Adaptability and stability study of soybean lines developed for high yield in Paraná State using four methodologies

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ABSTRACT

An adaptability and stability study was carried out using soybean yield data from several locations in Paraná State, obtained from 1990 to 1999. The main objectives were: a) to check the efficiency of the Embrapa Soja breeding program for selecting the highest yielding lines with specific (regional) or broad adaptation; b) to analyze the performance of the control cultivars under favorable and unfavorable conditions; c) to identify the best stability methodology for inbred line evaluation. The evaluated lines were classified into early (L), semi-early (M) and medium (N) maturity groups. A randomized complete block design with four replications was used in each location and all analyses were carried out by maturity group. The number of M maturity lines that scored higher than the controls BR-16 and Embrapa 4 increased along the years, especially in unfavorable environments. On the other hand, the number of L and N maturity groups scoring higher than the controls either remained constant or fluctuated (increasing or decreasing) with time. The controls FT-Guaíra, Embrapa 4, BR-16 and FT-10 and the great majority of the tested lines showed broad adaptation. IAS 5 and FT-Abyara showed adaptation to poor environments and also broad adaptation. The analysis of the means in favorable and unfavorable environments was the most efficient method for soybean line evaluation. A methodology to classify soybean genotypes was proposed, based on these means.

KEY WORDS: *Glycine max*, genetic breeding, genotype, environment interaction.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is the fourth most widely cultivated crop in the world. It is well known for its protein rich grains that can be used for human and animal nutrition and for its soil N enriching properties from nitrogen fixing bacteria. Brazil is presently the second largest world producer (20.16%), where production in the states of Mato Grosso (7.9 million tons), Paraná (7.1 million tons) and Rio Grande do Sul (4.9 million tons) ranks first to third, respectively, corresponding to 63.6% of the total yield in the 1999/2000 season (Anuário Brasileiro de Soja, 2000).

In Paraná, there are 69,738 soybean growers for a planted area of 2,824,600 hectares (Anuário Brasileiro de Soja, 2000). Continuous breeding of new cultivars showing high yield and stability and better adaptation to several state growing regions is essential to maintain soybean competitiveness and increase economic returns comparatively to other crops.

Several methodologies have been proposed to evaluate genotype adaptability and stability in a set of environments, each adopting different criteria to define and estimate these parameters. Lin at al. (1986), Ramalho et a. (1993), Cruz and Regazzi (1994) and Carneiro (1998) presented reviews on the most accepted methods. Studies of genotype adaptability and stability allow for the identification of those which best respond in a predictable manner to environmental variation (Cruz and Regazzi, 1994).

In spite of the importance and availability of such methods, the criteria for selecting and releasing a cultivar is frequently based solely on the average of the yield in trial locations. The soybean breeding program in the state of Paraná uses mainly the mean yield as criteria for cultivar release. However, generalized indication of cultivars for cultivation in good and poor environments may incur in wrong choices due to specific adaptation of genotypes to these environments. The studies of Alliprandini (1992) using different years and locations, and those of Donato (1994) and Lima (1997) using different sowing dates, are among the few available for the Paraná state.

In this study, the adaptability and stability of soybean lines were assessed using data from yield trials carried out by the Embrapa Soja breeding program in several location in the state of Paraná during the 1989/90 to

1998/99 growing seasons. The main objectives were: a) to check the efficiency of the breeding program for selecting the highest yielding lines with region specific or broad adaptation; b) to analyze the performance of the control cultivars under favorable and unfavorable conditions; c) to compare some methodologies frequently used to assess the adaptability and stability with results from evaluations based on the mean yield of lines in favorable and unfavorable environments. Based on the means obtained , a procedure for genotype classification according to adaptability was proposed.

MATERIAL AND METHODS

Data from soybean lines included in the soybean yield and adaptation trials carried out in several locations in the state of Paraná by the Embrapa Soybean and other plant breeding institutions from the cooperative group, from 1989/90 to 1998/99 , were analyzed.

The assessed lines belong to the early (L – 110 to 115 days from germination to maturity), semi-early (M – 116 to 125 days) and medium (N- 126 to 137 days) maturity groups, which are the most important for the State (Alliprandini, 1992). Each year different lines are used in tests and only the best ones remain for a period of two years. The number of tested lines ranged from 12 to 16 for each maturity group in the years. Cultivars IAS 5 and FT-Guaíra, Embrapa 4 and BR-16 and FT-10 and FT-Abyara were used as controls for the L, M and N maturity groups, respectively. Other controls such as the cultivars Paraná (1989/90 to 1991/92) and Lancer (1989/90) for group L, Bragg (1989/90 and 1990/91), FT-6 (1989/90), OC-4 (1990/91 and 1991/92) and OCEPAR 13 (1998/99) for group M and FT-2 (1989/90 and 1990/91) and BRS 134 (1998/99) for group N were also used.

The locations of the experiments were selected according to diversity and cropping area expression (Table 1). Sowing dates varied according to year and location, ranging mainly from 15 to 25 of November. Randomized complete blocks with four replications were used . Each plot was formed by four five-meter rows spaced at 0.45m. The two external rows and 50 cm at each end were discarded as guards or borders, resulting in an useful area of $3.6m^2$. Plant population for the maturity groups L, M and N were composed of 18 and 16 plants/linear meter respectively. Fertilization, weeding, disease and pest control, irrigation and other cultural practices were carried out to provide optimum growth conditions for the plants.

Individual analyses of variance were carried out for each location and year according to maturity group (Silva Filho et al., 1987; Alliprandini, 1992). After checking for residual variance homogeneity, a joint analysis was carried out. Residual variances were considered homogeneous when the ratio between the smallest and largest was less than 7.0 (Gomes, 1985; Banzato and Kronka, 1989).

Stability and adaptability studies were carried out for set of locations and year, according to the methodologies of Eberhart and Russel (1966), Lin and Binns (1988) and Cruz et al. (1989) ,using the GENES computer program (Cruz, 1997). Line

Table 1. Main characteristics of the Soybean Regional Yield Trial Locations in the state of Paraná - 1990/2000[1/].

Local	Year of Assessment	Latitude	Altitude (m)	Soil type[2/]
Cambé	1992, 1993, 1994	$23^0$16´33”	650	Euthorthox
Campo Mourão	1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$24^0$02´44”	585	Haplorthox
Cascavel	1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$24^0$57´21”	781	Acrohumox
Castro	1992, 1993, 1994, 1995, 1996, 1997	$24^0$47´28”	999	Acrohumox
Congonhinhas	1990, 1991, 1992, 1994, 1995, 1996, 1997	$23^0$33´04”	753	Haplorthox
Guarapuava	1990, 1991, 1992, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$25^0$23´43”	1098	Acrohumox
Londrina	1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$23^0$18´37”	585	Haplorthox
Mariópolis	1994, 1995, 1996, 1997, 1998, 1999	$26^0$21´17”	879	Haplorthox
Maringá	1990, 1991, 1992, 1993, 1994	$23^0$25´31”	596	Haplorthox
Palotina	1990, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$24^0$17´02”	333	Euthorthox
Ponta Grossa - 1	1990, 1991, 1992, 1994, 1995, 1996, 1997, 1998, 1999, 2000	$25^0$05´42”	969	Acrohumox / haplorthox
Ponta Grossa - 2	1991, 1992, 1993, 1994, 1995, 1996, 1997	$25^0$05´42”	969	Acrohumox / haplorthox
Sertaneja	1990, 1991, 1994, 1995, 1996	$23^0$02´13”	401	Euthorthox

[1/] The Ponta Grossa-2 location trials were carried out by FT – Pesquisas e Sementes; [2/] Source: Larach et al. (1984).

comparison was carried out within each maturity group (Arantes, 1979). The partitions of the P_i (Lin and Binns, 1988) parameter into P_{if} - favorable locations and P_{id} - unfavorable locations were done according to Carneiro (1998). Lines with the following characteristics regarding these estimated parameters were selected as ideal genotypes: a) Eberhart and Russel (1966) – the ideal line has high yielding capacity (large mean), general adaptation ($B_1* = 1$) and high predictability ($s^2_d* = 0$); b) Lin and Binns (1988) – each line has a P_i value, which is the mean square of the distance between the its performance and that of the best line (M_j) in each location. Since M_j is the maximum response and P_i is the mean square of the distance in relation to M_j, the lines showing the smallest P_i values are best adapted; c) Cruz et al. (1989) – the ideal line shows high yielding capacity, low response to poor environments ($B_1 < 1$), good response in favorable environments ($B_1 + B_2 > 1$) and high predictability ($s^2_d = 0$) and d) Carneiro (1998) – Lines showing the smallest P_{if} and P_{id} are considered ideal.

Classification of experimental locations as favorable and unfavorable depended on their respective environmental indexes, which were calculated by the difference between the average of lines per location and the overall average of lines, for all locations , in a given year. Locations with values larger than zero were considered favorable while those with negative values were considered unfavorable.

For each maturity group, the adaptability and stability results obtained by each method were compared to the mean performance in poor and good environments. For this analysis, the number of lines in the unfavorable (X_d) and favorable (X_f) environments with performance better than a given line (Li) was obtained. When the difference between X_d and X_f was equal or greater to 1/3 of the number the assessed lines (N), the line was classified as adapted to favorable environments. Li showed adaptability to unfavorable environments whenever $X_d - X_f \leq -1/3$ N, and whenever $-1/3 N < X_d - X_f < 1/3 N$, Li showed general adaptability. In this study, Li was made equal to 4, 5 and 5, respectively when N was equal to 12, 14 or 16. The adaptability of the controls IAS 5 and FT-Guaíra (maturity group L), Embrapa 4 and BR-16 (M) and FT-10 and FT-Abyara (N) was investigated using this method. The variations of the X_d/N and X_f/N ratios, estimated for the controls in the period 1988/89 to 1998/99, were used to evaluate the efficiency of the Paraná State soybean breeding program in selecting superior lines which outyielded these controls in specific or general environments.

According to the mean analysis, the superior lines show the highest means in the superior and inferior environments, indicating general adaptation to both types of environments. Whenever a line shows high mean in favorable environments but low in poor environments, it can be indicated for the superior environments. On the other hand, when the reverse occurs, the line can be recommended for poorer environments.

A correlation between the mean yield of a line in all environments (MT) and its respective P_i adaptability value was made to assess their relationship. The correlations between the mean of a line in unfavorable environments (MU) and its respective P_{id} and the mean of a line in favorable environments (MF) and its P_{if} were also made.

Table 2 - Joint analyses of variance of soybean yield assessed in different locations in Paraná from 1989/90 to 1998/99.

Year of assessment	Maturity group								
	Early (L)			Semi-early (M)			Medium (N)		
	MSLIxLO[3/]	C.V.%[4/]	Mean (Kg/ha)	MSLIxLO	C.V.%	Mean (Kg/ha)	MSLIxLO	C.V.%	Mean (Kg/ha)
1990	187741.069[2/]	9.12	2540.444	312641.078[2/]	11.99	2682.419	481619.823[2/]	11.30	2615.381
1991	330689.732[2/]	12.72	3217.091	366667.708[2/]	11.79	3235.695	540431.413[2/]	11.02	3058.966
1992	301065.687[2/]	13.03	2854.556	262763.700[2/]	13.53	2926.721	256121.155[2/]	12.52	3245.832
1993	257165.357[1/]	13.24	3135.652	364854.104[2/]	12.85	3002.559	422226.322[2/]	14.23	3096.019
1994	258167.056[2/]	11.64	3205.658	278614.312[2/]	11.53	3115.141	432742.788[2/]	12.64	3023.164
1995	209212.555[2/]	10.87	3243.920	324303.461[2/]	12.02	3281.592	409844.183[2/]	14.44	3207.935
1996	311932.485[2/]	11.16	3244.861	389248.424[2/]	9.15	3379.147	355080.316[2/]	11.43	3304.706
1997	315653.099[2/]	11.25	2845.320	233257.162[2/]	10.65	2870.660	301935.515[2/]	11.03	2827.144
1998	177564.438[2/]	10.32	2601.616	254684.694[2/]	10.06	2872.916	377326.369[2/]	10.53	2744.624
1999	315207.769[2/]	11.49	2854.679	289939.781[2/]	12.73	2820.993	279484.142[2/]	12.43	2831.722

[1/, 2/] Significant at the 5% and 1% level of probability, respectively, by the test F; [3/] MSLIxLO: means square of line x location interaction; [4/] C.V.: coefficient of variation.

The analyses of the means and the methodologies of Cruz et al. (1989) and Carneiro (1998) were not carried out whenever the number of favorable or unfavorable environments was equal to or less than two for a given maturity group. The method of Cruz et al. (1989) was also not used when the number of assessed environments was less than eight (Cruz and Regazzi, 1994).

RESULTS AND DISCUSSION

Preliminary analyses

Changes in yield performance among locations for the L, M and N maturity group soybean lines were investigated using the significance of the lines x locations ($P < 0.01$) interaction in the majority of the years (Table 2). They justify the adaptability and stability studies.

The coefficient of variation of the joint analyses of variances ranged from 9.12% to 13.24% (maturity group L), from 9.15% to 13.53% (M) and from 10.53% to 14.44% (N), suggesting that the experimental precision was either good or very good, according to the classification of Gomes (1985).

The average yield of the trials was always superior to 2,500 kg/ha. Similar results were obtained by Toledo et al. (1990) and Alliprandini (1992), in an analysis of soybean intermediary yield trials in the state of Paraná, during the period 1981/82 to 1989/90.

Mean and Pi

Modules for the large majority of correlations between MT and P_i, MU and P_{id} and MF and P_{if} were above 0.9 (Table 3). This finding suggests that the mean of a line reflected its adaptability as defined by Lin and Binns (1988). These results are in line with those of Carvalho (1999), who obtained negative close to unit correlations between the mean over all locations and P_i in a cocoa hybrids evaluation in Rondônia. The fact that the yield parameter weighed by the line differential behavior in each environment is a component of the P_i, P_{id} and P_{if} statistics makes them measures of adaptability and stability (Carneiro, 1998). Therefore, MT, MU and MF reflected the lines adaptability and stability. It is worth mentioning that the use of the mean instead of the P_i has the advantage of simplifying the adaptability and stability analyses and allows for the use of tests of significance. Line comparison based on P_i, P_{id} and P_{if} is difficult since no significance test for these parameters has been suggested by Lin and Binns (1988) and Carneiro (1998) .

In some yield final trials, line means tended to correlate slightly less with the P_i value. For example, in 1998, the N group lines showed a correlation between MT and P_i and between MT and P_{if} lower than 0.8 but higher to 0.65. In these situations, the use of the mean to compare line performance for yield was generally more suitable. This could be detected in the analyses of favorable environments of the referred assessment year. The BR93-8072 and OC94-2062 lines from group N showed the fifth and twelfth greatest MF, respectively. However, the P_{if} value for BR 93-8072 was greater than the P_{if} estimated for OC94-2062 , although the mean of the first line was greater than the second, in four of the five locations assessed. In 1996 (Group N), when the correlation between MT and P_i was close to 0.9, the BR91-6445 mean was greater than the OC91-672 mean in nine of the ten locations assessed regardless of the fact that the Pi value of the first line was greater. The OC91-672 line showed lower P_i because it presented higher mean than the BR91-6445 in the location with the greatest environmental index.

In many yield final trials, the correlations between MT and MU and between MT and MF were relatively high (above 0.8). However, in other experiments, values for these correlations were low, as for the N group line in 1991 (MT and MF) and in 1997 (MT and MU). This shows that a generalized cultivar indication, without considering favorable and unfavorable environments, may benefit or be detrimental to cultivars with specific adaptation to these two types of environments. In 1991, the FT84-1167 line presented the fifth greatest MF and the twelfth greatest MT. In 1997, FT92-10748 had the greatest MU and only the sixth greatest MT. It is important to mention that the classification of the locations into the unfavorable and favorable environmental groups permitted grouping locations with distinct means in the final experiments (Table 4). The mean for the favorable environments was greater than that for the unfavorable by 19.29% (1990 - L group) to 63.0% (1991 - L group). These values support the inferences made by the adaptability and stability study with environment partition. In spite of the fact that the classification of a determined location depended on the assessed year, it can be observed that for all maturity groups, Cascavel, Londrina and Sertaneja were generally considered favorable and Castro unfavorable.

Table 3. Correlation between adaptability and stability parameters of soybean lines assessed for yield in Regional trials of Paraná state from 1989/90 to 1998/99 [1/].

Maturity Group	Parameter	Year of Assessment									
		90	91	92	93	94	95	96	97	98	99
L	MT e P_i	-0.97	-0.96	-0.97	-0.98	-0.95	-0.98	-0.93	-0.94	-0.96	-0.95
	MT e MU	0.68	0.80	0.94	0.93	0.86	0.85	0.68	-	0.76	0.92
	MT e MF	0.94	0.85	0.81	0.80	0.91	0.86	0.93	-	0.85	0.82
	MU e P_{id}	-0.97	-0.95	-0.95	-0.95	-0.97	-0.97	-0.84	-	-0.95	-0.96
	MF e P_{if}	-0.97	-0.96	-0.97	-0.96	-0.95	-0.97	-0.93	-	-0.95	-0.94
M	MT e Pi	-0.92	-0.94	-0.93	-0.98	-0.97	-0.97	-0.94	-0.98	-0.96	-0.98
	MT e MU	-	0.80	0.66	0.91	0.88	0.93	0.86	0.67	0.80	0.91
	MT e MF	-	0.82	0.71	0.81	0.92	0.87	0.85	0.95	0.96	0.90
	MU e Pid	-	-0.93	-0.96	-0.96	-0.98	-0.96	-0.92	-0.95	-0.95	-0.96
	MF e Pif	-	-0.95	-0.96	-0.97	-0.95	-0.97	-0.88	-0.98	-0.97	-0.97
N	MT e Pi	-0.98	-0.90	-0.96	-0.95	-0.98	-0.95	-0.89	-0.91	-0.68	-0.97
	MT e MU	-	0.83	-	0.81	0.86	0.64	0.67	0.42	0.60	0.79
	MT e MF	-	0.34	-	0.86	0.83	0.94	0.88	0.88	0.87	0.93
	MU e Pid	-	-0.93	-	-0.90	-0.97	-0.87	-0.96	-0.97	-0.95	-0.96
	MF e Pif	-	-0.96	-	-0.97	-0.96	-0.95	-0.90	-0.93	-0.78	-0.97

[1/] MT: mean of a line in all environments; MU: mean of a line in unfavorable environments; MF: mean of a line in favorable environments; Pi: Lin and Binns (1988) adaptability parameters; Pid: Lin and Binns (1988) adaptability parameters to unfavorable environments and Pif: Lin and Binns (1988) adaptability parameters to favorable environments.

Check cultivars performance

The adaptability and stability parameters were estimated based on the fixed set of genotypes assessed and, consequently, the estimates depend on the values of this set. Although the soybean breeding program in Paraná has tested different lines each year, in different locations, the adaptability of the check cultivars to specific environments, or to non-specific environments remained relatively constant (Table 5). For example, in five out of the eight years IAS 5 participated in the final yield trials, the number (X_d) of lines which presented greater means (and consequently lower P_{id}) than that of IAS 5 in the unfavorable environments was much inferior to the number of lines (X_f) that showed greater means (and consequently, lower P_{if}) in the favorable environments. During these years, as $X_d - X_f \leq -5$, IAS-5 showed adaptability to unfavorable environments. On the other hand, in 1994, 1996 and 1998, the number of lines out-yielding IAS 5 in the unfavorable and favorable environments was similar ($-5 < X_d - X_f < 5$), indicating general adaptability. In no one of the assessed years has IAS 5 performed better in favorable environments. Adaptation to unfavorable environments or general adaptation was also a characteristic of FT-Abyara. Based on the analysis of the line means, it was further observed that FT-Guaíra, Embrapa 4, BR-16 and FT-10 showed general adaptability.

No test of significance was carried out to compare the means of the lines and check cultivars. However, considering that lines present similar performances in favorable and unfavorable environments whenever $-1/3\ N < X_d - X_f < 1/3\ N$, a good agreement (90.69%) was found between the check cultivars classification for adaptability based on the analysis of the means and the Eberhart and Russel (1966) B_1 estimates (Tables 5 and 6). In the referred analysis, other values

Table 4. Yield mean (kg/ha) of soybean lines assessed in Paraná final trials from 1989/90 to 1999/2000. Embrapa Soja, 2002.

Year of assessment	Environment	Maturity group		
		Early (L)	Semi-early (M)	Medium (N)
90	Unfavorable	2316.87	-	-
	Favorable	2764.01	-	-
91	Unfavorable	2211.47	2783.14	2657.75
	Favorable	3604.74	3688.24	3593.92
92	Unfavorable	2541.88	2392.85	-
	Favorable	3323.56	3353.81	-
93	Unfavorable	2896.39	2640.88	2541.17
	Favorable	3534.42	3484.79	3650.86
94	Unfavorable	2794.40	2646.20	2675.79
	Favorable	3548.36	3517.08	3631.06
95	Unfavorable	2838.80	2995.62	2850.62
	Favorable	3581.51	3624.74	3446.14
96	Unfavorable	2510.15	2784.89	2672.93
	Favorable	3832.62	4121.96	3936.47
97	Unfavorable	-	2079.68	2066.96
	Favorable	-	3209.65	3152.93
98	Unfavorable	2137.44	2354.89	2191.76
	Favorable	3065.78	3287.33	3186.91
99	Unfavorable	2505.11	2476.02	2472.04
	Favorable	3291.62	3252.20	3191.39

different from 1/3N could have been used. However, the good fit between the two methodologies is an indication that the 1/3N proportion was satisfactory to classify soybean lines for adaptability. This classification would have been more difficult if it had been based on significant tests. In this case, adaptability could depend on the type of statistical test adopted.

Whenever the means analysis reflected less the B_1 value, it was observed that the use of the first methodology was more adequate. For example in 1992, fourteen lines out-yielded Embrapa 4 in the unfavorable environments but only three in the favorable. In the means analysis, this check cultivar was characterized as adapted to favorable environments (Table 5). However, it showed general adaptability by the Eberhart and Russel (1966) methodology (Table 6). Also, in 1996, when fourteen (in the unfavorable environments) and fifteen (in the favorable environments) lines had means greater than FT-10, the classification of adaptability given by the mean analysis (general adaptability) differed from that given by the Eberhart and Russel (1966) methodology (adaptability to unfavorable environments).

Among the checks, FT-10, FT-Guaíra and IAS-5 were the most stable by the Eberhart and Russel (1966) methodology. However, negative variances of the regression deviations were estimated in 20.83% of the analyses carried out with the check cultivars. A similar percentage (18.60%) of negative variances was found using the Cruz et al. (1989) methodology (Table 7). According to this methodology, no check cultivar showed low response ($B_1 < 1$) to unfavorable environments and responsiveness in favorable environments ($B_1 + B_2 > 1$). Furthermore, in some analyses, the adaptability parameters had negative estimates. Although the Eberhart and Russel methodology does not break down the environments, the classification of the lines for adaptability based on their methodology was closer to the means analysis than that of Cruz et al. (1989) (Tables 5 to 7).

In this study, lines that showed greater means than the standards were also used to measure the efficiency of the soybean breeding program in selecting higher yielding lines from 1988/89 and 1998/99. For the M group during the 1990s, there was an increase in the number of lines assessed in the final yield trials that out-yielded BR16, mainly when the unfavorable environments were considered (Table 5). Similar , but less evident, results were observed for Embrapa 4. However, for the L and N groups, the number of lines that out-yielded the checks was either constant or variable (increasing or decreasing) along the decade. Although no test of significance was made for the means comparison, the results obtained for the L and N groups showed that it is difficult to obtain genetic progress in soybean breeding. This difficulty may be observed in the two last assessment years, when few lines out-yielded IAS-5 in the favorable and unfavorable environments, and FT-10 and FT

Table 5. Adaptability[1/] of check cultivars and respective yield performance to unfavorable and favorable environments compared to soybean advanced inbred lines assessed in Paraná state final trials from 1989/1990 to 1998/99. Embrapa Soja, 2002.

Year of assessment	Environment	Line adaptability and performance according to maturity group[2/]											
		Early (L)				Semi-early (M)				Medium (N)			
		IAS 5	Adaptability	FT-Guaíra	Adaptability	Embrapa 4	Adaptability	BR-16	Adaptability	FT-10	Adaptability	FT-Abyara	Adaptability
90	Unfavorable	-	-	-	-	-	-	-	-	-	-	-	
	Favorable	-		-		-		-		-		-	
91	Unfavorable	0/15	AU	-	-	-	-	-	-	8/3	AF	0/11	AU
	Favorable	11/4		-		-		-		3/8		9/2	
92	Unfavorable	2/13	AU	-	-	14/1	AF	-	-	-	-	-	
	Favorable	12/3		-		3/12		-		-		-	
93	Unfavorable	3/8	AU	4/7	AG	7/4	AG	3/8	AG	15/0	AG	4/11	AG
	Favorable	9/2		7/4		7/4		5/6		15/0		8/7	
94	Unfavorable	12/3	AG	14/1	AG	10/3	AG	0/13	AU	10/5	AG	3/12	AG
	Favorable	10/5		12/3		9/4		5/8		9/6		3/12	
95	Unfavorable	5/10	AU	4/11	AG	10/5	AG	5/10	AG	12/3	AG	5/10	AU
	Favorable	13/2		5/10		6/9		8/7		13/2		15/0	
96	Unfavorable	8/5	AG	7/6	AG	11/2	AG	8/5	AG	14/1	AG	7/8	AG
	Favorable	7/6		3/10		10/3		6/7		15/0		4/11	
97	Unfavorable	-	-	-	-	10/3	AG	11/2	AG	9/4	AG	4/9	AG
	Favorable	-		-		10/3		7/6		10/3		2/11	
98	Unfavorable	3/12	AG	15/1	AF	15/0	AF	13/2	AG	4/9	AU	5/10	AU
	Favorable	2/13		10/5		9/6		11/4		15/0		13/2	
99	Unfavorable	3/12	AU	6/8	AG	-	-	13/2	AG	-	-	3/12	AU
	Favorable	9/6		10/5		-	-	13/2		-	-	13/2	

[1/] AU, AF and AG refer to adaptability to unfavorable environments, adaptability to favorable environments and general adaptability, respectively; [2/] Numbers quoted at the left and right hand side in a cell refer to number of inbred lines with performance above or below the check cultivars, respectively.

Table 6. Estimates of Eberhart and Russel (1966) adaptability (B_1^*) and stability ($s^2_d{}^*$) parameters based on soybean check cultivars yield assessed in Paraná final trials from 1989/1990 to 1998/99. Embrapa Soja, 2002.

Year of assessment	Parameter	Check cultivars in Respective Maturity Group					
		Early (L)		Semi-early (M)		Medium (N)	
		IAS 5	FT-Guaíra	Embrapa 4	BR-16	FT-10	FT-Abyara
90	B_1^*	-	-	-	-	$1.85^{2/}$	-
	$\sigma^2_d{}^*$	-	-	-	-	$69146.5^{2/}$	-
91	B_1^*	$0.49^{2/}$	-	-	-	$1.30^{2/}$	$0.35^{2/}$
	$\sigma^2_d{}^*$	-1161.8^{ns}	-	-	-	30759.85^{ns}	$139495.2^{2/}$
92	B_1^*	$0.72^{1/}$	-	1.21^{ns}	-	0.79^{ns}	$1.43^{1/}$
	$\sigma^2_d{}^*$	-16325.4^{ns}	-	30936.9^{ns}	-	-14547.9^{ns}	13166.9^{ns}
93	B_1^*	$0.59^{1/}$	1.04^{ns}	0.98^{ns}	0.75^{ns}	0.94^{ns}	1.10^{ns}
	$\sigma^2_d{}^*$	-17474.1^{ns}	12514.5^{ns}	32524.3^{ns}	11260.2^{ns}	54466.7^{ns}	49046.9^{ns}
94	B_1^*	0.90^{ns}	0.87^{ns}	1.04^{ns}	$0.67^{2/}$	0.97^{ns}	0.88^{ns}
	$\sigma^2_d{}^*$	13584.6^{ns}	7730.1^{ns}	$57901.7^{2/}$	$31060.2^{1/}$	$36486.6^{1/}$	$41965.9^{1/}$
95	B_1^*	0.76^{ns}	0.98^{ns}	0.92^{ns}	0.84^{ns}	0.73^{ns}	$0.29^{2/}$
	$\sigma^2_d{}^*$	-11708.7^{ns}	$30145.5^{1/}$	$38557.2^{1/}$	-1478.5^{ns}	15793.7^{ns}	$186088.8^{2/}$
96	B_1^*	1.03^{ns}	1.10^{ns}	0.91^{ns}	0.91^{ns}	$0.68^{2/}$	1.00^{ns}
	$\sigma^2_d{}^*$	$73977.0^{2/}$	12437.0^{ns}	$32496.5^{1/}$	$135244.3^{2/}$	16626.6^{ns}	-10585.2^{ns}
97	B_1^*	$0.67^{2/}$	$1.32^{2/}$	1.08^{ns}	1.10^{ns}	0.97^{ns}	1.05^{ns}
	$\sigma^2_d{}^*$	$87699.9^{2/}$	9226.1^{ns}	$82982.6^{2/}$	-573.2^{ns}	10204.6^{ns}	-6169.55^{ns}
98	B_1^*	0.91^{ns}	1.09^{ns}	$1.19^{1/}$	1.05^{ns}	$0.69^{2/}$	$0.64^{2/}$
	$\sigma^2_d{}^*$	11168.4^{ns}	15180.5^{ns}	7665.7^{ns}	-4671.3^{ns}	4725.7^{ns}	$102240.7^{2/}$
99	B_1*	$0.68^{1/}$	0.83^{ns}	-	0.93^{ns}	-	$0.50^{1/}$
	$\sigma^2_d{}^*$	$35048.7^{1/}$	$59624.6^{2/}$	-	$42912.3^{1/}$	-	$74901.7^{2/}$

^{ns}, $^{1/}$, $^{2/}$ non-significant at the 5% level of probability and significant at the 5% and 1% levels of probability, respectively, by test F.

Table 7. Estimates of Cruz et al. (1989) adaptability (B_1, $B_1 + B_2$) and stability (s^2_d) parameters based on soybean check cultivars yield assessed in Paraná final trials from 1989/1990 to 1998/99. Embrapa Soja, 2002.

Year of assessment	Parameter	Check cultivars in respective maturity group					
		Early (L)		Semi-early (M)		Medium (N)	
		IAS-5	FT-Guaíra	Embrapa 4	BR16	FT-10	FT-Abyara
90	B_1	-	-	-	-	-	-
	$B_1 + B_2$	-	-	-	-	-	-
	σ^2_d	-	-	-	-	-	-
91	B_1	$0.46^{2/}$	-	-	-	$1.30^{2/}$	$0.24^{2/}$
	$B_1 + B_2$	0.67^{ns}	-	-	-	1.37^{ns}	1.19^{ns}
	σ^2_d	5059.7^{ns}	-	-	-	45273.2^{ns}	$130938.7^{2/}$
92	B_1	0.76^{ns}	-	$1.25^{1/}$	-	-	-
	$B_1 + B_2$	0.39^{ns}	-	0.00^{ns}	-	-	-
	σ^2_d	-19033.3^{ns}	-	22061.8^{ns}	-	-	-
93	B_1	0.58^{ns}	0.89^{ns}	0.99^{ns}	0.81^{ns}	0.91^{ns}	0.99^{ns}
	$B_1 + B_2$	0.63^{ns}	1.49^{ns}	0.82^{ns}	-0.02^{ns}	1.01^{ns}	1.34^{ns}
	σ^2_d	-12502.0^{ns}	6145.5^{ns}	49292.6^{ns}	7680.8^{ns}	$73556.4^{1/}$	49137.7^{ns}
94	B_1	1.02^{ns}	0.96^{ns}	1.06^{ns}	$0.70^{2/}$	0.95^{ns}	0.90^{ns}
	$B_1 + B_2$	0.54^{ns}	0.59^{ns}	0.76^{ns}	0.42^{ns}	2.40^{ns}	-0.55^{ns}
	σ^2_d	7768.7^{ns}	5725.0^{ns}	$64943.5^{2/}$	$35680.9^{1/}$	$35952.7^{1/}$	42032.7
95	B_1	0.76^{ns}	0.97^{ns}	0.89^{ns}	0.91^{ns}	0.76^{ns}	$0.22^{2/}$
	$B_1 + B_2$	0.73^{ns}	1.02^{ns}	1.58^{ns}	$-0.54^{1/}$	0.51^{ns}	0.86^{ns}
	σ^2_d	-9310.6^{ns}	376999.9^{ns}	$44354.4^{1/}$	-14054.0^{ns}	24803.4^{ns}	$214168.0^{2/}$
96	B_1	1.04^{ns}	1.09^{ns}	1.01^{ns}	1.01^{ns}	$0.72^{2/}$	1.01^{ns}
	$B_1 + B_2$	0.88^{ns}	1.26^{ns}	$0.47^{2/}$	$0.43^{2/}$	$0.59^{2/}$	0.98^{ns}
	σ^2_d	$90483.1^{2/}$	18640.9^{ns}	1471.1^{ns}	$115101.1^{2/}$	21187.9	-7254.6^{ns}
97	B_1	-	-	1.05^{ns}	1.13^{ns}	0.95^{ns}	1.01^{ns}
	$B_1 + B_2$	-	-	$1.66^{1/}$	0.59^{ns}	1.54^{ns}	$1.93^{1/}$
	σ^2_d	-	-	$87203.7^{2/}$	-5427.4^{ns}	8220.3^{ns}	-20165.9^{ns}
98	B_1	0.95^{ns}	1.12^{ns}	1.14^{ns}	1.01^{ns}	$0.74^{2/}$	0.85^{ns}
	$B_1 + B_2$	0.70^{ns}	0.91^{ns}	$1.42^{1/}$	1.22^{ns}	$0.50^{2/}$	$-0.18^{2/}$
	σ^2_d	13366.9^{ns}	$19309.0^{1/}$	6701.1^{ns}	-5244.3^{ns}	4319.4^{ns}	$31313.4^{1/}$
99	B_1	$0.73^{1/}$	0.86^{ns}	-	0.92^{ns}	-	$0.49^{2/}$
	$B_1 + B_2$	$-0.16^{1/}$	0.24^{ns}	-	1.05^{ns}	-	0.80^{ns}
	σ^2_d	$35039.1^{1/}$	$69042.1^{2/}$	-	$55237.5^{1/}$	-	$94787.2^{2/}$

^{ns}, $^{1/}$, $^{2/}$ non-significant at the 5% level of probability and significant at the 5% and 1% levels of probability, respectively, by test F.

Guaíra in the unfavorable environments. Between 1985/86 and 1989/90, the genetic progress estimated in Paraná was 0.89% and 0.38% of the lines from the L and M groups, respectively (Alliprandini et al. 1993). In the five previous years, the gain had been 1.8% and 1.3% for the same maturity groups (Toledo et al., 1990). According to Toledo et al. (1990), complex inheritance and low heritability of the yield and stability traits are the main factors affecting the increase of the genetic progress.

Line adaptability and stability

Although slightly lower than the values obtained for the check cultivars, there was good agreement between the means analysis and the Eberhart and Russel (1966) methodology for determining the adaptability of the lines in group L (72.14%), M (82.08%) and N (74.59%). Between 1989/90 and 1998/99, the majority (over 50%) of the lines tested in the soybean breeding programs in Paraná showed general adaptability (-1/3 N < X_d - X_f < 1/3 N e B_1* = 1) based on these methodologies (Table 8). This was also observed in the adaptability study of the five lines from each maturity group that presented greater yield in each assessment year (Table 9).

Similar to the check cultivar analyses, the means analysis was more adequate than the Eberhart and Russel (1966) methodology whenever they differed in the line classification for adaptability. The Eberhart and Russel (1966) methodology, for example, classified the BR91-1241 line (M group) as adaptable to favorable environments (B_1 > 1) in 1995/96 even though it showed the greatest mean in favorable and unfavorable environments. The BR93-14135 (L group - 1997/1998) and OC91-671 (N group - 1995/1996) lines had the second greatest mean in the unfavorable environments and the thirteenth in the favorable, but were classified as having general adaptability (B_1 = 1). The BR94-00493 line (M group) was recommended for unfavorable environments (B_1 < 1) although a lower number of lines had out-yielded it in the favorable environments (X_f = 12) rather than in the unfavorable (X_d = 14) in 1997/98.

In the mean analysis, an inbred line is said to show general adaptability when its performance in favorable and unfavorable environments are similar. Thus the predominance of lines with general adaptability found in the final Paraná experiments may explain the reasonable correlation estimated between MT and MU and MT and MF, mentioned previously. The greater these correlations, the greater will be the sufficiency of MT as a selection criterium. It has been pointed out that in the analysis of means with tests of significance, genotype with relative yield differences may not differ statistically among each other, depending on the means test used. This little distinction may result in a doubtful classification of many genotypes as ideal. In these cases, the adaptability study based on the difference between X_d and X_f seems to be a simple and viable alternative, as was found in the present study.

The majority (over 50%) of the lines tested showed Cruz et al. (1989) adaptability parameters (B_1 and B_1 + B_2) equal to unit (Tables 8 and 9). This was also found by Carneiro (1998) when assessing final experiments of maize genotypes between 1992/1993 and 1994/1995, which reflects the difficulty in finding the ideal genotype by this methodology. In this study, carried out between 1989/90 to 1998/99, only three

Table 8. Percentage of soybean advanced inbred lines with general adaptability based on means analysis (X_d - X_f) and Eberhart e Russel (1966) – B_1^* parameter – and line percentage with adaptability parameters equal to unit based on Cruz et al. (1989) – B_1 / B_1 + B_2 parametrs – assessed in Paraná final yield trials from 1989/1990 to 1998/99. Embrapa Soja, 2002.

Year of assessment	Percentage of line in each maturity group								
	Early (L)			Semi-early (M)			Medium (N)		
	X_d - X_f	B_1^*	B_1 / B_1 + B_2	X_d - X_f	B_1^*	B_1 / B_1 + B_2	X_d - X_f	B_1^*	B_1 / B_1 + B_2
90	68.8	75.0	-	-	93.8	-	-	50.0	-
91	62.5	75.0	68.8 / 87.5	75.0	87.5	87.5 / 75.0	25.0	41.7	-
92	56.3	68.8	93.8 / 87.5	43.8	68.8	62.5 / 87.5	-	81.3	-
93	58.3	75.0	75.0 / 91.7	66.7	75.0	-	68.8	87.5	87.5 / 87.5
94	68.8	81.3	81.3 / 81.3	78.6	78.6	85.7 / 71.4	68.8	81.3	81.3 / 100.0
95	62.5	87.5	100 / 93.8	75.0	75.0	81.3 / 87.5	68.8	93.8	87.5 / 93.8
96	78.6	62.5	93.8 / 37.5	78.6	64.3	85.7 / 35.7	56.3	43.8	87.5 / 31.3
97	37.5	56.3	-	57.2	57.1	57.1 / 78.6	42.9	64.3	57.1 / 85.7
98	50.0	75.0	87.5 / 81.3	68.8	75.0	81.2 / 68.8	50.0	37.5	81.2 / 37.5
99	81.3	87.5	81.2 / 62.5	87.5	87.5	87.5 / 75.0	68.8	93.8	81.3 / 81.3

Table 9. Percentage of five best yielding soybean lines assessed in Paraná final trials from 1989/1990 to 1998/99 showing general adaptability based on means analysis (X_d - X_f) and Eberhart e Russel (1966) – B_1* parameter – and adaptability parameters equal to unit based Cruz et al. (1989) – B_1 / B_1 + B_2 – respectively. Embrapa Soja, 2002.

Year of assessment	Percentage of five best lines of maturity group								
	Early (L)			Semi-early (M)			Medium (N)		
	X_d - X_f	B_1*	B_1 / B_1 + B_2	X_d - X_f	B_1*	B_1 / B_1 + B_2	X_d - X_f	B_1*	B_1 / B_1 + B_2
90	60.0	60.0	-	-	80.0	-	-	40.0	-
91	60.0	60.0	60.0 / 100.0	80.0	100.0	100.0 / 80.0	20.0	40.0	-
92	60.0	40.0	80.0 / 100.0	20.0	40.0	40.0 / 100.0	-	60.0	-
93	60.0	60.0	40.0 / 80.0	80.0	80.0	-	60.0	100.0	80.0 / 100.0
94	60.0	60.0	80.0 / 60.0	40.0	40.0	60.0 / 60.0	60.0	60.0	60.0 / 100.0
95	100.0	100.0	100.0 / 100.0	100.0	80.0	80.0 / 100.0	80.0	100.0	100.0 / 80.0
96	100.0	60.0	100.0 / 40.0	100.0	40.0	100.0 / 20.0	60.0	60.0	100.0 / 40.0
97	-	60.0	-	60.0	60.0	60.0 / 60.0	60.0	60.0	60.0 / 60.0
98	60.0	80.0	80.0 / 80.0	60.0	80.0	80.0 / 80.0	60.0	60.0	80.0 / 80.0
99	60.0	60.0	60.0 / 60.0	80.0	100.0	80.0 / 60.0	100.0	100.0	80.0 / 80.0

soybean lines (one from L group an two from group M) showed $B_1 < 1$ and $B_1 + B_2 > 1$. Among them, that from the L group is included among the five most productive lines of the corresponding group when it was assessed. The difficulty in finding the ideal line increased when the adaptability study and that of stability were associated, as 20.98% of the variances of the regression deviations were negative and 42.60% greater than zero. With this association, no line was considered ideal according to Cruz et al. (1989). As for the Eberhart and Russel (1966) stability similar results to that of the Cruz et al. (1989) methodology were found.

The comparison of the four methodologies showed that the Lin e Binns parameter (1988) and the mean analysis based on the (X_d - X_f) difference were slightly more adequate than the B_1* of Eberhart and Russel (1966) for analyzing the adaptability of soybean lines. But the use of the mean instead of the P_i has the advantage of simplifying the analysis. The fact that the yield weighed by the line differential behavior in each environment is a component of the Lin e Binns parameter makes P_i also a measure of stability. Therefore, since the mean is highly correlated to P_i, it reflects the lines stability. On the other hand, some of the regression deviations (variances) estimated by the Eberhart and Russel (1966) methodology were negative. Since these can result either from a small deviation estimate, which would suggest high stability, or from an unreliable estimate of a non-small deviation, dubious interpretations concerning the true line stability values will result. Among all the evaluated methodologies, that of Cruz et al. (1989) showed the lowest efficiency. The majority of the tested lines showed Cruz et al. (1989) adaptability parameters (B_1 and $B_1 + B_2$) close to unit, and some of them showed negative estimates of the regression deviation (variances) parameters. These genotypes ($B_1 = 1$ and $B_1 + B_2 = 1$) do not show general or specific (to a region) adaptability.

RESUMO

Estudo de adaptabilidade e estabilidade de linhagens de soja desenvolvidas para alto rendimento no Estado do Paraná usando quatro metodologias

Foi realizado um estudo de adaptabilidade e estabilidade de linhagens de soja avaliadas em diversos locais do Paraná, no período 1990/1999. O estudo teve como objetivos a) verificar a eficiência do programa de melhoramento em selecionar linhagens mais produtivas e adaptadas a regiões específicas ou não específicas, b) caracterizar o desempenho das linhagens padrão em condições favoráveis e desfavoráveis e c) identificar a metodologia que mais se adequou para as avaliação das linhagens. As linhagens avaliadas pertencem aos grupos de maturação precoce (L), semiprecoce (M) e médio (N). O delineamento experimental usado foi blocos completos casualizados, com quatro repetições. Todas as análises foram feitas considerando apenas linhagens de um mesmo grupo de maturação. No decorrer da década de 90, foi possível verificar um razoável aumento no número de linhagens do grupo M que superaram a produtividade de BR-16 e Embrapa 4, principalmente quando foram considerados os ambientes

desfavoráveis. Contudo, para os grupos L e N, o número de linhagens que superaram os padrões manteve-se constante ou oscilou (aumentando ou diminuindo). Os padrões FT-Guaíra, Embrapa 4, BR-16 e FT-10, além da maioria das linhagens testadas, apresentaram adaptabilidade geral. Com adaptabilidade a ambientes desfavoráveis ou adaptabilidade geral, foram caracterizadas IAS 5 e FT-Abyara. A análise de médias nos ambientes favoráveis e desfavoráveis mostrou ser a metodologia mais adequada para avaliar linhagens de soja. Com base nessas médias, uma proposta de classificação de genótipos, quanto à adaptabilidade, foi sugerida.

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