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Original Research Article

An Assessment of Soybean (*Glycine max*, L. Merrill) Grain Yield in Different Environments Using AMMI and GGE Biplot Models in Humidorest Fringes of Southeast Nigeria

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Abstract

The yield of four soybean (*Glycine max*, L. Merrill) genotypes under six planting dates in two years was assessed using the Additive Main Effect and Multiplicative Interaction (AMMI) and Genotype and Genotype-by-Environment biplot models. The results of combined analysis of variance for grain yield of the four genotypes of soybean grown in 12 environments showed that soybean grain yield was significantly ($P < 0.01$) affected by environments (E), genotypes (G) and genotype by environment interactions (GE). Genotypes and environments accounted for about 6.56% and 47.66% of the variation, respectively, while the GE explained 14.47% of the variation, which is more than double of the genotypic effects of the total variation. AMMI biplot indicated genotype TGx1485-1D and the early July 2012 environment were above average for grain yield and had positive specific interactions with each other. However, TGx1485-1D had negative interactions with the other environments while genotypesTGx14482E, TGx1987-10F and TGx1835-10E had positive interactions with all the environments except E5. In the differential yield ranking of genotypes across the twelve environments TGx1485-1D had the highest yield in seven out of the twelve environments. TGx1835-10E was the highest yielding genotype in three environments, while TGx1448-2E gave the greatest yield in two environments. Although TGx1485-1D exhibited high GEI, in the GGE biplot it was ranked as the most desirable genotype. GGE biplot identified early July 2012(E5) as the best environment. The result showed that application of AMMI and GGE biplots facilitates visual comparison and identified superior genotypes for each target set of environments.

Keywords: soybean; genotype; genotype and environment interaction; selection; variation.

INTRODUCTION

Soybean (*Glycine max*, L. Merrill) is one of the most important crops in the world because of its high oil content and nutritional value (Vaughan and Geissler, 2008). It has the highest protein content of all food crops and is second only to groundnut in terms of oil content among food legumes (Alghamdi, 2004; Fekadu et al., 2009). Planting date is one of the major factors that influence soybean yield and performance (Pal et al., 1983; Olufajo et al., 1984; Bello et al., 1996). The optimum planting date for soybean varies according to genotype and the agronomic environment (Hartman et al., 2011; Lal, 2009). It is therefore necessary to study the genotype × environment interaction (GEI) to identify the genotypes that are stable in different environments (Calvino et al., 2003).

The expression of traits in soybean especially quantitative traits, results from the interaction of the genes and the environment (Cicek et al., 2006). High environmental effect is challenging to genetic studies because it reduces the heritability and makes selection difficult. The evaluation of crops for stability of performance across different environments is essential to the successful selection of high yielding and consistently performing genotypes. Stable genotypes are less dependent upon good environments to perform well, and this makes their yield more predicable (Crossa, 1990; Dashiell et al., 1994; Baiyeri and Nwokocha, 2001). Study of GEI is important to plant breeders because it can limit the progress in the selection process; hence it is a basic cause of differences among genotypes for yield stability (Asad et al., 2009). Different workers (Lin et al., 1986; Thiyagu et al., 2013) have applied various stability techniques in different crops to identify the relative yield stability of individual genotypes across environments.

They are important and efficient tools for plant breeders and agronomists and help in identifying and selecting the most stable, high performing genotypes that are best suitable under a given set of environmental conditions (Jandong et al., 2011). Some of the different methods that have been used in performing GEI analysis include stability analysis following the additive main effects and multiplicative interaction model (AMMI), principal component analysis (PCA) and linear regression analysis, analysis of variance (ANOVA) and GGE biplot analysis (Abay et al., 2009; Miranda et al., 2009; Akcura et al., 2011; Mitrovic et al., 2012). The ANOVA explains only main effects and gives no information on individual genotypes and localities, which are components of the interaction (Mitrovic et al., 2012). The AMMI allows for a large set of technical interpretations and uses a principal component to interpret cultivar performance by integrating the use of ANOVA and PCA. The AMMI analysis combines additive components in a single model for the main effects of genotype and environment as well as multiplicative components for the interaction effect. The graphic analyses bring out phenotypic stability, genotypic behaviour of the cultivars and environments that optimize performance (Miranda et al., 2009). The AMMI model displays main effects of genotypes and environment and their interactions. It also estimates the genotype responses and separates noise from real sources of variation through partitioning of the GEI. It also contributes to improved genotype evaluation, recommendations and selection of test environment (Abay et al., 2009). It is useful in summarizing and approximating patterns of response which exist in the original data (Akcura et al., 2011). The GGE biplot analysis is another method which integrates the genotype and genotype by environment effects in the evaluation of cultivars. The GGE that uses graphic axes identifies superior cultivars in the mega environments (Akcura et al., 2011). Mega environments comprise groups of environments which consistently share the same test genotypes (Abay et al., 2009). It also combines ANOVA and PCA by partitioning together the sum of squares of genotypes and the sum of squares of genotype by environment interaction using the PCA method. It is also used for the presentation and estimation of genotypes in different environments (Miranda et al., 2009). These two statistical analyses (AMMI and GGE) have broader relevance for agricultural researchers because they pertain to any two-way data matrices, and such data emerge from many kinds of experiments (Naroui Rad et al., 2013). The objective of this study was therefore to evaluate the yield stability of soybean genotypes in different planting dates using the additive main effects and multiplicative interaction (AMMI) and genotype and genotype-by-environment interaction (GGE) biplot models.

MATERIALS AND METHODS

The experiment was carried out in 2012 and 2013 cropping seasons at the research farm of the National Cereal Research Institute (NCRI), Amakama, South-Eastern Nigeria. Amakama falls within latitude 05^{o} 28^{1}N and longitude 07^{o} 29^{1}E with an altitude of 154 m. The soil is light sandy and moderately acidic. Four genotypes of soybean were used: TGx 1448-2E (medium maturing), TGx 1485-1D, TGx 1987-1F and TGx 1835-10E (Early maturing). Seeds were obtained from the National Cereal Research Institute (NCRI) Badeggi, Niger State, Nigeria. These four genotypes were planted in 2012 on 11th and 26th June, 10th and 24th July and 8th and 23rd August while in 2013, plantings were done on 11th and 21st June, 5th and 22nd July and then 2nd and 20th August; corresponding to Early June, Late June, Early July, Late July, Early August and Late August in each year. The experiment was laid out in a split plot design with planting date randomized within the main plot treatments and soybean genotypes randomized within the sub-plot treatments with four replications. The subplot size was 3 m × 3 m with 1 m spacing between each main plot. Pre-planting soil sample analysis was done to determine the physicochemical properties of the planting site. Soil samples from depths of 5 cm -15 cm were randomly collected from different points of the planting site, bulked and then taken to the laboratory for analysis.

The land was plowed and harrowed. The seeds were sown on flats with a spacing of 50 cm between rows and 20 cm within rows giving a population density of 100,000 plants per hectare. Weed control measures were carried out using both post-emergence (Round up^{TM} and Paraquat^{TM}) and pre-emergence (Pendillin^{TM}) herbicides at the rate of 160 ml/20L of water in a knapsack sprayer. Manual weeding was done at 8 weeks after planting (WAP) and 12(WAP). Insect infestations were controlled using Cypermethrin 10 Ec at the rate of 180 ml/15L of water in a knapsack sprayer at 3WAP and 6WAP. Basal fertilizer application was done at 4WAP using NPK 15:15:15. Data were collected on grain yield. The grain yield data were subjected to analysis of variance and the AMMI model was analyzed using GenStat Discovery Edition statistical software (2011). The GGE Biplot was analyzed with R statistical package (R core team 2013). In the analyses, each year/planting date combination was considered as an environment (Table 1).

RESULTS

Basic information about the experiments is presented in Tables 1-3.

Table 1. Combination of the six planting dates and two years that formed the twelve environments

Environmental code	Date of planting
E1	11th June, 2012
E2	11th June, 2013
E3	26th June, 2012
E4	21th June, 2013
E5	10th July, 2012
E6	5th July, 2013
E7	24th July, 2012
E8	22nd July, 2013
E9	8th August, 2012
E10	2nd August, 2013
E11	23rd August, 2012
E12	20th August, 2013

Table 2. Soil Properties of experiment sites in 2012 and 2013

Parameter	2012	2013
Texture	Sandy loam	Sandy Loam
Sand (%)	73.00	72.20
Silt (%)	10.20	11.40
Clay (%)	16.80	15.40
pH (H_2O)	5.06	4.89
Phosphorus (Mg/Kg)	10.50	14.30
Nitrogen (%)	0.056	0.035
Organic Carbon (%)	0.97	0.85
Organic Matter (%)	1.32	1.31
Calcium (C mol kg^{-1})	2.75	2.40
Magnesium (C mol kg^{-1})	1.20	1.20
Potassium (C mol kg^{-1})	0.08	0.077
Sodium (C mol kg^{-1})	0.144	0.270
TEA (C mol kg^{-1})	2.50	2.56
ECEC (C mol kg^{-1})	6.321	6.507

Table 3. Average monthly rainfall (mm) of experimental site during 2012 and 2013

Month	2012	2013
January	0.0	0.0
February	92.7	56.3
March	29.4	23.5
April	258.3	87.3
May	296.3	405.5
June	250.5	265.3
July	362.0	189.8
August	212.2	241.3
September	338.2	284.1
October	251.2	264.6
November	110.1	48.9
December	0.0	106.6
Total	**2200.9**	**2023.2**
Mean	**183.4**	**168.6**

Source: Meteorological unit of National Cereal Research Institute (NCRI), Amakama

Table 4. Analysis of variance for grain yield (kg·ha^{-1}) of 4 soybean genotypes grown at 12 environments (Combination of 6 planting dates and two years).

Source	DF	SS	MS	F-Value	P-Value	% SS
Replication	3	327245	109082	1.51	0.22	
Environment (E)	11	16015831	1455985	20.14	0.00	47.66
Genotypes (G)	3	2205943	735314	10.17	0.00	6.56
GE	33	4861759	147326	2.04	0.00	14.47
Error	141	10192263	72286			30.33
Total	191	33603041				

GE = Genotype × Environment interaction; DF = Degree of freedom; SS = Sum of squares; MS = Mean squares.

Combined Analysis of Variance

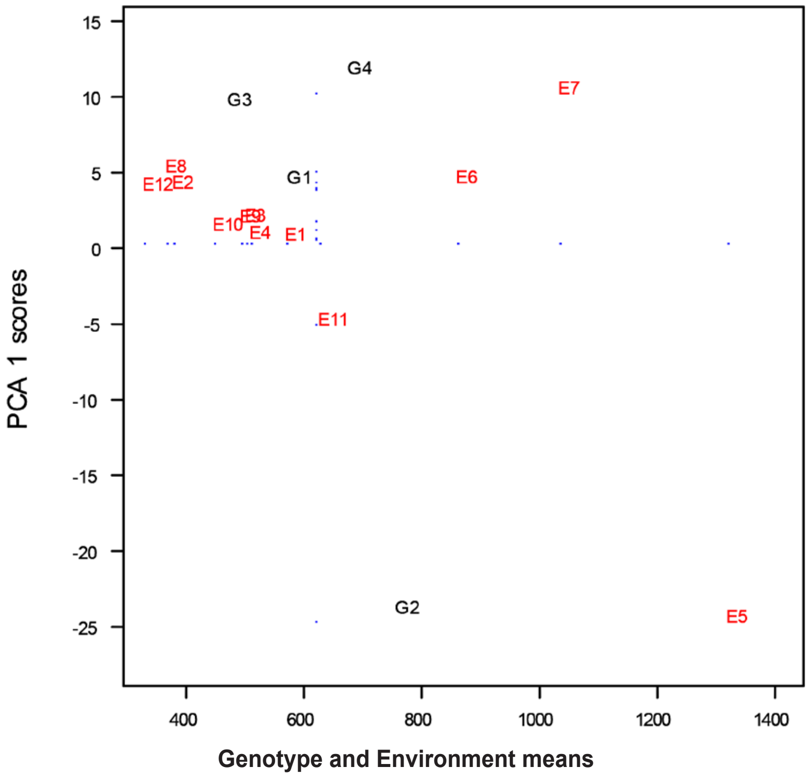
The result of combined analysis of variance for grain yield in four genotypes of soybean grown in twelve environments is presented in Table 4. The soybean grain yield was significantly (P < 0.01) affected by environments (E), genotypes (G) and genotype by environment interactions (GEI). Genotype and environment accounted for about 6.56% and 47.66% of the variation, respectively, while the GE explained 14.47% of the variation which is more than double compared with the genotypic effect on total variation. Table 5 revealed differential yield ranking of genotypes across the twelve environments. TGx1485-1D had the highest yield in seven out of the twelve environments; TGx1835-10E was the highest in three environments while TGx1448-2E gave greatest yield in the remaining two environments.

AMMI Model

AMMI model demonstrated the presence of GEI and this has been partitioned among the first two IPCA axes (Table 4). The model revealed significant differences between the genotypes, environments and GEI Partitioning of the interaction sum of squares by AMMI was very effective as the mean square for the first PCA axis was more than 10 times the mean square for the residual. The first two interaction PCA axes were highly significant and cumulatively contributed 95.39% of the total GEI. IPCA 1 and IPCA

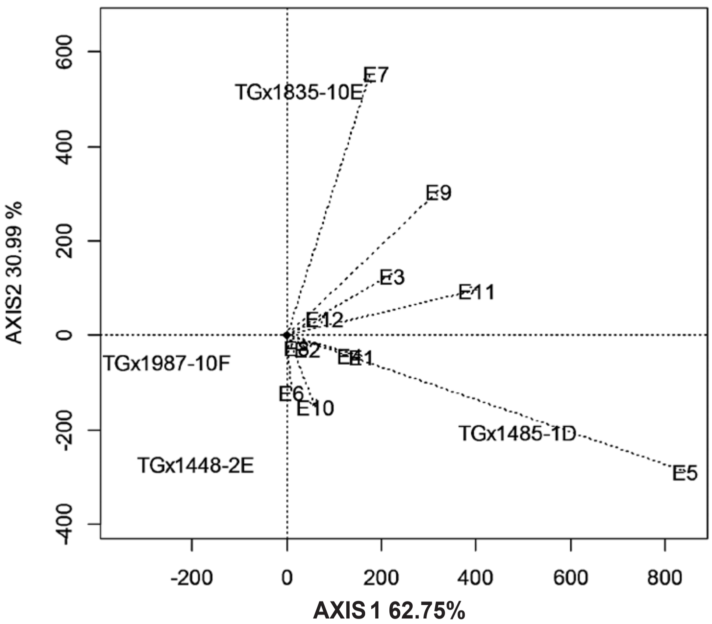
Table 5. Mean grain yield (kg ha^{-1}) of 4 soybean genotypes tested at 12 environments (from six planting dates in 2012 and 2013)

	Environments												
	Early June		Late June		Early July		Late July		Early August		Late August		
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	
Genotypes	(E1)	(E2)	(E3)	(E4)	(E5)	(E6)	(E7)	(E8)	(E9)	(E10)	(E11)	(E12)	Genotype mean
TGx1448-2E	603	403	455	458	1160	1073	753	446	293	511	398	298	571
TGx1485-1D	683	408	606	630	2068	850	988	363	630	533	923	373	755
TGx1987-10F	420	325	288	461	903	703	876	278	256	406	455	266	470
TGx1835-10E	563	366	648	478	1136	808	1511	370	783	330	720	368	673
Environment mean	567	375	499	507	1317	859	1032	364	491	445	624	326	



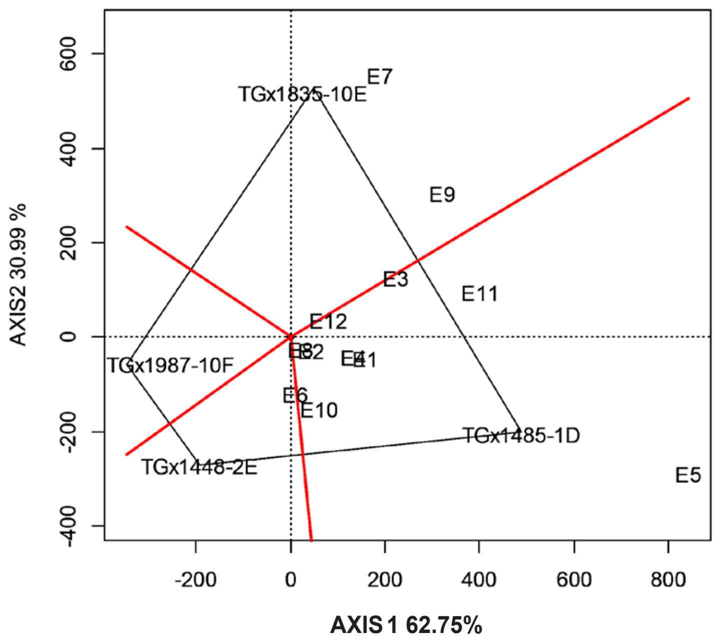
G1=TGx1448-2E; G2=TGx1485-1D; G3=TGx1987-10F; G4=TGx1835-10E;
E1=11th June 2012; E2=11th June 2013; E3=26th June 2012; E4=21st June 2013;
E5=10th July 2012; E6=5th July 2013; E7=24th July 2012; E8=22nd July 2013;
E9=8th August 2012; E10=2nd August 2013; E11=23rd August 2012; E12=20th August 2013

Figure 1. The AMMI biplot (IPCA1 vs mean)



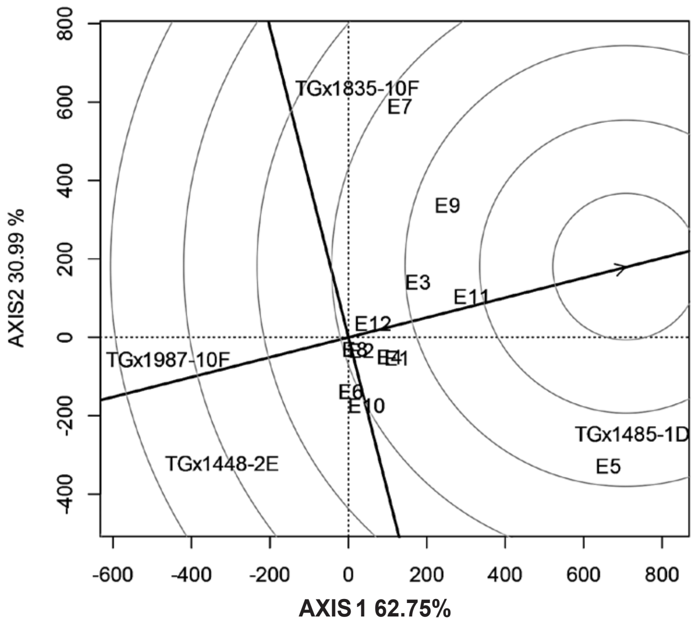
E1=11th June 2012; E2=11th June 2013; E3=26th June 2012; E4=21st June 2013;
E5=10th July 2012; E6=5th July 2013; E7=24th July 2012; E8=22nd July 2013;
E9=8th August 2012; E10=2nd August 2013; E11=23rd August 2012; E12=20th August 2013

Figure 2. GGE biplot of soybean yield of four genotypes of soybean in two years trials across six planting dates



E1=11th June 2012; E2=11th June 2013; E3=26th June 2012; E4=21st June 2013;
E5=10th July 2012; E6=5th July 2013; E7=24th July 2012; E8=22nd July 2013;
E9=8th August 2012; E10=2nd August 2013; E11=23rd August 2012; E12=20th August 2013

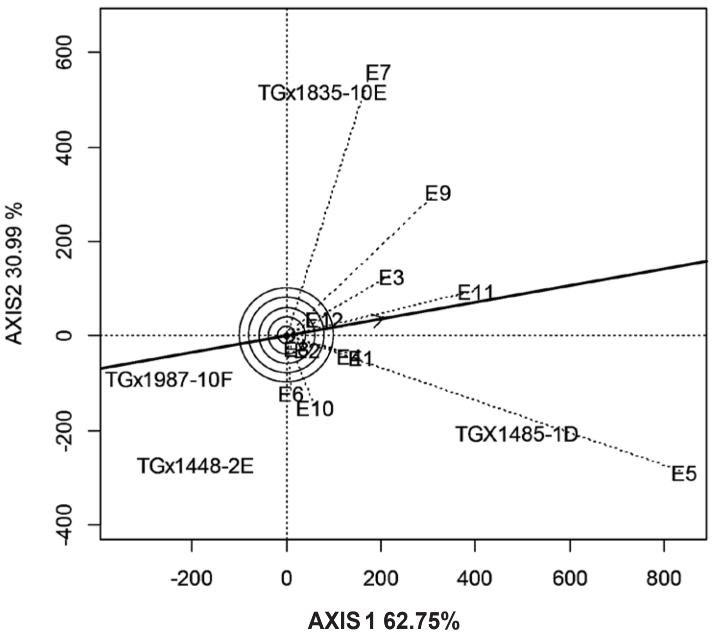
Figure 3. Polygon view of the GGE biplot showing which soybean genotype had the best grain yield in which environment



E1=11th June 2012; E2=11th June 2013; E3=26th June 2012; E4=21st June 2013;
E5=10th July 2012; E6=5th July 2013; E7=24th July 2012; E8=22nd July 2013;
E9=8th August 2012; E10=2nd August 2013; E11=23rd August 2012; E12=20th August 2013

Figure 4. Ranking genotypes based on both mean and stability relative to an ideal genotype

2 explained 55.51% and 39.88 of the total GEI sums of squares percentage at 14.47% of the interaction degrees of freedom respectively..The AMMI biplot (IPCA1 vs mean) is displayed in Figure 1. The biplot captured 90.63% of the treatment sum of squares and the abscissa showed the genotype and environment means, and the ordinate showed the IPCA1 genotype and environment scores. AMMI biplot indicated genotype TGx1485-1D and environment. Early



E1=11th June 2012; E2=11th June 2013; E3=26th June 2012; E4=21st June 2013;
E5=10th July 2012; E6=5th July 2013; E7=24th July 2012; E8=22nd July 2013;
E9=8th August 2012; E10=2nd August 2013; E11=23rd August 2012; E12=20th August 2013

Figure 5. The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness of the test environments

July 2012 were above average for grain yield and had positive specific interaction. However, TGx1485-1D had negative interactions with the other environments while TGx14482E, TGx1987-10F and TGx1835-10E had positive interactions with all the environments except early July 2012.

GGE Biplot

Figure 2 shows the result of the GGE biplot of grain yield. PC1 and PC2 jointly accounted for 93.74% (PC1 = 62.75%, PC2 = 30.99%) of the total variation relative to the genotypes and their interaction with the environments (i.e G + GE). The PC1 in a GGE biplot identifies the G (mean performance) while The PC2 in the GGE biplot identifies the GE associated with each genotype, which is a measure of variability (stability). Figure 3 displayed a polygon view of four soybean genotypes evaluated at twelve environments. Four projecting lines from the origin divided the quadrilateral into four sectors. From the quadrilateral view of this biplot, test environments and genotypes fell into two and four sectors*,* respectively. E2 (11th June 2013) and E8 (22nd July 2013) were closest to the biplot origin while E7 (24th July 2012) and E5 (10th July 2012) were farthest. Two of the sectors (sector 3 and 4) in the quadrilateral had no test environment and the genotypes (TGx1448-2E and TGx1987-10F) in this sector performed below average. Sectors 1, 2, 3 and 4 had genotypes TGx1835-10E, TGx1485-1D, TGx1448-2E and TGx1987-10F as their vertex genotypes respectively. TGx1835-10E won in three environments - E3 (26th June 2012), E7 (24th July 2012) and E9 (2nd August 2013). TGx1448-2E won in two environments - E6 (5th July 2013) and E8 (22nd July 2013) while TGx1485-1D won in the remaining environments.

The ranking of genotypes for both mean yield and stability performance across the 12 environments is shown in Figure 4. TGx1485-1D had the highest mean yield and ranked closest to the 'ideal genotype', followed by genotypes TGx1835-10E, TGx1448-2E and TGx1987-10F in descending order. TGx1987-10F was the most stable though it is the poorest yielder and ranked furthest away from the 'ideal genotype' while TGx1485-1D and TGx1835-10E that were high yielding were highly unstable. Figure 4 also shows the ranking of test environments relative to an 'ideal test environment' (represented by centre of the concentric circles). E5 (10th July 2012) and E11 (23rd August 2012) are the closest to this point and are therefore ideal environments.

Figure 5 displays the discriminating power and representativeness of the test environments among the twelve environments, E5 (10th July 2012) was most discriminating followed by E7 (24th July 2012) and E9 (8th August 2012) while E8 (22nd July 2013) and E2 (11th June 2013) were least discriminating. The second most important aspect of test environment evaluation is its representativeness of the mega-environment. The smaller the angle, the more representative the test environment would be. E11

(23rd August 2012) had the smallest angles with the abscissa of average environment axis and it was considered as the most representative for soybean grain yield.

DISCUSSION

Multi-locational testing in which the relative performance of the test genotypes almost invariably varies from one environment to another often precedes selection of specific crop genotypes in plant breeding. The presence of GEI makes it difficult for breeders to decide which genotypes should be selected. There is a need to select for stability whenever such interactions assume a practical importance in a testing programme (Makinde et al., 2013). The different performance of genotypes across environments could also be indicative of wide variation in these growing environments related to differences in planting date. Similar findings have been reported in soybean by Pal et al. (1983), Olufajo et al. (1984), and Bello et al. (1996). The mean yield of soybean genotypes used in this experiment across 12 environments differed substantially. This is indicative of the wide genetic background of the genotypes. The relatively large magnitude of the GE interaction sum of squares which was about two times larger than that for genotype indicates that there were sizeable differences in responses of the genotypes across environments (Karimizadeh et al., 2013). According to Yan and Kang (2003), this suggests the possible presence of different mega-environments with different winner genotypes. Partitioning of the interaction sum of squares by AMMI was very effective as the mean square for the first PCA axis was several times the mean square for the residual (Makinde et al., 2013). The complete AMMI model contained 95.39% of the sum of square due to G × E and the residual only 4.60%. This observation is in line with that of Adomou et al. (1997) and Makinde and Ariyo (2011). The result of the AMMI model indicated TGx1485-1D as the highest yielding genotype but with the highest IPCA1 score while E5 which was the highest yielding environment also had a high IPCA1 score. Large IPCA1 score is an indication of high interaction and hence high instability (Thiyagu et al., 2013). TGx1485-1D had positive interaction with E5 but negative interactions with the other environments while TGx1448-2E, TGx1987-10F and TGx1835-10E which had similar interactions but differed in their mean yield had negative interactions with E5 but positive intercations with the other environments (Makinde et al., 2013; Thiyagu et al., 2013).

In the GGE biplot, the GEI was a crossover interaction as there was differential yield ranking of genotypes across the twelve environments. The polygon view of the GGE biplot, which indicates which genotype was highest yielding in which environment, showed that TGx1835-10E won in three environments (E3, E7 and E9), TGx1448-2E won in two environments (E6 and E8) while TGx1485-1D won in the remaining environments. In the ranking of genotypes for both mean yield and stability performance across the 12 environments TGx1485-1D had the highest mean yield, followed by genotypes TGx1835-10E. However, both were highly unstable while TGx1987-10F, which was the poorest yielder, was the most stable. This result is in agreement with the assertion of Kamadi (2001) that the high yielding genotypes are usually unstable. However, in the ranking of the genotypes, TGx1485-1D was ranked closest to the "ideal genotype" indicating it as the most desirable of the four genotypes (Karimizadeh et al., 2013). The purpose of test-environment evaluation is to identify test environments that effectively identify superior genotypes for a mega-environment. An "ideal" test environment should be both discriminating of the genotypes and representative of the mega-environment (Yan et al., 2007). Out of the 12 environments E5 (10th July 2012), E7 (24th July 2012) and E9 (8th August 2012) were the most discriminating and E11 (23rd August 2012) was most representative for soybean grain yield. In addition, E5 (10th July 2012) and E11 (23rd August 2012) were ranked closest to the ideal environment. An environment is more desirable if it is located closer to the ideal environment (Jandong et al., 2011). The outstanding performance of these four environments might be attributed to variation in rainfall. These four environments (planting dates) shared the same year (2012) which had more rain than the other (2013). According to Van Euwijk and Elgersma (1993); Makinde and Ariyo (2011) within year similarity and between years differences in crop performance indicated that meteorological information might be useful in the classification of genotypes by trial interaction. The results of the present study have demonstrated that with the use of biplot models, the adaptive responses of the test genotypes to environment as well as the different patterns of GE interaction over a broad range of environments could be determined. The adaptive responses can be used for selecting genotypes with a broad or specific adaptation depending on the strategy of the breeding program (Yan and Hunt, 2001). GGE biplot and AMMI biplot models indicated TGx-1485-1D and E5 (10th July 2012) as the highest yielding genotype and environment, respectively. Though they exhibited large interactions, in the GGE biplot ranking TGx1485-1D was identified as the genotype of choice suggesting it as a genotype that will be of value in breeding program geared towards the development of high yielding and stable soybean genotypes in the region where the study was done. The result of GGE biplot and AMMI model were similar in their ranking of the genotypes based on yield and stability, this similarity might be due to the fact that both methods explained similar amounts of total variation by the two PC axes. GGE and AMMI methods were adequate to explain the

GEI in soybean. However, the GGE biplot provides more useful information than AMMI through its discriminating power of representativeness view and mega-environment analysis in evaluation of test environment. Superiority of GGE biplot over AMMI model has been reported (Yan et al., 2007; Alake and Ariyo, 2012; Amira et al., 2013).

CONCLUSIONS

The study showed that both GGE and AMMI methods were adequate to explain the GEI in soybean.Both methods indicated TGx-1485-1D as the preferred genotype. The genotype is suitable for cultivation in high rainfall areas and could be exploitedin future breeding programs. However, GGE biplot was superior to AMMI as it provided more useful information through its discriminating power of representativeness view and mega-environment analysis in evaluation of test environment.

REFERENCES

Abay F., Bjornstad A. (2009): Specific adaptation of barley varieties in different locations in Ethiopia. Euphytica 167, 181-195.

Adomou M., Ntare B. R., Williams, J. H. (1997): Stability of pod yields and parameters of a simple physiological model for yield among peanut lines in Northern Benin. Peanut Science 24(2): 107-112.

Akcura M., Taner S., Kaya Y. (2011): Evaluation of bread wheat genotypes under irrigated multi-environment conditions using GGE biplot analyses. Agriculture 98(1), 35-40.

Alake C. O, Ariyo O. J. (2012): Comparative Analysis of Genotype × Environment Interaction Techniques in West African Okra, (*Abelmoschuss caillei,* A. Chev Stevels). Journal of Agricultural Science 4(4): 135-150.

Alghamdi S.S. (2004): Yield stability of some soybean genotypes across diverse environments. Pakistan Journal of Biological Science 7(12): 2109-2114.

Amira J. O., Ojo D. K., Ariyo O. J., Oduwaye O. A., Ayo-Vaughan M. A. (2013): Relative Discriminating Powers of GGE and AMMI Models in the selection of Tropical Soybean Genotypes. African Crop Science Journal 21 (1): 67-73.

Asad M.A., Bughio H.R., Odhano I.A., Arain M.A., Bughio M.S. (2009): Interactive effect of genotype and environment on the paddy yield in Sindh Province. Pakistan Journal of Botany 41(4): 1775-1779.

Baiyeri K.P., Nwokocha H. N. (2001): Evaluation of sweet potato Genotypes for yield stability in Southeastern Nigeria. Journal of Sustainable Agriculture and Environment 3(2): 254-262.

Bello L.L., Ojo A.A., Adeyemo M.O., Omojor Y.M. (1996): Effect of planting date on yield component and seed viability in soybean in southern Guinea Savanna, Nigeria. African Crop Science Journal 4: 393-397.

Calvino P.A., Sadras V.O., Andrade F.H. (2003): Quantification of environmental and management effects on the yield of late-sown soybean. Field Crops Research 83: 67-77.

Cicek M.S., Chen P., Saghai Maroof M.A., Buss G.R. (2006): Interrelationships among Agronomic and Seed Quality Traits in an interspecific Soybean Recombinant Inbred Population. Crop Science 46**:**1253-1259.

Crossa J. (1990): Statistical analyses of multilocation trials. Advances in Agronomy 44: 55-85.

Dashiell K. E., Ariyo O.J., Bello L. (1994): Genotype × environment interaction and simultaneous selection for high yield and stability in soybeans (*Glycine max* (L.) Merr.). Annals of Applied Biology 124, 133-139.

Fekadu G., Hussein M., Getinet A. (2009): Genotype x Environment interactions and stability of soybean for grain yield and nutrition quality. African Crop Science Journal 17(2): 87-99.

GenStat (2011): GenStat Release 10.3DE, Discovery Edition 4, VSN International Ltd. (Rothamsted Experimental Station).

Hartman G.L., Ellen D.W., Herman T.K. (2011): Crops that feed the World 2.Soybean - worldwide production, use, and constraints caused by pathogens and pests. Food Security 3: 5-17.

Jandong E.A.,Uguru M.I., Oyiga B.C. (2011): Determination of yield stability of seven Soybean (*Glycine max*) genotypes across diverse soil pH levels using GGE biplot analysis. Journal of Applied Biosciences 43: 2924- 2941.

Kamadi R. E. (2001): Relative stability, performance and superiority of crop genotypes across environments. Journal of Agricultural, Biological and Environmental Statistics 76: 197-199.

Karimizadeh R., Mohammadi M., Sabaghni N., Mahmoodi A.A., Roustami B., Seyyedi F., Akbari F. (2013): GGE Biplot Analysis of Yield Stability in Multi-environment Trials of Lentil Genotypes under Rainfed Condition. Notulae Scientia Biologicae 5(2): 256-262.

Lal R. (2009): Soil degradation as a reason for inadequate human nutrition. Food Security 1: 45-57.

Lin C. S., Binns M. R., Lefkovitch L. P. (1986): Stability analysis: where do we stand? Crop Science 26: 894-899.

Makinde S.C.O., Ariyo O. J. (2011): Analysis of Genotype× Environment interaction of groundnut (*Arachis hypogaea* L.). Malaysian Journal of Applied Biology 40 (2): 19-26.

Makinde S.C.O., Ariyo O.J., Akinbowale R.I. (2013): Assessment of groundnut performance in different environments using Additive Main effects and

Multiplicative Interaction (AMMI) model. Canadian Journal of Plant Breeding 1(2): 60-66.

Miranda G. V., Souza L. V., Guimarães L. J. M., Namorato H. L., Oliveira R., Soares M. O. (2009): Multivariate analyses of genotype × environment interaction of popcorn. Pesquisa Agropecuaria Brasileira 44(1): 45-50.

Mitrovic B., Stanisavljevic D., Treski S., Stojakovic M., Ivanovic M., Bekavac G., Rajkovic M. (2012): Evaluation of experimental Maize hybrids tested in Multi-location trials using AMMI and GGE biplot analysis. Turkish Journal of Field Crops 17(1): 35-40.

Naroui Rad M.R., Abdu Kadir M., Rafii M.Y., Jaafar H.Z.E., Naghavi M.R., Ahmadi F. (2013): Genotype × environment interaction by AMMI and GGE biplot analysis in three consecutive generations of wheat (*Triticum aestivum*) under normal and drought stress conditions. Australian Journal of Crop Science 7(7): 956-961.

Olufajo O.O., Pal U.R., Nnadi L.A., Adu J.K., Asenime I.O.R. (1984): Influence of cultural practices on soybean yield in Nigeria Savanna. Proceedings of the 4th National Meeting of Nigerian soybean Scientists 4: 112-131.

Pal U.R., Olufajo O.O., Nnadi L.A. (1983): Response of soybean to sowing date, planting arrangement and fertilizer application in Nigeria savanna. Proceedings of the 3rd National Meeting of Nigerian Soybean Scientists 3: 108-124.

R Core Team (2013): A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URLhttp://www.R-project.org/.

Thiyagu D., Rafii M.Y., Mahmud T.M.M., Latif M.A., Malek M.A., Sentoor, G. (2013): Genotype by environment assessment in sweet potato as Leafy vegetable using AMMI model. Pakistan Journal of Botany 45(3): 843-852.

Vaughan J. G., Geissler C.A. (2008): The New Oxford Book of Food Plant. Oxford University Press, 280 p.

Van Euwijk F.A., Elgersma A. (1993): Incorporating environmental information in an analysis of G × E interaction for seed yield in perennial ryegrass. Heredity 70: 447-457.

Yan W., Hunt L.A. (2001): Interpretation of genotype x environment interaction for winter wheat yield in Ontario. Crop Science 41: 19-25.

Yan W., Hunt L.A., Sheng Q., Szlavnics Z. (2000): Cultivar evaluation and mega-environment investigations based on the GGE biplot. Crop Science 40: 597-605.

Yan, W., Rajcan I. (2003): Prediction of cultivar performance based on single-versus multiple-year test in soybean. Crop Science 43: 549-555.

Yan W., Kang M. S, Ma B., Woods S., Cornelius P. L. (2007): GGE biplot*vs*.AMMI analysis of genotype-by-environment data. Crop Science 47: 643-655.

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