Ethiop. J. Biol. Sci. **11(1): 43-55, 2012**

ISSN: 1819-8678

COMPARISON OF STABILITY MODELS IN MULTI-ENVIRONMENT RICE TRIALS IN THE SOMALI REGIONAL STATE OF ETHIOPIA

Zelalem Fisseha[1,*], Kifle Dagne[1] and Kassahun Tesfaye[1]

ABSTRACT: Twelve upland rice varieties, deemed NERICA (*Oryza sativa* x *O. glaberrima*) were planted at three locations of the Somali Regional State of Ethiopia in April 2010 with the objective of identifying the most stable varieties and suitable stability models. Data were collected on eight yield and yield-related phenological and agronomic traits. The analysis of variance across locations for grain yield indicated that genotypic variations were highly significant to significant in all locations. The combined analysis of variance using Analysis of Variance (ANOVA) indicated that location, genotype, and genotype x location (G x L) mean squares were highly significant. The six stability models considered in the experiment (ANOVA, Eberhart and Russell, Additive Main Effects and Multiplicative Interactions (AMMI), Wricke's ecovalence; Nassar and Hühn's; and Shukla's) identified different genotype(s) to be the most stable ones. On the other hand, comparison among the stability models using the criteria of Zobel *et al.* (1988) and Spearman's rank correlation coefficients indicated, AMMI and Eberhart and Russell's model outsmarted ANOVA and AMMI's Interaction Principal Component Axis (IPCA); Wricke's ecovalence (W_i); Nassar and Hühn's absolute rank difference (S_1); and Shukla's stability variance (σ_i^2) were in best correspondence with the ranking of the genotypes, respectively.

Key words/phrases: Correlation, Ecovalence, Genotypes, NERICA, Stability models.

INTRODUCTION

The Somali Regional State, which is located in the eastern dryland areas of Ethiopia, belongs to the completely arid and semi-arid agro-ecological zone classification (Somali Region Pastoral and Agro-pastoral Research Institute, 2009). The region is endowed with a huge fertile flat land; vast water resources (with about four annual/perennial rivers); and rich human power (Ministry of Agriculture and Rural Development, 2010). Owing to these potentials, it is expected that the region will be amongst the most promising regions in Ethiopia in complementing the nationwide effort to ensure food security in Ethiopia (Somali Region Pastoral and Agro-pastoral Research Institute, 2009).

---

[1] Department of Microbial, Cellular and Molecular Biology, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia. E-mail: woldemerkorios@gmail.com

[*] Author to whom all correspondence should be addressed

In multi-environment trials, the occurrence of genotype x environment interaction (GEI) is inevitable, and causes differences between genotypes in yield stability and presents limitations on selection and recommendation of varieties for target set of environments (Navabi *et al.*, 2006). Even though introduced only recently, rice has proven to be of promising potential in the endeavour to ensure food security in Ethiopia (Ministry of Agriculture and Rural Development, 2010). In line with this, the Somali Region Pastoral and Agro-pastoral Research Institute (SoRPARI) has put rice as a major target research crop, endeavoured to adapt elite/commercial upland/irrigated rice varieties towards ensuring fast and sustainable technology delivery to customers (pastoralists/agro-pastoralists) in the region. Pertinent to these efforts, it has delivered 5 upland and 3 irrigated rice varieties to end-users in the region (Somali Region Pastoral and Agro-pastoral Research Institute, 2009). Nonetheless, as the occurrence of genotype x environment interaction (GEI) impedes the stable performance of varieties and the varieties released so far have not faired equally well in the various agro-ecological zones of the region (Somali Region Pastoral and Agro-pastoral Research Institute, 2009). Hence, there has been a dire need to determine the extent of GEI in the target rice research and promotion environs. Although several statistical techniques have been developed to estimate the level of interaction of genotypes to varying environments (Anandan and Eswaran, 2006), not all of them are always effective enough in analyzing the multi-environment data structure in breeding programs (Zobel *et al.*, 1988; Navabi *et al.*, 2006). Hence, efficient stability models, which best explain the pattern of GEI and specific/wide range adaptability of genotypes, should be identified so as to make the whole varietal development endeavour effective (Ebdon and Gauch, 2002). Therefore, this study was aimed at assessing the aforementioned six models for their parsimony; effectiveness; meaningfulness; and optimum positive rank correlations with the others in rice yield trial data sets conducted in the year 2010 at three locations in the Somali Regional State, which belongs to rain-fed/irrigation supplemented growing cultures.

MATERIALS AND METHODS

Twelve upland rice varieties were planted at three locations, Gode, Kelafo, and Dolo-Ado in April 2010. All the trials were laid out in Randomized Complete Block Design (RCBD) with three replications. Spacing between rows was 20 cm and within rows 10 cm. Four rows of an equal length of 5 m were planted in each plot. Randomization was kept the same at all locations. All necessary agronomic packages were applied as per the recommended package for rice. Data were taken on the basis of ten plants from the middle two rows (harvestable rows) on the following parameters: plant height in cm; number of effective tillers per plant; number of spikelets per spike; and panicle length. On the other hand, data were taken on the following parameters on a plot basis (from the middle two rows): stand count after emergence; days to 50% flowering; days to 50% maturity; stand count at harvest; and grain yield.

The plot mean values were subject to environment-wise analysis of variance, as per the RCB design for all the characters. Subsequently, means file were generated and a two-way G x E table created. Then, combined analysis of variance as per combined RCBD ANOVA: Environment x Entry model was undertaken for each character. Statistical analyses for genotypic x environment interaction and stability were carried out on grain yield per plot for ANOVA; Eberhart and Russell regression model; Wricke's ecovalence stability model; Nassar and Hühn's non-parametric stability model; Shukla's stability variance and AMMI model. On the other hand, analyses of variance across locations and over locations were carried out for yield-related traits mentioned in the previous section so as to assess the extent of variation with respect to main and interaction effects.

Details of the stability models used

The classic model for analyzing the total yield variation contained in GEI observations is the analysis of variance. The within-environment residual mean square measures the error in estimating the genotype means due to differences in soil fertility and other factors, such as shading and competition from one plot to another. After removing the replicate effect when combining the data, the GE observations are partitioned into two sources: (a) additive main effect for genotypes and environments and (b) non-additive effects due to GEI. The analysis of variance of the combined data expresses the observed (Y_{ij}) mean yield of the i^{th} genotype at the j^{th} environment as:

$$Y_{ij} = \mu + \mathrm{G}_{\mathrm{i}} + E_j + GE_{ij} + e_{ij}$$

Where μ is the general mean; G_i, E_j, and GE_{ij} represent the effect of the genotype, environment, and the GEI, respectively; and e_{ij} is the average of the random errors associated with the r^{th} plot that receives the i^{th} genotype in the j^{th} environment.

Eberhart and Russell (1966) proposed pooling the sum of squares for environments and GEI and subdividing it into a linear effect between environments (with 1 df), a linear effect for genotype x environment (with E-2 df). In effect the residual mean squares from the regression model across environments is used as an index of stability, and a stable genotype is one in which the deviation from regression mean squares (S_{di}^2) is small. The model equation for Eberhart and Russell's model is:

$$Y_{ij} = m + b_i I_j + \delta_{ij} \qquad (i = 1, 2, \ldots, t \text{ and } j = 1, 2, \ldots, s).$$

Where Y_{ij} is the mean of the i^{th} variety in j^{th} environment, m is mean of all varieties over all the environments, b_i is the regression coefficient of the i^{th} variety on the environmental index, I_j is the environmental index, which is defined as the deviation of the mean of all the varieties at a given location from the overall mean and δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment.

Wricke (1962; 1964) defined the concept of ecovalence as the contribution of each genotype to the GEI sum of squares. The ecovalence (W_i) or stability of the i^{th} genotype is its interaction with the environments, squared and summed across environments, and expressed as:

$$W_i = \left[\overline{Y_{ij}} - \overline{Y_{i.}} - \overline{Y_{.j}} - \overline{Y_{..}}\right]^2$$

Where Y_{ij} is the mean performance of genotype i in the j^{th} environment and $Y_{i.}$ and $Y_{.j}$ are the genotype and environment mean deviations, respectively, and $Y_{..}$ is the overall mean. For this reason, genotypes with a low W_i value have smaller deviations from the mean across environments and are thus more stable.

Shukla (1972) defined the stability variance of genotype i as its variance across environments after the main effects of environmental means have been removed. Since the genotype main effect is constant, the stability variance is thus based on the residual (GE_{ij} + e_{ij}) matrix in a two-way classification. The stability statistic is termed "stability variance" (σ_i^2) and is estimated as follows:

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)}\left[G(G-1)\sum_j \left(Y_{ij} - \overline{Y_{i.}} - \overline{Y_{.j}} + \overline{Y_{..}}\right)^2 - \sum_i \sum_j \left(Y_{ij} - \overline{Y_{i.}} - \overline{Y_{.j}} + \overline{Y_{..}}\right)^2\right]$$

Where Y_{ij} is the mean yield of the i^{th} genotype in the j^{th} environment, $Y_{j.}$ is the mean of the genotype i in all environments, $Y_{.j}$ is the mean of all genotypes in jth environments and $Y_{..}$ is the mean of all genotypes in all environments.

AMMI combines analysis of variance (ANOVA) into a single model with additive and multiplicative parameters.

The model equation is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$$

Where Y_{ij} is the yield of the ith genotype in the jth environment, μ is the grand mean, G_i and E_j are the genotype and environment deviations from the grand mean, respectively, λ_k is the eigen value of the Principal Component Analysis (PCA) axis k, α_{ik} and γ_{jk} are the genotype and environment principal component scores for axis k, n is the number of principal components retained in the model and e_{ij} is the error term.

The comparison between the conventional stability parameter of ANOVA, the univariate Eberhart and Russell's and the multivariate AMMI models was done firsthand, using the criteria set by Zobel *et al.* (1988): parsimony (as to whether the model allots the fewest possible degrees of freedom to itself; effectiveness (in that the model explained most of the total sum of squares); and meaningfulness (the model provides extra pieces of information apart from its analysis of variance tables). Furthermore, all the models (the aforementioned plus the alternative ecovalence stability model, Shukla's stability variance model and the non-parametric Nassar and Hühn's stability model) were compared using the standard Spearman's coefficient of rank correlation (r_S) (Steel and Torrie, 1980).

RESULTS

Analysis of genotype x environment with different statistical models

Analyses of the multi-location data set using ANOVA showed that the location and G x E sources of variation were highly significant. Using coefficient of variability (CV_i) and mean yield jointly, as stability parameters (Francis and Kannenberg, 1978), NERICA-1 was the most stable variety, as it had one of the highest yield values and the lowest CV_i (%) ratio (Table 1).

The analysis of variance with the Eberhart and Russell's linear regression model shows that there were non-significant variations among genotypes and genotypes x environment (linear), the residual. As the G x E (linear) sum of squares were not as large portion of the G x E interaction when compared with the environment E (linear) sum of squares and the residual sum of squares, only the deviation mean square was considered important. Combining the criterion stating b_i values close to unity and higher yield levels to select stable genotypes, NERICA-15 was the most stable genotype (mean yield=0.84; b_i=1.2042; and S_{di}^2= -0.0005) (Table 1).

Table 1. Stable genotypes with the different stability models.

S.N.	Model	Stability parameter	Stable genotypes
1.	ANOVA	CV_i and mean yield	NERICA-1
2.	Eberhart and Russell	b_i, S_{di}^2, yield	NERICA-15
3.	AMMI	IPCA-1 and yield	FOFIFA-3730; NERICA-14; and NERICA-16
4.	Wricke's Ecovalence	W_i	FOFIFA-3737; NERICA-14; and FOFIFA-3730
5.	Nassar and Hühn's	S_1	FOFIFA-3737; NERICA-14; and FOFIFA-3730
6.	Shukla's stability variance	σ_i^2	FOFIFA-3730; NERICA-14; and FOFIFA-3737

AMMI analysis of variance indicated that all genotype, G x E, and environment variations were significant. AMMI partitioned the data set in one Interaction Principal Component Axis (IPCA), as the 2nd IPCA was insignificant and of negligible sum of squares (considered as a noise). According to the IPCA 1 scores, FOFIFA-3730 was the most stable genotype followed by NERICA-14, NERICA-16 and FOFIFA-3737 (Table 1). In addition, AMMI indicated that there was a stronger cross over interaction, as there was a keener fluctuation in the top-ranking genotypes from one location to another. Moreover, rank of AMMI adjusted means flagged different unadjusted ranks in 13 out of 18 instances (Table 2). In a nutshell, there were 5 groups of genotypes:

1. Higher yielding and higher positive interaction, NERICA-1;
2. Higher yielding and higher negative interaction, NERICA-11;
3. Moderate yielding and lower interaction, NERICA-14 and NERICA-12;
4. Moderate yielding and moderate interaction, NERICA-13, NERICA-10, and NERICA-15; and
5. Below average (lower than the grand mean) yields and lower interactions, FOFIFA-3737, NERICA-16, FOFIFA-3730, FOFIFA-4129, and NERICA-17.

Wricke's ecovalence method identified FOFIFA-3737 (W_i=0.0034); NERICA-14 (W_i =0.0101); and FOFIFA-3730 (W_i=0.0086) with the lowest ecovalence values, as the most stable ones. On the other hand, according to the Nassar and Hühn's stability model, FOFIFA-3737; FOFIFA-3730; and NERICA-14 were the most stable. On the other hand, the most stable varieties, as per the Shukla's stability variance parameter were FOFIFA-3730; NERICA-14; and FOFIFA-3737 (Table 1).

Comparison among stability models

Method 1: Parsimony, effectiveness and meaningfulness

Zobel *et al*. (1988) stated that when a data structure agrees with the model, the analysis of variance achieves the following three goals: parsimony (the model contains relatively few of the total degrees of freedom); effectiveness (the model contains relatively most of the total SS, leaving a residual with most of the degrees of freedom but few SS); and meaningfulness (the model provides agronomically meaningful insights in to the data structure). In light of these, the Eberhart and Russell's model (model degree of freedom= 32.71% of the total degree of freedom) and AMMI (model df=38.32% of the total degrees of freedom) successfully met the first criterion, parsimony (Table 3). On the other hand, with respect to the second criterion, effectiveness, ANOVA outsmarted both the Eberhart and Russell's and AMMI models. Nonetheless, it was inefficient in that it allots the lowest portion of the model SS to the G x E interaction term. With regards to the criterion of meaningfulness, the AMMI model was the best one, as it gave the following in depth insights in to the data set:

- Analysis of G x E interaction was discerned in to 1 or more IPCA axes.
- It provided a detailed information on the interaction of a genotype and an environment in its biplot (Fig. 1).
- AMMI means which are adjusted and unadjusted for interaction effects, which clearly show that basing on ANOVA's arithmetic means per se may lead to a relatively imprecise conclusion (Table 2).

Table 2. AMMI means at the three locations adjusted and unadjusted for interaction effects.

	Gode				**Kelafo**				**Dolo Ado**			
	Adjusted		**Unadjusted**		**Adjusted**		**Unadjusted**		**Adjusted**		**Unadjusted**	
Genotype	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**
NERICA-11	1.355	1	1.434	1	0.266	9	0.313	6	1.537	1	1.410	1
NERICA-15	0.910	2	0.892	2	0.335	5	0.324	5	1.285	3	1.313	2
NERICA-13	0.857	3	0.847	3	0.223	11	0.216	12	1.210	4	1.227	4
NERICA-12	0.777	4	0.788	5	0.219	12	0.226	11	1.159	7	1.140	8
NERICA-14	0.749	5	0.798	4	0.364	4	0.394	3	1.196	5	1.117	9
FOFIFA-3730	0.633	6	0.587	7	0.263	10	0.235	10	1.086	9	1.160	7
NERICA-1	0.626	7	0.771	6	0.933	1	1.020	1	1.334	2	1.102	10
NERICA-17	0.594	8	0.526	10	0.332	6	0.290	7	1.087	8	1.197	6
NERICA-16	0.570	9	0.480	12	0.294	7	0.239	9	1.058	11	1.203	5
NERICA-10	0.564	10	0.485	11	0.615	2	0.567	2	1.175	6	1.301	3
FOFIFA-3737	0.550	11	0.559	8	0.276	8	0.282	8	1.039	12	1.025	12
FOFIFA-4129	0.537	12	0.556	9	0.380	3	0.391	4	1.070	10	1.040	11
	Grand Mean=0.73				**Grand Mean= 0.37**				**Grand Mean= 1.19**			

Table 3. Sum of squares and mean square values of 12 upland rice varieties in three locations in 2010.

Model	**SS genotype**	**SS environment**	**SS G x E**	**MS genotype**	**MS environment**	**MS G x E**
ANOVA	1.803	11.941	2.639	0.164*	5.971**	0.120**
Eberhart and Russell	0.591	--	0.356	0.054^{ns}	--	0.032^{ns}
AMMI	1.773	11.921	2.706	0.161*	5.961**	0.123**

NOTE: *=significant at 5% value of α; **=significant at 1% value of α; ns=not significant

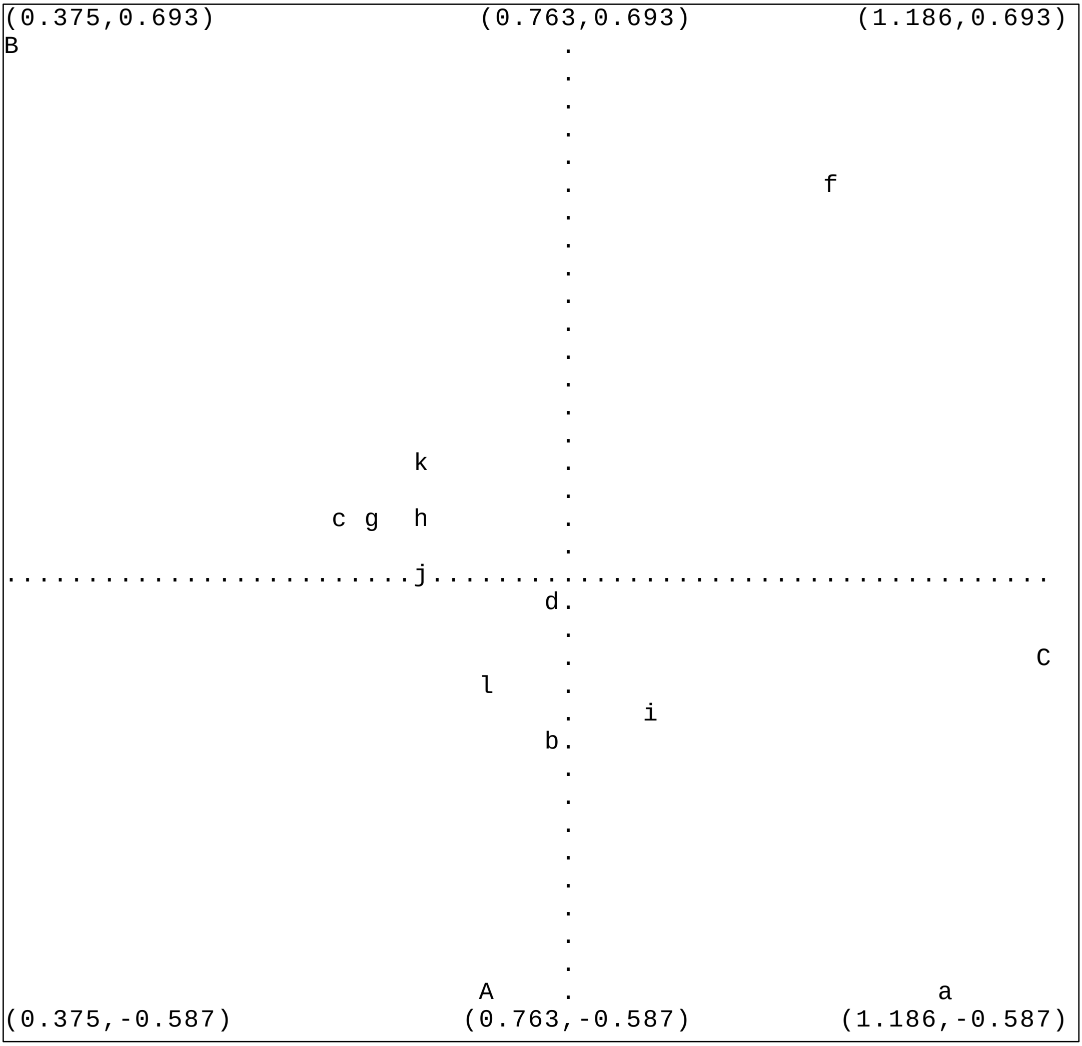

Fig. 1. Comparative study of various stability models…, Biplot with abscissa (X-axis) plotting means from 0.375 to 1.186 and with ordinate (Y-axis) plotting IPCA-1 from -0.587 to 0.693.

(Note:1 genotype (e=NERICA-10) in place of others with similar means and not shown)

Legend locations: A=Gode, B=Kelafo, C=Dolo Ado
Genotypes: a=NERICA 11; b=NERICA-13; c=FOFIFA-3737; d=NERICA-14; f=NERICA-1; g=NERICA-16; h=NERICA-17; i=NERICA-15; j=FOFIFA-3730; k=FOFIFA-4129; l=NERICA-12

Method 2: Comparison with Spearman's rank correlation coefficient

All the genotypes were ranked according to the assigned values from each procedure's analysis and definition. The ranked orders were, then, used to determine Spearman's ranked correlation coefficient between the different procedures. As per the rank correlation values, IPCA, Wricke's Ecovalence (W_i), Nassar and Hühn's absolute rank difference (S_1), and Shukla's stability variance (σ_i^2) had the highest values (Table 4). These stability models are recommended for future use in multi-environment rice trials. Of all the stability parameters, W_i had the highest number of significant positive rank correspondences with most of the traits. On the other hand, stability parameters of the conventional ANOVA, mean yield and CV_i showed the greatest deviation from all the other procedures, and were the most unsuitable for future application (Table 4).

Table 4. Spearman correlation coefficients for various stability models in 12 upland rice varieties in April 2010.

	MYLD	CV_i	S_{di}^2	b_i	IPCA	W_i	S_1	σ_i^2
MYLD		0.65035*	-0.20280	-0.41958	-0.76224**	-0.70629*	-0.56643	-0.64336*
CV_i	0.65035*		-0.15385	-0.02797	-0.44755	-0.21678	-0.16084	-0.21678
S_{di}^2	-0.20280	-0.15385		0.06993	0.22378	0.30769	0.39161	0.33566
b_i	-0.41958	-0.02797	0.06993		0.36364	0.58741*	0.53147	0.54545
IPCA	-0.76224**	-0.44755	0.22378			0.83217**	0.74825**	0.86713**
W_i	-0.70629*	-0.21678	0.30769		0.83217**		0.95105**	0.97902**
S_1	-0.56643	-0.16084	0.39161		0.74825**	0.95105**		0.93007**

NOTE: *=significant at 5% value of α; **=significant at 1% value of α.

DISCUSSION

Even though data across various locations/years would yield more conclusive information to compare the various stability models used in the study, the location variability as used in this study can provide baseline information on the performance of stability models in relation to multi-environment rice trials in the Somali Regional State of Ethiopia. Further studies using data across varying location/year can strengthen the findings of the study.

Vange and Obi (2005) reported significant variability in location and G x E interaction in upland rice multi-location trials. On the other hand, the superlative importance of deviation mean square (S_{di}^2) towards identifying stable genotypes in the Eberhart and Russell regression model was also reported by Adugna Wakjira and Labuschagne (2001) and Alberts (2004) in linseed and maize Multi-Environment Trial (MET).

The analysis of the current data set with AMMI showed that the location sum of squares were the largest of all other variation terms. Misra *et al.* (2009) reported similar findings with the above. On the other hand, G x E SS was about 1.5 times that of genotype SS (Table 3), which parallels with the findings of Yang *et al.* (1999) in rice MET. Furthermore, none of the varieties deemed stable in the AMMI were identified as stable in the Eberhart and Russell's Linear Regression Model (Table 1). Misra *et al.* (2009) gave an agreeing remark in this regard. There was a significant fluctuation with respect to adjusted and unadjusted AMMI mean yield values (Table 2), which was also reported by Aina *et al.* (2007) and Asrat Asfaw *et al.* (2009).

ANOVA allotted the least proportion of the total model SS to the G x E source of variation (Table 3). Similarly, Zobel *et al.* (1988) argued that as ANOVA is a strictly additive model, it often confounds main effects with interaction sum of squares. Moreover, they noted this limitation of the model makes it unsuitable to be used as a model of analysis in MET.

The strongest rank correlations among W_i, IPCA, S_1, and σ_i^2 has also been reported by Alberts (2004).

CONCLUSION

The parsimony, effectiveness, and meaningfulness criteria of comparison between ANOVA, Eberhart and Russell's, and AMMI models showed that AMMI outsmarted the other two models in satisfying all the three criteria.

According to Spearman's rank correlation coefficients (Steel and Torrie, 1980) the following procedures were in correspondence with the ranking of the genotypes, namely: AMMI's IPCA; Wricke's ecovalence (W_i); Nassar and Hühn's absolute rank difference (S_1); and Shukla's stability variance (σ_i^2). Furthermore, stability parameters like the Eberhart and Russell's regression coefficient (b_i) and mean deviation from regression (S_{di}^2) can also be used in conjunction with the aforementioned models, which had higher correspondences with respect to ranking of genotypes across varying locations. On the other hand, the procedures of ANOVA, namely mean yield and CV_i showed the greatest deviation from all the other procedures, showing negative or non-significant correlation with the other procedures. Therefore, these two procedures should not be used as stability parameters in multi-environment rice trials.

In a nutshell, from the results of both comparisons (methods 1 and stage 2), it can be inferred that the conjunctive use of IPCA, W_i, and σ_i^2 is the most efficient with respect to explaining GEI and yield stability in multi-location upland rice trials in agro-ecologies similar to the target environment.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support and contributions rendered by the following. Firstly, they want to acknowledge the tremendous support rendered by the Rural Capacity Building Project (RCBP) via availing the financial resources needed for undertaking the experiment. Subsequently, yet importantly, they want to seize this opportunity to thank staff and management of the Somali Region Pastoral and Agro-pastoral Research Institute (SoRPARI) for availing the necessary infrastructure and human power required to conduct the field experiment.

REFERENCES

Adugna Wakjira and Labuschagne, M.T. (2001). Genotype-environment interactions and phenotypic stability analyses of linseed in Ethiopia. *Plant Breeding* **121**: 66-71.

Aina, O.O., Dixon, A.G.O. and Akrinide, E.A. (2007). Additive main effects and multiplicative interactions analysis for yield of cassava in Nigeria. *J. Biol. Sci.* **7**: 796-800.

Alberts, M.J.A. (2004). A comparison of statistical methods to describe genotype x environment interaction and yield stability in multi-location maize trials. M. Sc. Thesis, University of the Free State, South Africa.

Anandan, A. and Eswaran, R. (2006). Genotype by environment interactions of rice (*Oryza sativa* L.) hybrids in the east coast saline region of Tamil Nadu. In: **The Proceedings of 2nd International Rice Congress**, pp. 2-26, New Delhi, India.

Asrat Asfaw, Fistum Alemayehu, Fekadu Gurum and Mulugeta Atnaf (2009). AMMI and SREG GGE biplot analysis for matching varieties onto soybean production environments in Ethiopia. *Sci. Res. Essays* **4**: 1322-1330.

Ebdon, J.S. and Gauch, H.G. (2002). Additive main effect and multiplicative interaction analysis of national turf grass performance trials: I. Interpretation of genotype x environment interaction. *Crop Sci.* **42**: 489-496.

Eberhart, S.A. and Russell, W.A. (1966). Stability parameters for comparing varieties. *Crop Sci.* **6**: 36-40.

Francis, T.R. and Kannenberg, L.W. (1978). Yield stability studies in short-season maize. I. A descriptive method for grouping genotypes. *Can. J. Plant Sci.* **58**: 1029-1034.

Ministry of Agriculture and Rural Development (MOARD) (2010). National Rice Research and Development Strategy of Ethiopia, pp. 11-12, Addis Ababa, Ethiopia.

Misra, R.C., Das, S. and Patnaik, M.C. (2009). AMMI model analysis of stability and adaptability of late duration finger millet (*Eleusine coracana*) genotypes. *World Appl. Sci. J.* **6**: 1650-1654.

Navabi, A., Yang, R.C., Helm, J. and Spawer, D.M. (2006). Can spring wheat growing mega-environments in the northern great plain be dissected for representative locations or niche-adapted genotypes? *Crop Sci.* **46**: 1107-1116.

Shukla, G.K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity* **29**: 237-245.

Somali Region Pastoral and Agro-pastoral Research Institute (SoRPARI) (2009). Annual Report, Jijiga, Ethiopia.

Steel, R. G. and Torrie, J. H. (1980). **Principles and Procedures of Statistics**. McGraw-Hill, New York.

Vange, T. and Obi, I.U. (2005). Yield stability and environmental responses of some improved upland rice (NERICA) lines in the Southern Guinea savanna of Nigeria. *Heredity* **31**: 21-25.

Wricke, G. (1962). Über eine methode zur erfassung der ökologischen Streubreite in feldversuchen. *Z. Pflanzenzüchtung*. **47**: 92-96.

Wricke, G. (1964). Zur berechnung der ökovalenz bei sommerweizen und hafer. *Z. Pflanzenzüchtung.* **52**: 127-138.

Yang, S., Shen, X., Wang, L., and Xie, F. (1999). AMMI model analysis of regional trials on second cropping japonica rice varieties in Southern China. *Jiaganso Agricultural Research* **20**: 33-35.

Zobel, W.R., Wright, W.J. and Gauch (Jr.), J.H. (1988). Statistical analysis of a yield trial. *Agron. J.* **80**: 388-393.