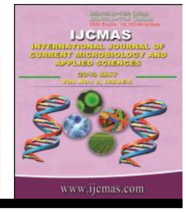
Int.J.Curr.Microbiol.App.Sci (2019) *8*(5): 1-7

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 8 Number 05 (2019)**
Journal homepage: http://www.ijcmas.com



Original Research Article https://doi.org/10.20546/ijcmas.2019.805.001

AMMI Model to Estimate GxE for Grain Yield of Dual Purpose Barley Genotypes

Ajay Verma*, V. Kumar, A.S. Kharab and G.P. Singh

ICAR-Indian Institute of Wheat and Barley Research, Karnal 132001 Haryana, India

**Corresponding author*

Keywords

Genotype × environment interaction, Multi-environment trials, Principal component analysis

Article Info

Accepted:
04 April 2019
Available Online:
10 May 2019

ABSTRACT

Combined analysis of variance, for 16 dual purpose barley genotypes evaluated across 08 environments of the country, showed significant differences for genotypes, environments and their interactions. Most of type 1 measures (EV1, AMGE1, SIPC1 and D1) favored G5, G6, G8 and G10 genotypes while type 2 identified (EV2, AMGE2, SIPC2, D1 and ASV) G11, G14, G10 and G9 as promising genotypes whereas type 3 selected (EV3, AMGE3, SIPC3 and D3) G13, G14, G7 and G8 genotypes and most of the signal accounted by type 5 measures pointed towards (MASV, EV5, AMGE5, SIPC5 and D5) G13, G14, G8 and G16 as desirable genotypes. Hierarchical clustering of AMMI based measures along with yield could be divided into five distinct groups. Group I contains EV3, EV2, EV5, MASV, IPCA4 and AMGE3. Group II contains AMGE5, IPCA6, IPCA1 and average yield. Group III consists of SIPC3, SIPC5, SIPC2, IPCA2, IPCA3 and IPCA5. Group IV combined ASTAB1, ASTAB3, ASTAB5, ASTAB2 with D2, D3 and D5. Smallest cluster grouped ASV with EV1. Genotypes G6 and G10 were of stable performance with average yield while G13 and G5 of moderate yield.

Introduction

Degree and direction of GxE interaction aid breeders to reduce the cost of genotypes evaluation by avoiding uninformative testing locations (Akbarpour *et al.,* 2014). Sufficient understanding of GE interaction and its exploitation can contribute significantly to genotype improvement (Akter *et al.,* 2014). Under multi environments trials genotypes are evaluated at many locations as stable performance accompanied with higher yield are more important as compared to yield at specific environment (Athanase *et al.,* 2017). Plant breeders explore for genotypes with consistency yield performance across environments (Beleggia *et al.,* 2013). Numbers of statistical methods such as ANOVA, joint linear regression model, principal component analysis have been observed in literature to study GxE interaction (Carlos *et al.,* 2006; Dehghani *et al.,* 2010; Gauch *et al.,* 2008). Largely recommended AMMI method is a combination of ANOVA and multiplicative GxE interaction obtained from a singular value decomposition of the matrix of residues (Mohammadi *et al.,* 2015). This analytic tool has an edge over joint linear regression as well as principal components analysis (Kendal and Tekdal, 2016).

Yield stability of genotypes may be very well assessed by AMMI based statistical measures. Zobel (1994) introduced averages of the squared Eigen vector (EV) values as the AMMI stability parameter. AMGE and SIPC stability parameters of AMMI model to describe the contribution of environments to GxE interaction suggested by Sneller *et al.*, (1997). AMMI stability value (ASV) benefits from the first two IPCA of AMMI analysis (Purchase, 1997).

The Euclidean distance from the origin of significant interaction IPCA axes as D parameter was suggested by Annicchiarico (1997). Any of these measures may also be of interest for breeding programs as an alternative to the conventional stability methods such as joint linear regression model (Kilic, 2014). This investigation was carried out to evaluate the effect of GxE interaction on the grain yield of improved genotypes of dual purpose barley by AMMI based measures.

Materials and Methods

Sixteen dual purpose promising barley genotypes were evaluated at eight barley producing locations of the country during cropping season 2017-2018 in field trials via randomized complete block design with four replications. Fields were prepared nicely and agronomic recommendations were followed to harvest good crop.

More over grain yield was analysed further to estimate the GxE interaction component by AMMI analysis. The description of widely used AMMI based measures was mentioned for completeness.

Zobel	**1994**	**EV1**	**EVF**	$EV = \sum_{n=1}^{N} \lambda_{in}^2 / n$
Sneller *et al.*,	1997	SIPC1	SIPCF	$SIPC = \sum_{n=1}^{N} \lambda_n^{0.5} \gamma_{in}$
Sneller *et al.*,	1997	AMGE1	AMGEF	$AMGE = \sum_{n=1}^{N} \sum_{g=1}^{M} \lambda_n \gamma_{in} \delta_{jn}$
Purchase	1997	ASV		$ASV = [\frac{SSIPC\ 1}{SSIPC\ 2}(PC1)^2 + (PC2)^2]^{1/2}$
Annicchiarico	1997	D		$D = \sqrt{\sum_{n=1}^{N}(\lambda_n \gamma_{in})^2}$
Rao and Prabhakaran	2005	ASTB		$ASTAB = \sum_{n=1}^{n} \lambda_n \gamma_{ni}^2$
Rao and Prabhakaran	2005	I_i stability indexes		$I_i = \frac{Y_i}{\mu} + \alpha \frac{(1/ASTAB_i)}{(\sum_{n=1}^{n} ASTAB)/N}$
Zali *et al.*,	2012	MASV		$MASV = [\sum_{n=1}^{N-1} \left(\frac{SSIPC_n}{SSIPC_{n+1}}\right)(PC_n)^2 + (PC_{n+1})^2]^{1/2}$

Results and Discussion

Combined analysis of variance was conducted to determine the effects of environments, genotypes, and their interactions; on grain yield of dual purpose barley genotypes. Effects of environments, genotypes and their interactions were highly significant (Table 2). Highly significant GxE interactions confirmed crossover and non-crossover types of interaction. Grain yield of dual purpose barley genotypes is the joint effect of genotype, environment and GxE interaction. Larger magnitude of GxE interaction for yield was observed in other crops yield analysis (Mirosavlievic *et al.,* 2014; Mortazavian *et al.,* 2014).

The presence of GxE interaction reduces the progress from selection in any one environment (Sabaghnia *et al.,* 2013). However, five types of AMMI parameters were calculated as EV1, AMGE1, SIPC1 and D1 parameters (using only one IPCA), EV2, AMGE2, SIPC2 and D2 parameters (based on RMSPD results and using IPCA1 and IPCA2), EV3, AMGE3, SIPC3 and D3 parameters (using the first three IPCAs), EV5, AMGE5, SIPC5 and D5 parameters (using the first five IPCAs). Considering explained variation due to each IPCAs, type 1-based measures benefits 44.8%, type 2-based parameters benefits 65.4%, type 3-based parameters benefits 81.9%, and type 5 – based used 96.2 of GxE interaction variations (Table 2). Calculating AMMI stability parameters considering larger numbers of significant IPCAs results in the most usage of GxE interaction variations.

Ranking of genotypes as per lower values of EV1 are G2,G6,G5, G11, whereas by D1 are G8 G10, G13, G1, measures ASTAB1 identified as G8, G10, G13, G 1 and by SIPC1 are G5, G6, G3, G14. Two IPCAs in ASV measures accounted for 65.4% of GxE interaction. The two IPCAs have different values and meanings and the ASV parameter using the Pythagoras theorem and to get estimated values between IPCA1 and IPCA2 scores to produce a balanced parameter between the two IPCA scores (Purchase, 1997). The results of ASV parameter have many similarities with the other AMMI stability parameters which calculated from the first two IPCAs scores. ASV considered two IPCA's identified as G11, G2, G14, G12 and the values of EV2 pointed out G11, G7, G8, G14 and by D2 as G13, G1, G10, G8. Stable genotypes based on ASTAB2 are G13, G1, G9, G10 and of SIPC2 are G5, G3, G6, G9.

AMMI based measured defined by significant three principal components as EV3 selected G13 G14, G1, G12, and by D3 measures as G13, G8, G9, G10 whereas by SIPC3 as G5, G3, G7, G8 and values of ASTAB3 pointed towards G13, G8, G9, G14, and measure AMGE3 selected G2 G7, G16, G15 as desirable genotypes.

Since five based measures had considered 96.2% most of the interaction variation their selection of genotypes would be more appropriate to recommend as by MASV measures identified G3, G14, G13, G8, while values of D5 for G13, G8, G9, G10, and by EV5 values as G13, G8, G14, G3, measure SIPC5 pointed towards G5, G7, G16, G8 and stable genotypes as per ASTAB5 are G13, G8, G9, G14 and lastly by AMGE5 are G16, G7, G8, G15.

Finally as per type 1 of AMMI parameters (EV1, AMGE1, SIPC1 and D1), genotypes G5, G6, G8 and G10; based on the type 2 of AMMI parameters (EV2, AMGE2, SIPC2, D1 and ASV), genotypes G11, G14, G10 and G9; due to type 3 of AMMI parameters (EV4, AMGE4, SIPC4 and D4), genotypes G13, G14, G7 and G8; according to the type 5 of AMMI parameters (MASV, EV5, AMGE5, SIPC5 and D5) desirable genotypes would be G13, G14, G8 and G16. To better reveal associations among the AMMI based measures and using all information of total variation, the dataset of was analyzed using Ward's hierarchical clustering procedure. The dendogram of clustering showed that the twenty one studied AMMI based measures and yield could be divided into five major groups (Figure 1). Group I contains EV3, EV2, EV5, MASV, IPCA4 and AMGE3. Group II contains AMGE5, IPCA6, Mean, IPCA1. Group III contains SIPC3, SIPC5, SIPC2, IPCA2, IPCA3 and IPCA5. Group IV contains ASTAB1, ASTAB3, ASTAB5, ASTAB2 with D2, D3, D5 (Table 1–4).

Table.1 Parentage details and environmental conditions

Code	Genotype	Parentage	Code	Environments	Latitude	Longitude	Altitude (m)
G 1	RD2715 ©	RD387/BH602//RD2035	E 1	Hisar	29◦10 'N	75◦ 46 ' E	215.2
G 2	UPB1075	RD2552/RD2670	E 2	Durgapura	26◦51 'N	75◦ 47 ' E	390
G 3	UPB1073	EIBGN Plot 58 (2015-16)	E 3	Ludhiana	30°54 ' N	75° 52' E	247
G 4	AZAD ©	K12/K19	E 4	Varanasi	25◦ 20 ' N	83◦ 03 ' E	75.5
G 5	JB364	K 1185/DL 88	E 5	Kanpur	26◦ 29 ' N	80◦ 18 ' E	125.9
G 6	NDB1682	I[st] GSBSN-97(2013-14)	E 6	Faizabad	26◦ 47 'N	82◦ 12 ' E	113
G 7	RD2973	PL 472/BL 2//RD-2508	E 7	Udaipur	24◦ 34 ' N	70˚ 42 ' E	582
G 8	RD2976	RD-2636/RD-2521//RD-2503	E 8	Jabalpur	23°90' N	79 ° 58' E	394
G 9	RD2975	RD-2715/RD-2552					
G 10	UPB1074	UPB 1006/Jyoti					
G 11	RD2974	RD-2660/13[th]EMBGSN-4					
G 12	RD2035 (c)	RD103/PL101					
G 13	RD2552 ©	RD2035/DL472					
G 14	KB1638	K551/NDB1295					
G 15	KB1636	K141/K603					
G 16	KB1640	Jagriti/RD2552					

Table.2 AMMI analysis of dual purpose barley genotypes

Source	df	MS	Level of significance	% of TSS	% of GxE SS	Cumulative % contribution
Treatments	127	463.1569	***	93.44		
Genotypes	15	505.7926	***	12.05		
Environments	7	4946.531	***	55.00		
GxE	105	158.1744	***	26.38		
IPC1	21	354.003	***		44.76	44.76
IPC2	19	180.4973	***		20.65	65.41
IPC3	17	161.176	***		16.50	81.91
IPC4	15	81.99557	***		7.41	89.31
IPC5	13	88.13567	***		6.90	96.21
IPC6	11	36.27768	***		2.40	98.61
Residual	9	25.56212	*			
Error	384	10.75586				
Total	511	123.1921				

GxE total 16608.31 with GxE noise 1129.36523 or 6.80% and GxE signal 15478.949 or 93.20%

Table.3 Principal components of dual purpose barley genotypes

	Mean	IPCA 1	IPCA 2	IPCA 3	IPCA 4	IPCA 5	IPCA 6	ASV	MASV	EV1	EV2	EV3	EV5
G 1	28.34	-1.9342	0.6305	0.2320	-1.7831	0.7088	-0.1514	2.92	3.42	0.0434	0.0251	0.0171	0.0313
G 2	36.78	0.2014	1.8715	-1.1713	0.8152	1.5940	0.3973	1.89	3.51	0.0005	0.0301	0.0288	0.0361
G 3	31.38	0.9268	-1.9015	-0.9785	-0.4890	0.0374	1.6029	2.34	2.33	0.0100	0.0359	0.0300	0.0194
G 4	32.31	-1.3352	1.5130	1.1139	1.2858	0.6487	1.5571	2.48	3.95	0.0207	0.0299	0.0278	0.0286
G 5	33.16	0.6285	-2.3016	-2.3799	0.8451	0.0143	-0.5407	2.48	4.13	0.0046	0.0475	0.0677	0.0447
G 6	34.09	0.5722	-2.1154	0.8110	0.2391	1.3389	0.0820	2.28	2.93	0.0038	0.0401	0.0309	0.0295
G 7	25.22	-1.3263	0.8670	-1.7371	-0.8319	0.2054	-1.1398	2.14	3.25	0.0204	0.0166	0.0303	0.0224
G 8	26.69	-1.6473	0.3273	-1.0854	-0.5462	-0.3968	-0.0297	2.45	2.80	0.0315	0.0167	0.0186	0.0138
G 9	24.47	-4.1025	-0.9709	0.0553	0.8788	-0.8896	-0.0483	6.12	6.27	0.1952	0.1056	0.0705	0.0514
G 10	33.94	1.7795	0.3772	1.0365	1.3393	0.5034	-0.9029	2.65	3.79	0.0367	0.0196	0.0199	0.0237
G 11	22.50	-0.8099	-0.7604	2.9509	-0.3226	-1.0338	-0.7016	1.41	4.96	0.0076	0.0087	0.0613	0.0437
G 12	31.34	1.0079	1.2879	0.8711	-0.9197	1.1777	-0.2072	1.96	3.08	0.0118	0.0201	0.0182	0.0239
G 13	33.84	1.6902	-0.5322	0.3650	-0.1688	0.5639	-0.9801	2.54	2.62	0.0331	0.0190	0.0135	0.0101
G 14	30.34	1.0929	-1.1152	0.9168	-0.5887	-0.6927	0.7793	1.96	2.47	0.0139	0.0175	0.0170	0.0150
G 15	28.59	1.1421	1.4878	-0.4207	1.8719	-2.0046	-0.2148	2.25	4.09	0.0151	0.0265	0.0188	0.0550
G 16	30.59	2.1138	1.3351	-0.5797	-1.6253	-1.7749	0.4979	3.39	4.22	0.0518	0.0411	0.0296	0.0514

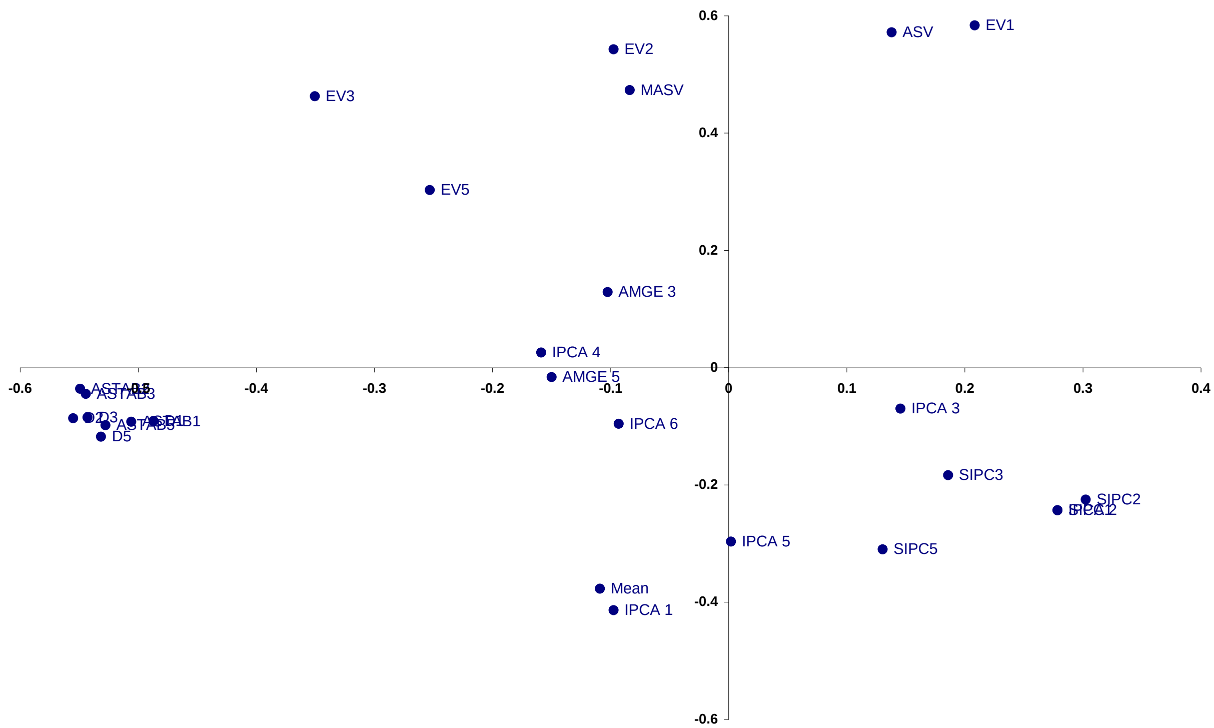
IPCA, principal component of interaction, ASV = AMMI stability value, MASV = Modified AMMI Stability value

Table.4 AMMI based estimates for GxE interactions for dual purpose barley genotypes

	D1	D2	D3	D5	SIPC1	SIPC2	SIPC3	SIPC5	ASTAB1	ASTAB2	ASTAB3	ASTAB5	AMGE 3	AMGE 5
G 1	5.86	6.12	14.27	14.90	0.63	0.86	-0.92	-0.36	3.69	4.10	27.09	30.20	-0.0004	-0.00147
G 2	17.39	19.56	20.43	22.62	1.87	0.70	1.52	3.51	32.54	43.03	47.84	63.80	-0.00304	-0.00063
G 3	17.67	19.19	19.51	21.63	-1.90	-2.88	-3.37	-1.73	33.59	40.92	42.64	57.60	0.000923	0.000471
G 4	14.06	16.44	18.88	21.30	1.51	2.63	3.91	6.12	21.27	30.76	42.71	59.32	-0.0004	0.001535
G 5	21.38	28.08	28.74	28.91	-2.30	-4.68	-3.84	-4.36	49.21	92.54	97.71	99.41	-7.8E-05	0.000781
G 6	19.65	20.61	20.68	22.15	-2.12	-1.30	-1.07	0.36	41.57	46.60	47.02	57.67	0.002926	0.004504
G 7	8.05	15.54	16.66	17.98	0.87	-0.87	-1.70	-2.64	6.98	30.07	35.07	42.88	-0.0026	-0.00323
G 8	3.04	8.84	9.68	9.97	0.33	-0.76	-1.30	-1.73	0.99	10.01	12.16	13.10	-0.00141	-0.00236
G 9	9.02	9.03	11.04	12.24	-0.97	-0.92	-0.04	-0.97	8.76	8.78	14.36	19.06	0.001026	0.001015
G 10	3.50	8.67	13.00	14.33	0.38	1.41	2.75	2.35	1.32	9.54	22.51	28.75	0.000659	0.002502
G 11	7.06	23.65	23.77	24.88	-0.76	2.19	1.87	0.13	5.37	71.99	72.74	81.93	0.003711	0.002355
G 12	11.96	13.69	15.22	16.79	1.29	2.16	1.24	2.21	15.41	21.21	27.33	35.79	-0.00042	-0.00016
G 13	4.94	5.68	5.81	8.80	-0.53	-0.17	-0.34	-0.75	2.63	3.65	3.86	11.33	0.000897	0.001292
G 14	10.36	12.51	13.21	14.56	-1.12	-0.20	-0.79	-0.70	11.55	17.98	20.49	26.86	0.002032	0.000751
G 15	13.82	14.19	19.61	22.96	1.49	1.07	2.94	0.72	20.56	21.92	47.25	71.31	-0.00191	-0.00204
G 16	12.40	13.17	17.65	20.75	1.34	0.76	-0.87	-2.15	16.56	19.13	38.23	58.32	-0.00191	-0.00531

EV = Eigenvector, SIPC = Sum of the value of the IPC Scores, D = Parameter of Annicchiarico (1997); SIPC1 = SIPC for first IPCA, SIPC 2 = SIPC for first two IPCAs, for AMGE1, AMGE2 and AMGE3; AMGE = Sum across environments of GEI

Fig.1 Clustering of AMMI based measures



Smallest cluster consisted of ASV with EV1. Although there was not any significant correlation between SIPC parameters and mean yield, but they grouped together. Also, the most stable genotypes based on these three parameters (SIPC4, SIPC6 and SIPC8) were moderate mean yielding genotypes. Each of the AMMI stability parameters relates to a different concept of yield stability and may be useful to plant breeders attempting to select genotypes with high, stable and predictable yield across environments. However, it seems that there is not a way to consider all of these measures simultaneously, whereas few of them should be used in MET with respect to significant IPCAs.

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How to cite this article:

Ajay Verma, V. Kumar, A.S. Kharab and Singh, G.P. 2019. AMMI Model to Estimate GxE for Grain Yield of Dual Purpose Barley Genotypes. *Int.J.Curr.Microbiol.App.Sci.* 8(05): 1-7.
doi: https://doi.org/10.20546/ijcmas.2019.805.001