The Andhra Agric. J 58(2):156-166, 2011

Phenotypic Stability Analysis in Italian Millet Utilizing Regression and AMMI Models for Yield Characters

G Usha Kiran, C Panduranga Rao, J S V Samba Murthy, V Srinivasa Rao and M Lal Ahamed
Department of Genetics and Plant Breeding, Agricultural College, Bapatla 522 101, Andhra Pradesh

ABSTRACT

Twenty italian millet genotypes were evaluated for several characters over 16 environments (8 sowing dates with 2 fertility levels).The analysis of variance of Eberhart and Russell indicated that G×E interaction was significant for all 5 characters under study and that genotypes differed significantly. AMMI is a useful tool for interpreting genotype × environment interaction in multi environment trials. Among the AMMI component first four IPCA axis were explained most of the portion of G × E interaction than other IPCA axis for the five characters under study. The ANOVA indicated non-significant G × E interaction for 1000 grain weight and ANOVA of (Eberhart and Russell,1966) indicated non-significant G × E (linear) interaction for productive tillers per plant, ear length, 1000 grain weight, when tested against pooled deviation. As per AMMI analysis the $IPCA_1$ significantly contributed to productive tillers per plant, ear length, ear weight, 1000 grain weight and grain yield per plant while $IPCA_2$ contributed significantly to G × E interaction for productive tillers per plant, ear length, ear weight and 1000 grain weight . This brings out clearly the advantage of AMMI ANOVA in bringing out G × E interaction through $IPCA_1$ which gets combined with error in the other two ANOVA and points out the utility of AMMI models in studying the significant G × E interaction and identifying stable genotypes for characters which so undetected in the other analysis. According to AMMI analyses the genotypes GS 463 and GS 480 (for productive tillers plant^{-1}); GS 477, GS 486 and SRL (for ear length); GS 467, GS 477, GS 479 and NSR (for ear weight); GS 440, GS 444 and NSR (for 1000 grain weight); most of the genotypes (for grain yield plant^{-1}) were more stable as the IPCA score was near zero indicating less interaction with environments. According to Eberhart and Russell the genotypes GS 480 and GS 489 (for productive tillers plant^{-1}); GS 487 and GS 444 (for ear length); GS 440 and GS 477 (for ear weight); SRL (1000 grain weight); GS 450 and GS 467 (for grain yield plant^{-1}) showed stage performance.

Key words : AMMI,Foxtail millet, Stability.

Italian millet [*Setaria italica* L. Beauv] provides approximately six million tonnes of food to millions of people, mainly in Southern Europe and in temperate and sub-tropical Asia. Its domestication and cultivation is estimated to have occurred over 4000 years ago (Chang, 1968). The analysis of variance (ANOVA) is useful for identifying and testing sources of variability. It does not provide insight into the EXE interaction as ANOVA model is additive and effectively describes the main (additive) effects, while the interaction (residual from the additive model) is non-additive and requires other techniques, such as Principal Component Analysis (PCA) to identify interaction patterns. Thus, ANOVA and PCA models were combined to constitute the Additive Main effects and Multiplicative Interaction (AMMI) model (Gauch and Zobel, 1988).

MATERIAL AND METHODS

Twenty genotypes, namely, GS 440(1), GS 444 (2), GS 445 (3), GS 450 (4), GS 462 (5), GS 463 (6), GS 465 (7), GS 467 (8), GS 477 (9), GS 479 (10), GS 480 (11), GS 482(12), GS 486(13), GS 487(14), GS 488 (15), GS 489(16), Krishnadevaraya (17), Narasimharaya (18) , Srilakshmi (19) and Prasad (20) were sown during *kharif* 2009 (four sowing dates) and *rabi* 2009-10 (four sowing dates) with two fertility levels (high fertility N: 80 kg ha^{-1}, P_2O_5 20 kg ha^{-1}, K_2O 20 kg ha^{-1} and normal fertility N : 40 kg ha^{-1}, P_2O_5 20 kg ha^{-1}, K_2O 20 kg ha^{-1}), thus providing 16 environments at Agricultural College Farm, Bapatla, Andhra Pradesh. Material was grown in randomized block design with three replications in 3m long plots of 4 rows per genotype per replication. An inter and intra row spacing of 25 cm and 10 cm was practiced. The observations were recorded on five characters *viz.,*

Table 1. Analysis of variance for stability of characters in Italian millet [*Setaria italica* (L.) Beauv]

Source	d.f.	Productive tillers plant^{-1}	Ear length (cm)	Ear weight (g)	1000 grain weight (g)	Grain yield plant^{-1} (g)
		Mean squares				
Genotype	19	73.433**++	32.823**++	5.119**++	0.73**++	413.443**++
Environments	15	1.169++	0.494*++	0.074**++	0.034**++	1.866**+++
Genotype ´ environment	285	0.869++	0.300++	0.032++	0.008	1.021++
Environment (linear)	1	17.533**++	7.404**++	1.103**++	0.509**++	27.988**++
Genotype ´ environment (linear)	19	1.689++	0.499++	0.039++	13.34++	2.061**++
Pooled deviation	280	0770++	0.272++	0.030++	0.008++	0.900++
Pooled error	608	0.199	0.164	0.017	0.009	0.458

+ = Significant at 0.05 level
++ = Significant at 0.01 level
When tested against pooled error

productive tillers per plant, ear length (cm), ear weight (g), 1000 grain weight (g) and grain yield per plant. Stability parameters were analysed using regression (Eberhart and Russell, 1966) and AMMI (Gauch, 1988) model. According to Eberhart and Russell the genotype with high mean, unit regression coefficient and non-significant deviation from regression was considered to be stable over environments. According to AMMI model, when one interaction PCA axis accounts for most of GXE, the biplot procedure in which genotypes and environments taking mean values on abscissa and $IPCA_1$ scores on ordinate are plotted on the same diagram, facilitating inference about specific interactions as indicated by the sign and magnitude of $IPCA_1$ values of individual genotypes and environments (Sharma *et al.*,1998).The biplot of the first two IPCA axis demonstrates the relative magnitude of the GE interaction for specific genotypes and environments. Since the GE interaction effect is determined by the product of the correct PCA scores, cultivars or environments with a small GE interaction will have small scores and be close to the center of the axis *i.e.*, they are stable across environments (Bahman Shafi *et al.*, 1992).

RESULTS AND DISCUSSION

The analysis of variance (Table1) indicated significant genotypic differences for all the characters. The environments also varied widely as evidenced from significant differences for environments and environment (linear) components for all the characters. The genotype-environment interaction component also showed high significance for all the characters except 1000 grain weight. This indicated valid differences among genotypes for regression over environmental means. In general, the genotype – environment (linear) component showed significance for all the characters except productive tillers per plant, ear length and 1000 grain weight thus indicating the importance of non-linear component in the genotype-environment interaction of Italian millet genotypes. With expected desirable

Table 2. Analysis of variance of the AMMI model in Italian millet [*Setaria italica* (L.) Beauv]

Source of variation	df	Sum of squares	Mean squares	F ratio	% of G × E sum of squares
Productive tillers plant^{-1}					
Genotypes	19	1395.21	73.43**		
Environments	15	17.53	1.16**		
G ´ E	216	247.76	0.86**		
IPCA 1	33	100.54	3.24**	3.75	40.57
IPCA 2	31	60.01	2.3**	2.67	24.22
IPCA 3	29	38.05	1.41**	1.63	15.35
IPCA 4	27	28.79	1.06**	1.23	11.62
GXE residual	96	20.34			
Total	250	1660.51			
Ear length					
Genotypes	19	623.63	32.82**		
Environments	15	7.39	0.49**		
GXE	216	85.55	0.30**		
IPCA 1	33	32.75	1.04**	3.46	38.28
IPCA 2	31	22.93	0.77**	2.56	26.80
IPCA 3	29	14.67	0.53**	1.76	17.14
IPCA 4	27	8.02	0.29**	0.96	9.37
GX E residual	96	7.16			
Total	250	716.58			
Ear weight					
Genotypes	19	97.25	5.11**		
Environments	15	1.10	0.07**		
G ´ E	216	9.07	0.03**		
IPCA 1	33	4.58	0.14**	4.66	50.49
IPCA 2	31	1.89	0.05**	1.66	20.83
IPCA 3	29	1.15	0.03**	1.00	12.67
IPCA 4	27	0.77	0.02**	0.66	8.48
GX E residual	96	0.65			
Total	250	107.43			
1000 grain weight					
Genotypes	19	3.29	0.17**		
Environments	15	0.50	0.03**		
G X E	216	2.38	0.08**		
IPCA 1	33	0.77	0.02**	3.12	32.35
IPCA 2	31	0.56	0.02**	2.50	23.52
IPCA 3	29	0.44	0.01**	2.00	18.48
IPCA 4	27	0.29	0.01**	1.25	12.18
GXE residual	96	0.29			
Total	250	6.18			
Grain yield plant^{-1}					
Genotypes	19	7855.41	413.44**		
Environments	15	27.99	1.86**		
G XE	216	291.03	1.02**		
IPCA 1	33	145.83	4.52**	4.43	50.10
IPCA 2	31	74.04	2.49**	2.44	25.44
IPCA 3	29	34.18	1.28**	1.25	11.74
IPCA 4	27	19.15	0.70	0.68	6.58
GXE residual	96	7855.41	413.44**		
Total	250	27.99	1.86**		

Table 3. Stability parameters of yield componets using Eberhart & Russell (1966) noble in Italian millet [*Setaria italica* (L.) Beauv]

Genotypes	Productive tillers plant^{-1}			Ear length			Ear weight			1000 grain weight			Grain yield plant^{-1}		
	$\overline{X}$	b	S^2d	$\overline{X}$	b	S^2d	$\overline{X}$	b	S^2d	$\overline{X}$	b	S^2d	$\overline{X}$	b	S^2d
GS440	9.45	0.97	2.06***	17.21	2.22	0.80***	4.44	0.38*	-0.01	2.55	1.38	0.006*	19.00	3.05	2.85***
GS444	13.21	1.18	0.52***	19.19	0.70	0.00	5.62	-0.61*	0.01	2.85	0.22*	-0.007	24.16	0.08	0.29
GS445	10.39	0.75	1.23***	15.36	1.13	0.01	4.27	-0.15	0.22***	2.60	2.35	0.0004	21.00	0.01	0.25
GS450	13.90	0.64	0.33***	18.76	1.34	0.05	5.43	1.52	0.01	2.84	0.19*	-0.071	25.26	-0.22*	-0.35
GS462	10.11	2.24	0.60***	16.05	1.30	-0.03	4.47	0.82	0.00	2.63	0.73	0.00	20.35	0.80	-0.20
GS463	11.00	3.27	1.98***	15.75	0.90	-0.12	4.51	1.56	0.05***	2.61	1.17	0.00	21.85	1.29	0.56**
GS465	7.38	1.02	0.31**	15.24	1.44	-0.04	4.08	0.88	-0.01	2.63	1.62	0.00	9.66	1.08	-0.37
GS467	7.19	0.26	-0.02	15.07	1.04	-0.08	4.25	0.92	-0.01	2.63	1.11	0.00	9.75	0.99	-0.36
GS477	8.35	0.26*	-0.12	17.50	-0.15*	-0.07	4.23	0.47	-0.01	2.57	0.65	0.01**	15.96	0.78	-0.10
GS479	13.43	0.02	0.47***	19.22	2.06	0.03	5.36	0.31	-0.01	2.84	0.12*	-0.01	24.22	-0.19	0.85***
GS480	8.70	0.46*	-0.14	16.78	-1.44	1.08***	4.08	1.65	0.01	2.59	0.68	0.01	18.41	1.00	-0.09
GS482	9.22	2.62*	0.22**	15.15	1.36	0.00	4.45	1.43	0.00	2.56	0.67	-0.00	19.96	1.40	-0.26
GS486	10.28	5.23*	2.21***	16.94	1.85	-0.03	3.75	2.79*	0.01	2.60	2.11	-0.00	19.62	4.44	6.38***
GS487	12.87	-0.28	1.14***	19.18	1.08	-0.03	5.43	1.33	0.00	2.84	0.29*	-0.01	23.92	0.30	0.61**
GS488	9.78	1.25	0.87***	16.96	1.65	-0.05	3.84	1.43	0.00	2.60	0.68	-0.00	20.73	1.20	-0.06
GS489	8.46	0.22	-0.14	15.96	2.38	0.06	3.85	1.25	0.00	2.57	1.02	-0.00	15.46	2.02*	-0.24
KDR	7.27	0.21*	0.09	17.08	-2.05*	0.45***	4.18	0.79	-0.01	2.60	1.12	-0.00	10.14	0.71	-0.36
NSR	7.52	-0.31*	0.08	15.71	1.84	0.02	4.49	0.17	0.00	2.59	1.55	-0.00	10.48	-1.24*	0.43*
SRL	8.45	-0.32*	-0.13	17.58	-0.27	0.24**	3.93	2.57	0.03***	2.65	1.04	-0.00	15.55	1.04	-0.31
PRD	8.27	0.34	-0.05	15.14	1.66	0.01	4.40	0.50	-0.01	2.59	1.27	-0.0003	14.90	1.46	-0.25
General mean	9.76			16.79			4.45			2.65			18.02		
S.Em ±	0.22	0.93		0.13	0.85		0.04	0.73		0.02	0.55		0.24	0.80	

Figure 1.

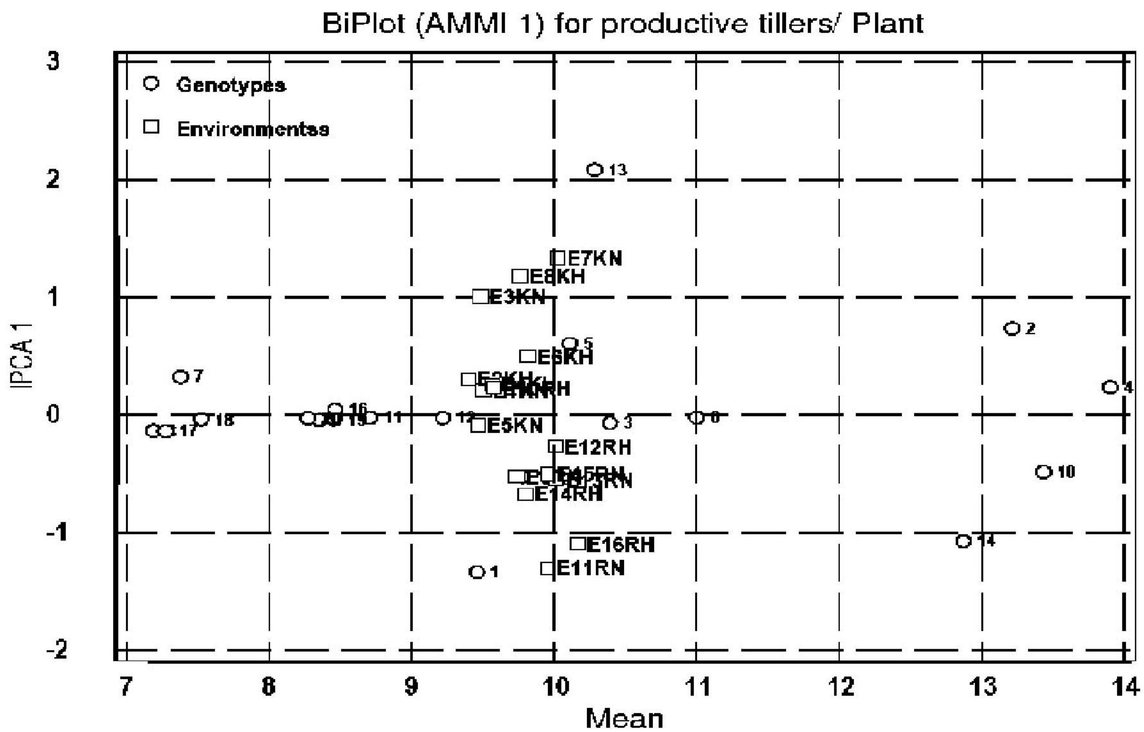
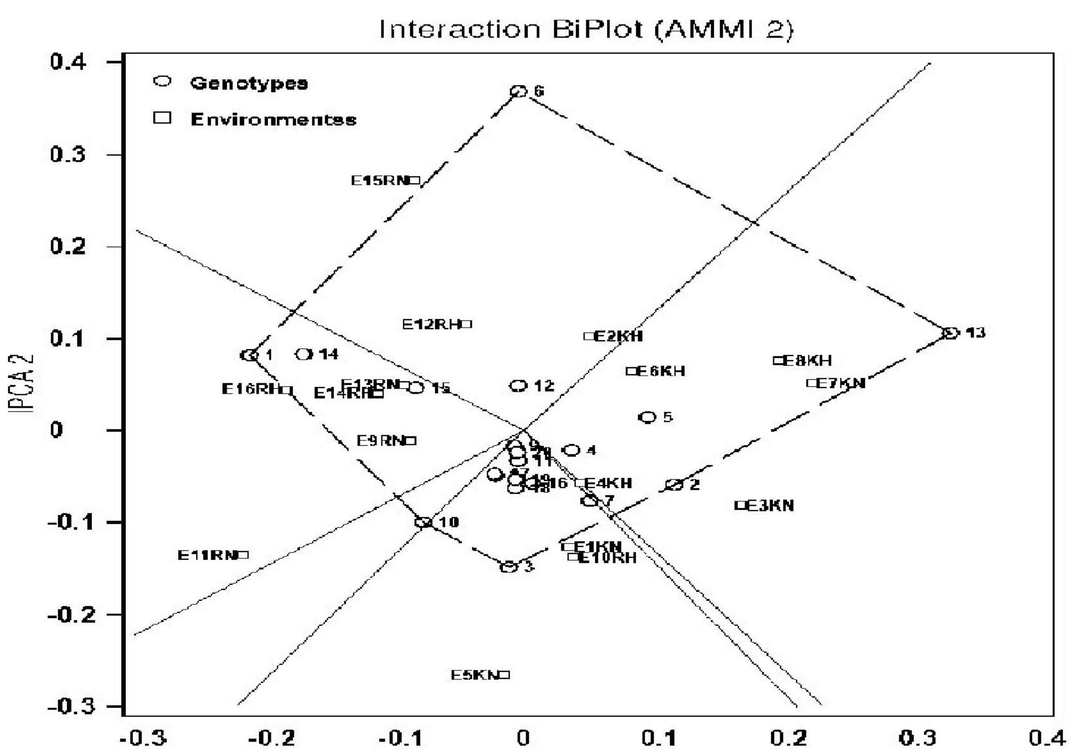


Figure 2.



IPCA 1

Figure 3.

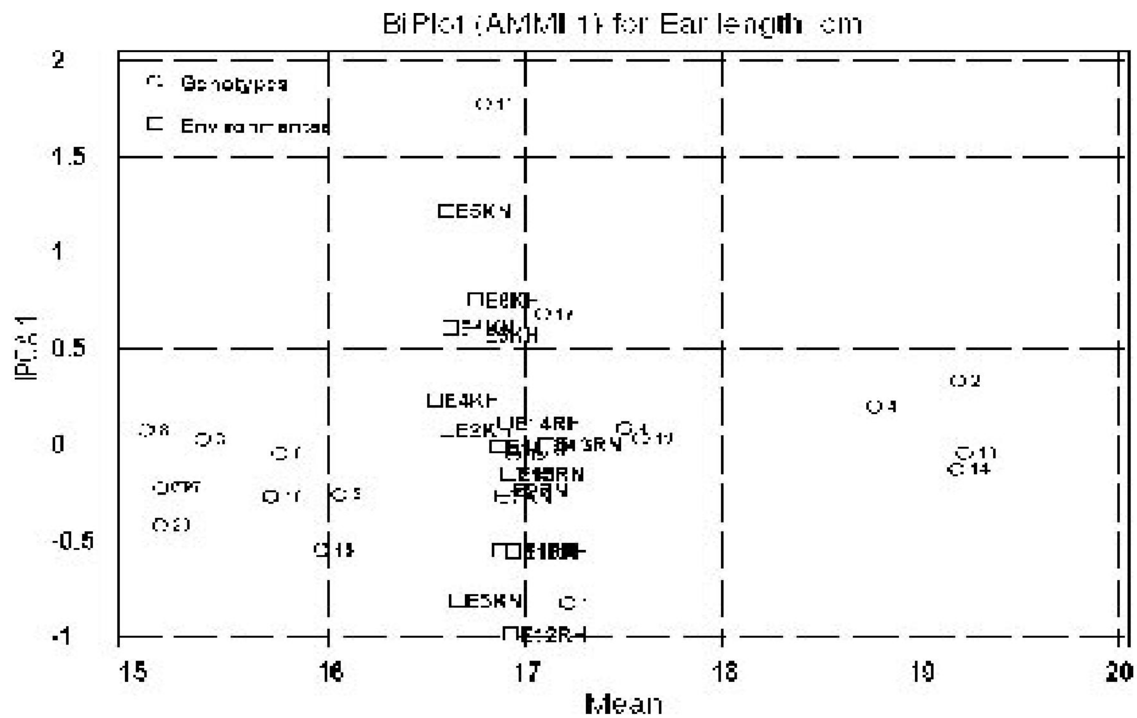
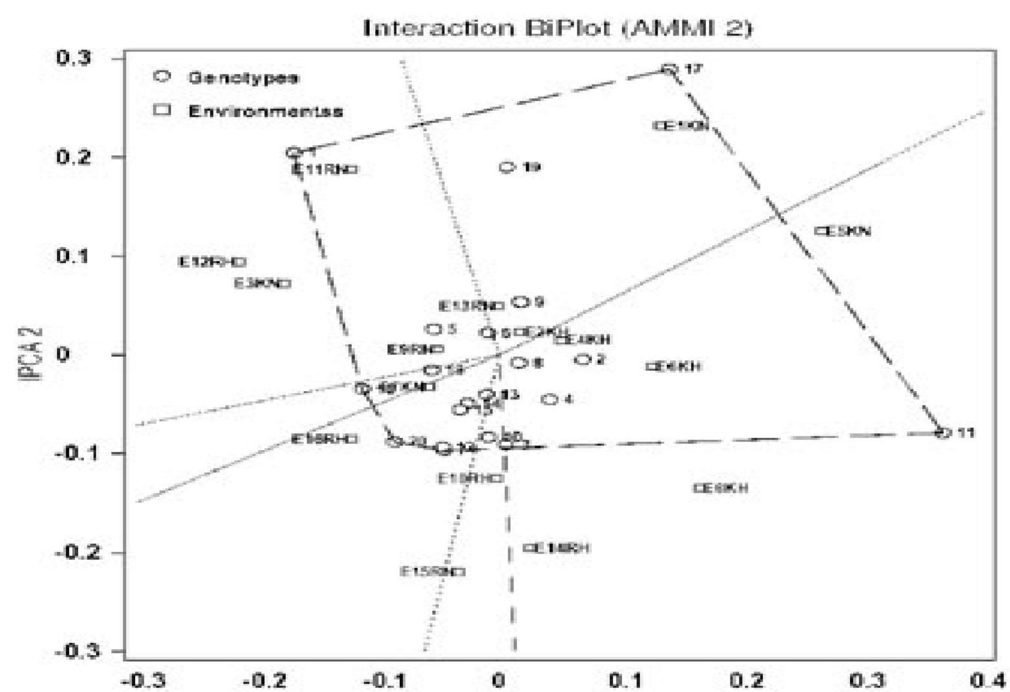


Figure 4.



IPCA 1

Figure 5.

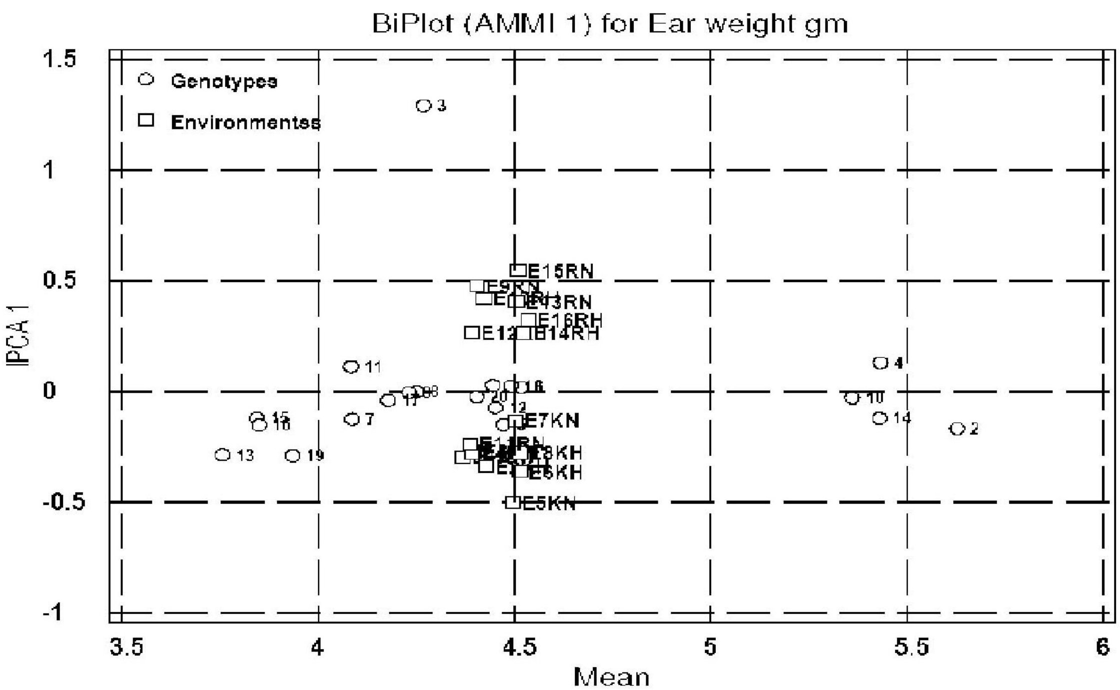
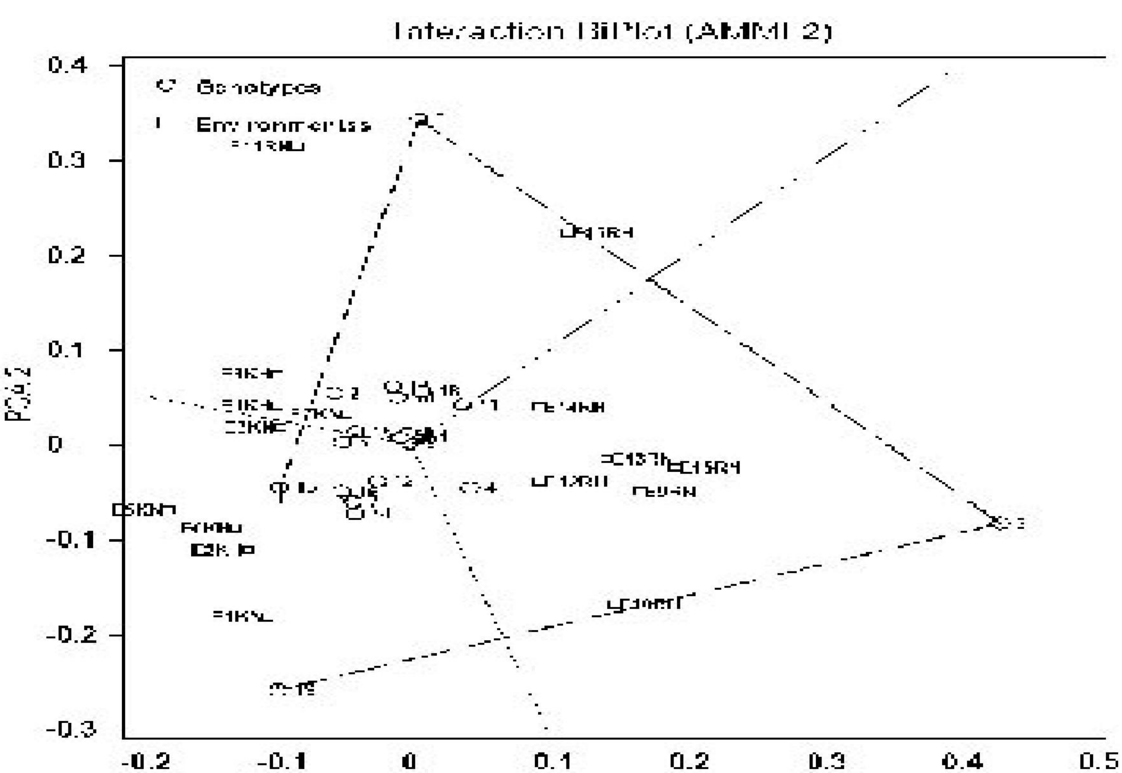


Figure 6.



IPCA 1

Figure 7.

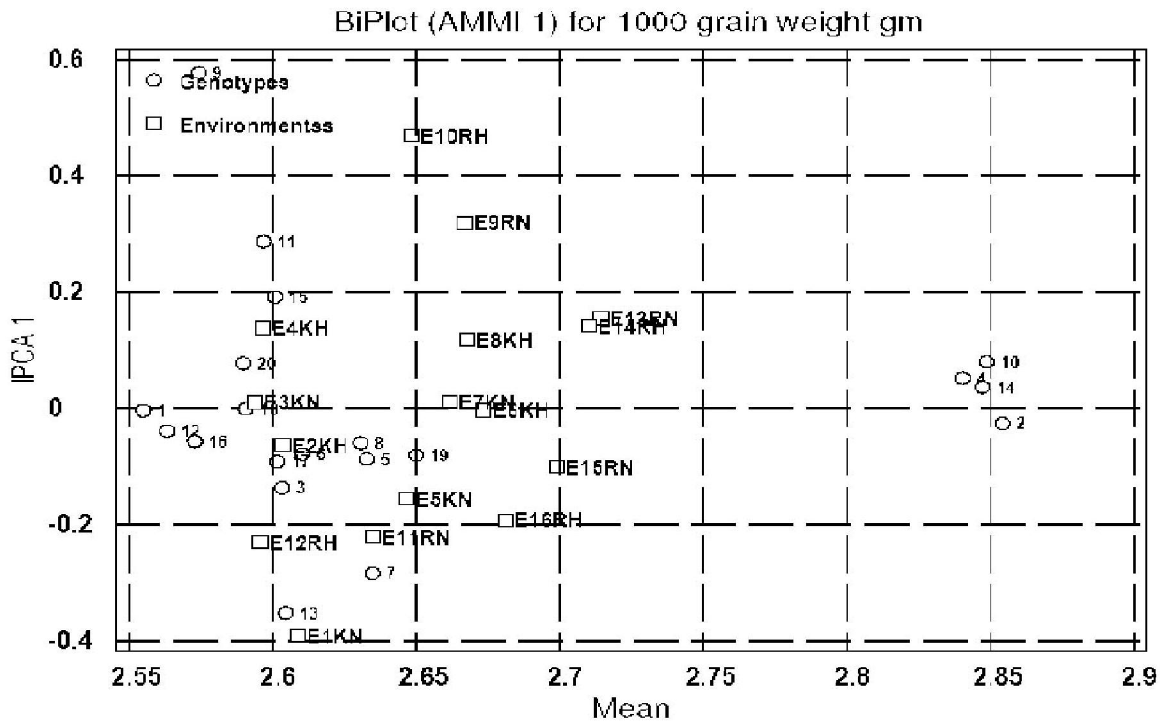


Figure 8.

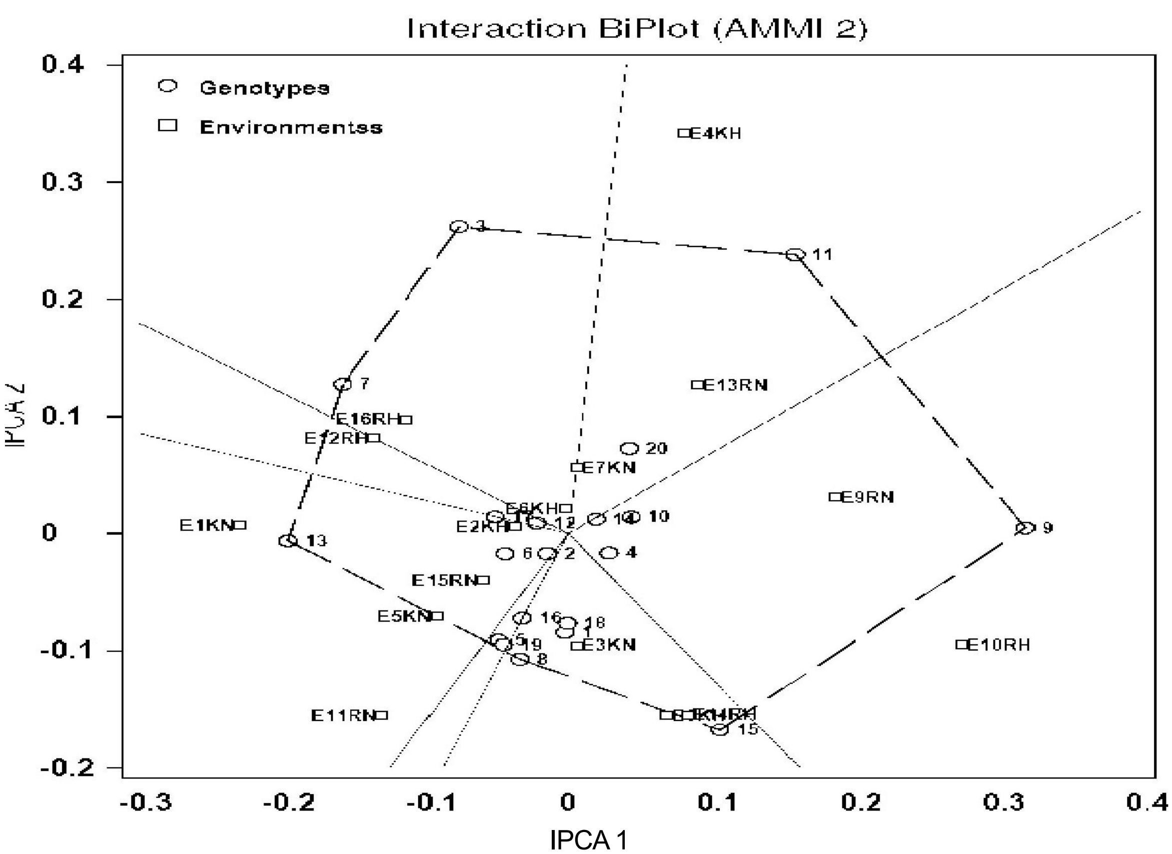


Figure 9.

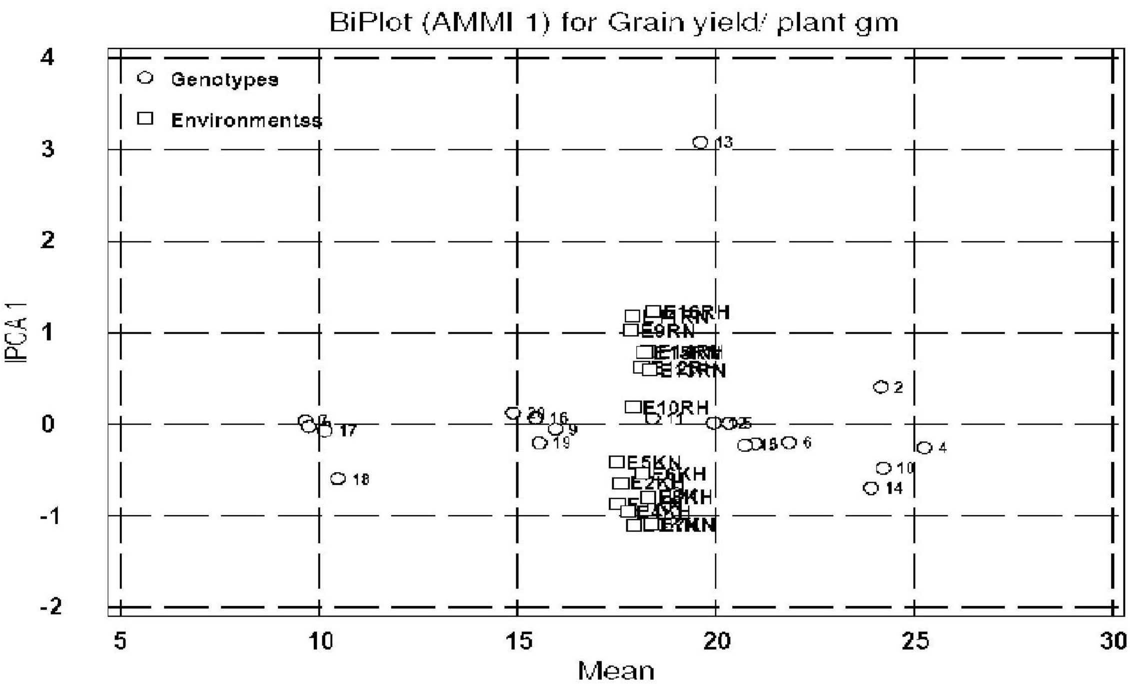
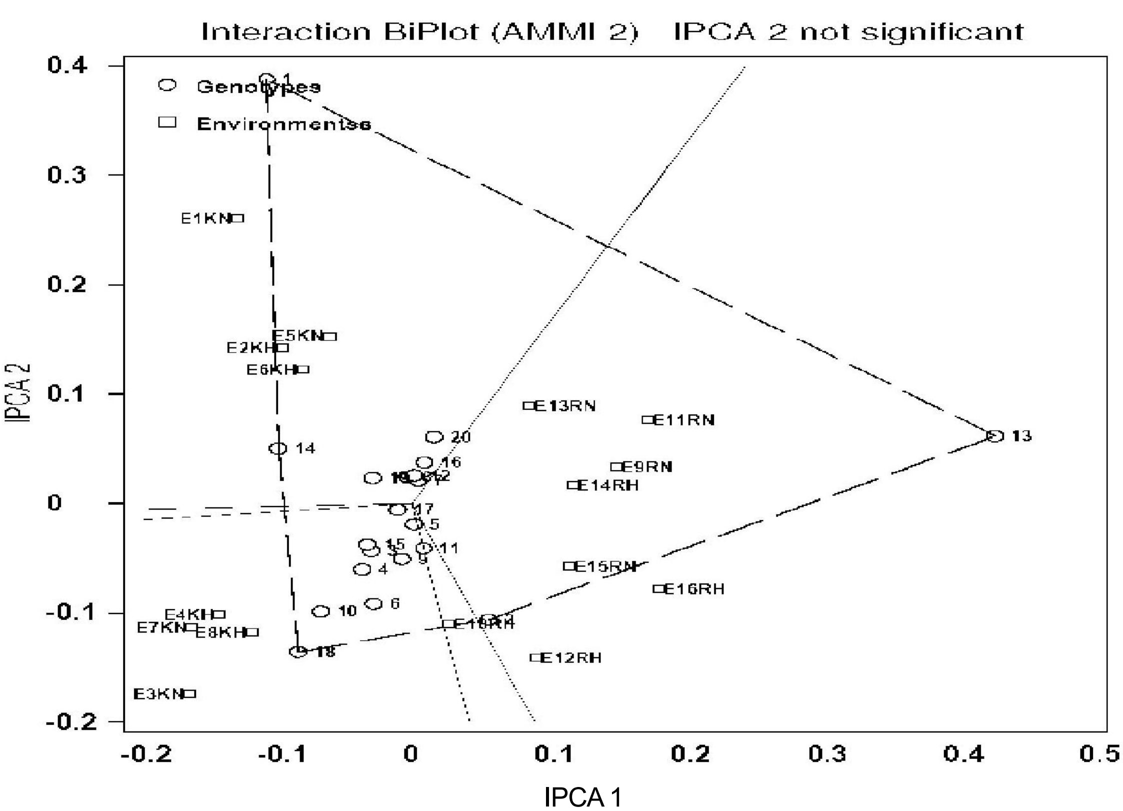


Figure 10.



performance, the genotypes GS 480 and GS 489 (for productive tillers plant^{-1}), GS 477 (for ear weight), GS 487 and GS 444(for ear length), SRL for 1000 grain weight; and GS 450 and GS 467 (for grain yield plant^{-1}) may proved to be promising for cultivation (Table 2).

All the characters showed significant S^2d values and non-significant regression coefficients among all the genotypes. This indicates that predominance of non-linear components which leads to unpredictable response of the genotypes. Marimuthu *et al.* (1994) studied stability of yield in 5 promising genotypes of foxtail miilet [*Setaria italica* (L.) Beauv] The mean square values were significant when tested against the pooled error. However, the differences in yield among the genotypes tested were not significant when tested against genotype × environment interaction mean squares indicating that all of them were at par with regard to yield potential. The differences among environments were significant so also the genotype × environment (linear) component indicating the differential response of genotypes to varying environments.

For productive tillers per plant, the GXE interaction was significant and was further partitioned into AMMI components with the contribution of 40.57, 24.22, 15.35 and 11.62% to the total GXE interaction variance. In AMMI1, the genotypes 3 and 14 are specifically adapted to certain environments. The genotypes, 6, 11, 12 and 20 were stable genotypes because this IPCA1 score is near to zero. By AMMI2 interaction biplot the genotypes like 4, 9, 11 and 20 were identified as most stable ones because they are situated close to the center of IPCA axis. The environments III, V, XI and XV were more discriminating ones as indicated by the longest distance between their marker and origin.

For ear length, AMMI analysis of variance indicated that the genotype, environment and genotype x environment interactions accounted for 87.02, 1.03 and 11.93% of the total variance respectively. In Table 2 four IPCA axis showed significance by an F-test with contribution of 38.28, 26.80, 17.14 and 9.37% to the total GXE interaction variance. The first four AMMI components representing interaction pattern were significant and jointly contributed 91.59% of the interaction component and the remaining AMMI components got combined in the residual. According to AMMI1 biplot genotypes 9, 13 and 19 were adaptable to all environments and more stable. Zaval-Garcia *et al.* (1992) in sorghum predicted the stability of genotypes on the basis of mean performance and the magnitude of $IPCA_1$ scores. Genotype 2 had high mean and large value of $IPCA_1$ score hence specifically adapted to certain environments. By AMMI 2, the genotypes 6, 8 and 18 were more stable over environments.

For ear weight per plant, AMMI analysis of variance partitioned the treatment sum of squares into additive genotype and environment effects and non-additive GE interaction effects. These sources were all significant at the 0.01 probability level and accounted for 90.52, 1.02 and 8.44% of the treatment combinations sum of squares respectively (Table 3). The four IPCA axis showed significant values with contribution of 50.49, 20.83, 12.67 and 8.48% to the total GXE interaction variance. According to AMMI1 (Fig 5), genotypes 8, 9, 10, 18 and 20 were more stable because their IPCA scores are near to zero and genotypes like 13 and 14 are specially adapted to a particular environment. By AMMI 2, stable genotypes over environments were 1, 8 and 20.

For 1000-grain weight, AMMI analysis of variance showed that the genotype main effect, environmental additive effect and GXE non additive effect were significant with the contribution of 53.23%, 8.09% and 38.51% of the total variance respectively. In this model, the GXE interaction was significant and was further partitioned into AMMI components with the contribution of 32.35%, 23.52%, 18.48% and 12.18% to the total GXE interaction variance using 285 degrees of freedom (df) for 19 genotypes, 15 for environments and 120 for $IPCA_1$ to $IPCA_4$. According to AMMI1 (Fig 7) genotypes 1, 2 and 18 were more stable because as the IPCA scores are near to zero. In AMMI2 biplot genotypes 2, 12 and 14 were stable across environments.

For grain yield per plant, AMMI analysis of variance indicated that all the three sources *i.e.,* genotype main effect, environmental additive effect and GXE (non-additive) effects have significant effects accounted 52.24, 9.71 and 19.01% of the total variance respectively indicating differential response of genotypes. By AMMI1 (Fig 9), most of genotypes and environments having IPCA score near zero and their interactions are positive hence they are more responsive to all environments. Genotype 13 had high mean and high IPCA score hence specifically adopted to certain environments. For this trait $IPCA_2$ is non-significant and genotypes 1 and 9 were more stable. Environments I, IV, III, VII, XIII, XII, and XVI were discriminent ones. Crossa *et al.* (1991) in wheat conducted AMMI analysis and predicted the stability of genotypes on the basis of mean performance and the magnitude of $IPCA_1$ scores.

The ANOVA indicated non-significant GXE interaction for 1000 grain weight and ANOVA of Eberhart and Russell (1966) indicated non-significant GXE (linear) interaction for productive tillers per plant, ear length and 1000 grain weight when tested against pooled deviation. As per AMMI analysis the $IPCA_1$ significantly contributed to all five characters, productive tillers per plant, ear length, ear weight, 1000 grain weight and grain yield per plant while $IPCA_2$ contributed significantly to G XE interaction for productive tillers per plant, ear length, ear weight and 1000 grain weight. This brings out clearly the advantage of AMMI ANOVA in bringing out GXE interaction through $IPCA_1$ which gets combined with error in the other two ANOVA and points out the utility of AMMI models in studying the significant GXE interaction and identifying stable genotypes for characters which are undetected in other analysis.

The results clearly here confirm that AMMI analysis with its bipot is a very useful tool in analyzing data. It explains comprehensively both the effects due to genotypes and environments and also their interaction patterns. ANOVA could explain only the genotypes and environments but not their interaction. AMMI partition the non-linear interaction component of genotype with environment interaction and also helps in having deeper insight into study of environmental contribution to GXE interaction as also pointed out by Zobel *et al*. (1988).

As per AMMI analysis, the genotypes 6 and 11 (for productive tillers per plant); 9, 13 and 19 (for ear length); 8, 9, 10 and 18 (for ear weight per plant); 1, 2 and 18 (for 1000 grain weight); most of the genotypes (for grain yield per plant) are more stable because they are having IPCA score near zero *i.e.,* less interaction with environments. According to Eberhart and Russell model the genotypes 11 and 16 (for productive tillers per plant); 2 and14 (for ear length); 1 and 9 (for ear weight per plant); 19 (1000 grain weight); 4 and 8 (for grain yield per plant) showed desirable performance.

LITERATURE CITED

Bahman Shafii, Karen A Mahler, Willian J P and Dick L Auld 1992. Genotype ´ environment interaction effects on winter rape seed and oil content.Crop Science 32:922-927.

Chang K 1968. Archeology of ancient China. Science 162:519-52

Crossa J, Fox P N , Pfeiffer W H, Rajaram S and Gauch H G 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. Theoritical and Applied Genetics 81: 27-37.

Eberhart S A and Russell W A 1966. Stability parameters for comparing crop varieties. Crop Science 6 : 36- 40.

Gauch H G 1988. Model selection and validation for yield trials with interaction. Biometircs 34:705-715.

Gauch H G and Zobel R W 1988. Predictive and postdictive success of statistical analysis of yield trials. Theoritical and Applied Genetics 76:1-10.

Marimuthu R Palanisamy S and Fazlulah Khan A K 1994. Stability of yield performance in foxtail millet (*Setaria italica* (L.) Beauv.) Madras Agricultural Journal 81 (6): 345-346.

Sharma P K, Gupta P K and Govila O P. 1998. AMMI analysis of a pearl millet yield trail. Indian Journal of Genetics and Plant Breeding 58(2): 183-192.

Zaval - Garcia F, Bramel - Cox P J and Eastin J D. 1992. Potential gain from selection for yield stability for grain sorghum populations. Theoritical and Applied Genetics 85: 112-119.

Zobel R W, Wright M J and Gauch H G 1988. Statistical analysis of a yield trial. Agronomy Journal 80: 388-393.

(Received on 18.10.2010 and revised on 09.11.2010)