Adaptability and stability of soybean cultivars in the region of Chapadões[1]

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ABSTRACT

Grain yield is a constant concern in soybean breeding programs for being highly influenced by the environment. This trait can be significantly affected by the sowing times. Thus, for the correct cultivar recommendation, methods of stability and adaptability analysis are used to verify the genotype x environment interaction at different sowing times. In this study, ten soybean cultivars were evaluated in 2016/2017 and 2017/2018 seasons, at different sowing times. Each experiment was carried out in a randomized block design with three replications. The methods of Eberhart & Russel and Lin & Binns were used for cultivars recommendation for general, favorable, and unfavorable environments. Cultivars CS2728, BONUS, and BRS1074 show high yield and predictability and therefore are the most suitable for the region of Chapadão do Sul.

Keywords: *Glycine max*; Eberhart & Russell; Genotype x environment interaction; Lin & Binns.

INTRODUCTION

Soybean [*Glycine max* (L.) Merril] is the most cultivated crop in Brazil. The country accounted for 238.5 million tons of grains in the 2018/2019 harvest (Conab, 2019). The significant increase in soybean yield in Brazil was driven by the development of technology and high-potential genetic materials provided by breeding programs. Compensatory increments and the obtaining of materials of genetic material adapted to the edaphoclimatic conditions of the different Brazilian regions have become necessary (Torres *et al.,* 2015). Soybean is grown in different environments and exposed to different characteristics of soil, temperature, photoperiod, and rainfall. Thus, the effect of genotypes x environments interaction (GxE) is crucial in cultivars recommendation. For this reason, the search for cultivars with wide adaptation to the different environments has increased due to the dependence on the climatic oscillations at sowing times (Carbonell *et al.,* 2001). To minimize these effects, breeding programs have invested in genotype analysis by performing several trials at the final stages. These trials occur at different locations and times to obtain greater representativeness and reliability in recommending a given genotype for a given region. The use of statistical methods to estimate and explore the GxE interaction is necessary for cultivars recommendation for a given region. The Eberhart & Russel (1966) and Lin & Binns (1988) methodologies stand out among the approaches used to analyze this interaction. The Eberhart & Russel method (1966) is based on the linear regression between the phenotypic value of a given trait based on the environmental index. The environmental index measures the quality of the environment, resulting in positive or negative values, according to its characterization. The predictability of the genotype behavior originates from the component of variance of the deviations of regression,

classified as stable, moderately stable, or unstable (Cruz *et al.*, 2012).

Lin & Binns method (1988) weighs the behavioral deviations of cultivars in environments and considers the yield and the relative response of the genotype (Murakami *et al.*, 2004). The method aims at identifying cultivars that maintain the maximum yield in a wide range of environments, using the statistic parameter P_i. The method is easy to interpret and specifies the cultivar recommendation to groups of favorable and unfavorable environments (Cargnin *et al.,* 2008; Peluzio *et al.,* 2008.; Silva *et al.*, 2008).

The methods described above have been used in the recommendation of soybean genotypes for different environments in Brazil (Maia *et al.,* 2006; Silva *et al.,* 2008; Barros *et al.,* 2008; Steiner *et al.*, 2021). This study aimed to investigate the GxE interaction in soybean cultivars grown at different sowing times and use methods of adaptability and stability for soybean cultivars recommendation.

MATERIAL AND METHODS

Five experiments were carried out in the 2016/2017 and 2017/2018 seasons, in the experimental area of Universidade Federal do Mato Grosso do Sul, located at 18°46'26"S, 52°37'28"W, with at approximately 810 m asl, in the municipality of Chapadão do Sul-MS. The sowing times were 11/20 and 12/3/2017 in the first season and 11/3, 11/18, and 12/8 in the second season. The climate of the region, according to Koppen, is classified as type Aw, defined as tropical humid, with wet summer and dry winter.

Each experiment was carried out in randomized blocks design with ten cultivars and three replications. The experiment used ten cultivars extensively cultivated by the farmers in the region: BRS 1003, BRS 1074, CD 2737, CD2687, CD 2728, NA 5909, TMG 7962, Geneze 5885, BMX DESAFIO RR, and BMX BÔNUS. The experimental unit consisted of four 5-m^2 rows, spaced at 0.45m between rows. Weeds, pests, and diseases control followed the technical recommendations for the crop. Figures 1 and 2 contain the climatic conditions observed at the sowing times in the 2016/2017 and 2017/2018 seasons, respectively.

Grain yield was evaluated in the central rows of each experimental unit, corrected to 13% moisture, and extrapolated to kg ha^{-1}. Data were subject to joint analysis, following the model described in Equation 1:

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

Where: Y_{ijk} is the observation in the k-th block, evaluated in the i-th genotype and j-th environment; μ is the overall mean of the experiments; B/E_{jk} is the effect of block k within environment j; is the effect of the i-th genotype,

considered as fixed; is the effect of the j-th environment, considered as random; G x E_{ij} is the random effect of genotype i x environment j interaction; ε_{ijk} is the random error associated with observation Y_{ijk}.

Scott-Knott test (1974) was applied to cluster the means of the cultivars evaluated. After verifying the significance of the GxE interaction, data were subject to adaptability and stability analyses, using Lin & Binns (1998) and Eberhart & Russell (1966) methodologies.

Initially, the environmental indices (I_j) were estimated for each sowing time, according to Equation 2, proposed by Eberhart & Russell (1966). Negative values of indicate unfavorable environments, while positive values indicate favorable environments.

$$I_j = \frac{\Sigma_i Y_{ij}}{g} - \frac{\Sigma_i \Sigma_j Y_{ij}}{ge}$$

Where: Y_{ij} is the yield of the i-th genotype in the j-th enviroment; g is the number of genotypes; e is the number of enviroments. Results are shown in Figure 3.

In the Eberhart & Russell method (1966), the adaptability is estimated by the parameter β_{1i} and the mean yield is estimated by the parameter β_{0i}. The stability is calculated from the variance of the deviations of regression ($\sigma^2\delta_i$). These parameters were obtained by the statistical model described in Equation 3:

$$Y_{ij} = \beta_{0i} + \beta_{1i}I_j + \Psi_{ij} \qquad (3)$$

Where:

Y_{ij} is the mean of genotype i in enviroment j;

β_{0i} is the linear coefficient of the i-th genotype;

β_{1i} is the coefficient of regression that measures the response of the i-th genotype to the variation of environment j;

I_j is the environmental index $I_j = \frac{\Sigma_j Y_{ij}}{g} - \frac{\Sigma_i \Sigma_j Y_{ij}}{ge}$;

Ψ_{ij} are random errors, in which each component can be decomposed as $\Psi_{ij} = \delta_i + \varepsilon_{ij}$, where δ_i is the deviation of regression, and ε_{ij} is the mean experimental error.

The analysis of adaptability and stability proposed by the Eberhart & Russell method (1966) is based on linear regression, in which genotypes with general or wide adaptability have $\beta_{1i}=1$; genotypes with specific adaptability to favorable environments have $\beta_{1i}>1$; and genotypes with specific adaptability to unfavorable environments have $\beta_{1i}<1$. The stability, calculated by the deviations of regression, considers genotypes with predictable and unpredictable behavior those with $\sigma^2_{di} = 0$ and $\sigma^2_{di} \neq 0$, respectively. The hypotheses to be analyzed are $H_0: \beta_{1i}=1$ *versus* $H_1: \beta_{1i} \neq 1$, tested by the t test; and $H_0 = \sigma^2_{di} = 0$ *versus* $H_1 = \sigma^2_{di} > 0$, tested by the F test. All procedures adopted the 5% of significance level.

By Lin & Binns (1988) methodology, the general performance of the genotypes is evaluated based on the lowest estimates of the parameter for each trait, according to Equation 4:

$$P_i = \frac{\sum_{j=1}^{e}(Y_{ij} - Y_{mj})}{2n} \qquad (4)$$

Where: Y_{ij} is the grain yield of cultivar i in environment j; Y_{mj} is the maximum grain yield in environment j; n is the number of sowing times (n = 5).

For the favorable (P_{if}) and unfavorable (P_{id}) environments, the adaptability and stability parameters were estimated according to Equations 5 and 6, respectively.

$$P_{if} = \frac{\sum_{j=1}^{f}(Y_{ij} - Y_{mj})^2}{2f} \qquad (5)$$

$$P_{id} = \frac{\sum_{j=1}^{d}(Y_{ij} - Y_{mj})^2}{2d} \qquad (6)$$

Where:
f is the number of favorable environments;

d is the number of unfavorable environments, according to the criterion of Eberhart & Russell (1966).

All analyses were carried out using Genes software (Cruz, 2013) and followed the procedures recommended by Cruz *et al.,* (2012).

RESULTS AND DISCUSSION

The analysis of variance for grain yield is shown in Table 1. The coefficient of variation of 13.87% reported for yield can be considered as adequate since this is a quantitative trait, i.e., it is highly influenced by the environment. The experimental coefficient of variation is considered as low. According to Carvalho *et al.* (2003), 16% is the maximum limit allowed for grain yield in soybean, indicating good control and experimental accuracy.

The significant GxE interaction can be attributed to cultivars that were grown in dynamic environments, where they are exposed to unpredictable climatic factors during the whole development cycle. The accumulated rainfall at each sowing time in the 2016/2017 (Figure 1) and 2017/2018 (Figure 2) seasons was higher than that required for
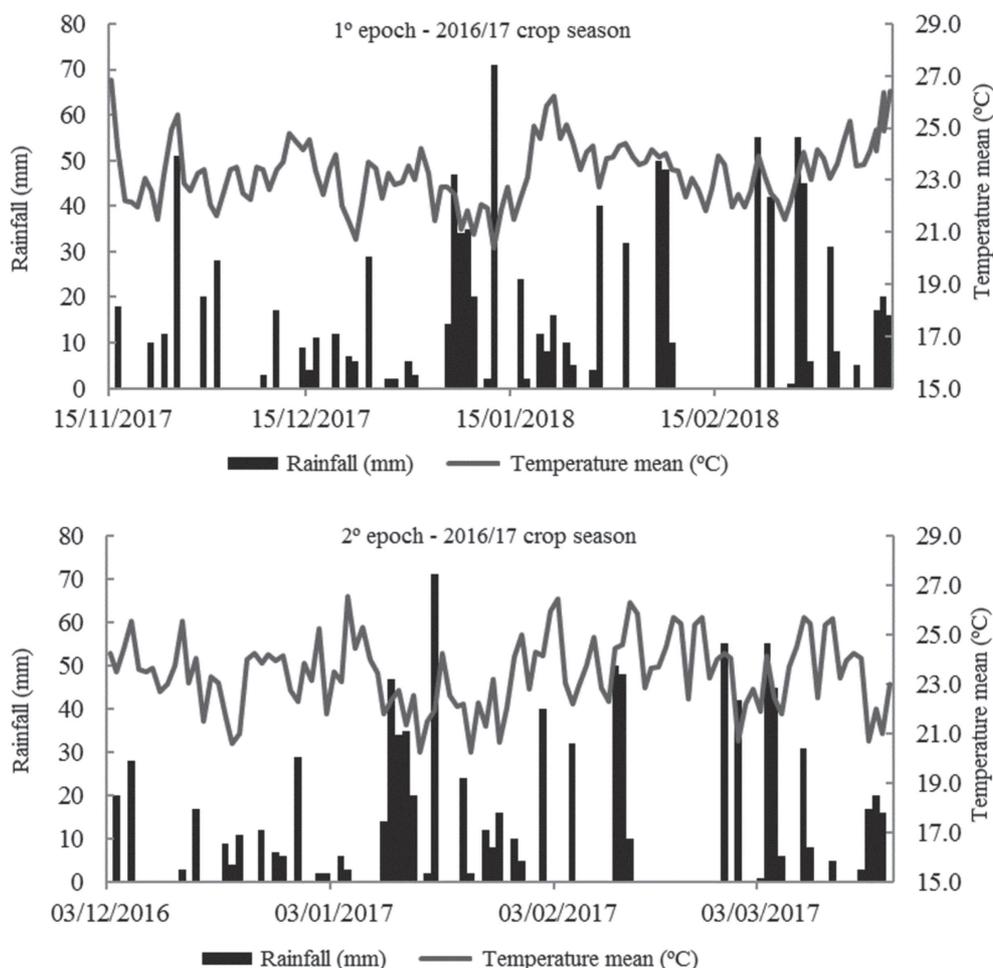

Figure 1: Climatic data of rainfall and temperature from November to February, in the 2016/17 season, for the municipality of Chapadão do Sul - MS.

the soybean crop. However, climatic variations led to different behavior among cultivars. This fact evidences the need for use methods of adaptability and stability for recommendation in the region of Chapadão do Sul.

Among the methods available in the literature, Eberhart & Russel (1966) and Lin & Binns (1988) methods stand out in the recommendation of soybean cultivars in different environments (Matsuo *et al*., 2008; Polizel *et al*., 2013; Cargnelutti Filho & Guadagnin, 2018). Figure 3

shows the estimates of the environmental indices obtained by Eberhart & Russel method (1966) and allow characterizing the quality of the study sites. Negative I_j values, i.e., unfavorable environments, identify areas that have adverse conditions to the crop, either due to soil and climatic conditions or the poor technology applied to the crop. Positive I_j values, i.e., favorable environments, identify areas that invest in inputs and use adequate technology. In the analysis, environments 11/03/2017 and
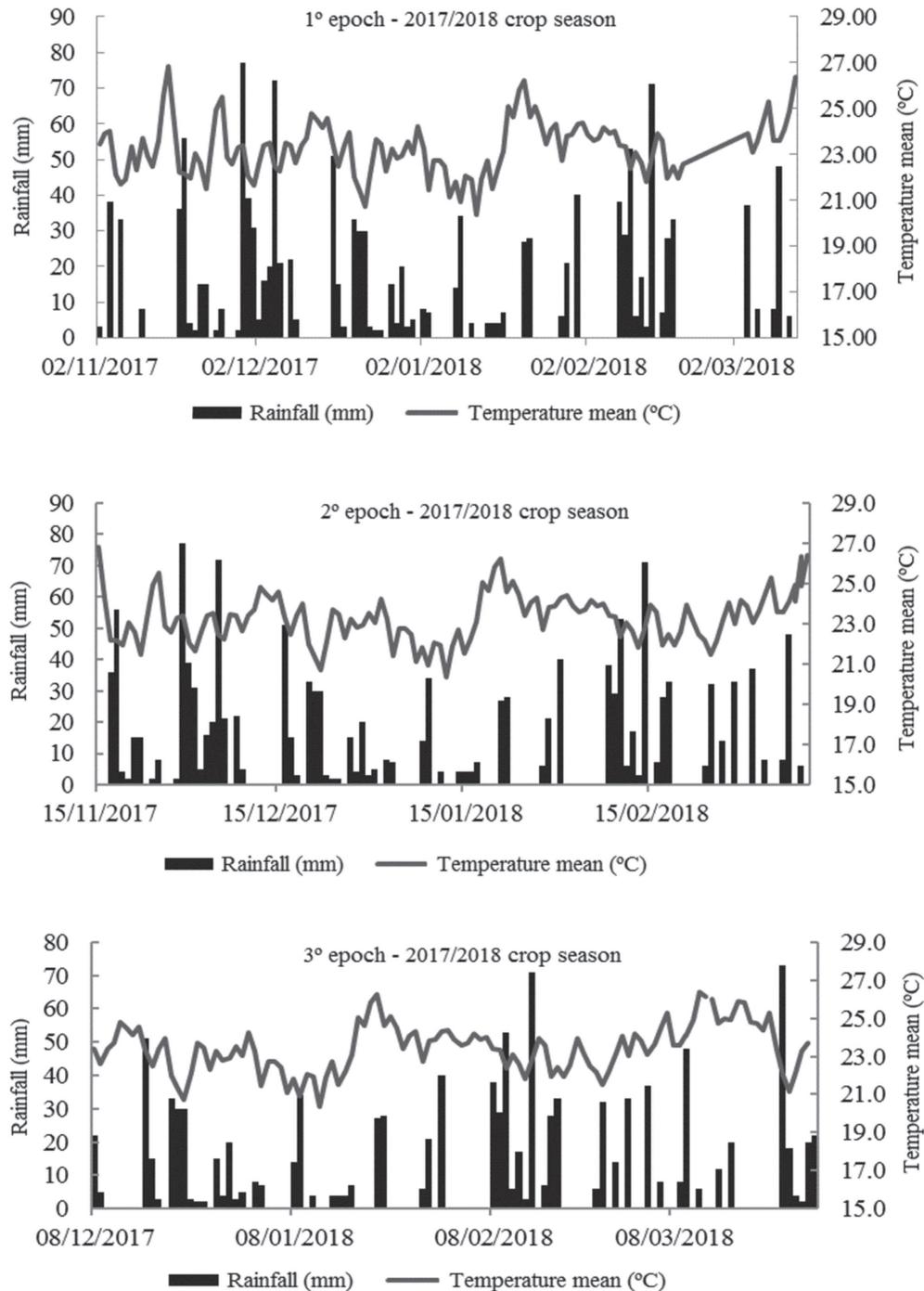

Figure 2: Climatic data of rainfall and temperature from November to February, in 2017/18 season, for the municipality of Chapadão do Sul - MS.

11/18/2017 led to positive values for the trait evaluated, characterized as favorable and appropriate to the ability of the crop. In these environments, the regular water availability at the vegetative and reproductive stages contributed to this result. The genotypes recommended for these environments must behave responsively to these favorable conditions.

Conversely, environments 11/20, 12/02/2016 and 12/08/2017 were classified as unfavorable due to the water deficit recorded at the critical stages of the crop development (Figure 1 and 2). The water deficit was verified during the period of full pod formation and grain filling, which correspond to the phenological stages R4, R5, and R6. In environment 12/08, water deficit was identified at the vegetative stage and at the beginning of flowering, corresponding to the phenological stages V8 and R1. For these environments, genotypes are classified into more rustic and tolerant to the climatic adverse conditions.

Table 2 shows the results based on the Eberhart & Russell (1966) method, the mean yield (β_0), and the parameters of adaptability (β_1) and stability ($\hat{\sigma}^2_{di}$ and R^2) for the soybean cultivars evaluated. Considering these parameters, BÔNUS and TMG 7062 genotypes stand out for their high yield and their specific adaptability for

cultivation in favorable environments ($\beta1 > 1$). BÔNUS reached 80% of predictability, despite the significant deviation. Considering the ability of the genotype to respond favorably to the environmental stimulus, these cultivars should be used by producers who adopt high level of technology.

The cultivars with a regression coefficient lower than one ($\beta_{1i} < 1$) had low mean yield (β_0) and low predictability ($R^2 < 20\%$). Therefore, among the materials evaluated, the method of Eberhart & Russel (1966) does not allow cultivars recommendation for unfavorable environments. However, according to the criteria of this method, a general recommendation is possible for sowing times, based on the genotypes with parameter β_{1i} statistically equal to one. In this sense, cultivars CD 2728 and BRS 1074 are the most suitable to be used at any sowing time in Chapadão do Sul since they had high yield (β_0), non-significant deviations, and high predictability.

The criteria for cultivars recommendation by Lin & Binns (1988) method are shown in Table 3. Genotypes CD 2728, BÔNUS, and BRS 1074 stood out for their high yield and for having lower deviation values in relation to the maximum yield, and thus, they are considered the most stable for general, favorable, and unfavorable environments. Therefore, these cultivars can be
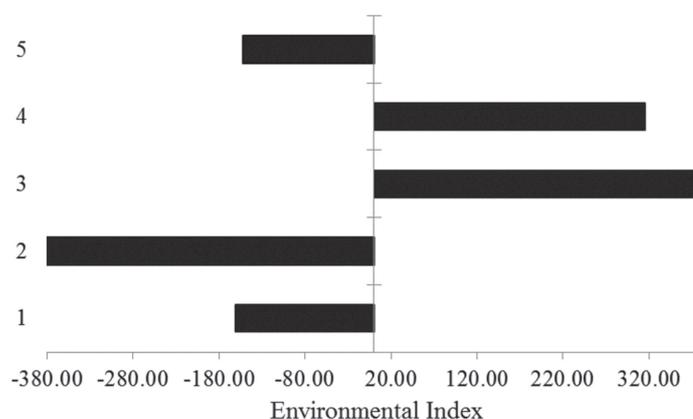

Figure 3: Behavior of soybean genotypes in relation to the trait yield at different sowing times in the region of Chapadão do Sul. Environments 1, 2, 3, 4, and 5 correspond to the sowing times of 11/20 and 12/03 (2016/17 season) and 11/03, 11/18, and 12/18 (2017/18 season), respectively.

Table 1: Summary of the analysis of variance for yield of ten soybean cultivars grown at five sowing times, in the 2016/2017 and 2017/2018 seasons, in the region of Chapadões

Sources of variation	Degrees of freedom	Mean Square
Blocks/Sowing times	10	3301535.63
Cultivars (C)	9	4754326.02*
Sowing Times (T)	4	407807.29*
CxE	36	697180.12*
Residue	90	185492.42
Coefficient of variation (%)		13.87

*: significant and not significant, respectively, by the F test at 5% probability level.

Table 2: Mean yield of ten soybean genotypes (kg ha^{-1}), coefficients of regression ($\hat{a}_1$), deviations of regression ($\acute{o}^2{}_{di}$), and coefficient of determination (R^2) obtained by the Eberhart & Russel method (1966)

Cultivar	Mean (β_0)	β_1	$\sigma^2{}_{di}$	R^2
CD 2728	3812.17 a	1.34^{ns}	-57237.98^{ns}	98.29
NA 5909	3216.61 a	1.04^{ns}	-4285.16^{ns}	73.37
BRS 1003	2593.88 b	-0.09*	174015.12*	0.57
CD 2687	2805.92 b	0.88^{ns}	-33902.71^{ns}	80.43
BONUS	3662.16 a	2.44*	156452.44*	80.00
BRS 1074	3704.25 a	1.18^{ns}	-60878.47^{ns}	99.53
CD 2737	3200.58 a	1.17^{ns}	-52689.28^{ns}	95.63
TMG 7062	3352.93 a	1.78*	55843.45^{ns}	79.75
GENEZE 5885	2589,34 b	0,35^{ns}	9138,55^{ns}	20,57
DESAFIO	2113,38 b	-0,85*	-43744,38^{ns}	17,93

*, ^{ns}: significant and non-significant, respectively, by the t and F tests at 5% probability level.

Table 3: Estimates of phenotypic adaptability and stability of ten soybean genotypes in the 2016/2017 and 2017/2018 seasons, by the Lin & Binns (1988) method, and the decomposition of (stability and adaptability parameter) into favorable (P_{if}) and unfavorable (P_{id}) environments (Lin & Binns)

Cultivar	Mean	P_i	P_{if}	P_{id}
CD 2728	3812.17 a	14133.64	1795.98	11692.09
NA 5909	3216.61 a	281917.00	37785.86	217939.18
BRS 1003	2593.88 b	1142416.96	1740279.73	743841.78
CD 2687	2805.92 b	681575.44	904750.39	532792.14
BONUS	3662.16 a	98625.41	0.00	164375.68
BRS 1074	3704.25 a	39710.18	54444.82	29887.09
CD 2737	3200.58 a	288533.01	365032.31	237533.48
TMG 7062	3352.93 a	185600.60	105441.43	239040.16
GENEZE 5885	2589.34 b	1017690.45	1379039.85	776790.85
DESAFIO	2113.38 b	1824208.04	-43744.38	1243840.42
Mean	3105.12			

recommended for Chapadão do Sul. These results are consistent with the genotypes evaluation by the Eberhart & Russel method, which recommended the same cultivars.

Similar results were found by Romanato *et al.* (2016) in a study on the phenotypic adaptability and stability of soybean yield in Ceará, and by Marques *et al.* (2011), in a study on the different sowing times in Uberlândia. The consistency in the use of the methods shown in the present work has also been verified in different crops, such as wheat and maize (Caierão *et al.,* 2006; Cargnelutti Filho *et al.,* 2007), reinforcing their reliability when compared with the use of an isolated method.

CONCLUSIONS

The Eberhart & Russel (1966) and Lin & Binns (1988) methodologies were similar for recommending soybean genotypes.

The genotypes CD 2728, BÔNUS, and BRS 1074 are the most recommended for the region of Chapadões due to their high grain yield and predictability.

CONFLICT OF INTERESTS

The authors declare no conflicts of interest.

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