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Stability analysis for physiological and yield traits in single cross hybrids of maize (*Zea mays* L.) by AMMI model

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Abstract
In the present investigation, forty five single cross maize (*Zea mays* L.) hybrids were tested over five environments (Seasons/ situations) to assess the stability for four characters using AMMI (Gauch, 1992) model. The combined ANOVA of forty five hybrids in five environments showed significant differences for genotype and environment interaction for four characters. IPCA1 explained most of the proportion of G × E interaction than IPCA2 and IPCA3 for most of the characters studied. AMMI model explained 90.46 % of total genotype × environment interaction component for chlorophyll content. Similarly, 92.51% for leaf area index; 98.19 for days to maturity and 85.77% for grain yield per plant. As per the AMMI model, the hybrids *viz.*, 7 (CM 119 × BML 7) and 37 (CM 211 × BML7) were identified as having general adaptability for grain yield and other two physiological traits *viz.*, chlorophyll content and leaf area index traits beside best *per se* performance in combined analysis. However, the hybrid 21 (CM 131 × BML 6) was found stable beside low *per se* performance for days to maturity. Hence, it could be suggested that this cross might be successfully utilized in future breeding programmes to isolate genotypes which can mature early.

Keywords: Stability analysis, AMMI model, Maize

Introduction
Maize breeding programmes, aimed towards improvement of higher productivity in single cross hybrids, should also take genotype × environment interaction effects into consideration which affect grain yield. In the past selection for yield improvement in corn has been primarily for visual morphological traits such as vigour, stalk strength, disease resistance and other readily measured traits such as ear number and principally grain weight. This practice still continues with varying emphasis. However, quite often it has been argued that yield ultimately is the end product of enzyme catalyzed processes routed through physiological parameters and selection based on these is likely to be perhaps more effective. Several characters, namely, leaf area, leaf area duration, photosynthetic efficiency, chlorophyll content have been looked into from breeding point of views. The estimation of genotype × environment interaction for major physiological traits beside yield is of major importance to the plant breeder in achieving rapid gains through selection. The study of genotype-environment interaction using a refined biometrical model would lead to successful identification of stable hybrids which would either be released for commercial cultivation or be used in future breeding programme in addition to identify the better hybrids for different niches. The AMMI model is a hybrid model involving both additive and multiplicative components of two way data structure. The AMMI model separates the additive variance and then applies principal component analysis (PCA) to the interaction portion to extract a new set of coordinate axes which explain in more detail the interaction pattern. As the maize crop is being cultivated throughout the year in different parts of the country for diversed uses in addition to grain yield, one of the greatest challenges to maize breeders is the obtainment of a hybrid with high mean yield with widest possible adaptation to the various seasons *viz*., *kharif*, *rabi* and *summer*. Besides various seasons, of late in the state of Andhra Pradesh, maize is also being grown under *rice fallow* situations and also has a wide scope for future improvement of this crop under these situations. However, there is a need to develop the hybrids with wide adaptability among various seasons and situations, so that the maize hybrids can be produced on large scale, lowering the production costs of the basic material and making it more accessible to producers. Many investigators determined the association of physiological traits *viz*., chlorophyll content and leaf area index had consistent positive and significant correlation with grain yield and yield components directly or indirectly (Ahsan, 1999 and Sadek *et al*., 2006) [2, 9]. Considering these aspects into consideration the present study was also undertaken for the identification of stable hybrids for yield and other

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important physiological traits in order to select superior recycled inbred lines with high yield and greater photosynthetic ability suitable to various seasons and situations.

Materials and Methods

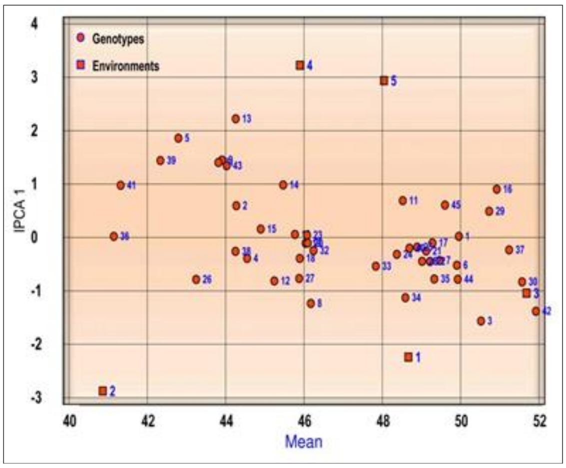
Ten inbred lines of maize *viz*., CM 119, CM 120, CM 131, CM 133, CM 210, CM 211, BML 6, BML 7,BML 13 and BML 10 were crossed in a half diallel during *kharif*, 2009 and *kharif*, 2010 at S.V Agricultural college farm, Tirupati. All the forty five cross combinations were evaluated during *rabi* 2009, *summer* 2010, *kharif* 2010, *rabi* 2010 -11 and *rice fallow* 2010-11 in a Randomized Block Design (RBD) with three replications. The crop was raised as per the recommended cultural practices. The row-to-row and plant to plant distance were maintained with 75 and 20 cm, respectively. The data were recorded on randomly selected five plants on chlorophyll content (SPAD), leaf area index, days to maturity and grain yield per plant. Analysis of variance of genotypes mean was computed for traits *viz.*, chlorophyll content, leaf area index, days to maturity and grain yield per plant in five environments. Then the data were pooled over environments after testing the homogeneity of error variance by using the Bartlett's test. The statistical analysis for AMMI model was carried out by following Gauch, 1992 [5].

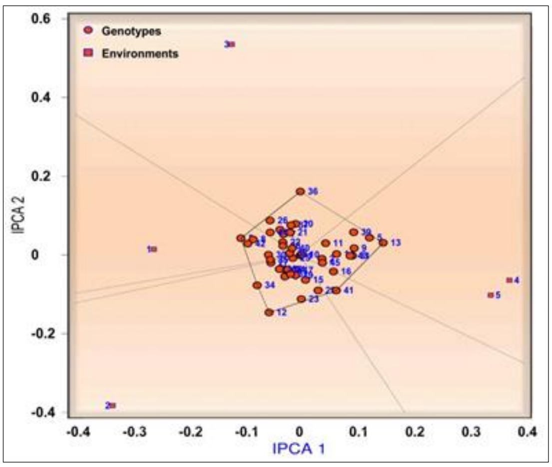
Results and Discussion

The results of the AMMI analysis of variance are presented in Table 1. It clearly indicated that the mean sum of squares for genotypes, environments and genotype × environment interaction were found to be highly significant for chlorophyll content, leaf area index, days to maturity and grain yield per plant. This suggested that broad range of diversity existed among genotypes and environments and that the performance of genotypes was differential over the seasons and situations.

According to AMMI model, the genotypes which are characterized by mean greater than the grand mean and the PCA scores nearly zero, are considered as generally adaptable to all the environments (Crossa *et al*., 1990) [4]. However, the genotypes with high mean performance and with large value of IPCA scores are considered as having specific adaptability to the environments. Two types of biplot, AMMI 1 and AMMI 2 were used to interpret GEI interaction in this study. In AMMI 1, the genotypic and environmental mean were plotted on the abscissa and the IPCA 1 scores for the genotypes and the environments on the ordinate. However, in AMMI 2, the IPCA1 scores were plotted on the abscissa and IPCA 2 scores on the ordinate.

For chlorophyll content the genotypes, environments and G × E interaction were accounted for 24.64%, 38.14% and 30.54% of the total treatment variation and the G × E interaction was partitioned into three (IPCA I, IPCA II, IPCA III) interaction principle component axis which explained 47.88%, 26.56% and 16.02% of the total G × E interaction sum of squares. This model explained 90.46% of the total genotype - environment interaction component (Table 1). In biplot (Fig.1) assay of AMMI 1, four hybrids *viz*; 1 (CM119 × CM 120), 17 (CM 120 × BML10), 21 (CM 131 × BML 6) and 37 (CM 211 × BML 7) were identified as having general adaptability as they scattered at the right hand side of the grand mean level and close to IPCA=0 line. However, the hybrid 13 (CM 120 × CM 211) was equipped with high mean and large IPCA1 scores, hence specially adapted to the environments *rabi* 2010-11and *rice fallow* 2010-11. Further, AMMI 2 biplot (Fig.2) exhibited that the hybrids 10 (CM 120 × CM 131), 25 (CM 133 × CM 210) and 40 (BML 6 × BML 7) with small interaction were located near the plot origin and were less responsive to the environments than the vertex hybrids. The environment *kharif* 2010 was identified as most suitable environment for chlorophyll content as indicated by high IPCA1 values and low IPCA 2 values.





●1 = CM119 × CM120 ●10 = CM120 × CM131 ●19 = CM131 × CM210 ●28 = CM133 × BML7 ●37= CM211 × BML7
●2 = CM119 × CM131 ●11 = CM120 × CM133 ●20 = CM131 × CM211 ●29 = CM133 × BML13 ●38= CM211 × BML13
●3 = CM119 × CM133 ●12 = CM120 × CM210 ●21 = CM131 × BML6 ●30 = CM133 × BML10 ●39= CM211 × BML10
●4 = CM119 × CM210 ●13 = CM120 × CM211 ●22 = CM131 × BML7 ●31 = CM210 × CM211 ●40= BML6 × BML7
●5 = CM119 × CM211 ●14 = CM120 × BML6 ●23 = CM131 × BML13 ●32 = CM210 × BML6 ●41= BML6 × BML13
●6 = CM119 × BML6 ●15 = CM120 × BML7 ●24 = CM131 × BML10 ●33 = CM210 × BML7 ●42= BML6 × BML10
●7 = CM119 × BML7 ●16 = CM120 × BML13 ●25 = CM133 × CM210 ●34 = CM210 × BML13 ●43= BML7 × BML13
●8 = CM119 × BML13 ●17 = CM120 × BML10 ●26 = CM133 × CM211 ●35 = CM210 × BML10 ●44= BML7 × BML10
●9 = CM119 × BML10 ●18 = CM131 × CM133 ●27 = CM133 × BML6 ●36 = CM211 × BML6 ●45= BML13 × BML10
■1 Rabi 2009-10; ■2 Summer 2010; ■3 Kharif 2010; ■4 Rabi 2010-11; ■5 Rice Fallow 2010-11.

Fig 1: AMMI 1 biplot-IPCA 1 scores of forty five crosses and five environments plotted against chlorophyll content (SPAD) in maize (*Zea mays* L.).

Fig 2: AMMI 2 biplot-IPCA 1 and IPCA 2 scores of forty five crosses and five environments plotted against chlorophyll content (SPAD) in maize (*Zea mays* L.).

For leaf area index the genotypes, environments and G × E interaction were accounted for 20.46%, 27.80% and 21.08%, respectively and the GEI was partitioned into three IPCA axis with contribution of 41.78%, 27.40% and 23.33% of the total G × E interaction sum of squares. AMMI model explained 92.51% of the total genotype -environment interaction component with the first three PCA scores (Table 1). AMMI biplot in Fig. 3 indicated that, the hybrids 6 (CM 119 × BML 6), 21 (CM 131 × BML 6), 22 (CM 131 × BML 7), 37 (CM 211 × BML 7) had good general adaptation and the hybrid 35 (CM 210 × BML 10) was specifically suited to the environment *rabi* 2009-10. However, AMMI 2 biplot (Fig.4) indicated that, the hybrids 4 (CM 119 × CM 210), 6 (CM 119 × BML 6), 22 (CM 131 × BML 7) and 26 (CM 133 × CM 211) were less responsive to the environments. Among the environments, *kharif* 2010 was found suitable for leaf area index as indicated by high IPCA1 and low IPCA 2 scores.

●1 = CM119 × CM120	●10 = CM120 × CM131	●19 = CM131 × CM210	●28 = CM133 × BML7	●37 = CM211 × BML7
●2 = CM119 × CM131	●11 = CM120 × CM133	●20 = CM131 × CM211	●29 = CM133 × BML13	●38 = CM211 × BML13
●3 = CM119 × CM133	●12 = CM120 × CM210	●21 = CM131 × BML6	●30 = CM133 × BML10	●39 = CM211 × BML10
●4 = CM119 × CM210	●13 = CM120 × CM211	●22 = CM131 × BML7	●31 = CM210 × CM211	●40 = BML6 × BML7
●5 = CM119 × CM211	●14 = CM120 × BML6	●23 = CM131 × BML13	●32 = CM210 × BML6	●41 = BML6 × BML13
●6 = CM119 × BML6	●15 = CM120 × BML7	●24 = CM131 × BML10	●33 = CM210 × BML7	●42 = BML6 × BML10
●7 = CM119 × BML7	●16 = CM120 × BML13	●25 = CM133 × CM210	●34 = CM210 × BML13	●43 = BML7 × BML13
●8 = CM119 × BML13	●17 = CM120 × BML10	●26 = CM133 × CM211	●35 = CM210 × BML10	●44 = BML7 × BML10
●9 = CM119 × BML10	●18 = CM131 × CM133	●27 = CM133 × BML6	●36 = CM211 × BML6	●45 = BML13 × BML10

■1 Rabi 2009-10; ■2 Summer 2010; ■3 Kharif 2010; ■4 Rabi 2010-11; ■5 Rice Fallow 2010-11.

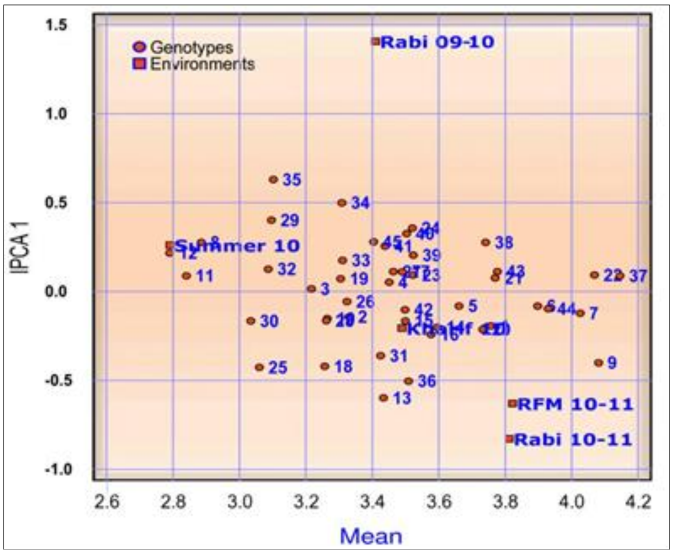


Fig 3: AMMI 1 biplot-IPCA 1 scores of forty five crosses and five environments plotted against leaf area index in maize (*Zea mays* L.).

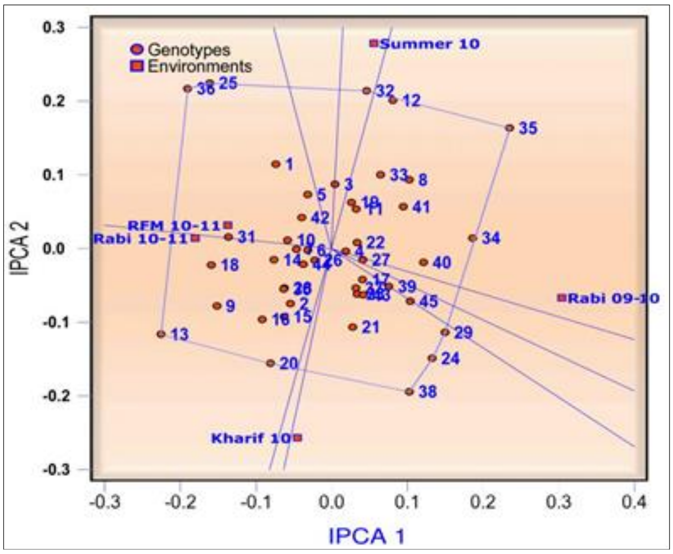


Fig 4: AMMI 2 biplot-IPCA 1 and IPCA 2 scores of forty five crosses and five environments plotted against leaf area index in maize (*Zea mays* L.).

For days to maturity, the AMMI analysis showed that genotypes, environments and G × E interaction were accounted for 44.54%, 24.61% and 25.16%, respectively. The GEI was partitioned into three IPCA axes which explained 48.15%, 39.07% and 10.97% of the total G × E interaction sum of squares and explained 98.19% of the total GEI components (Table1). AMMI 1 biplot (Fig.5) exhibited four hybrids *i.e.* 5 (CM 119 × CM 211), 37 (CM 211 × BML 7), 40 (BML 6 × BML 7) and 42 (BML 6 × BML 10) had general adaptation. However, the hybrid 27 (CM 133 × BML 6) showed specific adaptation to the *kharif* 2010. In AMMI 2 biplot (Fig.6) the hybrids 6 (CM 119 × BML 6), 34 (CM 210 × BML 13), 42 (BML 6 × BML 10), 43 (BML 7 × BML 13) and 45 (BML 13 × BML 10) exhibited less responsive to the environments and vertex hybrids were more responsive to the environments. Among the environments *rabi* 2010-11 and *rice fallow* 2010-11 were found most suitable for days to maturity.

For grain yield per plant the genotypes, environments and G × E interaction were accounted for 51.67%, 10.39% and 17.88% of the total treatment variation and the G × E interaction was partitioned into three IPCA axis which explained 35.05%, 28.32% and 22.40% of the total G × E interaction sum of squares. This model explained 85.77% of the total genotype -environment interaction component (Table 1). AMMI 1 biplot (Fig.7) indicated that, the hybrids 7 (CM 119 × BML 10), 21 (CM 131 × BML 6), 28 (CM 133 × BML7), 37 (CM 211 × BML 7) and 44 (BML 7 × BML 10) were found stable with high grand mean and close to IPCA of zero line. Hence, these hybrids could be recommended for all seasons besides *rice fallow* situation to exploit high grain yield. However, the hybrids 18 (CM 131 × CM 13), 19 (CM 131 × CM 120) and 26 (CM 133 × CM 211) were equipped with high mean with large IPCA 1 scores, hence specifically adapted to the environment *rabi* 2010-11. Further, the AMMI 2 biplot (Fig.8) showed the hybrids 7 (CM 119 × BML 10), 16 (CM 120 × BML 13), 35 (CM 210 × BML 10) and 44 (BML 7 × BML 10) had small interaction with environments which were located near the origin, reflecting their stability in yield performance across environments. The vertex hybrids 9 (CM 119 × BML 10) and 36 (CM 211 × BML 6) had positive responsive with *rabi* 2009-10 that were away from origin. The environment *rabi* 2009-10 was identified most suitable environment for grain yield per plant.

●1 = CM119 × CM120	●10 = CM120 × CM131	●19 = CM131 × CM210	●28 = CM133 × BML7	●37 = CM211 × BML7
●2 = CM119 × CM131	●11 = CM120 × CM133	●20 = CM131 × CM211	●29 = CM133 × BML13	●38 = CM211 × BML13
●3 = CM119 × CM133	●12 = CM120 × CM210	●21 = CM131 × BML6	●30 = CM133 × BML10	●39 = CM211 × BML10
●4 = CM119 × CM210	●13 = CM120 × CM211	●22 = CM131 × BML7	●31 = CM210 × CM211	●40 = BML6 × BML7
●5 = CM119 × CM211	●14 = CM120 × BML6	●23 = CM131 × BML13	●32 = CM210 × BML6	●41 = BML6 × BML13
●6 = CM119 × BML6	●15 = CM120 × BML7	●24 = CM131 × BML10	●33 = CM210 × BML7	●42 = BML6 × BML10
●7 = CM119 × BML7	●16 = CM120 × BML13	●25 = CM133 × CM210	●34 = CM210 × BML13	●43 = BML7 × BML13
●8 = CM119 × BML13	●17 = CM120 × BML10	●26 = CM133 × CM211	●35 = CM210 × BML10	●44 = BML7 × BML10
●9 = CM119 × BML10	●18 = CM131 × CM133	●27 = CM133 × BML6	●36 = CM211 × BML6	●45 = BML13 × BML10

■1 Rabi 2009-10; ■2 Summer 2010; ■3 Kharif 2010; ■4 Rabi 2010-11; ■5 Rice Fallow 2010-11.

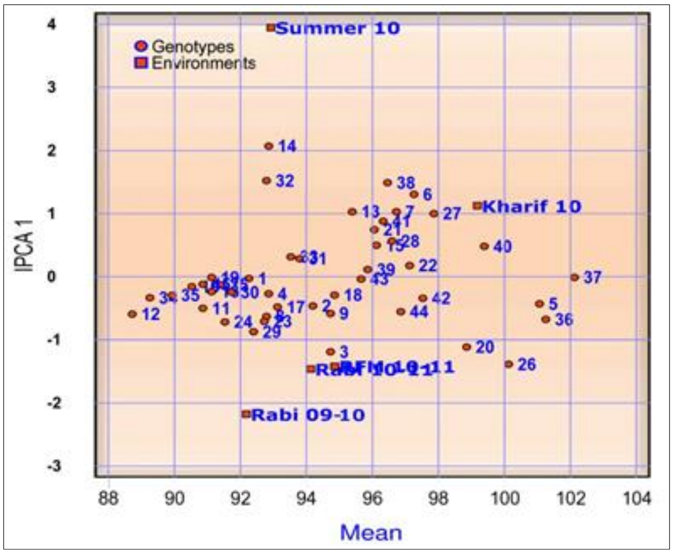


Fig 5: AMMI 1 biplot-IPCA 1 scores of forty five crosses and five environments plotted against days to maturity in maize (*Zea mays* L.).

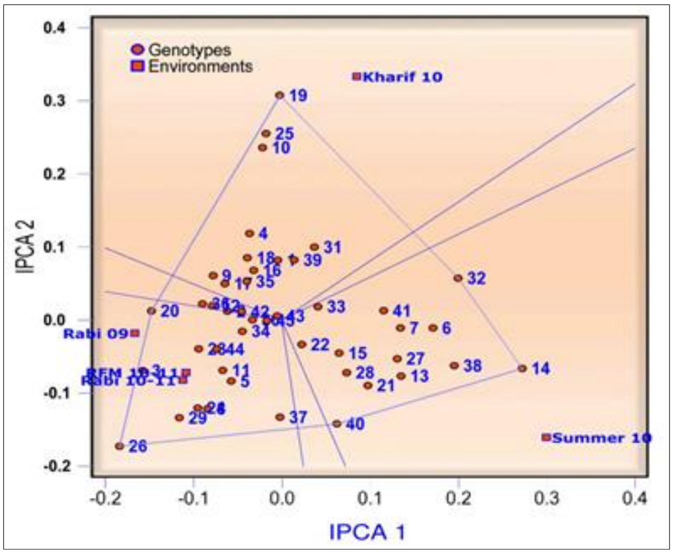


Fig 6: AMMI 2 biplot-IPCA 1 and IPCA 2 scores of forty five crosses and five environments plotted against days to maturity in maize (*Zea mays* L.)

●1 = CM119 × CM120	●10 = CM120 × CM131	●19 = CM131 × CM210	●28 = CM133 × BML7	●37 = CM211 × BML7
●2 = CM119 × CM131	●11 = CM120 × CM133	●20 = CM131 × CM211	●29 = CM133 × BML13	●38 = CM211 × BML13
●3 = CM119 × CM133	●12 = CM120 × CM210	●21 = CM131 × BML6	●30 = CM133 × BML10	●39 = CM211 × BML10
●4 = CM119 × CM210	●13 = CM120 × CM211	●22 = CM131 × BML7	●31 = CM210 × CM211	●40 = BML6 × BML7
●5 = CM119 × CM211	●14 = CM120 × BML6	●23 = CM131 × BML13	●32 = CM210 × BML6	●41 = BML6 × BML13
●6 = CM119 × BML6	●15 = CM120 × BML7	●24 = CM131 × BML10	●33 = CM210 × BML7	●42 = BML6 × BML10
●7 = CM119 × BML7	●16 = CM120 × BML13	●25 = CM133 × CM210	●34 = CM210 × BML13	●43 = BML7 × BML13
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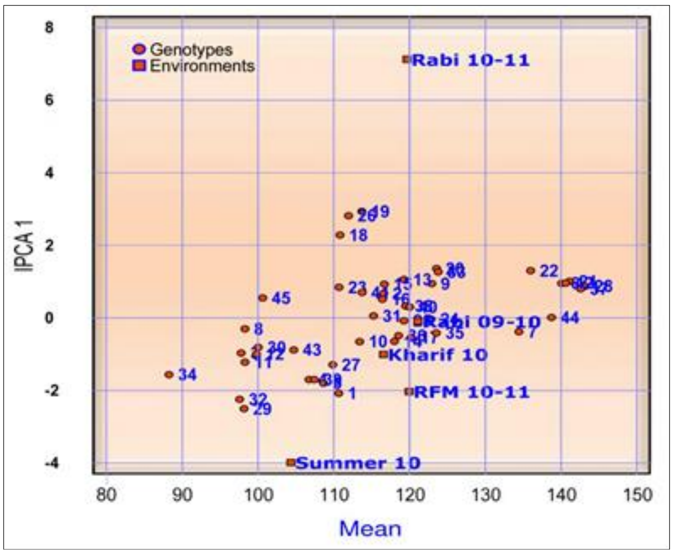

Fig 7: AMMI 1 biplot-IPCA 1 scores of forty five crosses and five environments plotted against grain yield per plant in maize (*Zea mays* L.).

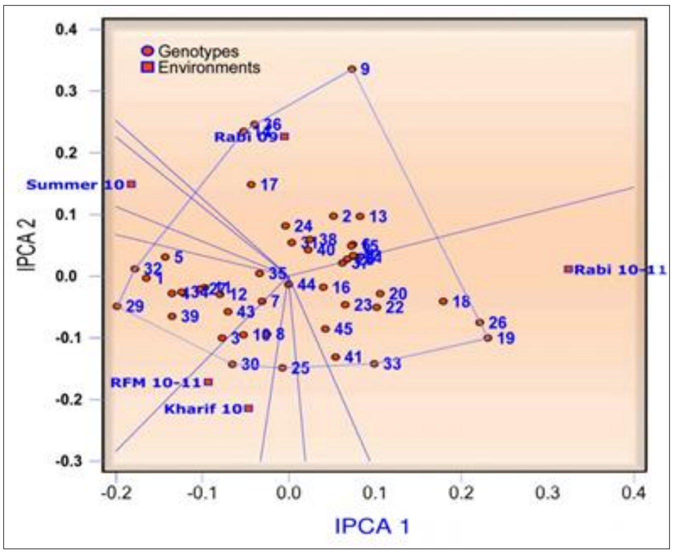

Fig 8: AMMI 2 biplot-IPCA 1 and IPCA 2 scores of forty five crosses and five environments plotted against grain yield per plant in maize (*Zea mays* L.).

Table 1: ANOVA for AMMI of crosses for chlorophyll content (SPAD), leaf area index, days to maturity and grain yield per plant in maize (*Zea mays* L.)

Source	Chlorophyll content (SPAD)			Leaf area index			Days to maturity			Grain yield per plant (g)		
	df	MSS	% explained	df	MSS	% explained	df	MSS	% explained	df	MSS	% explained
Trials	224	31.78**	-	224	0.35**	-	224	23.01**	-	224	293.48**	-
Genotypes	44	42.72**	24.64	44	0.53**	20.46	44	55.34**	44.54	44	965.69**	51.67
Environments	4	727.28**	38.14	4	7.95**	27.80	4	336.38**	24.61	4	2135.70**	10.39
G x E interaction	176	13.24**	30.54	176	0.14**	21.08	176	7.81**	25.16	176	83.56**	17.88
PCA I	47	23.73	47.88	47	0.21	41.78	47	14.09	48.15	47	109.68	35.05
PCA II	45	13.75	26.56	45	0.15	27.40	45	11.94	39.07	45	92.55	28.32
PCA III	43	8.68	16.02	43	0.13	23.33	43	3.51	10.97	43	76.60	22.40
Residual	41	5.42	9.54	41	0.04	7.48	41	0.60	1.80	41	51.02	14.23
Pooled error	1.12	13.23	-	0.08	0.09	-	0.67	2.09	-	36.06	74.03	-

*, ** Significant at 5 % and 1 % level, respectively.

Table 2: Mean performance of crosses for chlorophyll content (SPAD) and leaf area index for five environments in maize

S. No.	Crosses	Chlorophyll content (SPAD)						Leaf area index					
		Ra 09-10	Su 10	Kh 10	Ra 10-11	RF 10-11	Mean	Ra 09-10	Su 10	Kh 10	Ra 10-11	RF 10-11	Mean
1	CM 119 × CM 120	50.24	44.64	55.29	48.97	50.63	49.95	3.28	3.46	3.65	4.30	4.10	3.76
2	CM 119 × CM 131	47.01	39.62	50.15	41.52	43.07	44.27	3.20	2.30	3.45	3.85	3.85	3.33
3	CM 119 × CM 133	49.97	40.53	50.78	53.65	57.68	50.52	3.46	2.36	2.51	4.00	3.76	3.22
4	CM 119 × CM 210	44.97	35.42	51.84	43.49	47.04	44.55	3.68	2.50	3.15	3.97	3.95	3.45
5	CM 119 × CM 211	50.47	42.54	46.24	37.10	37.63	42.80	3.48	3.11	3.45	4.05	4.22	3.66
6	CM 119 ×BML 6	49.27	45.39	51.09	53.59	50.20	49.91	3.77	3.15	3.89	4.39	4.29	3.90
7	CM 119 ×BML 7	51.10	43.42	50.48	50.34	52.00	49.47	3.81	3.27	4.04	4.28	4.74	4.03
8	CM 119 ×BML 13	46.75	36.89	46.72	49.49	51.04	46.18	3.02	2.70	2.81	2.76	3.14	2.89
9	CM 119 ×BML 10	49.36	42.15	48.95	37.66	41.41	43.91	3.43	3.18	4.51	4.57	4.72	4.08
10	CM 120 × CM 131	45.22	41.13	51.48	44.16	46.86	45.77	2.82	2.78	3.54	3.42	3.77	3.27
11	CM 120 × CM 133	53.17	44.48	51.72	44.48	48.75	48.52	2.73	2.53	2.93	2.93	3.08	2.84
12	CM 120 × CM 210	47.97	29.69	55.42	44.70	48.46	45.25	2.74	2.95	2.51	2.80	2.95	2.79
13	CM 120 × CM 211	52.35	44.72	48.98	36.06	39.19	44.26	2.47	2.52	4.12	4.34	3.73	3.44
14	CM 120 ×BML 6	48.35	42.78	51.44	41.14	43.64	45.47	3.37	2.71	3.55	4.33	4.02	3.60
15	CM 120 ×BML7	47.75	36.38	52.65	42.73	44.97	44.90	3.11	2.70	4.02	3.59	4.07	3.50
16	CM 120 ×BML 13	53.09	46.64	59.40	45.61	49.87	50.92	3.20	2.61	3.96	3.98	4.13	3.58
17	CM 120 ×BML 10	52.04	40.62	55.28	48.42	50.05	49.28	3.65	2.65	3.53	3.62	3.99	3.49
18	CM 131 × CM 133	45.29	38.12	52.65	46.33	47.08	45.89	2.51	2.54	3.59	3.75	3.90	3.26
19	CM 131 × CM 210	46.77	38.05	53.59	44.39	47.41	46.04	3.44	2.64	2.96	3.67	3.82	3.31
20	CM 131 × CM 211	49.70	41.06	45.60	44.20	49.92	46.10	3.64	2.36	3.96	4.40	4.31	3.73
21	CM 131 ×BML 6	50.79	44.04	50.23	51.05	49.48	49.12	3.92	2.80	4.02	4.21	3.89	3.77
22	CM 131 ×BML 7	50.47	42.63	51.41	50.75	50.82	49.22	4.04	3.60	4.22	4.36	4.14	4.07
23	CM 131 ×BML 13	51.45	33.86	55.02	44.24	45.79	46.07	3.86	2.41	3.35	4.09	3.90	3.52
24	CM 131 ×BML 10	49.50	39.79	54.57	47.14	50.87	48.37	4.11	2.45	3.78	3.56	3.71	3.52
25	CM 133 × CM 210	48.83	42.58	54.38	46.80	51.88	48.89	2.38	2.69	2.39	3.65	4.19	3.06
26	CM 133 × CM 211	44.01	37.51	42.10	46.15	46.47	43.25	3.18	2.66	3.45	3.90	3.43	3.32
27	CM 133 ×BML 6	47.65	35.69	49.95	47.17	48.93	45.88	3.57	2.83	3.54	3.95	3.44	3.47
28	CM 133 ×BML 7	46.31	44.51	53.41	51.66	49.19	49.02	3.16	2.22	3.24	4.02	3.67	3.26
29	CM 133 ×BML 13	51.77	43.72	61.34	47.36	49.45	50.73	3.62	2.29	3.43	3.00	3.15	3.10
30	CM 133 ×BML 10	49.67	44.07	56.05	54.07	54.00	51.57	2.64	2.31	3.43	3.16	3.63	3.03
31	CM 210 × CM 211	52.70	39.11	48.27	37.03	41.96	43.81	2.67	2.94	3.76	3.85	3.91	3.43
32	CM 210 ×BML 6	50.05	36.04	51.98	45.80	47.36	46.25	3.37	2.66	2.09	3.76	3.56	3.09
33	CM 210 ×BML7	47.86	38.98	54.01	47.15	51.16	47.83	3.36	3.10	3.18	3.70	3.21	3.31
34	CM 210 ×BML 13	42.62	39.27	58.38	48.87	53.82	48.59	3.97	2.76	3.15	3.25	3.40	3.31
35	CM 210 ×BML 10	49.47	40.36	53.70	51.03	52.07	49.33	3.61	3.31	2.90	2.63	3.06	3.10
36	CM 211 ×BML 6	39.54	42.36	39.04	35.05	49.75	41.15	2.58	3.37	3.13	4.52	3.95	3.51
37	CM 211 ×BML 7	52.37	47.24	51.66	53.30	51.62	51.24	4.27	3.33	4.26	4.48	4.39	4.15
38	CM 211 ×BML 13	51.97	33.59	45.43	44.35	45.90	44.25	4.21	2.61	4.21	3.95	3.73	3.74
39	CM 211 ×BML 10	43.30	44.61	47.23	35.88	40.66	42.34	3.83	2.71	3.58	3.72	3.79	3.53
40	BML 6 ×BML 7	51.89	41.50	51.32	50.11	48.65	48.69	4.12	2.60	3.20	3.85	3.74	3.50
41	BML 6 ×BML 13	39.91	37.76	54.02	35.94	38.97	41.32	3.50	3.25	3.58	3.34	3.52	3.44
42	BML 6 ×BML 10	49.57	43.16	54.10	52.75	60.02	51.92	3.30	2.88	3.39	3.98	3.94	3.50
43	BML 7 ×BML 13	48.99	41.51	50.03	39.30	40.31	44.03	3.93	2.95	3.93	4.05	4.03	3.78
44	BML 7 ×BML 10	47.76	44.95	51.60	54.47	50.83	49.92	3.86	3.01	3.85	4.36	4.57	3.93
45	BML 13 ×BML 10	50.76	45.77	56.64	49.80	45.03	49.60	3.60	2.84	3.84	3.21	3.54	3.41
	Mean	48.67	40.86	51.68	45.89	48.04	47.03	3.41	2.79	3.49	3.81	3.82	3.47
	SEd	1.73	1.38	1.24	1.22	1.80	-	0.37	0.39	0.42	0.38	0.39	-
	CD (0.05)	3.45	2.75	2.47	2.42	3.57	-	0.73	0.77	0.80	0.75	0.77	-
	CV (%)	4.37	4.14	2.94	3.26	4.57	-	13.18	17.01	14.66	12.12	12.50	-

Ra09-10 = Rabi 2009-10; Su10= Summer 2010; Kh10= Kharif 2010; Ra 10-11 = Rabi 2010-11; RF 10-11= Rice Fallow 2010-11.

Table 3: Mean performance of crosses for days to maturity and grain yield per plant for five environments in maize

S. No.	Crosses	Days to maturity						Grain yield per plant (g)					
		Ra 09-10	Su 10	Kh 10	Ra 10-11	RF 10-11	Mean	Ra 09-10	Su 10	Kh10	Ra 10-11	RF 10-11	Mean
1	CM 119 × CM 120	92.00	89.67	99.00	91.33	89.33	92.27	115.70	107.83	119.31	98.67	111.93	110.69
2	CM 119 × CM 131	92.00	90.33	98.67	95.67	94.33	94.20	121.87	92.42	121.57	122.17	124.96	116.60
3	CM 119 × CM 133	97.00	89.67	95.67	96.00	95.33	94.73	97.29	104.07	91.93	98.93	96.75	97.79
4	CM 119 × CM 210	90.67	88.33	100.67	92.67	92.00	92.87	117.76	97.90	107.83	95.93	114.42	106.77
5	CM 119 × CM 211	102.33	99.33	102.33	100.67	100.67	101.07	109.61	104.70	113.73	99.94	115.35	108.67
6	CM 119 ×BML 6	91.00	100.67	103.00	95.33	96.33	97.27	140.82	123.29	139.75	150.89	145.70	140.09
7	CM 119 ×BML 7	92.67	99.33	102.00	94.67	95.00	96.73	142.71	123.65	128.56	134.84	142.50	134.45
8	CM 119 ×BML 13	92.00	90.33	93.00	95.00	93.67	92.80	100.72	99.05	95.14	102.54	94.04	98.30
9	CM 119 ×BML 10	94.33	90.00	100.33	94.33	94.67	94.73	108.35	95.19	142.73	133.13	135.36	122.95
10	CM 120 × CM 131	87.33	84.67	102.00	88.33	90.33	90.53	128.35	101.63	101.34	110.63	125.32	113.45
11	CM 120 × CM 133	90.67	88.33	92.67	91.33	91.33	90.87	99.14	97.30	101.73	94.85	98.67	98.34
12	CM 120 × CM 210	89.00	84.67	93.00	87.00	90.00	88.73	97.09	101.00	93.83	100.31	106.87	99.82
13	CM 120 × CM 211	91.67	99.00	98.67	93.33	94.33	95.40	117.47	100.14	120.53	130.89	127.39	119.28
14	CM 120 ×BML 6	86.33	100.33	97.67	90.33	89.67	92.87	105.66	101.61	122.14	119.17	141.59	118.03
15	CM 120 ×BML7	94.33	97.33	99.67	94.33	95.00	96.13	120.36	97.24	115.73	126.20	123.99	116.70
16	CM 120 ×BML 13	90.00	87.67	97.33	90.00	90.67	91.13	119.13	105.15	108.04	125.30	124.63	116.45
17	CM 120 ×BML 10	91.00	88.67	98.67	93.00	94.33	93.13	127.31	95.03	135.19	114.77	128.93	120.25
18	CM 131 × CM 133	92.33	90.67	101.67	94.33	95.33	94.87	116.80	95.30	119.50	129.97	92.72	110.86
19	CM 131 × CM 210	86.67	84.67	105.00	89.00	90.33	91.13	121.65	96.69	103.15	139.19	107.95	113.73
20	CM 131 × CM 211	97.67	92.33	102.67	101.00	100.67	98.87	133.53	105.03	125.73	134.75	119.09	123.63
21	CM 131 ×BML 6	92.67	98.67	98.67	94.67	95.67	96.07	144.08	124.08	141.06	151.73	144.71	141.13
22	CM 131 ×BML 7	93.00	96.33	101.00	98.00	97.33	97.13	153.91	111.35	134.74	144.03	135.97	136.00
23	CM 131 ×BML 13	91.33	88.67	95.33	93.33	95.00	92.73	116.89	97.92	103.40	120.84	114.51	110.71
24	CM 131 ×BML 10	90.67	88.67	91.67	92.67	94.00	91.54	129.98	99.45	118.23	123.71	143.03	122.88
25	CM 133 × CM 210	89.67	85.67	103.33	89.00	89.33	91.40	142.79	104.72	120.17	116.94	111.79	119.28
26	CM 133 × CM 211	100.67	95.33	98.00	103.67	103.00	100.13	112.56	101.27	108.57	138.69	98.73	111.96
27	CM 133 ×BML 6	92.33	100.67	102.00	96.67	97.67	97.87	111.38	108.14	110.60	105.81	113.43	109.87
28	CM 133 ×BML 7	92.33	98.00	99.67	96.67	96.33	96.60	145.91	127.32	143.54	153.00	146.18	143.19
29	CM 133 ×BML 13	91.33	89.00	92.00	93.33	96.33	92.40	105.49	97.76	97.42	83.76	106.53	98.19
30	CM 133 ×BML 10	89.67	89.00	96.00	91.67	92.33	91.73	115.62	95.46	101.08	95.80	92.42	100.08
31	CM 210 × CM 211	90.00	91.67	101.67	92.00	93.67	93.80	113.11	104.18	114.07	120.99	124.10	115.29
32	CM 210 ×BML 6	87.33	96.33	100.67	89.33	90.33	92.80	97.74	98.17	103.31	86.40	102.48	97.62
33	CM 210 ×BML7	89.67	92.67	99.00	92.00	94.33	93.53	147.18	101.47	111.64	131.83	126.81	123.79
34	CM 210 ×BML 13	87.00	86.33	93.00	89.00	91.00	89.27	88.45	89.86	91.87	82.76	88.40	88.27
35	CM 210 ×BML 10	88.33	86.33	95.67	89.00	90.33	89.93	135.03	105.54	120.80	121.25	135.26	123.58
36	CM 211 ×BML 6	97.33	96.00	106.00	102.67	104.33	101.27	106.70	103.50	143.08	118.89	120.75	118.58
37	CM 211 ×BML 7	96.67	101.67	103.00	104.33	105.00	102.13	145.77	127.07	142.08	151.90	146.28	142.62
38	CM 211 ×BML 13	91.67	101.67	100.67	93.67	94.67	96.47	122.34	102.78	123.41	124.50	124.49	119.50
39	CM 211 ×BML 10	92.67	93.33	103.00	94.67	95.67	95.87	128.65	92.20	107.63	93.08	115.82	107.48
40	BML 6 ×BML 7	94.67	101.33	100.33	99.33	101.33	99.40	120.58	107.11	121.92	126.31	124.37	120.06
41	BML 6 ×BML 13	90.67	97.67	102.33	95.00	96.00	96.33	118.77	110.94	103.11	125.31	110.76	113.78
42	BML 6 ×BML 10	96.00	94.33	102.00	97.67	97.67	97.53	143.39	123.75	140.47	150.99	144.75	140.67
43	BML 7 ×BML 13	93.00	93.67	100.33	95.00	96.33	95.67	112.12	99.26	103.80	101.95	106.59	104.74
44	BML 7 ×BML 10	94.67	93.33	99.67	97.33	99.33	96.87	146.53	125.36	139.65	141.10	141.20	138.77
45	BML 13 ×BML 10	94.00	89.67	94.67	87.67	88.33	90.87	104.62	95.00	92.43	110.48	100.68	100.64
	Mean	92.19	92.93	99.19	94.13	94.86	94.66	121.13	104.40	116.57	119.67	119.96	116.35
	SEd	1.07	1.38	1.28	0.91	1.10	-	9.44	7.56	7.81	9.09	8.40	-
	CD (0.05)	2.14	2.73	2.54	1.81	2.18	1.31	18.76	15.02	15.54	18.07	16.67	9.61
	CV (%)	1.43	1.81	1.58	1.19	1.42	-	9.54	8.87	8.21	9.30	8.57	-

Ra09-10 = Rabi 2009-10; Su10= Summer 2010; Kh10= Kharif2010; Ra 10-11 = Rabi 2010-11; RF 10-11= Rice Fallow 2010-11

In conclusion, physiological traits *viz*., chlorophyll content and leaf area index were important parameters to take consideration of grain yield in maize. For the trait grain yield per plant the hybrids *viz*., 7 (CM 119 × BML 10), 21 (CM 131 × BML 6), 28 (CM 133 × BML7), 37 (CM 211 × BML 7) and 44 (BML 7 × BML 10) were found suitable for all the seasons having general adaptability as they were scattered at the right-hand side of the grand mean level and close to IPCA1= 0 line. Among these, the hybrids 7 (CM 119 × BML 10) and 37 (CM 211 × BML 7) also showed best *per se* performance in pooled analysis for yield and other physiological traits viz., leaf area index and chlorophyll content and ascertained that these hybrids were hardly affected by genotype-environment interaction (GEI) and thus could be well utilized across a wide range of environments. Hence, these crosses could be exploited either directly after multilocational tests or to derive elite inbreds with stability and high yielding ability. However, out of these promising hybrids, the hybrid 21 (CM 131 × BML 6) was found stable beside low *per se* performance for days to maturity. Hence, it could be suggested that this cross might be successfully utilized in future breeding programmes to isolate genotypes which can mature early.

By and large, the AMMI analysis carried out for studying the performance and stability of maize hybrids has clearly indicated the usefulness of this model to have grater insight into the magnitude and nature of genotype × environment interaction. This model was found effective in identifying genotypes that have specific adaptation (Interacting) and those which are adoptable (non-interacting). It was also found useful for characterizing the environments/seasons which were suitable for growing a specific or group of the hybrids. Similarly, the effectiveness of AMMI procedure had also been clearly demonstrated by various authors *viz.*, Crossa *et al.*, 1990 [4]; Oliveira *et al.*, 2003 [7]; Reddy *et al.*, 2004 [8]; Admassu *et al.*, 2008 [8]; Banik *et al.*, 2010 [3] and Mortazavian *et al.*, 2012 [6] in maize using multilocational trial data.

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