makinde, 2021. Analysis of grain yield of early-maturing yellow-endosperm maize hybrids under nitrogen stress and optimal conditions using ammi biplot. Int. J. Plant Breed. Genet., 15: 24-33.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize is grown in many agro-ecologies characterized by contrasting biotic and abiotic environmental conditions as well as soils with varying fertility levels. Micro-environments are created by various agronomic practices, among which fertilizer application is significant. A major constraint to maize production in the tropics is inadequate soil nitrogen[1,2]. Nitrogen is required in various quantities by the crop depending on varieties. Productivity of hybrid maize depends on the fluctuating soil N status. Fertilizers increase cost of production, therefore, breeding for high-yielding hybrids for cultivation under low soil N conditions is important, especially for the resource-poor farmers who dominate maize production in sub-Saharan Africa.

Maize genotypes respond differently to varied environments depending on their genetic composition. Genotypes are evaluated in multi-environment trials (METs) to provide information on the genotypes' performance across environments and to select the best genotypes for specific environments. However, selection of superior genotypes in the METs is often complicated because of the existence of Genotypes×environments (G×E) interactions. Identification of high-yielding genotypes from METs depends on the effectiveness of the statistical method used to capture patterns and noise in the data and estimate yields[3]. Several statistical techniques have been proposed for this purpose. Some of these techniques involve the use parametric statistics including univariate methods such as environmental variance analysis[4], multivariate analysis such as AMMI[5] and non-parametric statistics, which are not affected by data distribution and are based on ranks. Among the effective non-parametric statistics are Wricke's ecovalence, Finlay and Wilkinson[6], superiority index[7] and Kang's rank-sum[8]. Though these strategies differ in appropriateness or efficiency, they give similar conclusions for a given dataset.

The most commonly used among the statistical techniques is the two-way cross classification ANOVA which explains only the main effects and identify G×E effect as a source of variation but cannot analyze the inherent effects. Joint regression analysis which is also used cannot effectively identify stable genotypes but can provide information on genotype performance under improving environments[9]. The AMMI model is a powerful tool used to evaluate many genotypes across multi-environments, identify stable and adapted genotypes and determine the magnitude of G×E[10,11]. The AMMI model graphically displays the genotype main effect and their interaction with the environments in a biplot. It is efficient because it captures a large portion of the G×E sum of squares and separates the effects of both genotypes and G×E[12]. Many studies have considered the suitability of AMMI effects for G effect, G×E and yield stability analyses of different crops[13-19].

Cost of fertilizer application is beyond the capacity of resource-poor farmers in Africa, especially in Nigeria. Besides, inorganic fertilizers are not eco-friendly. It is therefore imperative to develop low N tolerant maize varieties that will produce optimally in N deficient soils. However, the newly developed hybrids are tested in METs to ascertain their ability to harness and utilize the limited N in the soil. Screening breeding lines of crop in low and high N environments is critical to determining N use efficiency[20-22]. The objectives of this study were to examine response of 34 maize hybrids to varied N conditions in a trial conducted under three N conditions in two years in Nigeria, using the AMMI biplot statistical model.

MATERIALS AND METHODS

Germplasm and experimental site: Twelve yellow-endosperm maize inbred lines were crossed using the diallel mating design without the reciprocals[23] to generate 66 single-cross hybrids. The hybrids were evaluated along with four check hybrids in varied soil N conditions in 2014 and 2015 to determine the response of the hybrids to changing N condition with respect to variability in grain yield of the hybrids. The trial was conducted in Ibadan (3.56°E, 7.33°N and 168 m asl), Nigeria. The experimental soil was purposely depleted of its native N from continuously planting maize at a very high population density without application of N fertilizer and uprooting and removing the biomass completely after each cropping. This depletion procedure was repeated until the soil N had been completely removed. Soil analysis was carried out to confirm the N status after each depletion process. The soil was depleted to about zero level of N. Mean annual rainfall and mean temperature of the experimental site during the experiment were 141.3 mm and 25.8°C, respectively, for 2014 and 103.3 mm and 26.6°C, respectively, for 2015 (Appendix 1).

Experimental layout and crop management: The 66 hybrids along with four hybrid checks were planted in a 10×7 lattice design with three replicates in each year. Plots consisted of two 5 m long rows, with 0.75 m inter-row spacing and 0.5 m spacing between plants within a row. Three seeds were sown and thinning was done two Weeks After Planting (WAP) to two plants per hill to obtain a plant population density of

Appendix 1: Monthly mean amount of rainfall and mean temperature at the experimental sites during the trials from 2013 to 2015

	2014		2015	
Month	Rainfall (cm)	Temp. (°C)	Rainfall (cm)	Temp. (°C)
January	15.3	28.0	0.0	27.0
February	0.0	25.0	2.1	29.0
March	127.3	28.5	14.2	29.0
April	261.1	24.9	120.1	29.0
May	121.1	23.8	183.4	25.6
June	185.6	26.2	223.1	25.0
July	243.0	23.5	161.7	24.0
August	101.0	24.2	151.5	26.0
September	206.4	24.7	232.8	25.0
October	211.6	25.9	248.5	26.0
November	220.0	27.5	11.9	27.5
December	3.0	26.8	0.0	26.0
Mean	141.3	25.8	103.3	26.6

Temp: Mean temperature

53,333 plants ha^{-1}. There were three N conditions: 0, 30 and 90 kg N ha^{-1} denoting zero N, low N and optimal N, respectively. The fertilizer was applied in the form of NPK 15:15:15 at 30 kg ha^{-1} to each of low N and optimal N plots at 2 WAP. The optimal N plots received 60 kg N ha^{-1} in the form of urea to bring the total available N to 90 kg ha^{-1} two weeks later (4 WAP). Urea was not applied to zero N plots but all the plots received 60 kg P ha^{-1} as single super phosphate (P_2O_5) and 60 kg K ha^{-1} as muriate of potash (K_2O). Three N conditions applied in each of the two years constituted the six environments for the trial. Standard cultural practices were adopted for field maintenance, harvesting and seed processing.

Data collection and analysis: Ears were harvested when dry. The grains were shelled and weighed, after which moisture content was determined using a digital moisture tester. Grain yield in kg ha^{-1} was computed using grain moisture content = 15%, harvested plot area = 7.5 m^2 and 1 ha = 10,000 m^2 as follows[24]:

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{GWT (kg)}}{7.5\text{ m}^2} \times \frac{(100\text{ MC})}{(100-15)} \times 10{,}000\text{ m}^2$$

where, GWT is the grain weight and MC is the grain moisture content at harvest.

The grain yield data were subjected to analysis of variance (ANOVA) using SAS separately for each N condition and across N conditions, over the two years. Hybrids and N conditions were considered fixed effects, whereas replicates and years were considered random. The AMMI model was used to analyze the grain yield of the hybrids across N conditions and to investigate G×E effects. Statistical model, according to Yang *et al.*[25], used for the AMMI analysis was as follows:

$$Y_{ij} = \mu + \tau_i + \delta_j + \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$$

where, Y_{ij} is the mean of the ith genotype in the jth environment, μ is the overall mean, τ_i is the effect of the ith genotype, δ_j is the effect of the jth environment.

λ_k ($\lambda_1 \geq \lambda_2 \geq \cdots \lambda_t$): scaling constants (singular values) that allow the imposition of ortho-normality constraints on the singular vectors for genotypes [$\alpha_k = (\alpha_{1k}, \cdots\cdots, \alpha_{gk})$] and for environments [$\gamma_k = (\gamma_{1k}, \cdots\cdots, \gamma_{ek})$], such that $\Sigma_i \alpha^{2ik} = \Sigma_j \gamma^2 jk = 1$ and $\Sigma_i \alpha_{ik} \alpha_{ik}' = \Sigma_j \gamma_{jk} \gamma_{jk}' = 0$ for $k \neq k$.

The α_{ik} and γ_{jk} for k = 1, 2, 3.... were designated as primary, secondary, tertiary ... effects of genotypes and environments, respectively, ϵ_{ij} is the residual error.

For any genotype-environment combination, the main effect equals the genotype mean plus the environment mean minus the grand mean. The interaction is the product of genotype PCA and environment scores. When a genotype and environment have the same sign on the PCA axis, their interaction is positive, if different, their interaction is negative. On the biplot, genotypes and environments with large PCA1 scores either positive or negative have high interactions while those with PCA1 score of zero or nearly zero have small[10].

RESULTS

Grain yield of the hybrid maize in varied N conditions: Analysis of variance for each year showed that significant variation in genotypes existed under the three N conditions (Table 1). The significant difference in genotypes under no N condition in 2014 was $p<0.05$ and $p<0.001$ in 2015. The results further showed that significant variation was very high ($p<0.001$) for the trait under low N and optimal N conditions. Coefficient of variation (CV) for individual N condition ranged

Table 1: Mean squares from the analysis of variance of grain yield for the yellow endosperm maize

		Mean squares of individual analysis of variance by nitrogen condition					
		No nitrogen (0 kg N ha^{-1})		Low nitrogen (30 kg N ha^{-1})		Optimal nitrogen (90 kg N ha^{-1})	
Source of variation	df	2014	2015	2014	2015	2014	2015
Replicate	2	11117.22^{ns}	91383.42^{ns}	180463.60^{ns}	69968.61^{ns}	203588.90^{ns}	378869.80^{ns}
Genotype	32	228870.12*	1406051.54***	515457.15***	2447121.60***	1086847.9***	4693866.3***
Error	64	138341.03	364167.26	184024.48	237606.58	327725.71	455961.1
Mean (t ha^{-1})		904.42	2084.76	1480.48	3201.12	3450.00	4695.12
CV (%)		35.40	31.07	19.99	15.84	17.46	14.34

^{ns}: Non-significant, *p<0.05, ***p<0.001, df: Degree of freedom, CV: Coefficient of variation

Table 2: Mean squares from the combined analysis of variance of grain yield for the yellow endosperm maize

Source of variation	df	Mean square
Replicate (year)	4	531420.6^{ns}
Block (year×replicate)	36	435220^{ns}
Genotype	32	3912550.9***
Genotype×environment	160	1011907.6***
Year (Y)	1	237816940***
Nitrogen condition (N)	2	342108442***
Genotype×year (G×Y)	32	2317102.5***
Genotype×nitrogen (G×N)	64	575977.9***
Year×nitrogen (Y×N)	2	4277155.6***
Genotype×year×nitrogen	64	417525.2^{ns}
Error	356	327322
Mean (t ha^{-1})	2635.97	
CV (%)	21.07	

^{ns}: Non-significant, *p<0.05, **p<0.01, ***p<0.001, df: Degree of freedom, CV: Coefficient of variation

from 14.34% for optimal N in 2015 to 35.40% for no N condition in 2014. In the ANOVA for individual N condition for each year, highest mean square error was found for no N in 2014 while the least was observed for 90 kg N ha^{-1} in 2015.

Combined ANOVA, however, showed highly significant differences (p<0.001) for years (Y), genotypes (G), N condition (N), genotypes×year (G×Y), genotypes×nitrogen condition (G×N) and year×nitrogen condition (Y×N) (Table 2). The CV was 21.07% for combined ANOVA. Mean grain yield across locations was about 2636 t ha^{-1}.

Mean grain yield of the hybrids was lower in 2014 than in 2015 under the three N conditions (Table 3). Mean grain yield was about 1495 kg ha^{-1} under No N, about 2341 kg ha^{-1} under low N and about 4073 kg ha^{-1} under optimal N condition. Under no N conditions, grain yield ranged from 431 kg ha^{-1} for TZEI10×TZEI124 to 1537 kg ha^{-1} for TZEI146×TZEI124 in 2014 and from 1017 kg ha^{-1} for TZEI12×TZEI16 to 3183 kg ha^{-1} for TZEI146×TZEI128 in 2015 (Table 3). Under low N condition, grain yield ranged from 803 kg ha^{-1} for TZEI10×TZEI124 to 2451 kg ha^{-1} for TZEI12×BD74222 in 2014 and from 859 kg ha^{-1} for TZEI12×TZEI16 to 4382 kg ha^{-1} for BD74165×BD74161 in 2015. However, under optimal condition, grain yield ranged from 2505 kg ha^{-1} for TZEI124×BD74161 to 4530 kg ha^{-1} for TZEI13×TZEI128 in 2014 and from 3288 kg ha^{-1} for TZEI13×TZEI10 to 6453 kg ha^{-1} for TZEI16×BD74165 in 2015. The TZEI146×TZEI12, TZEI12×BD74222, TZEI146×TZEI128, TZEI146×TZEI16, TZEI146×TZEI124, TZEI12×BD74161, TZEI10×BD74165, TZEI16×BD74165 and BD74165×BD74161 were among the highest yielding genotypes across N environments, each of them yielded about or greater than 3000 t ha^{-1}.

AMMI analysis of grain yield of the maize hybrids: First PCA scores for environment ranged from -36.34 for optimum N condition in 2015 to 23.31 for zero N in 2014 while from -37.34 for TZEI16×BD64165 to 31.33 TZEI13×TZEI10 (Table 3). The PCA1 of the N conditions in 2015 were negative while those of 2014 were positive. The ANOVA for grain yield of the maize hybrids across environments is shown in Table 4. About 67.2% of the total sum of squares was attributable to environments, whereas 12.1% was attributed to genotypes and 11.4% to G×E interaction. Variances attributable to environments, genotypes and G×E were highly significant (p<0.001). Partitioning of the G×E into the two interaction principal component axes (IPCA 1 and 2) revealed that IPCA 1 had highly significant (p<0.001) effect, whereas the effect of IPCA 2 was significant at p<0.01. The IPCA 1 and IPCA 2 jointly accounted for 9.6% of the total sum of squares, while the residual accounted for only 1.8% of the total sum of squares.

Table 5 shows main effects, interaction and final yield of top three and least two grain yielding maize hybrids for each N condition in the two years. The result showed strong evidence that G×E interactions were significant in both years. Hybrid TZEI12×BD74222 exhibited least absolute interaction (26.0) while TZEI146×TZEI128 exhibited highest absolute interaction (674.1). Least interactions were obtained for no N in 2015 than others while highest were in optimal condition in 2015. Under no N condition, the effects of genotype on the grain yield of the hybrids were higher in 2015 than 2014 but

Table 3: Mean grain yield of best 19 and poorest 10 yellow endosperm maize hybrids with four checks

Hybrid		No N (kg ha^{-1}) 2014	No N (kg ha^{-1}) 2015	Low N (kg ha^{-1}) 2014	Low N (kg ha^{-1}) 2015	Optimum N (kg ha^{-1}) 2014	Optimum N (kg ha^{-1}) 2015	Mean	First PCA score
1	TZEI13×TZEI146	1498	1913	2044	3227	4094	4096	2812	19.82
2	TZEI13×TZEI10	1143	1543	1876	2524	4122	3288	2416	31.33
4	TZEI13×TZEI128	1129	1861	1025	3520	4530	4160	2704	10.20
5	TZEI13×TZEI11	606	1566	866	1979	2549	3596	1860	11.47
6	TZEI13×TZEI8	1086	2056	1530	2693	2836	4420	2437	4.43
7	TZEI13×TZEI16	473	1311	932	2409	2721	3542	1898	9.88
8	TZEI13×TZEI124	916	2102	1309	3113	4133	3933	2584	13.01
13	TZEI146×TZEI12	854	2192	1792	3721	4072	5341	2995	-6.26
14	TZEI146×TZEI128	1122	3183	1604	3752	3563	5934	3193	-18.55
17	TZEI146×TZEI16	1157	2432	2119	3608	3556	5377	3041	-5.07
18	TZEI146×TZEI124	1537	2481	2042	2820	4218	5148	3041	8.21
21	TZEI146×BD74222	729	1783	1392	2985	3235	3676	2300	11.67
27	TZEI10×TZEI124	431	2701	802	3913	3205	4890	2657	-17.57
28	TZEI10×BD74165	546	2803	1182	4158	3379	6164	3039	-31.62
30	TZEI10×BD74222	810	2314	1281	4053	3174	5650	2880	-21.99
32	TZEI12×TZEI11	731	2048	1364	2525	3045	4436	2358	2.82
34	TZEI12×TZEI16	744	1017	1361	1859	2974	4289	2040	11.56
35	TZEI12×TZEI124	1058	2224	1589	3476	3455	5106	2818	-4.77
37	TZEI12×BD74161	1008	2543	1888	4101	3904	5684	3188	-12.53
38	TZEI12×BD74222	1198	2822	2451	4207	4517	5762	3493	-5.16
44	TZEI128×BD74161	1142	2709	1626	3481	3457	4628	2840	0.10
46	TZEI11×TZEI8	470	2117	984	2704	2821	3818	2152	2.31
47	TZEI11×TZEI16	1171	1589	1509	2440	3058	3404	2195	21.38
50	TZEI11×BD74161	889	2238	1505	3814	3416	4953	2803	-7.52
58	TZEI16×BD74165	515	2673	1256	4318	3534	6453	3125	-37.34
61	TZEI124×BD74-165	731	1623	1243	2980	2820	4613	2335	-3.85
62	TZEI124×BD74161	628	1711	1102	2378	2505	4183	2084	1.46
63	TZEI124×BD74222	1177	1147	1389	3128	3899	5557	2716	-2.93
64	BD74165×BD74161	691	2234	1971	4382	3336	5805	3070	-22.61
67	TZEI14×TZEI25	1168	2131	1703	3222	3452	4671	2725	3.30
68	TZEI124×TZEI25	862	2054	1388	2951	4104	4349	2618	8.33
69	TZEI14×TZEI136	834	1606	1589	2507	2848	3750	2189	13.13
70	TZEI9×TZEI16	792	2070	1142	2689	3318	4263	2379	4.73
	Individual mean	904	2085	1480	3201	3450	4695	2636	
	Yearly mean	1495	2341	4073					
	LSD (p<0.05)	612	938	1004	1085	1185	1121	375	
	First PCA score	23.31	-5.03	18.26	-21.75	17.08	-36.34		

N: Nitrogen, PCA: Principal component axis, LSD: Least significant difference

Table 4: Additive main effect and multiplicative interactions analysis of variance for grain yield of the yellow endosperm maize hybrids

Source	df	Sum of squares	Mean of squares	Variation explained (%)
Total	593	1453060481		
Environment (E)	5	976118437.1	195223687.4***	67.18
Genotype (G)	32	176037260.7	5501164.4***	12.11
G×E	160	166294510.6	1039340.7***	11.44
IPCA 1	36	119395414.9	3316539.3***	8.22 (71.80)†
IPCA 2	34	20354831.1	598671.5**	1.40 (12.24)†
Residual	90	26544265.0	294936.3	1.80 (15.96)†
Error	396	134610273.0	339925.0	9.26

**p<0.01, ***p<0.001, df: degree of freedom, †: Values in parentheses are percentage of G×E

the absolute interaction effects were lower in 2015. Hence, the final yields were higher in 2015. Though the trend was similar under the two remaining N conditions but the interaction effects were variable.

Figure 1 represents the AMMI biplot showing the association among the best 19 and 10 poorest yielding hybrids under the varied N environments. In the AMMI biplot, about 83.2 and 8.4% of the total variation were explained by environments and genotypes, respectively. The AMMI biplot is divided into four quadrants, lower yielding environments in the two left quadrants and the higher yielding environments in the two right quadrants.

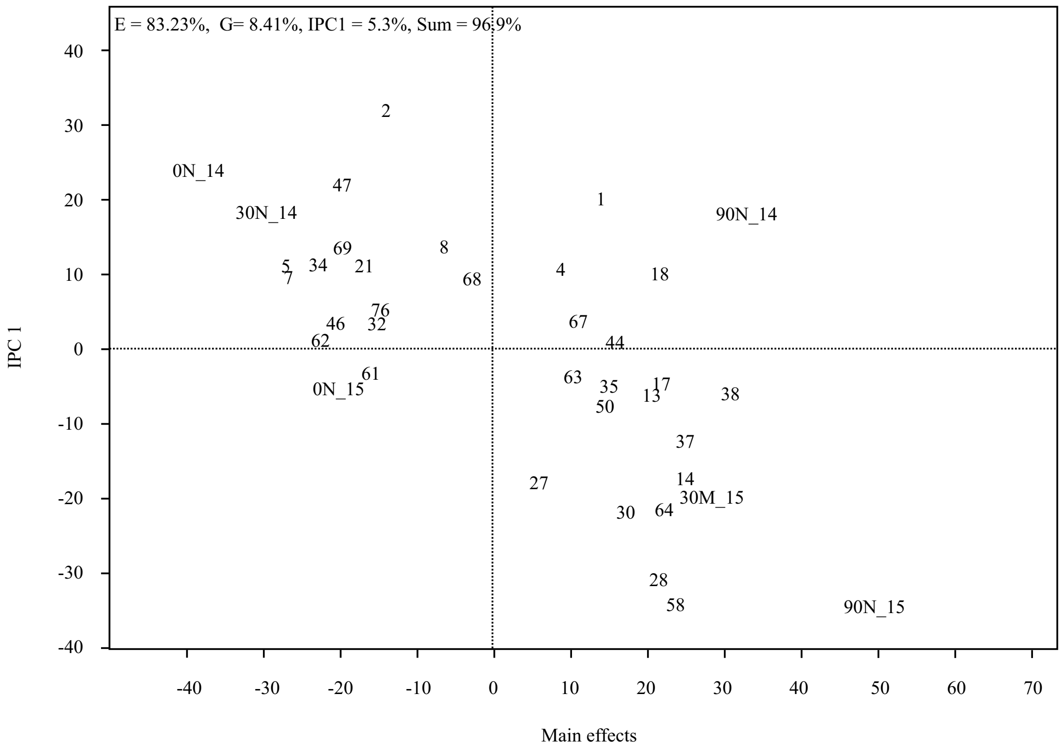
Table 5: Grain yield of the top three and least two yellow endosperm maize estimated by additive main effect and multiplicative interactions model

Hybrid				
Entry	Pedigree	Main effect	Interaction	Final yield
No N (0 kg N ha^{-1}) in 2014				
38	TZEI12×BD74222	1761	-120.3	1640.7
14	TZEI146×TZEI128	1461	-432.4	1028.6
37	TZEI12×BD74161	1456	-292.1	1163.9
7	TZEI13×TZEI16	166	230.3	396.3
5	TZEI13×TZEI11	128	267.4	395.4
No N (0 kg N ha^{-1}) in 2015				
38	TZEI12×BD74222	2942	26.0	2968.0
14	TZEI146×TZEI128	2642	93.3	2735.3
37	TZEI12×BD74161	2637	63.0	2700.0
7	TZEI13×TZEI16	1347	-49.7	1297.3
5	TZEI13×TZEI11	1309	-57.7	1251.3
Low N (30 kg N ha^{-1}) in 2014				
38	TZEI12×BD74222	2337	-94.2	2242.8
14	TZEI146×TZEI128	2037	-338.7	1698.3
37	TZEI12×BD74161	2032	-228.8	1803.2
7	TZEI13×TZEI16	742	180.4	922.4
5	TZEI13×TZEI11	704	209.4	913.4
Low N (30 kg N ha^{-1}) in 2015				
38	TZEI12×BD74222	4058	112.2	4170.2
14	TZEI146×TZEI128	3758	403.5	4161.5
37	TZEI12×BD74161	3753	272.5	4025.5
7	TZEI13×TZEI16	2463	-214.9	2248.1
5	TZEI13×TZEI11	2425	-249.5	2175.5
Optimal N (90 kg N ha^{-1}) in 2014				
38	TZEI12×BD74222	4307	-88.1	4218.9
14	TZEI146×TZEI128	4007	-316.8	3690.2
37	TZEI12×BD74161	4002	-214.0	3788
7	TZEI13×TZEI16	2712	168.8	2880.8
5	TZEI13×TZEI11	2674	195.9	2869.9
Optimal N (90 kg N ha^{-1}) in 2015				
38	TZEI12×BD74222	5552	187.5	5739.5
14	TZEI146×TZEI128	5252	674.1	5926.1
37	TZEI12×BD74161	5247	455.3	5702.3
7	TZEI13×TZEI16	3957	-359.0	3598
5	TZEI13×TZEI11	3919	-416.8	3502.2

Only TZEI124×BD74165 (61) was located in the low-yielding quadrant, whereas TZEI13×TZEI146 (1), TZEI13×TZEI128 (4), TZEI146×TZEI124 (18), TZEI14×TZEI25 (67) and TZEI128×BD74161 (44) were placed in the high-yielding quadrant. Hybrids TZEI128×BD74161 (44), TZEI14×TZEI25 (67), TZEI124×BD74222 (63) were placed close to the origin of the plot (low PC1) with high main effects. Although TZEI12×TZEI11 (32), TZEI11×TZEI8 (46), TZEI124×BD74161 (62) and TZEI124×BD74165 (61) had low PC1, they had low yield. TZEI13×TZEI146 (1), TZEI10×BD74165 (28) and TZEI16×BD74165 (58) were the farthest from the origin (absolute high PC1) with high mean effects. TZEI13×TZEI10 (2) and TZEI11×TZEI16 (47) among others had relatively high PC1.

DISCUSSION

Varying fertilizer levels create micro-environments and hybrids respond differently to the environments because of the differences in the genotypic constitution of the hybrids. The significant effects for year, nitrogen condition and their interactions demonstrated the divergent conditions that resulted in differences for environmental means causing variation in the hybrids. The various interactions of genotypes with environments introduce confusion in selection of promising genotypes. Statistical analyses are routinely carried out to separate the G×E interaction effects that result from the performance of different hybrids in the varying environments and to study the hybrid response and adaptability to be able to make precise decisions. Numerous



Entry	Hybrid	Entry	Hybrid	Entry	Hybrid
1	TZEI13×TZEI146	21	TZEI146×BD74222	47	TZEI11×TZEI16
2	TZEI13×TZEI10	27	TZEI10×TZEI12 4	50	TZEI11×BD74161
4	TZEI13×TZEI128	28	TZEI10 × BD74165	58	TZEI16×BD74165
5	TZEI13×TZEI11	30	TZEI10×BD74222	61	TZEI124×BD74165
6	TZEI13×TZEI8	32	TZEI12×TZEI11	62	TZEI124×BD74161
7	TZEI13×TZEI16	34	TZEI12×TZEI16	63	TZEI124×BD74222
8	TZEI13×TZEI124	35	TZEI12×TZEI124	64	BD74165×BD74161
13	TZEI146×TZEI12	37	TZEI12×BD74161	67*	*TZEI14×TZEI25
14	TZEI146×TZEI128	38	TZEI12×BD74222	68*	*TZEI124×TZEI25
17	TZEI146×TZEI16	44	TZEI128×BD74161	69*	TZEI14×TZEI136
18	TZEI146×TZEI124	46	TZEI11×TZEI8	70*	TZEI9×TZEI16

*Means check hybrid

Fig. 1: AMMI biplot of the grain yield of best 19 and poorest 10 grain yielding early maturing yellow-endosperm maize hybrids with four checks

scientists[13,14,18] have also reported confusing influence of environments on the expression of maize traits during breeding programmes by significant effects of G×E.

The CVs for individual N condition ranged from low to high indicating substantial amount of variability in the response of the hybrids to various N conditions. They were lower for optimal N, followed by low N and more variable for no N condition. The high CVs for low N and no N conditions may be attributed to the poor fertility status of the soil, which might have caused fluctuations in maize yield across replications. The relatively low values under other N conditions and for combined ANOVA, however, indicate uniformity of the management practices of the experiment. Significant variations among genotypes resulting from wide range of CVs pointed the differences in the ability of the genotypes to respond to changes in environment. The variability created can be exploited for maize improvement for grain yield under varying environmental conditions. Observations have also been made in this line[1,2,23].

Mean grain yield of the hybrids was lower in 2014 than in 2015 under the three N conditions. Variation in the mean yield is expected because crop genotypes perform differently in different growing condition because of variation in their response to changes in the effects of the growing condition. Amount of rainfall was higher in 2014 than in 2015 but mean rainfall was higher during the early and vegetative growth stage of the crop in 2015. Besides, rain was comparatively more consistent in 2015 than 2014. This could contribute to the differences in the yield between the two years. The significant variation among hybrids under all the N conditions suggests sufficient genetic variability that could be exploited by identifying promising hybrids in the various N conditions. Moreover, the significant effects of the genotypes, N condition, year, G×N, G×Y and Y×N interaction in the combined analysis shows that the parameters are important in the breeding process. The significant interaction effects suggested that each factor cannot independently explain all the variation observed. This resulted in different performances of the genotypes in the evaluated environments. Hence, further analysis of the data was essential to obtain information on the response of the hybrids to changes in N conditions. Several reports have suggested more detailed studies of G×E interaction to recommend superior crop genotypes[7,11,15,19,26,27].

In this study, the grain yield of the hybrids varied considerably among the environments. Hybrids TZEI12×BD74161 (37), BD74165×BD74161 (64) and TZEI16×BD74165 (58) had grain yield greater than 3000 kg ha^{-1} under low N, while TZEI13×TZEI11 (5) that yielded least under optimal N had higher grain yield than the best hybrid (TZEI128×BD74161) under no N conditions. This result confirmed the importance of soil N in determining grain yield of maize[1,2,23]. The AMMI yield estimates are adjusted hence, the final yields were different from the treatment means. More precise yield estimates have been reported to increase the probability of success selection[19,28]. The AMMI has been used to identify maize hybrids suitable for varying environments. The significant mean squares of the first two Interaction Principal Component Axis (IPCA) further suggest that the maize hybrids did not yield consistently under the three N conditions for the two years and that some hybrids were responded variously the different N conditions. This was also demonstrated by the 84% of the 11.4% sum of squares of G×E captured by AMMI as jointly explained by IPCA1 and IPCA2. Sum of square for the IPCA1 were about 4.5 times larger than that of the residual. This also revealed differences in grain yield among the maize hybrids across N conditions in the two years because of the presence of significant G×N as well as Y×N. This finding supported imperative that specific hybrids be identified for specific N condition.

The AMMI biplot for the maize in varied N conditions explained a total of 91.6% of the total sum of squares of the total variation. Considering the fact that the PC1 score of a particular hybrid in the AMMI analysis is an indication of the responsiveness of the hybrid to environment. Hybrids TZEI128×BD74161 (44) and TZEI124×BD74222 (63) were high yielding and their yield fluctuated less than the remaining hybrids across N conditions. So Thus, their yields were relatively high in all the N conditions. Hybrids TZEI12×TZEI11 (32), TZEI11×TZEI8 (46), TZEI124×BD74-161 (62) and TZEI124×BD74165 (61) were low yielding and did not respond actively to changes in N conditions because they were near the origin of the AMMI biplot (low PC1). The hybrids can be fitted well by an additive model.

However, hybrids TZEI13×TZEI10 (2) and TZEI11×TZEI16 (47) were low yielding because they had low main effect values on the AMMI biplot but they largely responded to zero N and low N conditions in 2014 (0N_14 and 30N_14) by having high IPC1 values. When a genotype and an environment have the same sign on the PCA axis, their interaction is positive, if different, their interaction is negative[12,16]. Therefore, hybrids TZEI13×TZEI10 (2), TZEI11×TZEI16 (47) and TZEI124×BD74165 (61) had positive interaction with N deficient (no N and low N) condition, while TZEI13×TZEI146 (1), TZEI13×TZEI128 (4), TZEI146×TZEI124 (18), TZEI10×BD74165 (28) and TZEI16×BD74165 (58) had positive interaction to optimal N condition. Hence, the yield of the hybrids were more stable under suitable cultivation conditions of environment created by climate and soil N conditions.

The effects of genotype on the grain yield of the hybrids were higher in 2015 than 2014 but the interaction effects were variable. Variation in the amount of rainfall cannot be overemphasized in this study because the interaction of rainfall might have affected utilization of the available N in the two years, thus, the hybrids were grouped by years. This can be explained by the amount of rainfall that was markedly different in the two years. Though the year 2014 had higher amount of rainfall than year 2015, the rainfall distribution was more even in 2015 especially during the growing period of the maize. In situations like this, several N conditions in a more diverse weather conditions may be required to separate the hybrids based on their tolerance to the stress. This kind of environment can be created with same N levels in a location for more than two years or same N levels in more than one location in a year. It has been reported that weather conditions affect performance and selection of cereals especially maize[27-31]. Similarly, Oluwaranti *et al*.[30] also reported significant influence of weather on production of maize in the tropics.

The AMMI biplot for the maize in varied N conditions explained a total of 91.6% of the total variation. High yielding hybrids TZEI128×BD74161 (44) and TZEI124×BD74222 (38) as well as low yielding TZEI12×TZEI11 (32), TZEI11×TZEI8 (46), TZEI124×BD74161 (62) and TZEI124×BD74165 (61) responded less to change in N conditions. Hybrids TZEI13×TZEI10 (2), TZEI11×TZEI16 (47) and TZEI124×BD74165 (61) had positive interaction with N deficient (no N and low N) condition, while TZEI13×TZEI146 (1), TZEI13×TZEI128 (4), TZEI146×TZEI124 (18), TZEI10×BD74165 (28) and TZEI16×BD74165 (58) had positive response to optimal N condition.

CONCLUSION

High yielding attributes of hybrids TZEI128×BD74-161 and TZEI124×BD74-222 were stable across the N conditions. Hybrids TZEI13×TZEI10, TZEI11×TZEI16 and TZEI124×BD74-165 had positive interaction with N stress (zero N and low N) condition, while TZEI13×TZEI146, TZEI13×TZEI128, TZEI146×TZEI124, TZEI10×BD74165 and TZEI16×BD74165 had positive response to optimal condition. Thus, the hybrids are suggested for the various N conditions.

SIGNIFICANCE STATEMENTS

This study identified high yielding attributes of hybrids TZEI128×BD74161 and TZEI124×BD74222 as stable across the three N conditions. They can therefore be recommended for cultivation in both deficient and optimal N conditions. Hybrids TZEI13×TZEI10, TZEI11×TZEI16 and TZEI124×BD74165 interacted with N stress condition, while hybrids TZEI13×TZEI146, TZEI13×TZEI128, TZEI146×TZEI124, TZEI10×BD74165 and TZEI16×BD74165 responded to optimal condition. Hence, the sets of hybrid are suitable for cultivation under N stress and optimal conditions, respectively. The hybrids identified for the various N conditions will help seed companies to make informed choices on the varieties to produce for farmers' use. Thus, the constraints to maize production due to soil fertility can be reduced.

ACKNOWLEDGMENT

The authors thank personnel involved in the Maize Improvement Programme of Institute of Agricultural Research and Training, Ibadan, Nigeria for their help with field work. Many thanks to IITA and CIMMYT for providing seeds for the study. This research was supported by the Institute of Agricultural Research and Training, Obafemi Awolowo University, Ibadan, Nigeria.

REFERENCES

1. Badu-Apraku, B., B. Annor, M. Oyekunle, R.O. Akinwale and M.A.B. Fakorede *et al*., 2015. Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments. Field Crops Res., 183: 169-183.
2. Li, L., T. Wegenast, H. Li, B.S. Dhillon and C.F.H. Longin *et al*., 2011. Estimation of quantitative genetic and stability parameters in maize under high and low N levels. Maydica, 56: 25-34.
3. Gauch, H.G. and R.E. Furnas, 1991. Statistical analysis of yield trials with MATMODEL. Agron. J., 83: 916-920.
4. Becker, H.C., 1981. Correlations among some statistical measures of phenotypic stability. Euphytica, 30: 835-840.
5. Zobel, R.W., M.J. Wright and H.G. Gauch Jr, 1988. Statistical analysis of a yield trial. Agron. J., 80: 388-393.
6. Finlay, K.W. and G.N. Wilkinson, 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res., 14: 742-754.
7. Lin, C.S. and M.R. Binns, 1988. A superiority measure of cultivar performance for cultivar × location data. Can. J. Plant Sci., 68: 193-198.
8. Kang, M.S., 1988. A rank-sum method for selecting high-yielding stable corn genotypes. Cereal Res. Commun., 16: 113-115.
9. Manrique, K. and M. Hermann, 2002. Comparative study to determine stable performance in sweet-potato (*Ipomoea batatas* Lam.) regional trials. Acta Hortic., 583: 87-94.
10. Crossa, J., 1990. Statistical analyses of multilocation trials. Adv. Agron., 44: 55-85.
11. Gruneberg, W.J., K. Maniique, D. Zhang and M. Hermann, 2005. Genotype × environment interactions for a diverse of sweet potato clones evaluated across varying eco-geographic conditions in Peru. Crop Sci., 45: 2160-2171.
12. Gauch, H.G., 2006. Statistical analysis of yield trials by AMMI and GGE. Crop Sci., 46: 1488-1500.
13. Bertoia, L., C. Lopez and R. Burak, 2006. Biplot analysis of forage combining ability in maize landraces. Crop Sci., 46: 1346-1353.
14. Dehghani, H., A. Ebadi and A. Yousefi, 2006. Biplot analysis of genotype by environment interaction for barley yield in Iran. Agron. J., 98: 388-393.
15. Dehghani, H., N. Sabaghnia and M. Moghaddam, 2009. Interpretation of genotype-by-environment interaction for late maize hybrids' grain yield using a biplot method. Turk. J. Agric. For., 33: 139-148.
16. Yan, W. and N.A. Tinker, 2006. Biplot analysis of multi-environment trial data: Principles and applications. Can. J. Plant Sci., 86: 623-645.

17. Gauch, H.G., H.P. Piepho and P. Annicchiarico, 2008. Statistical analysis of yield trials by AMMI and GGE: Further considerations. Crop Sci., 48: 866-889.
18. Asfaw, A., F. Alemayehu, F. Gurum and M. Atnaf, 2009. AMMI and SREG GGE biplot analysis for matching varieties onto soybean production environments in Ethiopia. Sci. Res. Essays, 4: 1322-1330.
19. Tena, E., G. Frehiwot, M. Hussein, T. Melaku, T. Diribu and S. Abebech, 2019. Genotype × environment interaction by AMMI and GGE-biplot analysis for sugar yield in three crop cycles of sugarcane (*Saccharum officinirum* L.) clones in Ethiopia. Cogent Food Agric., Vol. 5. 10.1080/23311932.2019.1651925.
20. Hitz, K., A.J. Clark and D.A. Van Sanford, 2017. Identifying nitrogen-use efficient soft red winter wheat lines in high and low nitrogen environments. Field Crops Res., 200: 1-9.
21. Das, B., G.N. Atlin, M. Olsen, J. Burgueño and A. Tarekegne *et al*., 2019. Identification of donors for low-nitrogen stress with maize lethal necrosis (MLN) tolerance for maize breeding in sub-saharan Africa. Euphytica, Vol. 215. 10.1007/s10681-019-2406-5.
22. Griffings, B., 1956. Concepts of general and specific combining ability in relation to diallel crossing system. Aust. J. Biol. Sci., 9: 463-473.
23. Kamara, M.M., 2015. Diallel analysis of some yellow maize inbred lines under low and normal nitrogen levels. Int. J. Plant Breed. Genet., 9: 32-43.
24. CIMMYT, 1985. Managing Trials and Reporting Data for CIMMYT`s International Maize Testing Program. CIMMYT, El Batan, Mexico.
25. Yang, R.C., J. Crossa, P. Cornelius and J. Burgueno, 2009. Biplot analysis of genotype × environment: Proceed with caution. Crop Sci., 49: 1564-1576.
26. Ogunbayo, S.A., M. Sie, D.K. Ojo, A.R. Popoola and O.A. Oduwaye *et al*., 2014. Comparative performance of forty-eight rice genotypes in diverse environments using the ammi and GGE biplot analyses. Int. J. Plant Breed. Genet., 8: 139-152.
27. Ogunniyan, D.J., D.K. Ojo, S.A. Olakojo, S.A. Makinde and O.A. Omikunle, 2019. Differential grain yield performance of single cross hybrid maize in varied nitrogen conditions. Afr. Crop Sci. J., 27: 445-461.
28. Nassir, A.L., 2013. Genotype×environment analysis of some yield components of upland rice (*Oryza sativa* L.) under two ecologies in Nigeria. Int. J. Plant Breed. Genet., 7: 105-114.
29. Ogunniyan, D.J., D.K. Ojo, S.A. Olakojo and O.A. Talabi, 2019. Diallel analysis of maize inbred lines for agronomic traits in nitrogen stress and optimal conditions. Ghana J. Agric. Sci., 54: 10-23.
30. Oluwaranti, A., M.A.B. Fakorode, A. Menkir and B. Badu-Apraku, 2015. Climatic conditions requirements of maize germplasm for flowering in the rainforest agro-ecology of Nigeria. J. Plant Breed. Crop Sci., 7: 170-176.
31. Rad, M.N., M.A. Kadir, M.Y. Rafii, H.Z.E. Jaafar, M.R. Naghavi and F. Ahmadi, 2013. Genotype environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum*) under normal and drought stress conditions. Aust. J. Crop Sci., 7: 956-961.