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Agronomic Performance Evaluation and Yield Stability Analysis of Upland Rice (*Oryza sativa* L.) Varieties Using AMMI and GGE Biplot

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Abstract: A field experiment was conducted in the rainfed upland rice producing areas of Ethiopia; Gonder, Pawe and Shire-Maitsebrie during 2017 and 2018 cropping seasons. Thirteen upland rice varieties were tested with the objective of examining the agronomic performance and yield stability of the varieties using Additive Main Effect and Multiplicative Interaction (AMMI) and Genotype and Genotype by Environment (GGE) biplot analysis. The AMMI analysis of variance for grain yield detected significant effects for genotypes, environments and genotype by environment interactions. Environment effect was responsible for the greatest part of the variation, followed by genotype by environment interaction and genotype effects. Based on the AMMI stability analysis G1, G2 and G5 were the most stable genotypes, while G13, G3 and G12 were the most responsive ones. The GGE biplot also showed that G13, G3, G12 and G10 have long vectors and located far away from the biplot origin and hence are considered to have larger contribution to GEI. Among the tested genotypes G1 (Fogera-1), G5 (Andassa) and G2 (Adet) gave high yield and good stability across environments and can be recommended for production for the testing sites and similar upland rice producing areas of Ethiopia.

Keywords: Genotype, GGE, AMMI, Stability

1. Introduction

Rice production and productivity is increasing even though it is recently introduced cereal crop. It is now produced under three main rice ecological zones in Ethiopia, namely rain fed upland, lowland and irrigated. With these ecologies the country has a huge potential of land which is estimated around five million of hectares [6]. After its introductions, research centers had dealing on different production constraints of the crop. As a result of releasing different rice varieties with their full packages and recommended for different rice producing areas, the production and productivity of the crop has been increasing from year to year.

Among the major rice production constraints lack of high yielding and adapted varieties, terminal moisture stress and low soil fertility, disease and cold effect, termite attack are the ones that hinder the expansion of the crop [1]. From the above-mentioned rice production constraints, lack of high yielding and adapted variety is the major bottleneck especially in the upland rice producing areas of Ethiopia. Some of the improved upland rice varieties were found to be adapted in the upland rice producing areas of Ethiopia, but majority of these have showed lower yield performance. These could be the changing of environments and its interaction with the environment. Evaluating genotypes across environments is a good indicator of the genotype performance in the absence of genotype by

environment interaction [15]. The presence of GEI complicates the selection of the variety and gain from selection. So, these leads screening of genotypes for high adaptation and stability under varying environmental conditions prior to their release. Many statistical procedures are available to evaluate the performance of the genotypes in a multi environment trial. For this study, AMMI and GGE biplot analysis were used.

2. Material and Methods

A field experiment was conducted at Gonder, Pawe and Shire-Maitsebrie Research Centers during 2017 and 2018 cropping seasons in the rain fed upland condition. The descriptions of the trail sites are indicated in Table 1. Thirteen upland rice varieties released from national and regional research centers (Table 2) were evaluated in a randomized complete block design replicated three times, on a plot size of 5 long × 1.5 widths. A spacing of 25 cm, 50 and 1.5 m cm were used between rows, between plots and between blocks respectively.

Data were recorded on 5 randomly selected plants from the middle four rows for panicle length, plant height, number of filled grains per panicle, and on plot bases for days for heading, days for maturity. Grain yield and thousand seed weight were taken on plot basis from the four harvestable rows. Fertilizer application and weeding were carried out following the recommended packages of the areas. Data were subjected to analysis of variance (ANOVA) using GenStat version 12 edition software package [8]. Genotype by environment interaction effects detected in ANOVA that leads to the genotype by environment interaction (GGE) biplot model based on singular value decomposition (SVD) of first two principal components as follows [16].

$$Y_{ijk} = \mu + G_i + E_J + \sum_{k=1}^{m} \lambda_k \, \alpha_{ik} \, \gamma_{jk} + p_{ij}$$

Where Y_{ijk} = the yield of ith genotype in the jth environment, G_i = the mean of the ith genotype minus the grand mean, E_J = the mean of the jth environment minus the grand mean, λ_k = the square root of the eigen value of the kth IPCA axis, α_{ik} and γ_{jk} = the principal component scores for IPCA axis k of the ith genotypes and the jth environment, p_{ij} = the deviation from the model AMMI with only two interaction principal component axes could be the best predictive model [17].

Table 1. Description of experimental locations.

Location	Elevation (m)	Latitude	Longitude	Annual rain fall (mm)	Mean temperature (°C)		Soil type
					Min	Max	
Gonder (Metema)	750	12°54'N	36°15'E	1100	22 .0	29.0	Vertisol
Pawe	1120	11°19'N	36°24'E	1587	16.3	32.6	Vertisols
Shire-maitsebre	1350	13°05'N	38°08'E	1296	15.0	36.0	Vertisol

Table 2. Description of experimental materials used for the study.

Varieties	Year of released	Released Center	Altitude (m.a.s.l)	Rain fall (mm)	Productivity (qt/ha)	
					On-farm	On-farm
Fogera-1	2016	Fogera	600-1800	800-1400	32-39	42-50
Adet	2014	Adet	600-1800	800-1400	24	42
Nerica-4	2006	Pawe	600-1850	800-1400	30	48
Hiddassie	2012	Adet	600-1850	800-1400	22-32	30-42
Andassa	2007	Adet	600-1850	800-1400	25	38
Chewaka	2013	Bako	<1650	800-1200	33	42
Superica-1	2006	Pawe	600-1850	800-1400	23	51
Nerica-12	2013	Adet	600-1850	800-1200	23-34	35-41
Nerica-13	2014	Maitsebri	1200-1400	650-800	33	38
Getachew	2007	Adet	600-1850	800-1400	21	30
Pawe-1	1998	Pawe	600-1850	800-1400	20	30
Tana	2007	Adet	600-1850	800-1400	24	44
Kokit	1999	Adet	600-1333	1000	28	36

3. Result and Discussion

3.1. Analysis of Variance and Agronomic Performance

The combined analysis of variance for all measured traits are presented in Table 3. The analysis result revealed that a highly significant difference (P ≤ 0.01) was observed for the main effects of genotype and location. A similar study on nine rice genotypes reported that environment, genotype and genotype × environment (GE) interactions had a significant effect on grain yield of rice [8]. A highly significant difference was also detected for years for all measured traits except for grain yield. Genotype x location interaction effect was highly significant (P ≤ 0.01) for days to heading, days to maturity, plant height while it was significant at (P ≤ 0.01) for number of filled grains per panicle, panicle length and grain yield. Genotype x year effect was also found highly significant (P ≤ 0.01) for days to heading, days to maturity, plant height, and grain yield, while a non-significant difference was detected for number of filled grains per panicle and panicle length. A highly significant difference (P ≤ 0.01) was observed for genotype x location effects on days to heading, days to maturity, number of filled grains per panicle, plant height, and grain yield, but a significant difference (P ≤

0.01) was detected for panicle length. The presence of a three-way interaction leads to the stability analysis for identifying which rice genotype adapted well in which location [10, 11]. As presented in Table 3, varieties respond differently for all measured agronomic traits for each location. A mean grain yield ranged from 3258.6 genotype Kokit to 4964.3 for genotype Tana

kgha^{-1}, 70days (Fogera-1, NERICA-4 and Hidassie) to 84 days (Getachew and Pawe-1), 102 days (Adte and Hidassie) to 117 days (Pawe-1), 88.5 (Kokit) to 118.9 (Hidassie), 88.4cm (Kokit) to 133.3cm (Tana) and 17.9 cm (Pawe-1) to 22.4 cm (Getachew) for days to heading, days to maturity, number of filled grain per panicle, plant height and panicle length respectively.

Table 3. *Combined mean grain yield and yield components of 13 upland rice varieties evaluated at three locations from 2017 to 2018 cropping seasons in upland rice producing areas of Ethiopia.*

Genotype	DH	DM	FGPP	PH	PL	GY
Fogera-1	70	103	118.5	92.1	20.4	4639.5
Adet	69	102	117.1	93.1	20.5	4557.5
Nerica-4	70	103	115.1	89.6	20.2	3883.1
Hiddassie	70	102	118.9	90.3	20.8	4509.5
Andassa	81	110	100.2	111.9	21.7	4610.3
Chewaka	82	109	107.2	101.0	20.8	3845.8
Superica-1	72	104	113.8	102.9	19.8	3907.8
Nerica-12	69	103	103.6	95.9	21.1	4177.1
Nerica-13	69	103	107.1	94.1	21.5	4025.7
Getachew	84	111	105.8	112.0	22.4	4505.6
Pawe-1	84	117	99.0	92.0	17.9	4024.4
Tana	82	110	98.9	113.3	21.9	4964.3
Kokit	71	104	88.5	88.4	19.5	3258.6
Mean	75	106	107.2	98.2	21.0	4223.8
CV (%)	2.6	1.9	13.3	5.3	6	15.7
Genotype (G)	***	***	***	***	***	***
Location	***	***	***	***	***	***
Year	***	***	***	***	***	NS
GxL	***	***	**	***	**	**
GxY	***	***	NS	***	NS	***
LxY	***	***	***	***	***	***
GxLxY	***	***	***	***	**	***

Note: **, *** Significant at 1% and 0.1% respectively, NS= Non- significant, DH=Days to heading, DM= Days to maturity, FGPP= Number of filled grains per panicle, PH= Plant height (cm) PL= Panicle length (cm), GY= Grain yield (kgha^{-1})

3.2. AMMI Analysis of Variance

The combined AMMI analysis of variance is presented in Table 4. A highly significant difference (p≤0.01) were observed for genotype, environment and their interactions for grains yield. These factors showed that upland rice grains yield was affected by genotype (8.4%), environment (59.8%) and their interaction (19.1%). A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing variation in the genotype grains yield. This might probably be due to differences in growing season rainfall pattern. Environments contributed more for the variation of genotypes than genotypes themselves [5, 7]. The AMMI model

demonstrated the presence of G x E interactions, and this has been partitioned in to the first and second IPCA (Interaction Principal Components Axes) [3]. Results from AMMI analysis (Table 4) also showed that a highly significant difference (p≤0.01) were observed for the first principal component axis which accounted for 52.35% and the second accounted for 29.4% of the variation. The two PCA axes together accounted 81.7% of the genotype by environment interaction mean squares (Figure 4). A similar study was also reported that the two PCAs explain 88.8% of the total variation on the study of GGE biplot analysis for genotype x environment interaction on yield and in trait of high iron content in rice genotypes in Indonesia under irrigated environment [12].

Table 4. *AMMI analysis of variance for grain yield of 13 upland rice varieties tested at six environments.*

Source	DF	SS	MS	% explained SS
Total	233	536181931	2301210	
Block	12	10034055	836171*	
Treatments	77	468043309	6078485***	
Genotype (G)	12	45263350	3771946***	8.4
Environments (E)	5	320594955	64118991***	59.8
G x E	60	102185005	1703083***	19.1
IPCA 1	16	47978704	2998669***	52.35
IPCA 2	14	43166560	3083326***	29.40
Residuals	30	11039740	367991NS	
Error	144	58104566	403504	

Note: *, *** significant at 5%, and 0.1% respectively, NS= not significant

3.3. AMMI Stability Analysis for Grain Yield

Yield stability study in genotype evaluation is important to see the ability of a genotype to avoid significant fluctuation in yield over a range of environmental conditions. Genotype stability can be either static or dynamic [2]. Static stability is a character that a genotype does not show variation over arrange of low to high environmental differences, while those genotypes having dynamic stability was characterized as a cultivar whose performance fluctuates, when regressed across a low to high environmental productivity range, mirrors the overall mean regression performance of all cultivars in the same trial [13].

On the other hand, if a genotype is not stable, genotype respond either differently in different environments or there is rank change in the genotype response in different environments [5, 14]. In this study inconsistent ranking of genotype grains yield was observed (Table 4). This is possibly an indication of the cross over and non-crossover types of genotype by environment interaction. A high grain yield was recorded on genotype Getachew (7894 kg/ha) in Gonder 2018 cropping season while the lowest grain yield was recorded on genotype Kokit (1719 kg/ha) at Shire-Maitsebrie testing site in 2018 (Table 4).

Table 5. *Grain yield predicted means (kg/ha) of 13 upland rice varieties across six environments and stability indicators of AMMI analysis.*

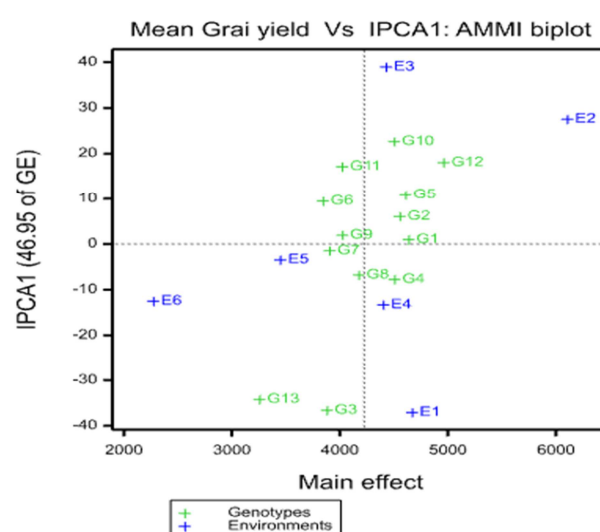| Varieties	Code	E1	E2	E3	E4	E5	E6	Mean	IPCA1	IPCA2
Fogera-1	G1	5528	5589	5884	4428	3695	2713	4640	0.959	-24.775
Adet	G2	5244	5672	5975	4288	3600	2566	4558	6.060	-24.136
Nerica-4	G3	5376	5395	2003	4803	3351	2372	3883	-36.637	16.352
Hiddassie	G4	5577	5511	5110	4530	3647	2682	4510	-7.777	-17.247
Andassa	G5	4229	7655	4343	4986	3952	2497	4610	10.818	22.179
Chewaka	G6	3963	5950	4463	3885	3034	1781	3846	9.444	-1.051
Superica-1	G7	4839	4888	4955	3768	2989	2008	3908	-1.490	-22.246
Nerica-12	G8	5048	5529	4478	4312	3368	2326	4177	-6.808	-8.896
Nerica-13	G9	4325	6119	4147	4242	3274	2048	4026	1.933	3.984
Getachew	G10	3677	7894	4678	4732	3810	2243	4506	22.625	22.656
Pawe-1	G11	3753	6550	4721	4044	3223	1856	4024	17.113	4.366
Tana	G12	4485	7867	5328	5111	4222	2772	4964	17.991	13.452
Kokit	G13	4681	4798	1512	4131	2711	1719	3259	-34.231	15.359
Mean		4671	6109	4431	4405	3452	2276			
IPCA1		-37.11	27.54	38.94	-13.33	-3.49	-12.54			
IPCA2		-19.24	38.84	-40.39	15.31	6.83	-1.35			

E1=Gonder2017, E2=Gonder2008, E3=Pawe2017, E4=Pawe2018, E5=Shire-maitsebre2017, E6= Shire-maitsebre2018

The AMMI 1 biplot of the the main effect (genotype and environment effects) and IPCA-1 scores are plotted aginst each other (Figure 1). In AMMI 1 biplot genotype difference in terms of direction and magnitude are lined along the x-axis (grain yield), while the Y-axis is labeled for IPCA1 scores. In the biplot display, genotypes or environments that appear almost on a perpendicular line of the graph had similar mean yields and those that fall almost on a horizontal line had similar interaction.

Varieties and environments on the same parallel line relative or ordinate have similar yields and a genotype or environment on the right side of the midpoint of this axis has higher yield than those of left-hand side. The score and sign of IPCA1 reflect the magnitude of the contribution of both varieties and environments to GEI, where scores near zero are characteristic of stability, whereas higher score (absolute value) considered as unstable and specific adapted to environment. From the tested upland rice varieties, G12, G10, G5 and G2 are generally showed high yield above the mean yield of the varieties with positive IPCA1 score. This indicated that these varieties are high yielding in high potential areas. Among these varieties, G12 was the overall best yielding verity with positive IPCA1 score. The lowest IPCA-1 scores were observed for G1, G7 and G9 which indicated that higher stability and less interaction with all the

environments (Table 5). Genotypes that have good grains yield and stable performance across the testing environments are good for production. In this study G1, and G2 and G5 are the overall best performing and widely adapted varieties.

Figure 1. *AMMI 1 biplot for grain yield of thirteen upland rice varieties tested in six environments Note: - E1=Gonder2017, E2=Gonder2008, E3=Pawe2017, E4=Pawe2018, E5=Shire-maitsebre2017, E6= Shire-maitsebre 2018.*

3.4. AMMI-II Biplot

The AMMI-II biplot for grain yield display interaction of PC1 and PC2 of the tested varieties in the six environments is presented in Figure 2. In this figure environmental vectors are joined to the origin by side lines. Sites with short spokes do not exert strong interactive forces and had strong contribution to the stability of the variety, while those with long spokes have strong interaction. From the above-mentioned figure environments E3, E1 and E2 had the long spokes which indicated the high discriminating ability of these environments. The distances from the biplot origin are indicative of the amount of interaction that was exhibited by genotypes over environments or environments over genotypes [9, 15].

On the other hand, environments E6, E5 and E4 had short spokes and tells these environments do not exert strong interactive forces. In addition to the environment effects, the genotypes near the origin are not sensitive to environmental interaction while those distant from the origins are sensitive and have large interaction. In this study genotypes G13, G3 and G10 were more responsive since they are far from the origin. On the other hand, genotype G9, G6, G8, G11 and G4 were close to the origin and hence they are less interactive to environmental differences.
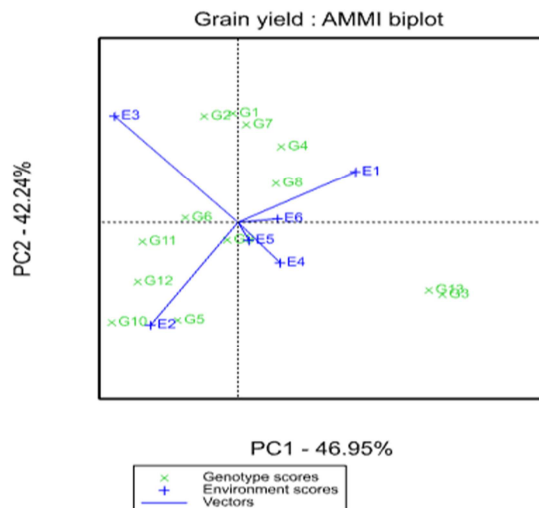

Figure 2. *AMMI-II biplot for grain yield display interaction of PC1 and PC2 of the tested varieties in the six environments.*

3.5. GGE Bi-plot Analysis

In the GGE biplot analysis, the first two PCs explained 81.75% of the total GEI for grain yield (Figure 4). Environments with low IPCA1 and IPCA2 scores which were placed near to the origin in the GGE biplot graph have low discriminating ability for genotypes evaluation and high contribution to the stability of the genotypes [15, 16]. According to the figure presented below (Figure 3), the corner genotypes which have the longest vectors are the highest yielding genotypes for the environments that fall with in the sector [10, 11]. The genotype with high yield in E3, E6, E5, E4, and E2 is genotype G12 followed by G10, G5 G11 and G9. In E1 the good performing genotype is G1 followed

by G2, G7, G4 and G8. There is no location that the vertex genotypes (G3 and G13) fall in and are considered as the poorest genotypes in all the testing environments [14].
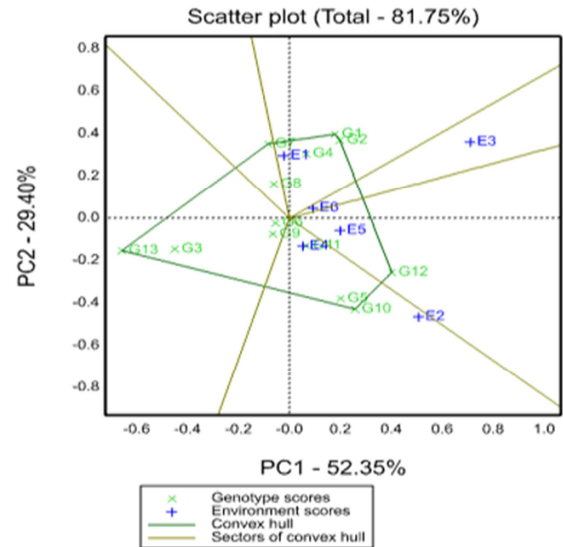

Figure 3. *GGE-biplot analysis of upland rice varieties with respect to the environments.*

3.6. Mean Grain Yield and Stability Performance

The grain yield performance rank of thirteen upland rice genotypes is presented in Figure 4. The genotypes were ranked along the average environment co-ordinate axis (AEC x-axis). The line which pass-through the origin and is perpendicular to AEC represents the stability of the genotypes. Those genotypes which are far from either direction of this line indicates greater GE interaction and low stability. As indicated in Figure 4, genotypes G12 followed by G5, G10, G2, and G1 are the high yielding genotypes. Variety Tana was the best performing genotype on the study of yield and yield related performance of upland rice genotypes in Tselemti district. [4]
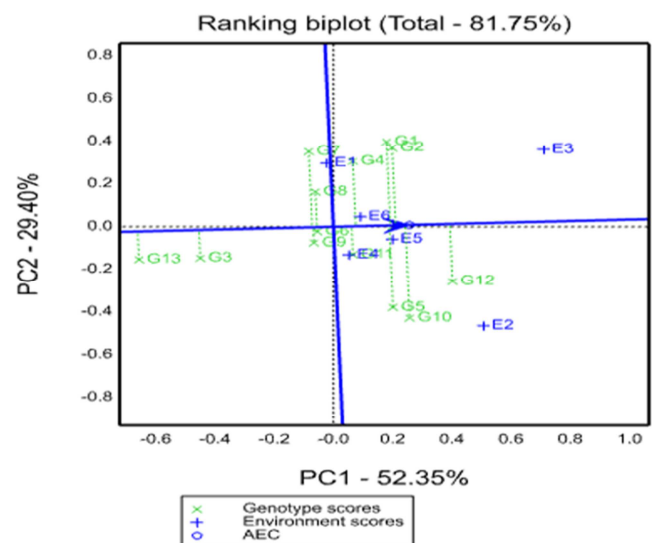

Figure 4. *Ranking genotypes based on mean grain yield performance and stability across environments.*

The other genotypes G2, G4, G11, G10 and G5 are genotypes gave high yield than the average yield, while genotypes on the left side and far away from the AEC axis row (G13, G3, G7, G8, G9 and G6) had mean yield less than the average. Among the tested genotypes G4 was the most stable and high yielding genotype with better average grain yield performance. On the other hand, G12 can be recommended for specific adaptation while genotype G1 and G5 and G2 are both high yielding and stable genotypes and can be recommended for production.

4. Conclusion and Recommendation

This study indicated the significance difference exhibited among the tested genotypes and its interaction with environments for grain yield. This is an indication of a wide variability among genotypes. The GGE and AMMI biplots are useful techniques that were able to effectively detect the existence of a significant amount of GE interaction between thirteen upland rice genotypes across six environments. Both models revealed genotype G12 (Tana) outperformed among the tested genotypes and can be used for specific site production. In variety selection, genotypes with high mean yield and high stability is preferred. As a result, genotypes G1 (Fogera-1), G5 (Andassa) and G2 (Adet) gave high yield and good stability across environments and can be recommended for testing sites and similar upland rice producing areas of Ethiopia.

Acknowledgements

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