Crop Breeding and Applied Biotechnology 7: 270-277, 2007
Brazilian Society of Plant Breeding. Printed in Brazil

Genotype x environment interaction in soybean: evaluation through three methodologies

Mauro Cucolotto[1], Valéria Carpentieri Pípolo[1], Deoclécio Domingos Garbuglio[2*], Nelson da Silva Fonseca Junior[2], Deonísio Destro[1], and Marcos Kazuyuki Kamikoga[3]

Received 06 October 2005

Accepted 20 May 2006

ABSTRACT - *Soybean is cultivated in the wide range of environments of Paraná State. Selection for genotypes of high and predictable yields with wide adaptability are main targets of the breeding programs for this region. The adaptability and stability of 30 soybean cultivars of three different maturity groups (early, semi-early and medium maturity) with a focus on grain yield were evaluated in the crop seasons 1999/2000, 2000/2001 and 2001/2002 through three different methodologies, in 30 different environments of the state of Paraná. The experiment had the design of random blocks with 3 replications. The genotypes performed differently regarding yield adaptability and stability. Cultivars CD 202 (early), M SOY 7202 and CD 206 (semi-early), and M SOY 7602 (medium) attained the highest level of adaptability and stability of the 30 evaluated environments.*

Key words: *Glycine max*, genotype x environment interaction, AMMI model.

INTRODUCTION

Soybean is grown in pratically all agricultural regions of Brazil and plays a special role on the national scenery as one of the main exportation products. According to data of the Companhia Nacional de Abastecimento (CONAB), about 4 million hectares were grown in Paraná in the crop season of 2003/2004 making soybean a species of great socio-economic interest in view of the grain yield and the possibility of adaptation to diverse environments.

The soy cultivars planted nowadays are result of intense genetic improvement that aimed mainly at higher grain yields per area. Such high-yielding cultivars are very spezialized plants that require specific environmental conditions to express their full yield potential. The most robust varieties adapt very well to unfavorable environments, but attain lower yields per area.

The interactions of genotypes with environments (GxE) makes it difficult for breeders to identify the best genotypes, be it during selection or for cultivar recomendation. The presence of interactions indicates that the relative genotype performance in the tests depends essentially on the given environmental conditions. The phenotypic response of any genotype in relation to others could therefore be inconsistent, which is demonstrated by changes of the relative position of the genotypes from one environment to another.

The GxE interaction can be partitioned in studies on the adaptability and phenotypic stability.

[1] Departamento de Agronomia, Universidade Estadual de Londrina (UEL), Campus Universitário, 86.051-990, Londrina, PR, Brasil
[2] Departamento de Melhoramento e Genética Vegetal, Instituto Agronômico do Paraná (IAPAR), Rodovia Celso Garcia Cid, km 375, C.P. 481, 86.001-970, Londrina, PR, Brasil. *E-mail: deocleciodg@yahoo.com.br
[3] Departamento de Agronomia, Centro de Ensino Superior dos Campos Gerais (CESCAGE), Avenida Carlos Cavalcanti, 8000, Campus Paraíso, 84.030-000, Ponta Grossa, PR, Brasil

Adaptability is the capacity a genotype has to make use of the environmental effects to warrant a high yield level; stability on the other hand is related with the yield maintenance or yield predictability in the diverse environments (Borém 1998).

There are various methodologies of analysis of adaptability and stability designed to evaluate a genotype group tested in a series of environments. Among these the most widely used are the ones based on linear regression (Finlay and Wilkinson 1963, Eberhart and Russel 1966, Verma et al. 1978, Cruz et al. 1989), and a more recent application method called AMMI analysis (Additive Main effects and Multiplicative Interaction analysis) that combines a univariate method for the additive effects of genotypes and environments, with a multivariate method for the multiplicative effect of GxA interaction (Zobel et al. 1988). The AMMI method is being used in studies on the GxE interaction of soybean (Oliveira et al. 2003).

This study aimed to evaluate the adaptability and stability of soybean cultivars in the state of Paraná and to test the efficiency of the AMMI multivariate method (Zobel et al. 1988) in comparison with the methods of Eberhart and Russel (1966) and Cruz et al. (1989) of evaluating cultivar stability.

MATERIAL AND METHODS

The adaptability and stability of 30 soybean cultivars (Table 1) indicated for cultivation in the state of Paraná were evaluated. State-wide representative cultivars were obtained from the improvement programs of COODETEC - Cooperativa Central de Pesquisa Agrícola (CD), EMBRAPA - CNPSo (BR, BRS and EMBRAPA) and Monsanto do Brazil (M SOY) and were separated in the maturity groups early (110 to 115 days), semi-early (116 to 125 days) and medium (126 to 137 days). The early cycle cultivar BR 16; semi-early cycle cultivar EMBRAPA 48; and medium cycle cultivar M SOY 7501 were used as controls.

The cultivars were evaluated in the crop seasons 1999/2000, 2000/2001 and 2001/2002 at 16 sites in the state of Paraná in the design of complete randomized blocks with three replications. Each plot consisted of four 5.0 m long rows, spaced 0.45 m between rows. 4.0 m of the two center rows were considered as useful area. The sowing density was 15 plants per meter in the regions below of 700 m of altitude (Campo Mourão, Floresta, Missal, Palotina, Paranavaí and Rolândia 1 and 2); and 12 plants in the regions of higher altitudes (Cambará, Cascavel, Castro, Guarapuava, Jaguariaíva, Pato Branco, Ponta Grossa 1 and 2 and Ventania).

The data were first submitted to individual analysis of variance for grain yield (adjusted to kg/ha 13% moisture) for each site and year, considering only cultivars of the same maturity group. Every year the existence of homogeneity of the residual variances obtained in these analyses was verified to make the performance of the joint analysis of the locations possible. It is considered that there is homogeneity when the relation between the highest and the lowest mean residual square is less than seven (Banzato and Kronka 1995).

Thereafter the analyses of stability and adaptability of the cultivars were realized in each region. The AMMI analysis was performed by the GLM procedure and SAS/IML software, according to the methodologies proposed by Duarte and Vencovsky (1999). Software GENES was used for the methodologies of Eberhart and Russel (1966) and Cruz et al. (1989).

RESULTS AND DISCUSSION

In the trial of the early maturity group, the relation between the highest and the lowest value of the residual mean square (RMS) exceeded 7:1, so the environment that presented the lowest mean square value and the two with the highest values were discarded. With this procedure, the relation came to be 6:1 and 27 environments were taken into account for the analysis. For the semi-early maturity group, this relation was 4:1 and for the medium group it was 6:1.

The experimental precision in the evaluated environments, verified by the coefficient of variation, oscillated from 4.2 to 16.4% for the group of early maturity; from 6.8 to 14.8% for the semi-early group; and from 7.9 to 14.8% for the medium group.

In the joint analysis of the trials (Table 2) significant differences ($P<0.01$) were observed regarding the genotypes, environments and genotypes x environments interaction for the three maturity groups. The significance of the GxE interaction suggests the existence of a differentiated linear performance of the genotypes in the different environments, which requires studies based on the proposed analysis of adaptability and stability.

Method of Eberhart and Russel (1966)

The estimates of the parameters of adaptability and stability of Eberhart and Russel (1966) are shown in Table 3. Values of $\beta_1 > 1$ indicate that a genotype is adapted to favorable environments, that is, as the environmental mean increases, the genotype mean rises pronouncedly; on the other hand, values of $\beta_1 < 1$ characterize genotypes

Table 1. Soybean cultivars used in the studies of adaptability and stability, regarding the trait grain yield and description of the environments used in evaluations in the state of Paraná

Early		Semi-early		Medium	
g1	M-SOY 5942	g1	M-SOY 7001	g1	M-SOY 7501
g2	M-SOY 6101	g2	M-SOY 7101	g2	M-SOY 7602
g3	M-SOY 6302	g3	M-SOY 7202	g3	M-SOY 7603
g4	M-SOY 6402	g4	M-SOY 7203	g4	M-SOY 7901
g5	IAS 5	g5	M-SOY 7204	g5	M-SOY 8001
g6	CD 202	g6	CD 201	g6	BRS 134
g7	CD 207	g7	EMBRAPA 48	g7	CD 204
g8	BRS 132	g8	EMBRAPA 59	g8	CD 205
g9	BRS 138	g9	CD 206	g9	M-SOY 7701
g10	BR 16	g10	BR 37	g10	BRS 133

Local	Code of the environment and respective year of evaluation			Latitude	Altitude (m)
Cambará	a1 1999	a13 2000	———	23°02’47"	545
Campo Mourão	a2 1999	a15 2000	a26 2001	23°16’33"	585
Cascavel	a3 1999	a14 2000	a25 2001	24°57’21"	781
Castro	———	a10 2000	———	24°47’28"	999
Floresta	———	a11 2000	———	23°35’56"	392
Guarapuava	a4 1999	a12 2000	a29 2001	25°23’43"	1098
Jaguariaíva	———	a17 2000	a30 2001	24°15’04"	850
Missal	———	a18 2000	———	25°05’31"	328
Palotina	———	a22 2000	———	24°17’02"	333
Paranavaí	a5 1999	———	———	23°04’23"	470
Pato Branco	a6 1999	a21 2000	a24 2001	26°13’43"	760
Ponta Grossa 1	a7 1999	a19 2000	———	25°05’42"	969
Ponta Grossa 2	a8 1999	a20 2000	———	25°05’42"	969
Rolândia 1	a9 1999	a16 2000	a27 2001	23°18’35"	670
Rolândia 2	———	———	a28 2001	23°18’35"	670
Ventania	———	a23 2000	———	24°14’45"	990

Table 2. Mean squares (MS) obtained by the joint and idividual analyses of variance of the trait grain yield in soybean cultivars of the three groups of maturity, evaluated in the crop seasons 1999/2000, 2000/2001 and 2001/2002

FV	Early		Semi-early		Medium	
	df	[1]MS	df	[1]MS	df	[1]MS
Genotypes (G)	9	2.032.8 **	9	608.7 **	9	1.533.8 **
Environments	26	4.210.9 **	29	5.996.1 **	29	6.992.2 **
GxE	234	404.8 **	261	269.4 **	261	449.4 **
Error	540	118.4	600	153.1	600	139.1
Total	809		899		899	
Overall mean		3231		3467		3300
CV (%)		10.7		11.3		11.3

[1] Mean squares x 10^3
** significant at 1% by the F test

Table 3. Mean grain yield (kg/ha) and estimates of adaptability and stability parameters, according to the methodologies of Eberhart and Russel (1966) and Cruz et al. (1989) for 30 soybean genotypes in 30 environments in the state of Paraná, in the crop seasons of 1999/2000, 2000/2001 and 2001/2002

Cultivars	Eberhart and Russel (1966)				Cruz et al. (1989)					
	$^a\beta_0$	$^a\beta_1$	$^2\sigma^2_{\delta i}$	R^2	D^+	F^{++}	$^a\beta_1$	$^a\beta_1+\beta_2$	$^2\sigma^2_{\delta i}$	R^2
Early maturity group										
M SOY 6402	3491	1.19	89.7 **	62	3115	3896	1.27 ‘	0.80	351.1 **	63
BRS 132	3376	1.03	36.5**	67	3107	3665	0.96	1.43	184.2 **	69
CD 202	3346	1.44 “	43.1**	78	2893	3834	1.48 “	1.23	215.1 **	79
M SOY 6302	3283	0.67	82.6**	35	3128	3449	0.72 ‘	0.38 ‘	334.6 **	36
BR 16	3277	0.96	52.1**	60	2983	3594	0.93	1.14	243.7 **	60
IAS 5	3256	0.73 “	57.4**	44	2991	3542	0.88	-0.07“	208.3 **	54
M SOY 6101	3128	1.05	50.2**	64	2815	3465	1.11	0.72	231.5 **	65
BRS 138	3125	1.04	76.4**	58	2828	3445	0.93	1.64 ‘	291.7 **	61
CD 207	3050	0.84	162.6**	34	2867	3248	0.64 “	1.90“	494.7 **	44
M SOY 5942	2978	1.05	152.3**	46	2683	3295	1.10	0.82	555.1 **	46
Means	3231				2941	3543				
Semi-early maturity group										
CD 206	3589	1.16	48.0**	74	3214	4153	1.20 ‘	0.96	49.8 **	74
M SOY 7202	3544	1.00	-2.0	81	3296	3917	0.91	1.42	-8.1	84
M SOY 7204	3533	1.02	49.2**	68	3279	3914	0.96	1.31	49.2 **	70
M SOY 7001	3529	0.89	52.8**	61	3242	3959	0.89	0.87	56.7 **	61
M SOY 7101	3453	0.94	25.9 *	70	3188	3851	0.99	0.69	25.9 *	71
EMBRAPA 48	3449	0.84	-1.11	74	3207	3813	0.85	0.76	0.5	75
CD 201	3445	0.80 ‘	45.6**	58	3198	3815	0.78 ‘	0.89	48.8 **	58
EMBRAPA 59	3423	1.04	39.0**	71	3082	3934	1.10	0.72	37.8 *	73
BR 37	3387	0.96	-0.2	79	3094	3827	0.96	0.98	1.6	79
M SOY 7203	3317	1.35 “	20.1	84	2938	3887	1.34 “	1.41	22.6	84
Means	3467				3174	3907				
Medium maturity group										
BRS 133	3507	1.06	90.3**	67	3147	4045	1.14	0.67	87.4 **	68
CD 204	3495	1.02	91.3**	65	3176	3973	1.04	0.94	96.0 **	65
M SOY 7603	3397	1.20 ‘	123.1**	67	3019	3966	1.24 “	0.99	127.2 **	68
M SOY 7602	3367	0.96	23.9 *	76	3098	3772	0.88	1.35	18.6	78
M SOY 7501	3242	0.89	67.0**	63	3013	3586	0.82 ‘	1.20	65.9 **	64
CD 205	3233	0.72 “	176.1**	36	2970	3627	0.85	0.08“	163.1 **	42
BRS 134	3221	0.89	37.9**	70	2929	3658	0.87	0.99	40.6 **	70
M SOY 7701	3198	1.02	41.2**	74	2857	3708	1.05	0.89	43.4 **	75
M SOY 7901	3177	1.16 ‘	122.1**	66	2824	3707	1.07	1.63“	117.1 **	68
M SOY 8001	3162	1.07	116.0**	63	2803	3701	1.03	1.27	120.0 **	64
Means	3300				2984	3774				

a , b: Estimates for β_1, $\beta_1+\beta_2$ and $\sigma^2_{\delta i}$ x 10^3 ‘, “ : Differs from one at 5 and 1% probability by the t test
*,**: Differs from zero at 5 and 1% probability by the F test, ns: non significant
++,+: Means of favorable and unfavorable environments, respectively

adapted to unfavorable environments; and values of $\beta_1=1$ are associated to genotypes of wide adaptability.

Early group cultivars

The highly significant (P<0.01) estimate of $\sigma^2_{\delta i}$ (Table 3) shows that the cultivars presented a little predictable performance. The cultivars M SOY 6402, BRS 132 and control BR 16, although of wide adaptability, are little predictable and their variations were poorly explained by the regression (62, 67 and 60%, respectively). Cultivar M SOY 6402 presented high yield and mean responsiveness in the evaluated environments.

Cultivar CD 202 combined specific adaptability to favorable environments and was very responsive to improvement of the environment. Cultivar M SOY 6302 attained a superior overall mean but demonstrated specific adaptation to the unfavorable environments with highly significant (P<0.01) and , while the variation explained by the regression was very low (R^2 = 35%).

Semi-early group cultivars

Cultivar M SOY 7202 stood out with a stable performance, that is, it was predictable under the environmental variations, and a high adaptability. The variations were best explained by the regression (R^2 = 81%). The cultivars M SOY 7204, M SOY 7001 and M SOY 7101, despite their wide adaptability (high mean and non significant), were little predictable (significant at 1 and 5% probability), and their variations were little explained by the regression (68, 61, 70% respectively), admitting the coefficient of determination (R^2) of 70.7 as point of selection that is equal to a correlation coefficient (r) of 50%.

The cultivars EMBRAPA 48 and BR 37 had been distinguished for showing general adaptability (non significant) and high predictability (non significant), while their variations were well explained by the regression (R^2 = 74 and 79%, respectively). Cultivar CD 201 presented similar yields to the mean but specific adaptation to unfavorable environments (significant) and low predictability (significant).

Medium group cultivars

Table 3 shows that all cultivars of the medium maturity group presented little predictable performances ($\sigma^2_{\delta i}$ significant).

The cultivars BRS 133 and CD 204, in spite of the wide adaptability (high mean and β_1 non significant), were little predictable and their variations were poorly explained by the regression (R^2 = 67, 65 respectively). The mean of cultivar M SOY 7602 exceeded the overall mean and β_1 was close to the unit, which accounts for a good adaptation to the environments while the determination coefficient of R^2 = 76% further indicated good stability in the considered environments.

Cultivar M SOY 7603 attained a high mean, but with specific adaptation to favorable environments (β>1) and low predictability ($\sigma^2_{\delta i}$ significant).

Method of Cruz et al. (1989)

This methodology is based on the bi-segmented regression analysis. The stability or predictability of genotypes is evaluated by the variance of regression deviation ($\sigma^2_{\delta i}$) of each cultivar, in function of the environmental variations. In this case, it is desirable that the most adapted genotype has a value that is β_1< 1 and that the value $\beta_1+\beta_2$ is significantly greater than 1 (Cruz and Regazzi 1994).

Early group cultivars

Of the 10 genotypes studied in the 27 environments, only 4 (M SOY 6402, CD 202, M SOY 6302, CD 207) presented estimates β_1 that were significantly different from one, while the other estimates were β_1 non significant (β_1 = 1), evidencing the differentiated performance of these genotypes in favorable and unfavorable environments. All cultivars presented significant values for the variance of regression deviation ($\sigma^2_{\delta i}$), which means a little predictable performance.

Considering that evaluation trials of cultivars frequently attain higher yield means than the farmers, for whom unfavorable environmental conditions are more common, the exploration of cultivars such as M SOY 6402 and CD 202, which have a significant response β_1>1 in these adverse conditions could indicate that these genotypes would respond intensively to small environment improvements in real cultivation conditions.

The cultivars M SOY 6402 and CD 202 presented high mean yield and were very responsive to unfavorable environments (β_1>1); in the favorable environments, only genotype CD 202 presented response to the improved environment ($\beta_1+\beta_2$> 1); while genotype M SOY 6402 did not respond to environment improvements ($\beta_1+\beta_2$ <1). Cultivar CD 202 presented R^2 = 79%, indicating a good adjustment of its variability to the model in function of the environment indices.

The mean yields of the genotypes M SOY 6101, BRS 138, CD 207 and M SOY 5942 were low but genotype CD 207 adapted well to unfavorable environments; and moreover, the genotypes CD 207 and BRS 138 were responsive to improvements of the environmental conditions, that is, adapted to environments of high productivity.

Semi-early group cultivars

The cultivars M SOY 7202, M SOY 7204 and M SOY 7001 presented superior mean yields over the overall mean (β_0>overall mean) and were little demanding under unfavorable conditions (β_1<1). In respect of the favorable environments, the 10 evaluated cultivars presented mean responsiveness, that is, the parameter $\beta_1+\beta_2$ did not differ from one at 1 and 5% probability by the t test.

Of the entire evaluated set, only cultivar M SOY 7202 expressed a yield mean above the overall and the favorable environments mean, the value of did not differ from zero and the estimate was $R^2 > 80\%$ ($R^2 = 84\%$), that is, its stability in the environments under study was high.

Medium group cultivars

Of the 10 medium group genotypes evaluated in the experiment, 9 presented significant variances of the regression deviations ($\sigma^2_{\delta i}$), associated with a determination coefficient $R^2<80\%$, which indicates a little predictable performance and poor data adjustment to the line of regression.

The estimate β_0 showed that the genotypes BRS 133, CD 204, M SOY 7603 and M SOY 7602 were found among the cultivars of best adaptation (β_0>overall mean). The performance in unfavorable environment of the genotypes M SOY 7603 and M SOY 7501, presented high and low responsivenesss, respectively (β_1 = 1.24** and 0.82*) and mean responsiveness when subjected to environmental improvement ($\beta_1+\beta_2$ ns). The yield of cultivar M SOY 7602 exceeded the mean of its maturity group, while the value for $\sigma^2_{\delta i}$ did not differ significantly from zero, which indicates good predictability. The genotypes BRS 134, M SOY 7701, M SOY 8001 presented β_0 values under the overall mean, mean responsivenesss in favorable as much as unfavorable environments and $\sigma^2_{\delta i}$ different from zero, indicating low stability. Genotype M SOY 7901 stood out with a high responsiveness in favorable environments (1.63**), although the yield was under the mean, the responsiveness in favorable environments intermediate (1.07 ns) and the predictability or stability low.

AMMI Method

The multiplicative effect of the genotypes x environments (GxE) interaction was diagnosed using the analysis of principal components (IPCA), by the partitioning of the sum of squares of the interaction GxA (SS_{GXE}) in axes or principal components of the interaction (PCI). The definition of the number "n" of retained principal axes was based on the F test of Gollob (1968) and Cornelius et al. (1992), as well as in the predictive evaluation procedure by cross validation, proposed by Gauch (1988).

Early group cultivars

An analysis of the GxE interaction through the principal component analysis (PCA), showed that the first three IPCAs for grain yields were significant (P< 0.01), and that the three axes together explained 67% of the SS_{GXE} (Table 4). The other axes represented SS_{GXE} variations that were mostly rich in noise. The genotypes that contributed most to the GxE were: g1 = M SOY 5942 and g7 = CD 207, since they attained highest score magnitudes on the axis of interaction.

Semi-early group cultivars

The analysis of the GxE interaction (Table 4) showed that only the two first IPCAs, for grain yield, were significant (P < 0.01), and that the two axes together explained 42% of the sum of SQ_{GXE}. The genotypes that contributed most to the GxA interaction were the genotypes g1 = M SOY 7001, g4 = M SOY 7203 and g5 = M SOY 7204, since they attained the highest score magnitudes on the axis of interaction.

Medium group cultivars

The results of the analysis of the GxE interaction showed that the 4 first IPCAs were significant at the level of 1% by the F test and the 4 axes together explained 74% of the SS_{GxE} (Table 4). The genotypes that contributed most to the GxE interaction were the cultivars g1 = M SOY 7501, g4 = M SOY 7901 and g5 = M SOY 8001.

The biplot of the AMMI analysis (Figure 1) shows that only 4 cultivars (g10 = BRS 133, g7= CD 204, g3 = M SOY 7603 and g2 = M SOY 7602) attained a higher mean than the genotype mean (3.299 kg ha^{-1}). The stability of genotype M SOY 7602 was graeater, while the genotypes g10= BRS 133, g7 = CD 204, g9 = M SOY 7701

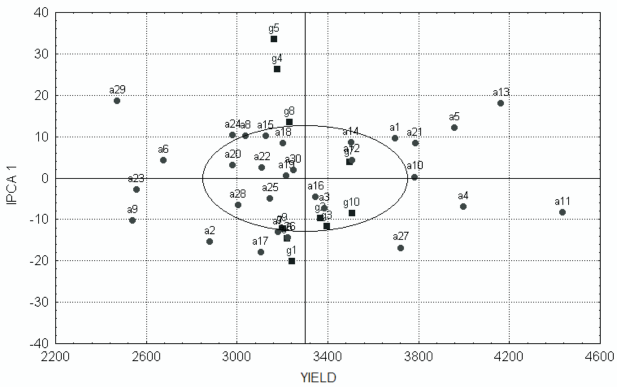

Figure 1. AMMI biplot: grain yield (kg ha^{-1}) x IPCA 1 (first principal component of the interaction). Analysis of 10 medium cycle cultivars (squares) in 30 environments (circles)

Table 4. Summary of the analyses of stability and adaptability, according to the AMMI methodology for 30 soybean genotypes of three maturity groups, evaluated in 30 environments in the state of Paraná in the crop seasons 1999/2000, 2000/2001 and 2001/2002

FV	EARLY		SEMI-EARLY		MEDIUM	
	df	[1]MS	df	[1]MS	df	[1]MS
REPLI/ENV	54	209.2 **	60	190.4	60	151.3
GENOTYPE	9	2032.8 **	9	608.7 **	9	6992.2 **
AMB	26	4210.9 **	29	5996.1 **	29	1533.8 **
GENOT*ENV	234	404.8 **	261	269.4 **	261	449.4 **
IPCA 1	34	273.4 **	37	142.3 **	37	257.3 **
IPCA 2	32	238.1 **	35	129.6 **	35	266.1 **
IPCA 3	30	143.9 **	——	—— —	33	183.1 **
IPCA 4	——	—— —	——	—— —	31	135.2 **
Res.GxE/AMMI	138	75.0 *	189	72.2	125	80.3
Erro mean	486	59.2	540	76.6	540	69.6
CP/Axis	**[2]Eigenvalue**	**% Accumulated**	**[2]Eigenvalue**	**% Accumulated**	**[2]Eigenvalue**	**% Accumulated**
1	929.6	29.438	526.4	22.459	952.1	24.351
2	761.8	53.562	453.7	41.817	931.2	48.167
3	431.8	67.237	352.6	56.864	604.2	63.620
4	268.8	75.750	319.8	70.508	419.0	74.336
5	204.8	82.235	243.9	80.916	290.9	81.776
6	173.7	87.735	195.5	89.257	238.4	87.874
7	157.0	92.707	120.0	94.379	205.9	93.140
8	141.2	97.177	90.2	98.229	152.2	97.033
9	89.1	100	41.5	100	116.0	100
Genotypes	**Means**	**IPCA1**	**Means**	**IPCA1**	**Means**	**IPCA1**
g1	2978	33.8	3529	21.4	3242	-20.1
g2	3128	15.9	3453	-18.1	3367	-9.8
g3	3283	5.2	3544	7.6	3397	-11.7
g4	3491	-12.0	3317	-20.0	3177	26.3
g5	3256	15.6	3533	18.7	3162	33.5
g6	3346	-5.3	3445	16.9	3221	-14.6
g7	3050	-32.5	3449	-10.2	3495	3.8
g8	3376	-10.2	3423	-13.2	3233	13.4
g9	3125	-4.4	3589	-9.8	3198	-12.3
g10	3277	-6.2	3387	6.6	3507	-8.5

[1]; Mean squares x 10^3
[2]; Eigenvalues x 10^4
*,**; significant at 5 and 1% probability by the F test

and g6 = BRS 134 presented intermediate stability. The genotypes g8 = CD 205, g5 = M SOY 8001, g4 = M SOY 7901, g3 = M SOY 7603 and g1 = M SOY 7501 were less stable once they presented the highest score magnitudes.

CONCLUSIONS

The methodologies ranked the genotypes similarly, however, differed in precision, explanations and information on the GxE interaction and genotype adaptability. The method of Cruz et al. (1989) enabled us to obtain additional information regardig the adaptability of the cultivars.

The interpretation of the AMMI analysis was effective to explain the environments and stability of the cultivars for models that include more than two axes; the adaptability was however best understood with the support of the means of the genotypes and environments.

The cultivars of each maturity group with wide adaptability as well as greatest predictability for the trait grain yield were: CD 202 (early), M SOY 7202 and CD 206 (semi-early) and M SOY 7602 (medium).

Interação x genótipo ambiente em soja: avaliação a partir de três metodologias

RESUMO - *A soja no Paraná encontra-se cultivada sob uma grande diversidade de ambientes onde a seleção de genótipos de alta produtividade, ampla adaptabilidade e previsibilidade de produção aos diferentes ambientes, são os principais objetivos dos programas de melhoramento. Este trabalho teve como objetivo avaliar a adaptabilidade e a estabilidade de 30 cultivares de soja, pertencentes aos grupos de maturação precoce, semi-precoce e médio, nos anos agrícolas de 1999/2000, 2000/2001 e 2001/2002, através de três metodologias, com ênfase na produtividade de grãos, em 30 ambientes no Paraná. O delineamento experimental utilizado foi de blocos casualizados, com 3 repetições. Os genótipos avaliados apresentaram comportamento diferenciado quanto à adaptabilidade e à estabilidade de rendimento. Os genótipos CD 202 (precoce), M SOY 7202 e CD 206 (semi precoce) e M SOY 7602 (médio), foram considerados altamente adaptados e mais estáveis a todos os ambientes considerados.*

Palavras-chave: *Glycine max*, interação genótipo x ambiente, modelo AMMI.

REFERENCES

Banzatto DA and Kronka SN (1995) **Experimentação agrícola**. Editora Funep, Jaboticabal, 247p.

Borém A (1998) **Melhoramento de plantas**. Editora UFV, Viçosa, 453p.

Cornelius PL, Seyedsadr M and Crossa J (1992) Using the shifted multiplicative model to search for "separability" in crop cultivar trials. **Theoretical and Applied Genetics 84**: 161-172.

Cruz CD and Regazzi AJ (1994) **Modelos biométricos aplicados ao melhoramento genético**. Editora UFV, Viçosa, 390p.

Cruz CD, Torres RA and Vencovsky R (1989) An alternative approach to the stability analysis proposed by Silva e Barreto. **Revista Brasileira de Genética 12**: 567-580.

Duarte JB and Vencovsky R (1999) Interação genótipos x ambientes: uma introdução à análise AMMI. **Série Monografias**. Sociedade Brasileira de Genética, Ribeirão Preto.

Eberhart SA and Russel WA (1966) Stability parameters for comparing varieties. **Crop Science 6**: 36-40.

Finlay KW and Wilkinson GN (1963) The analysis of adaptation in a plant-breeding program. **Australian Journal Agricultural Research 14**: 742-754.

Gauch HG (1988) Model selection e validation for yield trials with interaction. **Biometrics 44**: 705-715.

Gollob HF (1968) A statistical model which combines features of factor analytic e analysis of variance techniques. **Psychometrika 33**: 73-115.

Oliveira BA, Duarte JB and Pinheiro JB (2003) Emprego da análise AMMI na avaliação da estabilidade produtiva em soja. **Pesquisa Agropecuária Brasileira 38**: 357-364.

Verma MM, Chahal GS and Murty BR (1978) Limitations of conventional regression analysis: a proposed modification. **Theoretical e Applied Genetics 53**: 89-91.

Zobel RW, Madison JW and Gauch Jr HG (1988) Statistical analysis of a yield trial. **Agronomy Journal 80**: 388-393.