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G×E Interaction Analysis by Ammi Model for Fodder Yield of Dual Purpose Barley Genotypes

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Abstract

Numerous statistical methods have been proposed to estimate the yield behavior of genotypes to diverse environmental conditions. Large number of research studies has shown a significant effect of environmental as well as of G×E interaction yield of genotypes. G×E interaction has been analyzed by the additive main effects and multiplicative interaction model as this combines the analysis of variance for the genotype and environmental main effects and the principal component analysis with multiplicative indices.Combined AAMI 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 selected (EV1, AMGE1, SIPC1 and D1), genotypes G5, G6, G8 and G10; while type 2 favoured (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 measures accounted for maximum G×E interaction signal pointed towards (EV5, AMGE5, SIPC5 and D5) G13, G14, G8 and G16 desirable genotypes. Hierarchical clustering of AMMI based measures along with yield could be clustered with four distant groups. Group I contains AMGE3, AMGE5, IPCA2, IPCA3, IPCA4 and average yield. Group II contains only SIPC1, SIPC2 SIPC3 SIPC5 measures. Group III contains EV2, EV3, with IPCA5 and IPCA6. Largest group IV joined D1, D2, D3, D5, ASV, ASTAB1, ASTAB2 and ASTB5.

Keywords: AMMI, genotype×environment interaction

1. Introduction

Genotype×environment interaction resulted from differences in the genotypes response to the environmental conditions and leads to inconsistent performances of genotypes (Akbarpour et al., 2014, Bocianowsk et al., 2019a). This limits the efficiency of selection of superior genotypes. Genotypes whose GxE effects are not significant are said to be stable (Kendaland Tekdal, 2016, Edwards, 2016). Several methods have been used to assess the GxE effect and stability in crop performances (Carlosand Wojtek, 2006, Ferraudo et al., 2014). AMMI model is comprised of additive main effects of genotype and environment, and the multiplicative effect of G×E interaction, and thus can explain more information compared to other methods (Kilic, 2014,Guilly et al., 2017, Tena et al., 2019). AMMI model fits the sum of several multiplicative terms rather than only one multiplicative term in assessing the performance of genotypes in different environments (Mortazavian et al., 2014, Kamila et

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al., 2016). AMMI analysis can be used to determine stability of the genotypes across locations using the PCA (principal component axis) scores (Sabaghnia et al., 2012, Naroui et al., 2013, Nowosad et al., 2016, Regis et al., 2018). Zobel (1994) introduced averages of the squared eigenvector (EV) values as the AMMI stability parameter. AMGE and SIPC stability parameters of AMMI model to describe the contribution of environments to G×E interaction suggested by Snelleret 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). One or all of these measures may also be of interest for barley improvement programs as an alternative to the conventional stability methods (TekdalandKendal., 2018, Nowosad et al., 2018). Present study was conducted to evaluate the effect of G×E interaction on the fodder yield of dual purpose barley by AMMI based measures.

2. Materials and Methods

Sixteen dual purpose promising barley genotypes were evaluated at research fields during cropping season of 2017-2018 at eight major barley producing locations of the country via randomized complete block design with four replications. Fields were prepared to favour good germination and growth of barley. All agronomic managements were done as per the recommendations to harvest potential yield of the crop. More over fodder yield was analysed further to estimate the G×E interaction component by AMMI analysis. Parentage details along with environmental conditions of considered locations were described in Table 1 for ready reference. AMMI is a combination of ANOVA for the main effects of the genotypes and the environment together with principal components analysis (PCA) the genotype-environment interaction (Shahriari et al., 2018; Tena et al., 2019). AMMI models are usually called AMMI (1), AMMI(2), ….,AMMI (n), depending on the number of principal components used to study the interaction effects. Under biplot analysis, the first principal component represents responses of the genotypes that are proportional to the environments, which are associated with the GxE interaction. The second principal component provides information about locations that are not proportional to the environments, indicating that those are responsible of the GxE crossover interaction. In Biplot analysis with two PCA axis, second PCA scores of genotypes and environments are plotted against their respective first PCA scores. The better description of the interaction, first and second PCA scores of genotypes and environments may be considered for graphical representations. The description of AMMI based measures was mentioned for completeness in following Table 2.

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	IstGSBSN-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-2660/13thEMBGSN-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					

3. Results and Discussion

Combined analysis of variance was explained significant effects of environment, genotype, and their interactions on fodder yield of dual purpose barley genotypes. Effects of locations were 47.3, genotypes (6.5%) and their interactions (37.8%) were highly significant (Table 2). Highly significant GxE interactions indicated complicated crossover and non-

Table 2: AMMI based measures for G×E interactions

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		$ASV = [\frac{SSIPC\,1}{SSIPC\,2}(PCI)^2 + (PC2)^2]^{1/2}$
Annicchiarico,	1997	D		$D = \sqrt{\sum_{n=1}^{N}(\lambda_n \gamma_{in})^2}$
Rao and Prabhakaran,	2005	ASTB		$ASTAB = \sum_{n=1}^{n} \lambda_n \gamma_{ni}^2$

crossover types of interaction. Large magnitude of GxE interaction for yield was also observed in other crops (Ndhlela et al., 2014; Sabaghnia et al., 2013, Bocianowsk et al., 2019b). Additive Main effect and Multiplicative Interaction (AMMI) is a statistical tool which leads to identification of stable genotypes with their adaptation behaviour in an easy manner. AMMI first calculate genotype and environment additive effect using analysis of variance (ANOVA) and then analyse residual from these model using principal components analysis (PCA).

Five types of AMMI based measures were calculated as EV1, AMGE1, SIPC1 and D1 parameters (using only one IPCA), ASV, EV2, AMGE2, SIPC2, ASTAB2 and D2 parameters (considering 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 67.4%, type 2-based parameters benefits 79.1%, type 3-based parameters benefits 88.3%, and type 5 – based used 96.4 of GxE interaction variations (Table 3). Calculating AMMI stability parameters considering larger numbers of significant IPCAs results in the most usage of GxE interaction variations. GxE signal was about 93.9% and corresponding noise was restricted to 6.03% of total interaction sum of squares.

Ranking of genotypes as per lower values of EV1 are G9,G6,G14, G1, whereas by D1 are G9 G6, G14, G1, measures ASTAB1 identified as G9, G6, G14, G 1, AMGE1 identified G3, G5, G4, G7, and by SIPC1 are G3, G5, G4, G7 genotypes (Table 4). AMMI stability value (ASV) was proposed to quantify the stability measure by considering relative weight of $IPCA_1$ and $IPCA_2$ scores. First two IPCAs in ASV measure used 79.7% of GxE interaction and have different values and meanings. ASV measure used the Pythagoras theorem to get estimated values between IPCA1 and IPCA2 scores to produce a balanced measure between the two IPCA scores (Purchase, 1997). Also, ASV parameter of this investigation used advantages of cross validation due to computation from first two IPCAs. ASV considered two IPCA's identified as G6, G9, G1, G11 and the values of EV2 pointed out G6, G1, G11, G9 and by D2 as G6, G1, G9, G11. Stable genotypes based on ASTAB2 are G6, G9, G1, G11 and of SIPC2 are G14, G3, G7, G5. AMMI based measured defined by significant three principal components as EV3 selected G15 G9, G6, G11, and by D3 measures as G9, G6, G15, G11 whereas by SIPC3 as G14, G7, G5, G11 and values of ASTAB3 pointed towards G9, G6, G15, G11, and measure AMGE3 selected G3 G1, G8, G5 as desirable genotypes (Mohammadi et al., 2015, Vaezi et al., 2017, Bocianowsk et al., 2019c).

Since five based measures had considered most of the interaction variation their selection of genotypes would be more appropriate to recommend as by values of D5 for G9,

Table 3: Combined analysis of variance for fodder yield of dual purpose barley genotypes

Source	df	MSS		% of TSS	% of GxE SS	Cumulative % contribution
TRT	127	8958.41989	***	91.66		
GEN	15	5395.00299	***	6.52		
ENV	7	83885.59347	***	47.31		
GxE	105	4472.33454	***	37.83		
IPC1	21	15078.52688	***		67.43	67.43
IPC2	19	2880.57758	***		11.65	79.09
IPC3	17	2553.62466	***		9.24	88.33
IPC4	15	1429.78544	***		4.57	92.90
IPC5	13	1274.02882	***		3.53	96.42
IPC6	11	1101.67824	***		2.58	99.00
Residual	9	519.53913	*			
Error	384	269.69987				
Total	511	2429.12735				

GxE total: 469595.12695, GxE noise: 28318.48633 or 6.03%, GxE signal: 441276.64063 or 93.97%

Table 4: AMMI parameters estimates

	ASV	Mean	IPCA 1	IPCA 2	IPCA 3	IPCA 4	IPCA 5	IPCA 6	D1	D2
G 1	3.64	162.63	-1.5096	0.2076	4.0995	-1.5422	0.2471	-0.9780	35.78	35.92
G 2	10.79	152.34	4.4193	-1.8418	1.5187	0.9395	-3.2348	-1.6556	104.74	108.46
G 3	16.66	146.25	-6.9087	1.2026	3.5970	2.3966	0.5100	1.7914	163.74	164.77
G 4	8.02	134.22	-3.1797	2.4056	-1.0978	1.8246	-1.8665	2.0219	75.36	83.87
G 5	14.20	148.06	-5.8202	2.4002	-2.1185	-3.0085	-0.5193	-1.7196	137.94	142.74
G 6	1.40	136.66	-0.5054	0.6948	-2.4113	2.7295	-1.8175	-2.5559	11.98	16.01
G 7	7.32	141.88	-2.9737	-1.5741	-2.5868	1.9186	1.3768	-2.9632	70.48	74.48
G 8	6.91	163.63	-2.3034	4.1359	0.2940	-3.7832	0.8904	0.3084	54.59	83.57
G 9	1.58	179.34	0.3736	-1.3014	1.7813	-1.2609	1.4381	-2.4770	8.85	21.79
G 10	17.04	155.63	7.0788	-0.6104	-0.7514	0.0071	-0.0632	-1.0250	167.77	168.03
G 11	3.89	152.69	-1.5892	-0.7445	-2.9043	-0.5566	-1.7815	1.3815	37.66	39.35
G 12	15.28	167.59	6.2351	2.9226	3.1506	1.2373	3.5244	-0.1919	147.77	154.39
G 13	17.35	158.69	7.0726	3.3946	-4.1082	-0.2340	0.8022	2.4764	167.62	175.48
G 14	7.66	149.19	-1.3967	-6.8894	-2.2938	-1.9191	3.2497	1.7721	33.10	110.48
G 15	4.30	132.97	-1.6525	-1.6363	0.8513	3.6624	0.9830	1.9408	39.17	46.48
G 16	6.97	139.09	2.6599	-2.7660	2.9796	-2.4110	-3.7389	1.8737	63.04	75.93

Table 4: Continue...

	D3	D5	EV1	EV2
G 1	69.10	71.63	0.00405	0.00212
G 2	110.64	117.08	0.03471	0.02460
G 3	172.72	175.23	0.08482	0.04550
G 4	85.34	90.64	0.01797	0.02135
G 5	145.97	150.55	0.06020	0.04241
G 6	38.24	54.54	0.00045	0.00126
G 7	83.27	87.84	0.01571	0.01315
G 8	83.68	95.91	0.00943	0.04127
G 9	33.66	40.37	0.00025	0.00374
G 10	168.37	168.38	0.08905	0.04532
G 11	57.42	61.22	0.00449	0.00343
G 12	160.92	166.45	0.06909	0.05280
G 13	185.19	185.43	0.08889	0.06907
G 14	115.32	123.23	0.00347	0.10318
G 15	48.07	66.32	0.00485	0.00815
G 16	87.21	101.20	0.01257	0.02264

IPCA, principal component of interaction, ASV = AMMI stability value

G6, G11, G15, and by EV5 values as G9, G11, G10, G7, measure SIPC5 pointed towards G14, G11, G5, G7 and stable genotypes as per ASTAB5 are G9, G6, G11, G15 and lastly by AMGE5 are G3, G8, G1, G11 (Table 5).

Finally according to the most of 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

Table 5: AMMI parameters estimates based on EV, D and SIPC for fodder yield of dual purpose barley genotypes

	EV3	EV5	SIPC1	SIPC2	SIPC3	SIPC5
G 1	0.02830	0.02032	-1.51	-1.30	2.80	1.50
G 2	0.02009	0.02952	4.42	2.58	4.10	1.80
G 3	0.05103	0.03887	-6.91	-5.71	-2.11	0.80
G 4	0.01616	0.01966	-3.18	-0.77	-1.87	-1.91
G 5	0.03545	0.03405	-5.82	-3.42	-5.54	-9.07
G 6	0.01014	0.02139	-0.51	0.19	-2.22	-1.31
G 7	0.01947	0.01966	-2.97	-4.55	-7.13	-3.84
G 8	0.02765	0.03737	-2.30	1.83	2.13	-0.77
G 9	0.00757	0.00993	0.37	-0.93	0.85	1.03
G 10	0.03112	0.01868	7.08	6.47	5.72	5.66
G 11	0.01578	0.01482	-1.59	-2.33	-5.24	-7.58
G 12	0.05108	0.05204	6.24	9.16	12.31	17.07
G 13	0.07305	0.04490	7.07	10.47	6.36	6.93
G 14	0.07720	0.06776	-1.40	-8.29	-10.58	-9.25
G 15	0.00659	0.02377	-1.65	-3.29	-2.44	2.21
G 16	0.02930	0.04724	2.66	-0.11	2.87	-3.28

Table 5: Continue...

	ASTAB1	ASTAB2	ASTAB3	ASTAB5	AMGE 1	AMGE 3	AMGE 5
G 1	54.01	54.67	296.68	326.15	-0.0151	-0.09916	-0.11953
G 2	462.86	514.76	547.97	676.90	0.044193	0.032236	0.106328
G 3	1131.21	1153.34	1339.66	1412.10	-0.06909	-0.15305	-0.13929
G 4	239.62	328.16	345.51	425.16	-0.0318	-0.0339	0.021678
G 5	802.83	890.97	955.60	1068.17	-0.0582	-0.03983	-0.05953
G 6	6.05	13.44	97.16	224.64	-0.00505	0.036223	0.099869
G 7	209.58	247.49	343.85	409.81	-0.02974	0.037739	0.02939
G 8	125.75	387.46	388.71	570.85	-0.02303	-0.07027	-0.12591
G 9	3.31	29.22	74.91	117.52	0.003736	-0.01888	-0.06025
G 10	1187.59	1193.29	1201.42	1201.46	0.070788	0.09192	0.093255
G 11	59.85	68.33	189.80	229.41	-0.01589	0.049639	0.079702
G 12	921.38	1052.07	1195.01	1353.90	0.062351	-0.02989	-0.088
G 13	1185.50	1361.81	1604.84	1612.77	0.070726	0.118943	0.100559
G 14	46.23	772.43	848.20	1012.10	-0.01397	0.100804	0.016618
G 15	64.72	105.69	116.12	289.34	-0.01653	-0.01719	-0.00022
G 16	167.68	284.74	412.58	640.88	0.026599	-0.00533	0.045335

EV: Eigenvector; SIPC: Sum of the value of the IPC Scores; D: Parameter of Annicchiarico; SIPC1: SIPC for first IPCA; SIPC 2: SIPC for first two IPCAs, … for AMGE1, AMGE2 and AMGE3AMGE: Sum across environments of GEI

parameters (EV5, AMGE5, SIPC5 and D5)desirable genotypes would be G13, G14, G8 and G16 (Rahmatollah et al., 2016).

Association among the AMMI based stability measures studied by using Ward's hierarchical clustering procedure. Biplots help to visualize relationships among genotypes & environments; by depicting both main as well as interaction effects. Biplots enables to identify target breeding environments and to choose representative testing sites in those environments along with varieties with good adaptation to target breeding environments. Graphical analysis based on biplots reflected four major clusters for the twenty one studied the AMMI stability parameters along with mean yield (Figure 1). Group I contains AMGE3, AMGE5, IPCA2, IPCA3, IPCA4 and average yield. Group II contains only SIPC1, SIPC2SIPC3SIPC5 measures. Group III contains EV2, EV3, with IPCA5 & IPCA6. Largest group IV joined most of the AMMI based measures as D1, D2, D3, D5, ASV, ASTAB1, ASTAB2 and ASTB5.

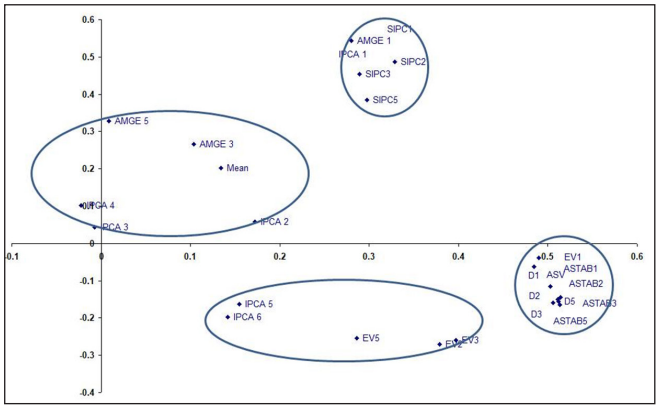

Figure 1: Clustering of AMMI based measures by biplot analysis

4. Conclusion

Each of the AMMI based measures correlates to a different concepts of stable performance and will be useful to plant breeders to select stable genotypes with respect to yield across environments. At the same time, there is not a way to consider all of these measures simultaneously, and few of them should be used in MET vis-a-vis number of significant IPCAs. AMMI analysis has been observed as useful for exploring complex GxE interaction, improving selections and increasing experimental efficiency (Tena et al 2019).

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