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METHODS OF ADAPTABILITY AND STABILITY APPLIED TO SOYBEAN CULTIVARS RECOMMENDATION

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Abstract: Currently, there are several methods for adaptability and stability analyses, which are distinguished according to the adopted concepts of stability and statistical principles. This study aimed to compare the adaptability and stability methods of Eberhart and Russell (1966), Cruz et al. (1989), and Lin and Binns (1988) modified by Carneiro (1998), besides to select soybean cultivars with high adaptability, stability, and grain yield. Ten trials of the competition were carried out with fifteen soybean cultivars during 2016/2017 and 2017/2018 crop seasons. The method of Lin and Binns (1988) modified by Carneiro (1998), stands out for recommendation of soybean cultivars, as it combines productivity, stability and adaptability for genotype classification, being an easy to interpret method.

Keywords: *Glycine max*, predictability, positioning, yield.

Introduction

The complex of soybean production is extremely important to Brazil's economy, since it holds first place among the most soybean producers in the world (Embrapa, 2021). Mato Grosso do Sul is one of the main grain producers states in the country, and such increases in production of this oilseed in the state are due to the cultivation area expansion, which has grown approximately 247% since 1977, additionally to gains in fitting and yield in Mato Grosso do Sul (Aprosoja, 2016).

The performance of the soybean crop depends on the conditions of humidity, temperature and photoperiod in which it is subjected (Bezerra, 2019). The choice of the cultivar most adapted to the environmental conditions is essential to achieve increases in yields and reduce the losses in production.

The correct positioning of soybean cultivars is essential to guarantee their consolidation in the market. Among the several factors that influence this position are genetic factors (Decinino, 2016). Studies focused on genotype x environment interaction do not provide detailed information about the behavior of each genotype facing environmental condition variations. To identify predictable and responsive cultivars to environmental variations, under specific or wide conditions, it is necessary to carry out adaptability and stability analyzes (Cruz et al., 2014).

The positioning of cultivars with enhanced grain yield, good stability, and predictability depends on the performance of several experi-menttal tests in local environments, since there are genotypes more adapted to certain regions which influence the crop profitability (Sedyama, 2009).

Currently, there are several methods of adaptability and stability analyses, which are distinguished based on the concepts of stability adopted and certain statistical principles (Cruz et al., 2014). Among the methods, there are Eberhart and Russell (1966), which is based on simple linear regression; Cruz et al. (1989), which considers the segmented regression analysis, and Lin and Binns (1988) modified by Carneiro (1998), which consider the *Pi* parameter, decom-posed in favorable and unfavorable environments.

This study compared the adaptability and stability methods of Eberhart and Russell (1966), Cruz et al. (1989), and Lin and Binns (1988) modified by Carneiro (1998) to recommend soybean cultivars that preserve high adaptability, stability, and grain yield.

Material and methods

Ten arrays of competition in soybean cultivars were carried out during 2016/2017 and 2017/2018 crop seasons, in the Mato Grosso do Sul state, Brazil. The environments were constituted by the interactions between the municipalities and crop seasons (Table 1). Information regarding the total monthly rainfall from the studied environments during crop seasons is shown in Figure 1. The treatments consisted of fifteen soybean cultivars (Table 2).

Table 1. Locations, abbreviations, and data regarding climatic conditions of the evaluated environments.

Environment	Abbrev.	Crop seasons	Sowing dates	Altitude (m)	ECR[1]	Latitude (S)	Longitude (W)	Average annual temp.
Antônio João	ANTJ1	2016-2017	07/10/2016	590	204	22° 11'	55° 47'	21.4°C
	ANTJ2	2017-2018	26/10/2017					
Amambaí	AMA1	2016-2017	20/10/2016	425	202	23° 00’	53° 19’	21.8°C
	AMA2	2017-2018	25/10/2017					
Bonito	BON1	2016-2017	27/10/2016	405	204	21° 05’	56° 31’	23.7°C
	BON2	2017-2018	30/10/2017					
Caarapó	CAA1	2016-2017	19/10/2016	390	202	22° 45'	54° 47'	22.5°C
	CAA2	2017-2018	17/10/2017					
Maracajú	MAR	2016-2017	09/10/2016	360	204	21° 38'	55° 06'	23.4°C
Naviraí	NAV	2016-2017	18/10/2016	370	202	22° 59'	54° 06'	22.4°C

1 ECR: Edaphoclimatic regions (MAPA, 2012)

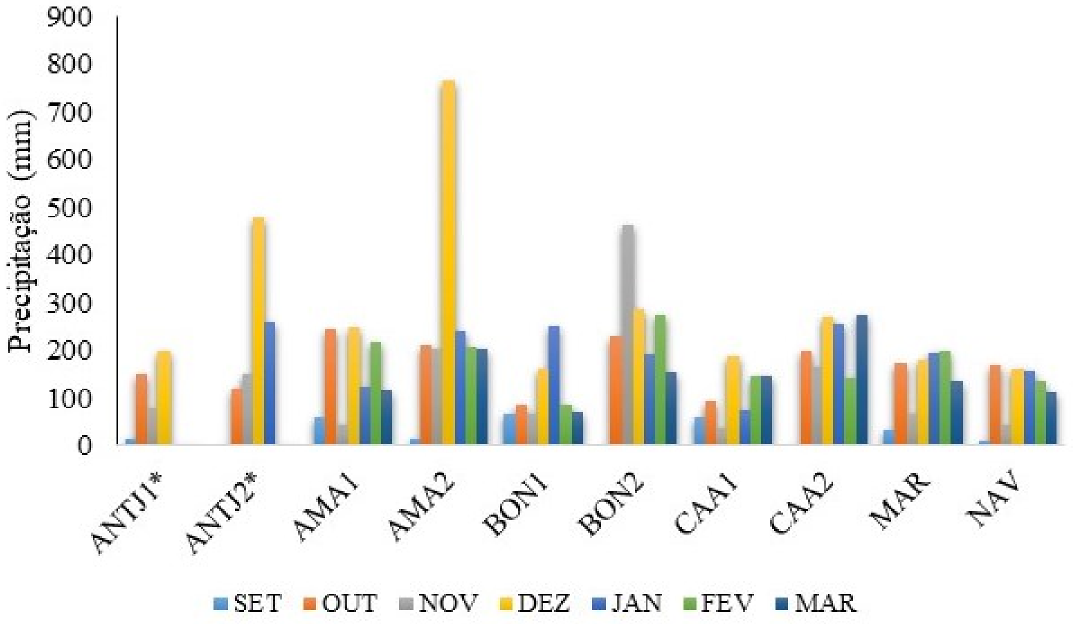

Figure 1. Monthly rainfall data recorded in evaluated environments during the trials. Note: * Environments with unregistered data. (Source: Fundação MS - Tecnologia e Produção: Soja Safra 2016/2017 and 2017/2018 and Cemtec).

Table 2. Soybean cultivars, Relative Maturity Group (RMG) and cycles used for trials test in Mato Grosso do Sul environments.

Cultivars	RMG	Cycle (days)
M6410 IPRO	6.4	113
BRASMAX POTÊNCIA RR	6.7	118
M5947 IPRO	5.9	113
BRASMAX GARRA IPRO	6.3	115
DM 6563RSF IPRO	6.3	113
BRASMAX ÍCONE IPRO	6.8	119
TEC 6702 IPRO	6.7	113
NS 6823 RR	6.7	114
BRS 388 RR	6.4	113
BRS 413 RR	6.2	109
BRS 1003 IPRO	6.3	113
FTR 2557 RR	5.7	107
FTR 2161 RR	6.1	110
FTR 4160 IPRO	6.0	108
SYN 1562 IPRO	6.2	110

The tests were conducted in a randomized block design, with 2 replicates. The experimental unit was composed of five plants per row, 12 m long, and 0.5 m between rows. For sowing density, it was considered the recommendation for each cultivar (Bezerra et al., 2017, 2018).

In each experimental unit, grain yield was evaluated from plants harvested from three central rows (useful area), which were corrected to 13% humidity, and then inferred to kg ha-1.

The joint analysis of the trials was performed according to the statistical model described by Equation 1:

$$Y_{ijk} = \mu + G_i + B/E_{jk} + E_j + GE_{ij} + \varepsilon_{ijk} \quad (1)$$

where:
Y_{ijk}: the observed value within the parcel that received the i-th genotype, for k-th block, and j-th environment;
μ: the overall mean;
G_i, E_j : the effects of the i-th genotype as fixed, and the j-th environment as random;
B/E_{jk}: effect of k-th block within the j-th environment;
GE_{ik}: effect of interaction between i-th genotype and the j-th environment;
ε_{ijk}: the experimental error within the parcel that received the i-th genotype, for k-th block and j-th environment.

Then, the environmental index (Ij) was estimated for each environment (Finlay and Wilkinson, 1963), according to Equation 2:

$$I_j = \frac{1}{g}\sum_j Y_{ij} - \frac{1}{eg}Y \quad (2)$$

where:
Y_{ij} is the yield of the i-th genotype within j-th environment;

g is the number of genotypes; while e is the number of environments.

To assess adaptability and stability by the method of Eberhart and Russell (1966), the linear regression model was performed, according to Equation 3:

$$Y_{ij} = \beta_{0i} + \beta_{1i}I_J + \delta_{ij} + \bar{\varepsilon}_{ij} \quad (3)$$

where,
Y_{ij}: mean of the genotype i within the environment j;
β_{0i}: overall mean of the genotype i;
β_{1i}: coefficient of linear regression, which infer the i-th genotype response to the environment variation;
I_j: coded environmental index;
δ_{ij}: regression deviation;
$\bar{\varepsilon}_{ij}$: mean of experimental error.

The Eberhart and Russell (1966) method based on simple linear regression analysis considers the following concepts (Cruz et al., 2014):

Genotypes with general or wide adaptability: $\beta_{1i} = 1$
Genotypes with specific adaptability to favorable environments: $\beta_{1i} > 1$
Genotypes with specific adaptability to unfavorable environments: $\beta_{1i} < 1$
Genotypes with high stability or high predictability: $\sigma_{di}^2 = 0$
Genotypes with low stability or predictability: $\sigma_{di}^2 > 0$

The significance of the adaptability and stability parameters are tested according to the following hypotheses:

H0: $\beta_{1i} = 1$ versus Ha: $\beta_{1i} \neq 1$, were evaluated by t-test
H0: $\sigma_{di}^2 = 0$ versus Ha : $\sigma_{di}^2 \neq 0$, were evaluated by F test
For Ha: $\beta_{1i} \neq 1$, the magnitude was observed to determine the specific adaptability.
The Ri2 determination coefficient was estimated aiming at the genotype's comparison, mainly to select genotypes with low stability ($\sigma_{di}^2 \neq 0$).

The model used for Cruz et al. (1989) method is given according to Equation 4:

$$Y_{ij} = \beta_{0i} + \beta_{1i}I_J + \beta_{2i}T(I_J) + \delta_{ij} + \bar{\varepsilon}_{ij} \quad (4)$$

where:
Ij: coded environment index
T(Ij) = 0 if Ij <0;
T(Ij) = $I_j - \bar{I}_+$ se Ij > 0, being $\bar{I}_+$ the mean of positive indices Ij.

This method is based on segmented regression analysis, considering the following parameters:

β_{0i} = mean of the genotype
$\beta_{1i} < 1$ = Unresponsive to unfavourable environments
$\beta_1 + \beta_2 > 1$ = Responsive to favorable environment

The significance of the parameters was tested according to the following hypotheses:

H0: $\beta_{1i} = 1$ versus Ha: $\beta_{1i} \neq 1$ were evaluated by t-test
H0: $\beta_{1i} + \beta_{2i} = 1$ versus Ha: $\beta_{1i} + \beta_{2i} \neq 1$ were evaluated by t-test

For Ha: $\beta_{1i} \neq 1$, the magnitude was then assessed.

The stability of the genotypes was evaluated by the regression deviations $\sigma_{\delta i}^2$, and the coefficient of determination Ri2 was also estimated seeking to determine the genotype stability.

The adaptability and stability were evaluated by Lin and Binns (1988) method modified by Carneiro (1998), and the genotypic performance (Pi) was estimated, which is defined as the mean square of the distance between the mean within cultivar and the maximum response on average for all environments, according to Equation 5:

$$\text{Pi} = \frac{\sum_{j=1}^{e}\left(Y_{ij} - M_j\right)^2}{2e} \quad (5)$$

where:
Pi is the estimate of stability parameter within the cultivar i; *Yij* is the yield of the i-th cultivar within the j-th environment; *Mj* is the maximum response observed among all cultivars in environment j; and *e* is the number of environments.

Carneiro (1998) decomposed the Pi estimator into favorable (Pif) and unfavorable (Pid) environments. The classification of environments into favorable and unfavorable was made based on environmental indices, defined as the difference between the average of the cultivars evaluated in each environment and the overall average of the experiments.

For favorable (P_{if}) and unfavorable (P_{id}) environments, the parameters of adaptability and stability were estimated according to the following Equations 6 and 7, respectively:

$$Pif = \frac{\sum_{j=1}^{f}\left(Y_{ij} - M_j\right)^2}{2f} \quad (6)$$

$$Pid = \frac{\sum_{j=1}^{d}\left(Y_{ij} - M_j\right)^2}{2d} \quad (7)$$

where:
f is the number of favorable environments, being considered as environmental indices higher than or equal to zero; d is the number of unfavorable environments, if presented negative environmental indices; Yij is the yield of the i-th cultivar within the j-th environment; Mj is the maximum response observed among all cultivars in the environment j.

All analyzes were performed by using Genes software (Cruz, 2013).

Results and discussion

The joint analysis of variance (Table 3) showed a significant effect (p <0.01) for environments and genotypes × environments interaction. This high significance indicates that the environments are not similar and presents a differenced behavior on the genotype's response under unfavorable environments evaluated. The general average in the 10 environments was 4010.40 kg ha^{-1}, exceeding the national yield in 2019/20 crop season (3373 kg ha^{-1}) (Conab, 2020). The variation coefficient was 7.73%, which indicates a high reliability of the outputting data. Matei et al. (2017) observed similar values in residual variation coefficient (CVe%), which ranged from 4.95% to 9.19% in yield of soybean cultivars tested in eight areas in the states of Paraná and São Paulo.

Table 3. Summary of the joint analysis of variance for grain yield (kg ha-1) in 15 soybean cultivars distributed by 10 different environments in Mato Grosso do Sul during 2016/2017 and 2017/2018 crop seasons.

Source of Variations	DF	Mean Square
Blocks/Envrionments	10	682282.84
Genotypes (G)	14	509264.62^{ns}
Environments (E)	9	698770.87**
G × E	126	309456.8**
Residual	140	96126.77
Mean	4010.40	
Coefficient of variation (%)	7.73	

**: significant at 1% probability by the F test; DF: degrees of freedom;

Other authors have also observed a significant effect of the G × E interaction on soybean adaptability behavior in Mato Grosso do Sul (Galvão et al., 1998; Morais et al., 2008).

The estimates of environmental indices (Ij) are important to indicate favorable and unfavorable environments (Table 4). An environment is considered favorable when the mean yield of the genotypes in such environmental conditions is higher than the general average in all tests. Thus, these environments assume positive rates and are classified as favorable environments, such as ANTJ1, AMA1, MAR, ANTJ2, BON2, and CAA2. BON1, CAA1, NAV, and AMA2 environments have negative indices; which means the average performance of the genotypes in such environments was lower than the general average, being, therefore, unfavorable environments.

Table 4. Environmental indices (Ij) obtained by using Cruz et al. (1989) method.

Environments	Mean	Index (Ij)	Type
ANTJ1	4121.54	111.13	F
AMA1	4277.26	266.86	F
BON1	3855.86	-154.54	D
CAA1	3401.51	-608.89	D
MAR	4440.61	430.20	F
NAV	3070.48	-939.92	D
ANTJ2	4600.91	590.50	F
AMA2	3869.79	-140.61	D
BON2	4435.5	425.10	F
CAA2	4030.56	20.16	F

Despite being at the same location, AMA 1 (16/17 crop) and AMA 2 (17/18 crop) environments presented two different classifications over the different years, the first favorable, and the second unfavorable. This may have occurred due to the concentration of a high volume of rain in December of 2017/2018 crop season, totaling 765 mm. accumulated. According to Farias et al. (2007), excessive rainfall and cloudy days can impair photosynthesis, soil aeration, root development, and nitrogen fixation, causing anomalies in soybean development, reducing grain yield.

The environments BON 1 and CAA 1 (harvest 16/17) were considered unfavorable, in counterpart to BON 2 and CAA 2 (harvest 17/18), which were classified as favorable. There was a lack of regularity in the distribution of rainfall over the period, with BON 1 showing a drought in November, and CAA 1 presenting a drought in November, December, and two times in January. These same environments - during the 2017/2018 crop season - presented a suitable regularity in rainfall, registering no drought period, besides a rainfall accumulation higher than observed in the 2016/2017 crop season for both locations.

According to Farias et al. (2007), the lack of uniformity in rainfall distribution limits the higher yields, especially during the flowering and grain filling stages. According to Flumignan et al. (2015), the weather in the southern region of Mato Grosso do Sul state is quite irregular, especially during the harvests.

Table 5 shows the results of grain yield, adaptability and stability estimates using the method of Eberhart and Russel (1966). The BRASMAX ÍCONE IPRO and M5947 IPRO cultivars presented the highest yields on average, although there was no significant difference between means of the genotype (*p*> 0.05). Carvalho et al. (2013), when studying the adaptability and stability of soybean genotypes in Tocantins, also observed no significant difference between the means of the studied genotypes.

Table 5. Grain yield (kg ha^{-1}) of 15 soybean cultivars and estimates of adaptability and stability parameters by the method of Eberhart and Russel (1966) - $\hat{\beta}_1$e $\hat{\sigma}^2_{\delta i}$, evaluated in 10 environments in Mato Grosso do Sul in the 2016/2017 and 2017/2018 harvests.

Cultivars	$\hat{\beta}_{0i}$	$\hat{\beta}_{1i}$	$\hat{\sigma}^2_{di}$	R²(%)
M6410 IPRO	4089.48	0.83ns	240486.79''	38.53
BRASMAX POTÊNCIA RR	4081.91	1.28ns	2172.30ns	89.51
M5947 IPRO	4240.34	0.86ns	128958.67''	52.47
BRASMAX GARRA IPRO	4080.41	1.97**	375084.24''	70.69
DM 6563RSF IPRO	3927.96	0.98ns	46194.06ns	72.77
BRASMAX ÍCONE IPRO	4354.18	1.44**	5895.32ns	92.79
TEC 6702 IPRO	4091.13	0.59**	156296.18''	30.81
NS 6823 RR	3930.72	0.78ns	25045.22ns	68.77
BRS 388 RR	3879.47	0.63*	20531.00ns	60.10
BRS 413 RR	4053.47	1.02ns	8732.57ns	82.73
BRS 1003 IPRO	3895.05	0.65*	23712.32ns	60.99
FTR 2557 RR	3831.22	1.14ns	91337.90''	70.90
FTR 2161 RR	3857.53	0.87ns	83434.06''	60.39
FTR 4160 IPRO	3770.01	0.73ns	2080.99ns	75.22
SYN 1562 IPRO	4073.15	1.21ns	25740.37ns	83.99
Mean	**4010.40**			

ns: non-significant. ** e *: significantly different from 1 by t-test at 1 and 5% probability, respectively, '': significantly different from 0 by F test at 1% probability.

According to Eberhart and Russel (1966), the ideal genotype presents high average yield, wide adaptability (regression coefficient β_1 equal to 1.0), and high predictability (deviations from regression σ^2_{di} equal to 0). Genotypes with a regression coefficient higher than the unit are adapted to favorable environments. Otherwise, genotypes adapted to unfavorable environments present a regression coefficient less than the unit.

The recommended cultivars would be BRASMAX POTÊNCIA RR, SYN 1562 IPRO and BRS 413 RR, as they presented average yields as showed above, as well as both wide adaptability ($\beta_1 = 1$) and high predictability ($\sigma^2_{di} = 0$).

The cultivars BRASMAX ÍCONE IPRO and BRASMAX GARRA IPRO were more adapted to favorable environments ($\beta_1 > 1$), however, only BRASMAX ÍCONE IPRO showed high predictability of behavior ($\sigma^2_{di} = 0$).

The cultivar M6410 IPRO, the most cultivated in the state, produced in 26% of the soybean farmers in Mato Grosso do Sul state, in Brazil (Famasul, 2019), despite presenting a high average yield and wide adaptability showed low stability. The same occurred for the cultivar M5947 IPRO.

The cultivars BRS 388 RR, BRS 1003 IPRO and TEC 6702 IPRO tended to be more adapted to unfavorable environments ($\beta_1 < 1$). The cultivars BRS 388 RR and TEC 6702 IPRO demonstrated high tolerance to soil water deficit and moderate tolerance to soil acidity (Pitol, 2015). Only the cultivars BRS 388 RR and BRS 1003 IPRO were stable ($\sigma^2_{di} = 0$).

The method of Eberhart and Russel (1966) evaluates a single regression coefficient, which is estimated in a single analysis and considers all the tested environments, and because of this, a false response may occur, in which an ideal genotype may be discarded due to the deviations being relatively high concerning the line estimated (Cruz et al., 2012). The method by Cruz et al. (1989) bypasses such obstacle by adjusting a single regression equation represented by a segmented line, when the linear response of the genotypes in favorable and unfavorable environments is obtained. The mathematical models used in the two methodologies are similar, the main difference is that the regression coefficient was introduced in unfavorable environments in Cruz et al. (1989) model, which forms two straight line segments.

Table 6 presents the parameters of stability and adaptability according to the methodology proposed by Cruz et al. (1989), being desirable the genotypes with high mean, not responsive to unfavorable environments ($\beta_1 < 1$); and responsive to favorable environment ($\beta_1 + \beta_2 > 1$), with the variance of the regression deviations ($\sigma^2_{\delta i}$) equal to zero.

Table 6. Parameters of stability and adaptability estimated according to Cruz et al. (1989) method for 15 soybean cultivars evaluated in 10 environments located in Mato Grosso do Sul state, during 2016/2017 and 2017/2018 crop seasons.

Cultivars	Mean of Environments			$\hat{\beta}_1$	$\hat{\sigma}^2_{\delta i}$	$\hat{\beta}_1 + \hat{\beta}_2$	R² (%)
	General	Unfavorable	Favorable				
M6410 IPRO	4089.48	3721.08	4335.09	0.67*	531247.33⁺⁺	2.14*	50.49
BRASMAX POTÊNCIA RR	4081.91	3483.31	4480.97	1.32*	107323.06ns	0.96ns	90.19
M5947 IPRO	4240.34	3789.25	4541.07	0.84ns	401180.35⁺⁺	1.08ns	52.87
BRASMAX GARRA IPRO	4080.41	3180.27	4680.51	1.79**	809666.24⁺⁺	3.43**	75.46
DM 6563RSF IPRO	3927.96	3488.39	4221.01	1.01ns	210976.53⁺	0.74ns	73.34
BRASMAX ÍCONE IPRO	4354.18	3651.85	4822.39	1.42**	94813.74ns	1.58ns	92.91
TEC 6702 IPRO	4091.13	3692.01	4357.22	0.73ns	372623.93⁺⁺	-0.54**	44.81
NS 6823 RR	3930.72	3538.58	4192.14	0.85ns	145320.11ns	0.24ns	72.84
BRS 388 RR	3879.47	3624.72	4049.31	0.70ns	129826.63ns	0.03*	66.96
BRS 413 RR	4053.47	3649.75	4322.62	0.95ns	109015.72ns	1.55ns	85.50
BRS 1003 IPRO	3895.05	3661.75	4050.59	0.63*	161397.86ns	0.84ns	61.62
FTR 2557 RR	3831.22	3390.04	4125.35	1.23ns	278368.90⁺⁺	0.40ns	74.58
FTR 2161 RR	3857.53	3481.42	4108.27	0.87ns	300482.58⁺⁺	0.91ns	60.40
FTR 4160 IPRO	3770.01	3397.98	4018.03	0.76ns	101123.92ns	0.50ns	76.16
SYN 1562 IPRO	4073.15	3490.78	4461.40	1.23ns	168213.22ns	1.14ns	84.04

ns: non-significant. ** e *: significantly different from 1 by t-test at 1 and 5% probability, respectively.
++ e +: significantly different from 0 by F test at 1 and 5% probability, respectively.

The M6410 IPRO cultivar was the closest to an ideal genotype, with high yield ability responsive to favorable environment ($\beta_1 + \beta_2 > 1$) besides good behavior in unfavorable environments ($\beta_1 < 1$). However, it presented a low predictability ($\sigma^2_{\delta i} \neq 0$), which was also indicated by the method of Eberhart and Russel (1966).

For favorable environments, the cultivar BRASMAX GARRA IPRO showed ($\beta_1 + \beta_2 > 1$), as the same as the M6410 IPRO. However, these cultivars presented low stability ($\sigma^2_{\delta i} \neq 0$). The cultivar BRASMAX ÍCONE IPRO was highly responsive to favorable conditions (4822,39 kg ha^{-1}), with a higher yield and wide adaptability ($\beta_1 + \beta_2 = 1$). However, this cultivar was very sensitive to unfavorable conditions, with a reduction in yield by approximately 24%, which is confirmed by ($\beta_1 > 1$), worse than only the cultivar BRASMAX GARRA IPRO, in which a 32% reduction in production performan-ce was observed at unfavorable environments. It is noteworthy that, among the cultivars, BRASMAX ÍCONE IPRO presented higher predictability of behavior, with an R2 = 92.91%, also observed by the method of Eberhart and Russel (1966).

For environments considered unfavorable, the cultivar BRS 1003 IPRO stands out, which obtained ($\beta_1 < 1$), and high stability ($\sigma^2_{\delta i}$ = 0). These results also corroborate those observed by the method of Eberhart e Russel (1966). The cultivar M5947 IPRO showed the highest yield upon this kind of environment, despite showed ($\beta_1 = 1$) e ($\beta_1 + \beta_2 = 1$).

It was observed that 53% of the cultivars demonstrated a similar response in both favorable and unfavorable environments ($\beta_{1i} = 1$) and ($\beta_{1i} + \beta_{2i} = 1$). Vicente et al. (2004), when assessing adaptability and stability by the method of Cruz et al. (1989), observed 80% of the top soybean lines with wide adaptability. Prado et al. (2001) also predicted non-significant results for the parameters, $\beta_{1i} = 1$ and $\beta_{1i} + \beta_{2i} = 1$, for all soybean cultivars. These authors suggest that the interpretation of the data assessed by using a simple linear regression model of Eberhart and Russel (1966) may be sufficient for respective traits.

The method to estimate the adaptability and stability proposed by Lin and Binns (1988) modified by Carneiro (1998) considers the ideal genotype to be the one with high mean and lower *Pi* value when compared to the other genotypes (Table 7).

Table 7. Estimation of adaptability and stability (Pi) by the method of Lin and Binns (1988) modified by Carneiro (1998) for yield parameter in 15 soybean cultivars over favorable and unfavorable environments.

Cultivars	Mean (kg ha^{-1})	*Pi* general	*Pi* favorable	*Pi* unfavorable
			X100.000	
M6410 IPRO	4089.48	2.56	3.59	1.01
BRASMAX POTÊNCIA RR	4081.91	2.47	2.22	2.85
M5947 IPRO	4240.34	1.69	2.32	0.75
BRASMAX GARRA IPRO	4080.41	3.33	1.75	5.70
DM 6563RSF IPRO	3927.96	4.66	5.60	3.26
BRASMAX ÍCONE IPRO	4354.18	0.97	0.56	1.60
TEC 6702 IPRO	4091.13	4.28	6.22	1.36
NS 6823 RR	3930.72	4.72	6.16	2.56
BRS 388 RR	3879.47	4.77	6.48	2.22
BRS 413 RR	4053.47	2.87	3.54	1.88
BRS 1003 IPRO	3895.05	4.75	6.56	2.05
FTR 2557 RR	3831.22	5.44	6.49	3.86
FTR 2161 RR	3857.53	4.80	6.62	2.08
FTR 4160 IPRO	3770.01	5.23	6.65	3.10
SYN 1562 IPRO	4073.15	3.00	2.45	3.82
Mean	**4010.4**			

The *Pi* parameter estimate measures the studied character deviation from a genotype in comparison to the best genotype in each environment. The lower its value does greater the adaptability and stability of the genotype's behavior. The modification proposed by Carneiro (1988) possibilities to determine the behavior of genotypes in favorable and unfavorable environments.

According to this method, the cultivars that stood out with higher productive averages and lowest general Pi estimate were BRASMAX ÍCONE IPRO and M5947 IPRO (Table 7). These same cultivars were the most recommended for favorable and unfavorable environments, respectively. The advantage of this method is the high correlation that exists between productivity, adaptability, and stability. This method can identify the most stable genotypes among the most productive, as observed by Silva et al. (2013). The same authors suggest that this method can be used in conjunction with other methods, such as that of Eberhart and Russel (1966). Silva and Duarte (2006) observed a low correlation between Eberhart and Russel (1966) and Lin and Binns (1988), and also indicated the combined use of the two methods, to provide additional and complementary information on phenotypic stability in soybean.

The methods of Eberhart and Russell (1966) and Cruz et al. (1989) are based on regression analysis, while the Lin and Binns (1988) method modified by Carneiro (1998) is a non-parametric analysis. Monteiro et al. (2017), when comparing the methodologies of Eberhart and Russell (1966) and Lin and Binns (1988) modified by Carneiro (1998), observed that five genotypes displayed the same classification in two methods and six genotypes with different results for oil productivity based on soybeans.

Pereira et al. (2009) predicted a low correlation between the methods of Eberhart and Russell (1966) and Cruz et al. (1989) coupled to the method of Lin and Binns (1988) modified by Carneiro (1998). In addition to different statistical principles, the methods of Eberhart and Russell (1966) and Cruz et al. (1989) do not necessarily consider the most productive genotypes more stable and adapted to all environments. The method by Lin and Binns (1988) modified by Carneiro (1998) classified the most productive cultivars, BRASMAX ÍCONE IPRO and M5947 IPRO as ideal genotypes. This fact was also observed by Pereira et al. (2009) when they compared the methods of adaptability and stability in bean crops. These authors also suggest the joint use of adaptability and stability methods, being mainly recommended the method of Lin and Binns (1988) modified by Carneiro (1998) with another method, such as Eberhart and Russell (1966) or Cruz et al. (1989).

At the level of cultivation, the most sensible recommendation comprises the use of more than one cultivar, forming a system of combining cultivars, seeking to meet the conditions of management and technological level, as well as the unpredictable conditions inherent in agricultural environments. Therefore, classification as to adaptability and stability is essential for the correct choice of cultivars aiming at diversification, and the analysis methods are fundamental for this process.

Conclusions

For the method of Eberhart and Russel (1966), the ideal cultivars are BRASMAX POTÊNCIA RR, SYN 1562 IPRO and BRS 413 RR. For the method of Cruz et al. (1989), the cultivar M6410 IPRO is the one that comes closest to the ideal genotype, despite having low predictability.

The method of Lin and Binns (1988) modified by Carneiro (1998), identified the more productive cultivars BRASMAX ÍCONE IPRO and M5947 IPRO such as those high stability and adaptability.

The method of Lin and Binns (1988) modified by Carneiro (1998), stands out for recommendation of soybean cultivars, as it combines productivity, stability and adaptability for genotype classification, being an easy to interpret method.

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