Original Article

# SELECTION OF SOYBEAN GENOTYPES FOR TO CERRADO/PANTANAL ECOTONE VIA REML/BLUP

## *SELEÇÃO DE GENÓTIPOS DE SOJA PARA O ECÓTONO CERRADO/PANTANAL VIA REML/BLUP*

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**ABSTRACT:** The objective of this work was to select soybean genotypes with high yield, adaptability and stability in different sowing seasons in the Cerrado-Pantanal ecotone region using the MHPRVG method (harmonic mean of the relative performance of genetic values). We evaluated 10 soybean genotypes at two sowing seasons in Aquidauana/MS in the agricultural year 2014/2015. At maturation, the following agronomic traits were evaluated: plant height (PH), first pod height (FPH), number of branches per plant (NB), number of pods per plant (NP), number of grains per pod (NGP), mass of hundred grains (MHG) and yield grain (YIE). Likelihood ratio test detected significant genotype x seasons interaction only for grain yield. The genotypes AS3730, 97R73 and SYN9070 showed high adaptability and can be growing in both sowing seasons in the Cerrado/Pantanal ecotone. The genotypes 97R21 and B4184 have high phenotypic stability and are indicated for growing in later sowing season.

**KEYWORDS:** *Glycine max*. genotypes interaction. sowing season. MHPRVG method.

## INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is the more cultivated oleaginous crop in the world with a production of 260 million tons of grains in 2014/2015, with Brazil accounting for 37% of this total, making it the second largest world producer (FAO, 2015). However, the average yield of 3.0 t $ha^{-1}$ obtained in this harvest can be considered low, since the yield potential of this crop can exceed 6 t $ha^{-1}$ (CONAB, 2015). Several factors are attributed to this low yield, among which stands out the lack of accurate genotypes recommendation for specific micro-regions. Thus, the selection of genotypes with high grain yield, adaptability and stability to the edaphoclimatic conditions of a specific locality is a way to increase the national average yield in medium-term.

Soybean is cultivated in the Cerrado-Pantanal ecotone region by small farmers, who need a reliable recommendation of the most adapted genotypes to their edaphoclimatic conditions, since this region has peculiar climatic attributes because it is inserted in a zone of transition between two national biomes: Cerrado and Pantanal (TEODORO et al., 2016). Agronomic performance of soybean genotypes in this region has already been evaluated by Torres et al. (2014, 2015) and preliminary results have shown that it is possible to exceed the national average grain yield. However, studies are needed to investigate the interaction between genotypes x sowing seasons to evaluate the genotypes performance over the years.

In recent years, new approaches have been employed to quantify the interaction between genotypes and environments, among which the following stand out: pattern analysis (CORREA et al., 2015a), Bayesian statistics (CORREA, 2016b), computational intelligence (CORRÊA et al., 2016c), among others. However, one of the assumptions for using these approaches is a large number of environments (local and/or years) available. Among the analysis available for a reduced number of environments, the method of harmonic mean of the relative performance of genetic values (MHPRVG), based on mixed models, can also be applied effectively (RESENDE, 2007).

This method provides estimates of adaptability and genotypic stability, whose genetic values are penalized by instability and have already been used for interpreting genotypic stability and adaptability of crops such as common bean (CARBONELL et al. 2007), rice (REGITANO NETO et al. 2013) and cowpea (TORRES et al. 2015 a/ 2015b). However, studies using this method to estimate stability and adaptability in soybean crop are scarce in literature.

Thus, the objective of this work was to select soybean genotypes with high grain yield, adaptability and stability in different sowing seasons in the Cerrado-Pantanal ecotone region using the harmonic mean of the relative performance of genetic values (MHPRVG method).

## MATERIAL AND METHODS

Two experiments were conducted in the agricultural year 2014/2015, in two different sowing seasons. The first sowing season was in the second fortnight of November (1st season), and the second in the first fortnight of December (2nd season), at the experimental area of the State University of Mato Grosso do Sul, Unit of Aquidauana (20º20'S, 55º48'W and altitude of 207 m), transition region between the Cerrado and Pantanal biomes. The soil of the area was classified by Schiavo et al. (2010) according to criteria established by Embrapa (2006) as Red Argisol dystrophic sandy texture, with the following characteristics in the layer 0 - 0,20 m: pH ($H_2O$) = 6.2; exchangeable Al (cmolc $dm^{-3}$) = 0.0; Ca+Mg (cmolc $dm^{-3}$) = 4.31; P (mg $dm^{-3}$) = 41.3; K (cmolc $dm^{-3}$) = 0.2; organic matter (g $dm^{-3}$) = 19.74; V (%) = 45; m (%) = 0.0; sum of bases (cmolc $dm^{-3}$) = 2.3; CEC (cmolc $dm^{-3}$) = 5.1. Region climate according to Köppen's classification is Aw (Savanna Tropical), with accumulated rainfall of 464 mm and maximum and minimum averages temperatures of 37.7 and 16.9 ºC, respectively, during the experiment.

The experimental design used in each experiment was a randomized block with 10 treatments and four replications. The plots consisted of seven rows with 5 m of length, spaced 0.45 m between them and density of 15 plants per meter. The treatments consisted of the following RR soybean cultivars: 97R21, 97R71, 97R73, 97Y07, AS3730, B4184, B4377, SYN1163RR, SYN13671 and SYN9070.

In the preparation of the experimental area, vegetal remains desiccation from the previous crop was performed with the glyphosate herbicide at 6 L $ha^{-1}$ of the commercial product, employing in the application a bar sprayer equipped with a cone-type nozzle. Seeds were treated with fungicide (Piraclostrobina + Metil Tiofanato) and insecticide (Fipronil) at 200 mL of the commercial product per 100 seeds in order to ensure protection against attack by soil pests and fungi. For the biological nitrogen fixation (BNF), seeds were inoculated with bacteria belonging the genus *Bradyrhizobium*, by using 200 mL concentrated liquid inoculant per 100 seeds.

At maturation, we evaluated the following agronomic traits: plant height (PH), first pod height (FPH), number of branches per plant (NB), number of pods per plant (NP), number of grains per pod (NGP), mass of hundred grains (MHG) and grain yield (YIE). For the evaluations, 10 plants from each plot were randomly collected, with the PH and FPH measured in cm by using a metric ruler. In these plants, the NB, NP and NGP were counted. To determine the YIE, the plants from the central rows from each plot were collected. The grains were weighed, corrected to 13% moisture and the values obtained were extrapolated to kg $ha^{-1}$. For obtaining the MHG, in g, a sample was taken from this amount, weighed and corrected for 13% moisture.

To evaluate the effect of the G x E interaction on each trait, the following statistical model was used:

$$y = Xm + Zg + Wp + Ti + e$$

Wherein $y$ is the observations vector; $m$ is the effects vector of the season-replication combinations (fixed) added to the overall mean with $m$ ~ N (Xm, V); $g$ is the genotypic effects vector (random) with $g \sim N(0, I\hat{\sigma}^2_g)$; $p$ is the permanent environment effects vector (plots) (random) with $p \sim N(0, I\hat{\sigma}^2_p)$; $i$ is the genotypes x season effects vector (random) with $i \sim N(0, I\hat{\sigma}^2_{gxe})$; $e$ is the errors vector (random) with $e \sim N(0, I\hat{\sigma}^2_e)$. Upper case letters represent the incidence matrices for these effects.

For the random effects analysis, the likelihood ratio test (LRT) was performed, based on the difference between the deviances for the models with and without the effect to be tested, with significance of this difference using the chi-square test with 1 degree of freedom.

The traits in which the deviance was significant were submitted to the adaptability and stability analysis by the REML/BLUP method. By means of this method, genotypic values in each environment (with interaction effect) were predicted according to Equation 1 and the genotypic values capitalizing the mean interaction in the different environments were predicted according to Equation 2:

$$Vg = \hat{\mu}_j + \hat{g}_{ij} + (\hat{ge})_i \quad (1)$$

$$Vg = \hat{\mu}_j + \hat{g}_i + \hat{ge}_m \quad (2)$$

Wherein $\hat{\mu}_j$ is the season mean j; $\hat{g}_{ij}$ is the genotypic effect of the i genotype, in j seasons; $(\hat{ge})_i$ is the G x E effect related to the i genotype; $\hat{g}e_m$ is the mean interaction in different years.

The values of the harmonic mean of the genotypic values (MHVG) for the stability evaluation; relative performance of the genotypic values (PRVG) for adaptability; harmonic mean of the relative performance of the predicted genotypic values (MHPRV) for simultaneous selection for grain yield, stability and adaptability were obtained according to Resend (2007), which are expressed by equations 3, 4 and 5, respectively:

$$MHVG_i = \frac{n}{\sum_{j=1}^{n} \frac{1}{Vg_{ij}}} \quad (3)$$

$$PRVG_i = \frac{1}{n} \frac{\sum_{j=1}^{n} Vg_{ij}}{M_j} \quad (4)$$

$$MHPRVG_i = \frac{n}{\sum_{j=1}^{n} \frac{1}{PRVg_{ij}}} \quad (5)$$

Where n is the number of sowing seasons (n = 2) in which the i genotype was evaluated; $Vg_{ij}$ is the genotypic value of the i genotype at j time, expressed as the ratio of this environment mean; $M_j$ is the trait mean at j time. The analysis were performed with the Selegen software (Resende, 2007).

## RESULTS AND DISCUSSION

The likelihood ratio test (LRT) was significant ($p<0.01$) for genotypes for all evaluated traits (Table 1). This makes it possible to infer that there is genetic variability for all traits and indicates the possibility of selecting the best genotypes according to each trait. Genotype x season interaction effect was significant only for grain yield. These results indicate that the other evaluated traits are less sensitive to physiological changes that provide modifications in their expression due to sowing seasons.

**Table 1.** Likelihood ratio test (LRT - $\chi^2$) for the traits plant height (PH, cm), first pod height (FPH, cm), number of branches per plant (NB), number of pods per plant (NP), number of grains per pod (NGP), mass of hundred grain (MHG) and grain yield (YIE, kg ha$^{-1}$) evaluated in 10 soybean genotypes grown in two sowing seasons in the Cerrado-Pantanal ecotone.

| Effect | PH | FPH | NB | NP | NGP | MHG | YIE |
|---|---|---|---|---|---|---|---|
| Genotypes (G)$^{+}$ | 12.45* | 9.76* | 10.12* | 9.56* | 13.10* | 10.88* | 24.89* |
| Sowing seasons (E) | 1.20$^{ns}$ | 1.16$^{ns}$ | 0.99$^{ns}$ | 0.87$^{ns}$ | 0.64$^{ns}$ | 0.98$^{ns}$ | 5.45* |
| G x E | 0.89$^{ns}$ | 0.46$^{ns}$ | 0.59$^{ns}$ | 0.80$^{ns}$ | 0.43$^{ns}$ | 0.79$^{ns}$ | 11.05* |

$^{+}$: Deviance of the fitted model without the corresponding effect; $^{ns}$ and *: not significant and significant at 1% probability by the chi-square test, respectively.

The presence of genotypes x seasons interaction for grain yield was already expected, since this trait is polygenic resulting from the expression of many small effect genes, and hence it is greatly influenced by environment (AHMED; AHMED, 2012). Therefore, for recommending the best soybean genotypes for the Cerrado/Pantanal ecotone region based on grain yield, it is necessary to employ the adaptability and stability analysis due to the differential response of the genotypes as a function of sowing seasons.

Variance of the genotypic effects ($\hat{\sigma}^2_g$) showed magnitude greater than the variance of environmental effects ($\hat{\sigma}_e^2$) and G x E interaction ($\hat{\sigma}_c^2$) for the traits PH, FPH and MHG (Table 2). These results led to high estimates of $h_g^2$ and $h_{mg}^2$ according to Resende (2007) criteria and reveals the predominant genetic control in the expression of these traits, indicating the possibility of obtaining gains with the selection (CRUZ et al, 2012). For the other traits, there was a marked residual effect and low estimates of $h_g^2$ and $h_{mg}^2$, which indicates that a greater number of replicates (blocks) should be considered for the next works.

**Table 2.** Variance components, genetic parameters for the traits plant height (PH, cm), first pod height (FPH, cm), number of branches per plant (NB), number of pods per plant (NP), number of grains per pod (NGP), mass of hundred grain (MHG) and grain yield (YIE, kg ha$^{-1}$) evaluated in 10 soybean genotypes grown in two sowing seasons in the Cerrado-Pantanal ecotone.

| Parameters | PH | FPH | NB | NP | NGP | MHG | YIE |
|---|---|---|---|---|---|---|---|
| $\hat{\sigma}_g^2$ | 141.36 | 11.96 | 0.05 | 21.33 | 0.03 | 2.94 | 120514.29 |
| $\hat{\sigma}_c^2$ | 0.47 | 6.08 | 0.01 | 30.77 | 0.00 | 0.00 | 422387.58 |
| $\hat{\sigma}_e^2$ | 49.55 | 7.38 | 0.87 | 91.14 | 0.07 | 0.64 | 32025.52 |
| $\hat{\sigma}_f^2$ | 191.39 | 25.43 | 0.94 | 143.25 | 0.10 | 3.60 | 574927.41 |
| $h_g^2$ | 0.73 | 0.47 | 0.05 | 0.14 | 0.28 | 0.81 | 0.20 |
| $h_{mg}^2$ | 0.95 | 0.72 | 0.30 | 0.41 | 0.72 | 0.97 | 0.62 |
| $\hat{r}_{g\hat{g}}$ | 0.97 | 0.85 | 0.55 | 0.64 | 0.85 | 0.98 | 0.79 |
| $c^2$ | 0.00 | 0.23 | 0.01 | 0.21 | 0.04 | 0.00 | 0.55 |
| $\hat{r}_{gloc}$ | 0.99 | 0.86 | 0.88 | 0.80 | 0.87 | 0.99 | 0.49 |
| $CV_g$ | 15.26 | 23.02 | 5.45 | 8.10 | 6.99 | 11.01 | 10.23 |
| $CV_e$ | 9.03 | 18.09 | 19.32 | 16.76 | 10.67 | 5.15 | 19.15 |

$\hat{\sigma}_g^2$: genotypic variance; $\hat{\sigma}_c^2$: genotypes x times interaction variance; $\hat{\sigma}_e^2$: residual variance between plots; $\hat{\sigma}_f^2$: individual phenotypic variance; $\hat{h}_g^2$: coefficient of individual heritability in the broad sense; $\hat{h}_{mg}^2$: heritability of the genotype mean; $\hat{r}_{g\hat{g}}$: accuracy in genotype selection; $c^2$: coefficient of determination of the genotype x times effects; $\hat{r}_{gloc}$: genotypic correlation over the times; $CV_g$: coefficient of genetic variation; $CV_e$: coefficient of experimental variation.

Due to the greater or lesser degree of adaptability/genetic stability of individuals, G x E interaction variance ($\hat{\sigma}_c^2$) can inflate the phenotypic expression of a trait (BASTOS et al., 2007). This measure quantifies the fraction of the total variation due to G x E interaction. Small magnitude estimates of $\hat{\sigma}_c^2$ indicate that G x E interaction has little influence on the phenotypic value (MAIA et al, 2009). In this context, a genotype with a higher mean for a particular trait in the first sowing season tends to maintain the same performance in sowing seasons that provide similar climatic conditions, since this genotype responds favorably to the environmental influences (high correlation between genotypic values over the sites), in addition to having high predictability against environmental variations. Estimates of $\hat{\sigma}_c^2$ can be considered low for all traits except grain yield, favoring the extremely high phenotypic correlation between sowing seasons.

It is important to mention that in the mixed models methodology, a procedure of multiple comparisons of genotype means should not be used, since this effect was considered as random in the deviance analysis (RESENDE, 2004). Thus, Table 3 expresses the genotypic means of the traits PH, FPH, NB, NP, NGP and MHG for the average environment, which corresponds to a weighting between the two sowing seasons, since the G x E interaction was not significant for these traits.

**Table 3.** Mean genotypic values for the traits plant height (PH, cm), first pod height (FPH, cm), number of branches per plant (NB), number of pods per plant (NP), number of grains per pod (NGP), mass of hundred grain (MHG) and grain yield (YIE, kg ha$^{-1}$) evaluated in 10 soybean genotypes grown in two sowing seasons in the Cerrado-Pantanal ecotone.

| Genotype | PH | FPH | NB | NP | NGP | MHG |
|---|---|---|---|---|---|---|
| 97R21 | 76.68 | 15.19 | 4.13 | 57.96 | 2.36 | 16.31 |
| 97R71 | 50.71 | 12.81 | 4.29 | 53.19 | 2.40 | 15.44 |
| 97R73 | 92.58 | 18.80 | 4.21 | 55.35 | 2.63 | 15.63 |
| 97Y07 | 73.43 | 12.25 | 4.13 | 69.16 | 2.52 | 15.44 |
| AS3730 | 78.18 | 13.45 | 3.92 | 58.46 | 2.75 | 16.39 |
| B4184 | 87.98 | 16.00 | 4.13 | 53.85 | 2.61 | 13.17 |
| B4377 | 83.71 | 16.71 | 4.35 | 59.93 | 2.45 | 16.41 |
| SYN1163 | 66.38 | 11.63 | 4.34 | 51.95 | 2.20 | 16.75 |
| SYN1367 | 70.80 | 12.15 | 4.07 | 51.55 | 2.53 | 18.06 |
| SYN9070 | 80.18 | 10.15 | 4.35 | 61.17 | 2.42 | 13.12 |

When analyzing the genotypic values predicted for the season (Table 4) for the grain yield, it was possible to verify that there was alteration in the ordering of the best genotypes as a function of the sowing season, which indicates complex interaction. The genotypes selected for the first sowing season were AS3730 and SYN9070, whereas for the second season were 97R21 and B4184. It is important to highlight that the yield obtained by most genotypes was higher in the first sowing season, mainly due to the more favorable climatic conditions. The second sowing season does not belong to the agroclimatic zoning for the region due to the photoperiod. In this sense, the best genotypes selected for the second season are those more stable against adverse conditions and are selected for the average environment. When conducting joint analysis of all sowing seasons, the mixed model methodology considers the genotypic standard deviation of the genotypes in each sowing season, penalizing genotypes whose values are high, which provides high reliability to the procedure (RESENDE, 2007).

**Table 4.** Mean genotypic values for grain yield at each sowing season and in the average environment (considering both seasons) of 10 soybean genotypes grown in the Cerrado-Pantanal ecotone.

| Genotype | Season 1 | Season 2 | Average environment |
|---|---|---|---|
| 97R21 | 3785.97 | **3997.06** | **3865.13** |
| 97R71 | 4008.25 | 3467.21 | 3279.89 |
| 97R73 | 4059.48 | 3414.43 | 2787.79 |
| 97Y07 | 3955.58 | 3375.99 | 3349.60 |
| AS3730 | **4167.66** | 3569.14 | 3256.05 |
| B4184 | 3838.35 | **3824.15** | **3858.26** |
| B4377 | 3895.90 | 3256.85 | 3483.58 |
| SYN1163 | 3672.86 | 3155.74 | 3562.99 |
| SYN1367 | 3743.67 | 3339.08 | 3558.95 |
| SYN9070 | **4154.27** | 3589.40 | 3232.12 |

The values of PRVG and MHPRVG indicate exactly the superiority of the genotype in relation to the average of the environment in which it is sown (ZENI-NETO et al., 2008). The three genotypes selected by the highest genotypic values for the first sowing season were the same recommended by the methods in which adaptability (PRVG) and adaptability and stability (MHPRVG) are capitalized simultaneously (Table 5). Thus, the genotypes AS3730, 97R73 and SYN9070 stand out for presenting the highest values for these estimates. Such results indicate that these genotypes presented adaptability and genotypic stability in relation to the two sowing seasons, besides having high grain yield, that is, maintaining this trait even in different climatic conditions. This reinforces that selection by the MHVG implies both selection for yield and stability (OLIVEIRA et al. 2005).

**Table 5.** Stability of genotypic values (MHVG), adaptability of genotypic values (PRVG and PRVGμ), adaptability and stability of genotypic values (MHPRVG and MHPRVGμ) for grain yield assessed in 10 soybean genotypes grown in two sowing seasons in the Cerrado-Pantanal ecotone.

| Genotype | MHVG | PRVG | PRVGμ | MHPRVG | MHPRVGμ |
|---|---|---|---|---|---|
| 97R21 | 3221.28 | 0.95 | 3236.16 | 0.95 | 3235.25 |
| 97R71 | 3534.40 | 1.05 | 3556.69 | 1.05 | 3556.43 |
| 97R73 | **3536.55** | **1.05** | **3559.90** | **1.05** | **3559.42** |
| 97Y07 | 3463.97 | 1.03 | 3483.46 | 1.03 | 3483.46 |
| AS3730 | **3833.46** | **1.14** | **3856.64** | **1.14** | **3856.52** |
| B4184 | 3493.01 | 0.96 | 3250.61 | 0.96 | 3250.61 |
| B4377 | 3597.53 | 0.99 | 3347.88 | 0.99 | 3347.88 |
| BG4184 | 2962.52 | 0.94 | 3201.24 | 0.94 | 3201.24 |
| BG4377 | 2975.42 | 0.95 | 3215.18 | 0.95 | 3215.18 |
| SYN1163R | 2765.75 | 0.82 | 2784.78 | 0.82 | 2784.20 |
| SYN13671 | 3275.09 | 0.97 | 3288.82 | 0.97 | 3284.45 |
| SYN9070 | **3845.47** | **1.14** | **3866.08** | **1.14** | **3866.04** |

Bold values correspond to the three genotypes selected by each statistic.

Bastos et al. (2007) also reported that the MHVG method is a safe option for selection for stability and yield. Carbonel et al. (2007), when using this methodology to select common bean lines for regions of São Paulo reported their main advantages: to provide estimates of adaptability and genotypic stability and to generate results in the self-greatness or scale of the evaluated trait, facilitating the recommendation of the genotypes, besides it can be applied to unbalanced and heterogeneous treatments.

## CONCLUSIONS

The genotypes selected for high grain yield and adaptability were AS3730, 97R73 and SYN9070, showing that these genotypes can be cultivated in both sowing seasons in the Cerrado-Pantanal ecotone region.

The genotypes 97R21 and B4184 have high phenotypic stability, therefore they are suitable for growing in later sowing seasons in the region.

**RESUMO:** O objetivo desse trabalho foi selecionar genótipos de soja com alta produtividade, adaptabilidade e estabilidade em diferentes épocas de semeadura na região do Ecótono Cerrado-Pantanal, empregando o método da média harmônica da performance relativa dos valores genéticos (MHPRVG). Foram avaliados 10 genótipos de soja em duas épocas de semeadura em Aquidauana/MS no ano agrícola 2014/2015. Foram avaliados os seguintes caracteres agronômicos na maturação: altura das plantas (AP), altura da inserção da primeira vagem (AIV), número de ramificações por planta (NR), número de vagens por planta (NV), número de grãos por vagem (NGV), massa de cem grãos (MCG) e produtividade de grãos (PROD). O teste de razão de verossimilhança detectou interação entre genótipos x anos significativa apenas para a produtividade de grãos. As cultivares AS3730 e SYN9070 apresentam alta adaptabilidade e podem ser cultivadas em ambas as épocas de semeadura na região do Ecótono Cerrado/Pantanal. As cultivares 97R21 e B4184 possuem alta estabilidade fenotípica e são indicados para cultivo em épocas de semeaduras mais tardias.

**PALAVRAS-CHAVE:** *Glycine max*. Interação genótipos. Épocas de semeadura. Método MHPRVG.

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