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Adaptability and stability of conventional early maturity soybeans in 15 different environments in Brazil

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ABSTRACT. The success of a plant breeding program depends on its ability to develop and release new cultivars with superior performance and capability to withstand biotic and/or abiotic stresses. We evaluated the genotype by environment interaction for grain yield in conventional early maturity soybean genotypes, grown in 15 environments (municipalties) distributed in five Brazilian states, to determine adaptability and stability of the genotypes. The experiments were carried out in the 2009/2010, 2010/2011, 2011/2012, 2012/2013 and 2013/2014 growing seasons. Twenty-eight soybean genotypes of early maturity were evaluated, among them 23 lines developed by the soybean breeding program of the Federal University of Uberlândia-UFU and five checks: M-SOY 6101, M-SOY 8001, Emgopa 316, UFUS Guarani, and UFUS Riqueza. The genotype and environment interaction was significant at 1% probability level by the F test, showing differential behavior among genotypes according to environment. The coefficient of genotypic determination was 79.44%, indicating that genetic variation was superior to environmental influences. The methods Annicchiarico and Lin and Binns modified by Carneiro were similar in the classification of the genotypes that stood out for the broad and specific adaptation to favorable and unfavorable environments; Wricke, Eberhart and Russel and AMMI methods identified UFU 21 and UFU 22 lines as the most stable, both presenting grain yields greater than 3,800 kg.ha^{-1}. UFU 06 line obtained an average of grain yield greater than 4,000 kg.ha^{-1} and showed wide adaptation by the Annicchiarico, Lin and Binns method, modified by Carneiro, and the Centroid method.

Key words: *Glycine max*; Yield potential; Adapatability

INTRODUCTION

As the second largest worldwide producer of soybeans, Brazil's cultivated area during the growing season of 2016/2017 was estimated at 33.79 million hectares, with an expected overall grain production of 104 million tons (Companhia Nacional de Abastecimento - Conab, 2017). The consultancy Céleres (2016) estimated that over the last growing season the area taken with soybean genetically modified cultivars (GM) was 32.70 million of hectares, which is, about 97% of the total area cultivated with the crop according to Conab (2017). Thus, the 3% remaining land (1.09 million hectares) are grown with conventional soybeans (non-GM).

Currently, market demand for conventional soybeans has increased, mainly for exportation, which has provided higher profitability compared to the production of GM soybeans. Farmers receive an award or additional value that can reach US$2.00 per conventional soybean bag (60 kg) (Conab, 2016).

According to Conab (2016), the lower cost for planting GM soybeans, which is usually considered to use less input and number of operations per hectare, is not a preponderant factor for farmers' decisions anymore. The option towards a more suitable technology should seek, obviously, beyond cost reduction, an increase in remuneration. In addition, the productivity evolution for the conventional soybean crop has grown at a rate similar, or in some cases, superior to that of GM soybean. The soybean breeding program of the Federal University of Uberlândia has worked to improve the technologies of conventional soybean production in tropical environments by developing new non-GM cultivars that are productive, resistant to biotic and abiotic stresses, with wide adaptation and high phenotypic stability (Pmsoja, 2017).

Early maturity cultivars are the target for many soybean breeding programs, since they allow the possibility of a second crop in the same area, as for example, off-season corn in the Cerrado biome. Also, it is used to reduce risks of high pressure of diseases and pests (Unêda-Trevisoli et al., 2010; Ferreira Junior et al., 2015; Silva et al., 2015).

At final stages of line development in a breeding program, preliminary, intermediate and final trials, as well as Cultivation Value and Use trials (CVU) in different locations and consecutive growing seasons are carried out under diverse edaphoclimatic conditions for producing high genotypic performance lines. Along with CVUs, quantitative and qualitative traits of agronomic interest, including grain yield, are accessed (Nogueira et al., 2015). Based on data collection during the trials, genotypic and environmental interactions (G x E) are assessed, followed by adaptability and stability measures. Those analyses help breeders to effectively identify widely adapted cultivars that are both stable and responsive to improved environmental conditions.

This research was aimed at evaluating the G x E interaction for grain yield trait in conventional soybean genotypes of early maturity groups, cultivated in 15 environments distributed over five Brazilian states, examining the adaptability and stability of soybean genotypes by parametric, non-parametric and multivariate methods.

MATERIAL AND METHODS

The experiments were carried out in 15 environments in five Brazilian states (Goiás, Maranhão, Mato Grosso, Piauí, and Tocantins), in 10 municipalities (Alto Taquari-MT, Balsas-MA, Bom Jesus-PI, Currais-PI, Lucas do Rio Verde-MT, Porangatu-GO, Porto Alegre do Norte-MT, Porto Nacional-TO, Querência-MT, and Urutaí-GO) (Table 1). We used 28 soybean early maturity genotypes, composed of 23 lines developed by the soybean breeding program at the Federal University of Uberlândia and five checks M-SOY 6101, M-SOY 8001, Emgopa 316, UFUS Guarani, and UFUS Riqueza.

Table 1. Municipalities, states, average altitude, and growing seasons used in competition assays of 28 early maturity soybean genotypes.

Municipalities	States	Average altitude	Season
Porangatu	Goiás	350	2009/2010
Balsas	Maranhão	250	2009/2010
Porto Nacional	Tocantins	250	2009/2010
Porto Alegre do Norte	Mato Grosso	210	2009/2010
Balsas	Maranhão	250	2010/2011
Bom Jesus	Piauí	400	2010/2011
Porto Alegre do Norte	Mato Grosso	210	2010/2011
Alto Taquari	Mato Grosso	870	2011/2012
Lucas do Rio Verde	Mato Grosso	410	2011/2012
Currais	Piauí	569	2011/2012
Urutaí	Goiás	820	2012/2013
Alto Taquari	Mato Grosso	870	2012/2013
Lucas do Rio Verde	Mato Grosso	410	2012/2013
Querência	Mato Grosso	350	2012/2013
Porangatu	Goiás	350	2013/2014

The experimental design used was randomized complete blocks with three repetitions for all experiments. Each experimental plot was formed by four soybean plant rows 5 m long, spaced 0.5 m within rows. The useful area was composed of the two central lines, wherein 0.5 m from each edge was discarded, resulting in a useful plot of 4 m^2.

Before sowing, the seeds were treated with fungicide (fludioxonil + Metalaxyl-M) and insecticide (thiamethoxam), both at a dosage of 200 mL of the commercial product per 100 kg of seeds.

Twenty seeds were sown per linear meter, three centimeters deep. Thinning was performed at V1 stage (Fehr and Caviness, 1977), reserving 12 to 13 plants per linear meter and a population of 240 to 260 thousand plants ha^{-1}.

Regarding crop operations, for weed control, we used pre-emergent and post-emergent herbicides. Diseases and pests were controlled according to technical recommendations for a soybean crop (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2013). Plant harvesting was carried out manually and processed with a soybean thresher. The grain yield (Y) was achieved through harvesting each useful plot and weighing the grains after being processed. Data obtained (grams per useful plot) were transformed into kg.ha^{-1} and grain yield corrected to a moisture content of 13%, following the equation below:

$$FW = IW\,\frac{100\text{-}IM}{100\text{-}FM} \qquad \text{(Eq. 1)}$$

Where:
FW: final weight of the sample;
IW: initial weight of the sample;
IM: initial moisture content of the sample;
FM: final moisture of the sample (13%).

For statistical analyses, analyses of variance (ANOVA) were run for each experiment. Subsequently, we evaluated the homogeneity of residual variances by the quotient between the highest and lowest mean-square error (MSE) of each individual experiment, considering seven as the limiting value for this quotient in order to carry on with the joint statistical analyses according to what was described by Ramalho et al. (2012).

A joint analyses of variance was conducted, adopting as fixed effects the genotypes and environments, as described below:

$$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B/E_{jk} + \varepsilon_{ijk} \qquad \text{(Eq. 2)}$$

Which is:
μ: grand mean
G_i: genotype effect i
E_j: environment effect j
GE_{ij}: effect of genotype and environment interaction
B/E_{jk}: effect of block k within environment j
ε_{ijk}: random error.

From the joint analyses of variance data, the genotypic determination coefficient (H^2) was estimated, based on:

$$H^2 = \frac{\widehat{\emptyset}_g}{MSG/r} \qquad \text{(Eq. 3)}$$

$$\widehat{\emptyset}_g = \frac{(MSG - MSE)}{r} \qquad \text{(Eq. 4)}$$

Which is:
H^2: genotypic determination coefficient;
$\widehat{\emptyset}_g$: quadratic genetic component;
MSG: mean square of genotype;
MSE: mean square error;
r: repetition number.

The study of G x E interaction was done using decomposition into a complex between pairs of environments, in line with what was described by Cruz and Castoldi (1991). Therefore, the complex part was represented by the expression:

$$C = \sqrt{(1\text{-}r)^3}\sqrt{Q_1 Q_2} \qquad \text{(Eq. 5)}$$

Q1 and Q2 is the correspondence to the genotypic mean square in environments 1 and 2, respectively, and r, the correlation between the genotypic means in both environments.

The phenotypic correlation between pairs of environments was estimated by:

$$r_f = \frac{\hat{Cov}(Y_{ij}, Y_{ij'})}{\sqrt{\hat{V}(Y_j)\hat{V}(Y_{j'})}} \qquad \text{(Eq. 6)}$$

$\hat{Cov}(Y_{IJ}, Y_{IJ})$: phenotypic covariance of an X characteristic accessed in environment j and j';
$\hat{V}(Y_j)$: phenotypic variance of an X characteristic in environment j; and

$\hat{V}(Y_{j'})$: phenotypic variance of an X characteristic in environment j'.

The genotypic correlation between pairs of environments was achieved through the estimator:

$$r_g = \frac{\hat{\phi}_{g(jj')}}{\hat{\phi}_{g(jj')} + \hat{\phi}_{ga(jj')}} \qquad \text{(Eq. 7)}$$

$\hat{\phi}_{g(jj')}$: genetic variability of an X characteristic between environments j and j'; and

$\hat{\phi}_{ga(jj')}$: interaction variability.

The statistical significance of the phenotypic correlation coefficient was tested by a t test at 5% probability. Once the significant G x E interaction wasdetected, phenotypic adaptability and stability analyses were run by Wricke (1965), Eberhart and Russel (1966), Lin and Binns (1988) modified by Carneiro (1998), Annicchiarico (1992), Centroid (Rocha et al., 2005), and AMMI (Zobel et al., 1988) methods.

Statistical analyses were performed with the program Genes (computational application in genetics and statistics) (Cruz, 2016), and stability (Ferreira, 2002).

RESULTS AND DISCUSSIONS

Based on individual variance analyses, we examined the possibility of soybean line selection based on grain yield potential in most environments. This was possible due because of significant genetic variability (F test, Table 2). Torres et al. (2014), found similar results finding genetic variability among soybean cultivars for grain yield trait, as was observed in the localities of Porangatu – GO, Balsas – MA, Bom Jesus – PI, and Urutaí – GO.

Table 2. Average yield per environment, mean squares, and coefficient of variation from the evaluation of 28 early maturity soybean genotypes cultivated in 15 environments.

#	Environment	MSG ^{1}	MSE ^{1}	CV (%) ^{1}	Yield (kg.ha^{-1})
1	Porangatu – GO (09/10)	633835.51 ^{ns}	557146.25	21.93	3403.25
2	Balsas - MA (09/10)	2407738.09 ^{ns}	1442150.30	27.12	4428.57
3	Porto Nacional - TO (09/10)	1969081.01 **	547406.10	23.06	3208.74
4	Porto Alegre do Norte - MT	1677567.68 **	585036.97	21.69	3527.00
5	Balsas – MA (10/11)	4044406.25 **	365239.66	18.05	3348.21
6	Bom Jesus - PI (10/11)	1051011.16 ^{ns}	836793.05	22.48	4069.37
7	Porto Alegre do Norte - MT	1181227.21 **	552394.75	15.37	4835.27
8	Alto Taquari - MT (11/12)	1231594.93 **	383633.07	21.51	2878.88
9	Lucas do Rio Verde - MT	4361678.35 **	1325799.01	22.32	5158.45
10	Currais - PI (11/12)	930881.37 *	451974.93	30.30	2218.62
11	Urutaí - GO (12/13)	566136.54^{ns}	764710.96	28.57	3060.64
12	Alto Taquari - MT (12/13)	1355622.85 **	368655.07	21.36	2842.15
13	Lucas do Rio Verde - MT	2099045.16 **	680768.46	15.89	5192.28
14	Querência - MT (12/13)	2511762.41 **	538786.00	23.17	3168.44
15	Porangatu - GO (13/14)	1375760.91 *	775401.75	21.95	4010.70

^{ns}: non-significant; * and **: significant at 5% and 1%, respectively, by F test; MSG: mean square of genotype; MSE: mean square of error; CV (%): coefficient of variation; ^{1}Results from the individual variance analyses.

The coefficient of variation fluctuated between 15.37 and 30.30%, being classified as medium to high, according to Pimentel-Gomes (2009). In field experiments, values of CVs are considered as low (<10%), medium (10% to 20%), and high (20% to 30%). The CV values found in our study resemble those of other studies with soybeans (Vasconcelos et al., 2015; Romanato et al., 2016).

The quotient between the highest and the lowest mean square error of the individual variance analyses (Table 2) was 3.95, indicating the possibility of doing joint variance analyses, which can be found in Table 3, for the 15 environments. We noticed significant effects for genotypic and environmental factors with a significant interaction between them (F test, P<0.01). Other studies on soybeans, including Barros et al. (2012), Hamawaki et al. (2015), Soares et al. (2015), Vasconcelos et al. (2015), Teixeira Júnior et al. (2015), and Romanato et al. (2016), also reported a significant G x E interaction for grain yield.

The genotypic determination coefficient shows the proportion of phenotypic variability attributed to genetic causes. The value of 79.44% (Table 3) is of high magnitude for the grain yield trait, which agrees with what was proposed by Cruz et al. (2012). Our study resembles that of Soares et al. (2015), who estimated 78.72% when evaluating 38 soybean cultivars over two growing seasons in Minas Gerais state.

Table 3. Joint variance analyses for grain yield trait (kg.ha^{-1}) evaluated for 28 early maturity soybean genotypes cultivated in 15 environments.

Source of Variation	Degrees of Freedom	Mean square
Blocks/Environments	30	1587003.02
Genotype (G)	27	3300418.31 **
Environment (A)	14	67104885.62 **
G x E Interaction	378	1721209.36 **
Error	810	678393.09
Mean		3690.03
CV (%)		22.32
H^2 (%)		79.44

^{ns}: non-significant; * and **: significant at 5% and 1%, respectively, by the F test; H²: genotypic determination coefficient; CV (%): coefficient of variation

The occurrence of a G x E interaction indicates that grain yield of genotypes varies with changes in the environment. In this scenario, the study of G x E interactions is important to determine their nature. By, it is possible to observe that The G x E interaction was predominantly of a complex nature (Table 4) as the decomposition of the complex part of the G x E interaction by the Cruz and Castoldi (1991) method, generally was above 50%.

Table 4. Decomposition estimates of G x E interaction's complex part (in %) by the Cruz and Castoldi (1991) method (below the diagonal) and classification of the interaction between simple and complex (above the diagonal), in the analyses of 28 early maturity soybean genotypes in 15 environments.

	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15
A 1	-	C	S	C	C	C	C	C	C	C	C	C	C	C	C
A 2	83.72	-	C	C	C	C	C	C	C	C	C	C	C	C	C
A 3	48.41	108.73	-	C	C	C	C	C	C	C	C	C	C	C	C
A 4	83.42	88.69	99.67	-	C	C	C	C	C	C	C	C	C	C	C
A 5	67.32	92.51	85.27	78.67	-	C	S	C	C	C	C	C	C	C	C
A 6	105.52	88.50	99.08	90.15	71.22	-	C	C	C	C	C	C	C	C	C
A 7	81.75	90.99	80.64	76.39	44.59	98.21	-	C	C	C	C	C	C	C	C
A 8	89.40	103.86	78.30	69.63	68.67	116.95	72.33	-	C	C	C	C	C	C	C
A 9	65.65	64.73	83.10	75.38	100.25	87.74	71.22	60.14	-	C	C	C	C	C	C
A 10	107.99	92.36	99.36	107.01	96.94	110.81	123.72	108.34	74.92	-	C	C	C	C	C
A 11	88.90	65.32	82.12	90.32	76.63	89.16	93.17	102.09	64.84	85.01	-	C	C	C	C
A 12	78.35	109.98	88.67	97.17	87.28	109.94	93.30	96.56	93.67	96.11	87.73	-	C	C	C
A 13	76.06	94.03	90.67	77.93	82.39	102.90	74.17	77.21	88.64	98.76	86.33	93.16	-	C	C
A 14	63.74	106.23	103.03	97.03	98.36	99.66	81.62	99.56	113.18	91.51	53.87	71.62	91.27	-	C
A 15	92.92	93.65	103.02	99.88	77.62	82.99	87.13	98.86	93.17	116.83	83.41	100.64	106.82	92.83	-

Environments: A1 (Porangatu/GO – 2009/2010), A2 (Balsas/MA – 2009/2010), A3 (Porto Nacional/TO - 2009/2010), A4 (Porto Alegre do Norte/MT - 2009/2010), A5 (Balsas/MA – 2010/2011), A6 (Bom Jesus/PI - 2010/2011), A7 (Porto Alegre do Norte/MT - 2010/2011), A8 (Alto Taquari/MT - 2011/2012), A9 (Lucas do Rio Verde/MT – 2011/2012), A10 (Currais/PI - 2011/2012), A11 (Urutaí/GO - 2012/2013), A12 (Alto Taquari/MT - 2012/2013), A13 (Lucas do Rio Verde/MT – 2012/2013), A14 (Querência/MT - (2012/2013) and A15 (Porangatu/GO - 2013/2014); C: complex interaction; S: simple interaction.

The estimates of genotypic correlations between all environmental combinations overcame the phenotypic correlations, which is explained by a high genetic variability for grain yield in most environments (Table 5). Nevertheless, the estimates of genotypic and phenotypic correlations were of low magnitude, which is below 0.70. This demonstrates the inconsistency of genotypic superiority when there is environmental variation (Cruz et al., 2012), making it difficult to recommend lines and cultivars. Similar results were reported by Barros et al. (2012), who studied 29 soybean genotypes in six different environments in the state of Mato Grosso.

Table 5. Phenotypic (r_p) and genotypic (r_g) correlation coefficient between pairs of environments in an analysis of 28 soybean genotypes in 15 environments.

Environment		**r_p**	**r_g**	**Environment**		**r_p**	**r_g**	**Environment**		**r_p**	**r_g**
A 1	A 2	-0,05	0,45	A 3	A 12	0,18	0,62	A 7	A 9	0,18	0,61
A 1	A 3	0.56**	0,92	A 3	A 13	0,18	0,63	A 7	A 10	-0.54 **	-0,16
A 1	A 4	0.10	0,59	A 3	A 14	-0,08	0,45	A 7	A 11	0,01	0,53
A 1	A 5	0,02	0,51	A 3	A 15	-0,93	0,42	A 7	A 12	0,12	0,60
A 1	A 6	-0,18	0,08	A 4	A 5	0,22	0,62	A 7	A 13	0.37*	0,79
A 1	A 7	0,24	0,80	A 4	A 6	0,13	0,64	A 7	A 14	0,21	0,64
A 1	A 8	0,10	0,59	A 4	A 7	0.39*	0,82	A 7	A 15	0,24	0,74
A 1	A 9	0,02	0,51	A 4	A 8	0.49**	0,86	A 8	A 9	0,36	0,72
A 1	A 10	-0,20	0,22	A 4	A 9	0,24	0,66	A 8	A 10	-0,19	0,34
A 1	A 11	0,21	-0,51	A 4	A 10	-0,23	0,32	A 8	A 11	-0,18	0,27
A 1	A 12	0,26	0,73	A 4	A 11	-0,64	0,43	A 8	A 12	0,65	0,55
A 1	A 13	0,15	0,61	A 4	A 12	0,04	0,53	A 8	A 13	0,34	0,74
A 1	A 14	0,27	0,67	A 4	A 13	0.38*	0,78	A 8	A 14	-0,11	0,43
A 1	A 15	0,00	0,50	A 4	A 14	0,02	0,51	A 8	A 15	0,02	0,52
A 2	A 3	-0,19	0,32	A 4	A 15	-0,01	0,49	A 9	A 10	0,02	0,51
A 2	A 4	0,18	0,32	A 5	A 6	0,17	0,59	A 9	A 11	-0,02	0,49
A 2	A 5	0,08	0,68	A 5	A 7	0.57**	0,79	A 9	A 12	-0,16	0,40
A 2	A 6	0,06	0,55	A 5	A 8	0,27	0,63	A 9	A 13	0,09	0,56
A 2	A 7	0,06	0,59	A 5	A 9	-0,01	0,50	A 9	A 14	-0,35	0,27
A 2	A 8	-0,18	0,56	A 5	A 10	-0,37	0,33	A 9	A 15	-0,15	0,40
A 2	A 9	0.50**	0,32	A 5	A 11	-0,21	0,41	A 10	A 11	0,22	1,07
A 2	A 10	-0,50	0,91	A 5	A 12	-0,01	0,49	A 10	A 12	0,04	0,53
A 2	A 11	0,22	0,45	A 5	A 13	0,22	0,63	A 10	A 13	-0,13	0,41
A 2	A 12	-0,29	0,84	A 5	A 14	-0,02	0,49	A 10	A 14	-0,05	0,47
A 2	A 13	0,11	0,23	A 5	A 15	0,16	0,59	A 10	A 15	-0.40 *	0,08
A 2	A 14	-0,13	0,60	A 6	A 7	0,03	0,54	A 11	A 12	0,06	0,57
A 2	A 15	0,05	0,39	A 6	A 8	-0.37 *	0,10	A 11	A 13	-0,08	0,44
A 3	A 4	0,02	0,56	A 6	A 9	-0,16	0,39	A 11	A 14	0.38*	0,75
A 3	A 5	0,16	0,59	A 6	A 10	-0,23	0,17	A 11	A 15	0,13	0,79
A 3	A 6	-0,07	0,43	A 6	A 11	0,12	0,00	A 12	A 13	0,09	0,56
A 3	A 7	0,29	0,71	A 6	A 12	-0,22	0,28	A 12	A 14	0.40*	0,75
A 3	A 8	0,33	0,73	A 6	A 13	-0,17	0,34	A 12	A 15	-0,01	0,49
A 3	A 9	0,17	0,61	A 6	A 14	-0,16	0,38	A 13	A 14	0,16	0,61
A 3	A 10	-0,12	0,42	A 6	A 15	0,29	0,93	A 13	A 15	-0,18	0,34
A 3	A 11	0,02	0,52	A 7	A 8	0.48*	0,89	A 14	A 15	0,05	0,54

^{ns}: non-significant; * and **: significant at 5% and 1%, respectively, by the t test. Environments: A1 (Porangatu/GO – 2009/2010), A2 (Balsas/MA – 2009/2010), A3 (Porto Nacional/TO - 2009/2010), A4 (Porto Alegre do Norte/MT - 2009/2010), A5 (Balsas/MA – 2010/2011), A6 (Bom Jesus/PI - 2010/2011), A7 (Porto Alegre do Norte/MT - 2010/2011), A8 (Alto Taquari/MT - 2011/2012), A9 (Lucas do Rio Verde/MT – 2011/2012), A10 (Currais/PI - 2011/2012), A11 (Urutaí/GO - 2012/2013), A12 (Alto Taquari/MT - 2012/2013), A13 (Lucas do Rio Verde/MT – 2012/2013), A14 (Querência/MT - 2012/2013) and A15 (Porangatu/GO - 2013/2014);

The environmental indexes and the classification of the environments; 40% of which were classified as favorable, are shown in Table 6. Unfavorable environments occur due to an influence of the environment, which in this case can negatively compromise soybean yields through biotic or abiotic stresses. Similarly, in evaluating the agronomic performance of soybean cultivars over two growing seasons in the Cerrado biome, Alcântara Neto et al. (2012) mentioned the occurrence of water deficit from the beginning of the vegetative stage to the beginning of flowering and pod filling. Consequently, this led to a yield reduction in the soybean cultivars during both of these growing seasons.

Table 6. Environment indexes in analyses of 28 early maturity soybean genotypes cultivated in 15 environments.

Environment	Mean	Index	Class
Porangatu-GO (2009/2010)	3403,25	-286,79	Unfavorable
Balsas-MA (2009/2010)	4428,57	738,53	Favorable
Porto Nacional-TO (2009/2010)	3208,74	-481,29	Unfavorable
Porto Alegre do Norte-MT (2009/2010)	3527,00	-163,04	Unfavorable
Balsas-MA (2010/2011)	3348,21	-341,83	Unfavorable
Bom Jesus-PI (2010/2011)	4069,37	379,33	Favorable
Porto Alegre do Norte-MT (2010/2011)	4835,27	1145,23	Favorable
Alto Taquari-MT (2011/2012)	2878,88	-811,16	Unfavorable
Lucas do Rio Verde-MT (2011/2012)	5158,45	1468,41	Favorable
Currais-PI (2011/2012)	2218,62	-1471,42	Unfavorable
Urutaí-GO (2012/2013)	3060,65	-629,39	Unfavorable
Alto Taquari-MT (2012/2013)	2842,15	-847,89	Unfavorable
Lucas do Rio Verde-MT (2012/2013)	5192,28	1502,24	Favorable
Querência-MT (2012/2013)	3168,44	-521,60	Unfavorable
Porangatu-GO (2013/2014)	4010,71	320,67	Favorable

Using the Wricke (1965) methodology, we determine the genotypic stability using the invariance principle; in other words, the genotypes that contribute less to the G x E interaction (Cruz et al., 2012). In, it is shown the estimates of Wi parameters oscillated from 0.89 to 8.33% (Table 7).

These were used to identify the most stable genotypes: UFU 22, UFU 09, UFU 08, UFU 18, and UFU 21. In contrast, the least stable genotypes were Emgopa 316, UFU 01, UFU 06, M-SOY 8001, and UFUS Riqueza. Among the least and most stable genotypes, the ones with higher grain yield were mostly involved. These results are similar to some findings of Gonçalves et al. (2007) who analyzed 28 soybean genotypes with the same methodology; they found superior values of Wi for the most productive soybean lines.

The stability accessed by the Annicchiarico (1992) method refers to genotype superiority measurement in relation to the mean of each environment and it is based on the estimation of the Wi confidence index. Regarding the general classification, it was observed that the most stable lines were UFU 07, UFU 09, UFU 06, UFU 05, and UFU 21, whose confidence indexes were superior to 100% (Table 7). Additionally, concerning the specific adaptation to favorable environments, UFU 06, UFU 05, UFU 07, UFU 09, and UFU 08 were the featured genotypes. Yet, in relation to unfavorable environment adaptability, UFU 21, UFU 07, UFU 09, UFU 17, and UFU 18 stood out from the other genotypes. Carvalho et al. (2013) also adopted the Annicchiarico (1992) methodology in studies of soybean genotypes cultivated in eight environments in the state of Tocantins. They achieved confidence indexes superior to 100% in the wide, favorable and unfavorable classifications.

Table 7. Grain yield and stability parameters based on Wricke (1965) and Annicchiarico (1992) methods, in 28 soybean conventional genotypes in 15 environments distributed over five Brazilian states.

Genotypes	**Grain yield (kg.ha-1)**	**Wricke (1965)**		**Annicchiarico (1992)**		
		Ecovalence	**Wi (%)**	**Wig (%)**	**Wif (%)**	**Wiu (%)**
UFU 01	3410,06	44852849,39	6,89	82,69	98,49	73,15
UFU 02	4008,24	33366423,37	5,13	101,42	102,16	100,59
UFU 03	3899,83	21710191,25	3,34	99,98	102,83	98,24
UFU 04	3719,57	18492171,95	2,84	93,98	102,11	88,79
UFU 05	4024,04	19006714,45	2,92	103,82	108,94	100,39
UFU 06	4225,51	44480818,54	6,84	104,44	113,21	98,67
UFU 07	4133,93	12425383,34	1,91	107,78	105,77	108,99
UFU 08	3863,67	8274653,67	1,27	100,83	104,43	98,52
UFU 09	3995,18	7269451,01	1,12	105,22	104,60	105,51
UFU 10	3793,97	19698467,80	3,03	97,22	93,83	99,77
UFU 11	3585,25	17556265,88	2,70	91,68	95,93	89,51
UFU 12	3444,54	15811841,61	2,43	90,26	86,39	93,01
UFU 13	3354,84	16378735,23	2,52	86,23	90,77	83,81
UFU 14	3539,35	22887915,02	3,52	92,20	82,78	99,33
UFU 15	3242,50	17163971,74	2,64	83,31	84,42	82,99
UFU 16	3326,02	30868640,01	4,74	84,96	84,69	85,12
UFU 17	3783,91	19262106,54	2,96	97,86	88,97	104,41
UFU 18	3975,10	10400459,05	1,60	102,85	101,55	103,86
UFU 19	3541,32	14766223,85	2,27	91,33	92,49	90,30
UFU 20	3804,51	22108247,80	3,40	98,46	96,84	100,05
UFU 21	3925,28	11127590,00	1,71	103,31	94,82	109,79
UFU 22	3805,63	5774695,48	0,89	100,74	99,71	101,30
UFU 23	3438,47	16213556,91	2,49	86,75	97,89	80,14
M-SOY 6101	3614,22	34589468,20	5,32	90,74	89,51	91,22
Emgopa 316	3577,82	54207254,48	8,33	90,80	83,99	95,31
UFUS Guarani	3380,61	28107332,09	4,32	88,32	79,16	95,88
UFUS Riqueza	3407,56	40283998,38	6,19	80,85	103,87	68,14
M-SOY 8001	3500,14	43531713,24	6,69	87,51	92,23	84,04

According to Eberhart and Russel (1966), the ideal genotype is the one that shows wide adaptation ($B_1 = 1$) and high stability (regression deviation variance equals to 0). On account of this, the genotypes UFU 07, UFU 08, UFU 09, UFU 18, UFU 19, UFU 21, and UFU 22 fit into this classification and beyond that, they also showed coefficient (R^2) of regression superior to 70% (Table 8), confirming the high behavior predictability of these lines. The most productive genotypes were: UFU 07, UFU 08, UFU 09, UFU 21, and UFU 22, with grain yields superior to 3800 kg.ha^{-1}. Therefore, these genotypes can respond in a satisfactory manner to environmental enhancement and, at the same time, show high yield capacity in favorable and unfavorable environments (Carvalho et al., 2013).The Eberhart and Russel (1966) method also allow identifying genotypes with specific adaptation to favorable ($B1 > 1$) and ($B1 < 1$) unfavorable environments.

Lines UFU 01, UFU 06 and the cultivar UFUS Riqueza were adapted to favorable environments; however, all of them showed low stability since the variance of regression deviation was significant (Table 8). Considering the genotypes adapted to unfavorable environments, the highlighted genotypes were UFU 12, UFU 14, UFU 16 and the cultivars Emgopa 316 and UFUS Guarani, but only the UFU 12 line exhibited non-significant regression deviations, and both high predictability and R2. These results agree with findings by Carvalho et al. (2013), who observed high behavior predictability and grain yield for one out of two cultivars with specific adaptation to favorable environments.

The non-parametric Lin and Binns (1988), modified by Carneiro (1998), method, allows analyzing the adaptation and stability of genotypes through only one parameter (Pi) (Table 8). Regarding wide adaptation, the highlighted lines UFU 07, UFU 06, UFU 09, UFU 05, and UFU 18 revealed lower estimates for general Pi parameter and a high grain yield average. Romanato et al. (2016), studying 30 soybean genotypes in Goiás state, also adopted the Lin and Binns (1988), modified by Carneiro (1998) method to classify genotypes as to stability. The lines UFU 06, UFU 05, UFU 07, UFU 08, and UFU 03 presented specific adaptation to favorable environments by the Lin and Binns (1988), modified by Carneiro (1998) method. Yet, adaptation to unfavorable environments was detected to lines UFU 07, UFU 21, UFU 17, UFU 09, and UFU 18 because they showed lower unfavorable Pi values (Table 8).

Table 8. Grain yield and parameters of stability and adaptability by Eberhart and Russel (1966), and Lin and Binns (1988) method modified by Carneiro (1998), from 28 conventional soybean genotypes cultivated in 15 environments distributed over five Bazilian states.

Genotypes	**Yield (kg.ha^{-1})**	**Eberhart and Russel (1966)**			**Lin and Binns (1988) modified by Carneiro (1998)**		
		B_{1i}	**S²di**	**R²(%)**	**Pigeneral**	**Pifavorable**	**Piunfavorable**
UFU 01	3410,06	1.44*	754680.8744++	64,64	2325539,52	1742758,91	2714059,93
UFU 02	4008,24	0.94ns	626195.799++	47,08	1196869,44	1793885,89	798858,47
UFU 03	3899,83	1.05ns	328264.2914++	63,18	1315220,16	1227208,80	1373894,40
UFU 04	3719,57	1.26ns	189856.8487+	76,65	1393124,96	1475002,95	1338539,63
UFU 05	4024,04	1.23ns	217191.3512+	74,48	1024099,33	906389,45	1102572,58
UFU 06	4225,51	1.70**	495699.915++	77,45	791773,81	605749,80	915789,82
UFU 07	4133,93	1.19ns	62524.7954ns	80,76	785522,83	1106508,70	571532,24
UFU 08	3863,67	1.20ns	-48432.0181ns	87,46	1108389,36	1111224,96	1106498,95
UFU 09	3995,18	1.09ns	-46653.0546ns	85,06	960373,65	1295815,79	736745,55
UFU 10	3793,97	1.01ns	278907.1493++	63,37	1372552,09	1813870,68	1078339,70
UFU 11	3585,25	0.97ns	223039.9095+	64,13	1641185,00	1856432,59	1497686,61
UFU 12	3444,54	0.67*	85870.5709ns	55,35	2078080,43	3071707,33	1415662,50
UFU 13	3354,84	0.86ns	176234.7921+	61,09	2144599,10	2301994,58	2039668,78
UFU 14	3539,35	0.64*	249476.1056+	42,59	1880393,20	3066438,41	1089696,39
UFU 15	3242,50	0.83ns	187961.554+	58,64	2340375,07	2759984,16	2060635,68
UFU 16	3326,02	0.68*	479931.4923++	36,37	2397220,32	2866405,86	2084429,95
UFU 17	3783,91	0.90ns	259887.2671+	59,14	1328776,45	2227286,03	729770,06
UFU 18	3975,10	1.11ns	30279.8769ns	80,50	1057936,83	1456978,18	791909,26
UFU 19	3541,32	1.04ns	150775.7048ns	71,35	1815580,04	2002652,18	1690865,28
UFU 20	3804,51	0.85ns	320934.9216++	53,09	1412436,67	1834092,61	1131332,70
UFU 21	3925,28	0.89ns	47838.4866ns	71,10	1087456,42	1848341,55	580199,67
UFU 22	3805,63	0.98ns	-78449.266ns	84,80	1286216,23	1695277,85	1013508,49
UFU 23	3438,47	1.15ns	170915.5241+	74,04	1967140,85	1941144,10	1984472,02
M-SOY 6101	3614,22	0.95ns	658478.9934++	46,65	1770608,76	2384374,06	1361431,89
Emgopa 316	3577,82	0.72*	1094010.8793++	25,00	2066970,02	3372857,08	1196378,65
UFUS Guarani	3380,61	0.37**	157547.5959ns	23,89	2219970,39	3597714,02	1301474,63
UFUS Riqueza	3407,56	1.49**	602244.5586++	69,68	2048387,54	1421067,53	2466600,88
M-SOY 8001	3500,14	0.81ns	859165.1182++	34,24	2282541,94	2899678,62	1871117,49

^{ns}: non-significant; * and **: significant at 5% and 1%, respectively, by t test; ^{ns}: non-significant; $^{+}$ and $^{++}$: significant at 5% and 1%, by F test; B_{1i}: adaptability parameter; S^2: regression deviation variance; R^2: regression determination coefficient.

The Centroid method consists in comparing the values and the Cartesian distance between the genotypes and four ideal genotypes classified as ideotypes. It allows the classification of these genotypes (Table 9) as widely adapted, specifically adapted to unfavorable and favorable environments, and low adapted (Rocha et al., 2005). Among the genotypes, 43% presented wide adaptation, among them, UFU 02, UFU 05, UFU 06, UFU 07, and UFU 09 stood out for their high yield, indicating the possibility of recommendation for all tested environments (Table 9). On the other hand, Barros et al. (2012) found that 31% of soybean genotypes were positioned in group I. In research with soybean lines and cultivars in six locations in Mato Grosso state, Barros et al. (2010) confirmed the predominance of genotypes with general adaptation.

Table 9. Grain yield and parameters of adaptability and stability by the Centroid method, for 28 conventional soybean genotypes cultivated in 15 environments in five Brazilian states.

Genotypes	**Grain Yield (kg.ha^{-1})**	**Classification**	**Prob (I)**	**Prob (II)**	**Prob (III)**	**Prob (IV)**
UFU 01	3410,06	II	0,22	0,33	0,19	0,25
UFU 02	4008,24	I	0,29	0,23	0,27	0,21
UFU 03	3899,83	I	0,28	0,26	0,23	0,23
UFU 04	3719,57	II	0,27	0,28	0,22	0,23
UFU 05	4024,04	I	0,31	0,28	0,21	0,20
UFU 06	4225,51	I	0,36	0,27	0,20	0,18
UFU 07	4133,93	I	0,34	0,24	0,23	0,19
UFU 08	3863,67	I	0,29	0,27	0,22	0,22
UFU 09	3995,18	I	0,31	0,25	0,24	0,20
UFU 10	3793,97	I	0,27	0,24	0,26	0,23
UFU 11	3585,25	IV	0,24	0,26	0,24	0,26
UFU 12	3444,54	IV	0,21	0,23	0,27	0,29
UFU 13	3354,84	IV	0,21	0,26	0,23	0,30
UFU 14	3539,35	III	0,22	0,21	0,30	0,27
UFU 15	3242,50	IV	0,21	0,25	0,24	0,31
UFU 16	3326,02	IV	0,21	0,25	0,24	0,30
UFU 17	3783,91	III	0,27	0,22	0,29	0,23
UFU 18	3975,10	I	0,30	0,24	0,25	0,21
UFU 19	3541,32	II	0,23	0,27	0,23	0,27
UFU 20	3804,51	I	0,27	0,24	0,26	0,23
UFU 21	3925,28	I	0,29	0,22	0,27	0,21
UFU 22	3805,63	I	0,27	0,25	0,25	0,23
UFU 23	3438,47	II	0,22	0,28	0,22	0,28
M-SOY 6101	3614,22	III	0,24	0,24	0,26	0,26
Emgopa 316	3577,82	III	0,23	0,22	0,28	0,27
UFUS Guarani	3380,61	III	0,21	0,20	0,30	0,29
UFUS Riqueza	3407,56	II	0,23	0,31	0,21	0,26
M-SOY 8001	3500,14	IV	0,22	0,25	0,25	0,28

Prob: Probability; I: Wide adaptability; II: Specific adaptability to favorable environments; III: Specific adaptability to unfavorable environments; IV: low adaptability.

Five genotypes, whose grain yield oscillated from 3408 to 3720 kg.ha^{-1} (cultivar UFUS Riqueza and line UFU 06, respectively) were classified with specific adaptability to favorable environments (Table 9). As a matter of fact, lines UFU 14, UFU 17 and cultivars M-SOY 6101, Emgopa 316, and UFUS Guarani, were adapted to unfavorable environments with a grain yield average fluctuating from 3380.61 to 3614.22 kg.ha^{-1}, between UFUS Guarani and M-SOY 6101, respectively (Table 9). In studies with soybean cultivars in Minas Gerais state, Marques et al. (2011) found that the cultivar UFUS Guarani was classified with wide adaptability, whereas UFUS Riqueza was classified with low adaptability. This differs from the results found in our study. The low adapted genotypes were 21% of the total, with UFU 15, UFU 16, and UFU 13 having the lowest grain yield average: 3242.50, 3326.02, and 3354.84 kg.ha^{-1}, respectively (Table 9). Pelúzio et al. (2010) using the Centroid method, detected that among all genotypes evaluated in Tocantins, 20% were classified as low adapted, similar to what we found.

According to Rocha et al. (2005), probability values close or superior to 0.50 indicate good reliability for genotypic groupings in relation to ideotypes. In our study, the probability values allowed us to classify the genotypes into groups that oscillated from 0.26 to 0.36 (Table 9).

With the aim to make inferences about the stability of genotypes by AMMI analyses (Zobel et al., 1988), the genotypes were represented on a Cartesian plane with both first principal components (CP1, CP2) (Figure 1).

In the decomposition of G x E interaction by the AMMI method, the principal components 1 and 2 were significant at 1% level of probability by the F test, which is also explained by both components being superior to 90%. These results are similar to what was found by Meotti et al. (2012) and Sousa et al. (2015).

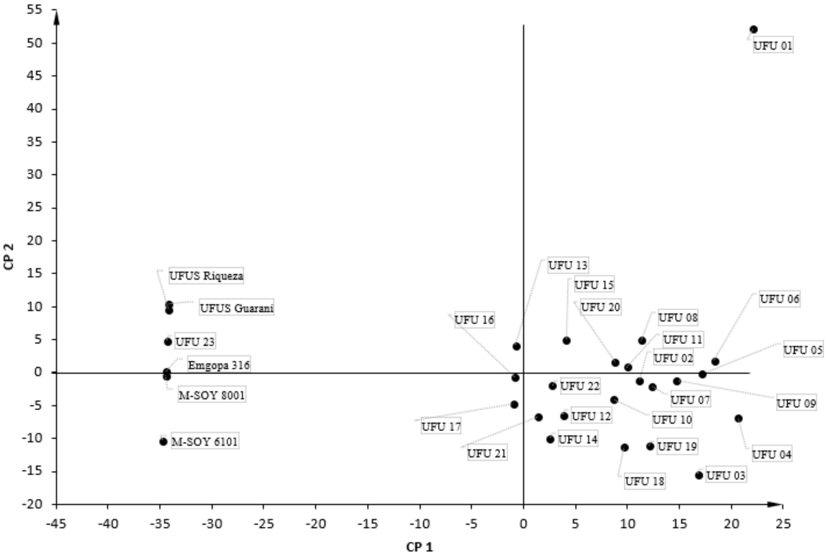

Figure 1. Plot scores of both first principal components following the AMMI model for grain yield trait, from 28 soybean early maturity genotypes.

The interpretation of stability is made by analyzing the plotted dots of genotypes that are considered more stable when positioned close to the origin. The closest lines to the origin were UFU 16, UFU 13, UFU 22, UFU 21, and UFU 17, but only UFU 21 and UFU 22 revealed the highest grain yield averages compared to the others. By doing a comparative analysis between the methodologies in this study of adaptability and stability, the line UFU 21 was classified as having wide adaptation by Eberhart and Russel (1966) and Annicchiarico (1992) methods, as well as being classified as stable by Wricke (1965) and AMMI methods. The same was found for line UFU 22, except for the Annicchiarico (1992) method.

Considering the concomitant methods Annicchiarico (1992), Eberhart and Russel (1966), and Lin and Binns (1988), modified by Carneiro (1998), line UFU 06 is adapted to favorable conditions. Furthermore, considering Annicchiarico (1992) and Lin and Binns (1988), modified by Carneiro (1998), lines UFU 5, UFU 7, and UFU 8 also are adapted to favorable environments. Regarding the classification in unfavorable environments, Annicchiarico (1992) and Lin and Binns (1988) modified by Carneiro (1998) methods were coincident in classifying the genotypes; also line UFU 17 was classified as adapted to favorable environments by the Centroid method. Carvalho et al. (2013) stated that the usage of concomitant methods such as Eberhart and Russel (1966), Lin and Binns (1988) modified by Carneiro (1998), and Annicchiarico (1992) allows enhanced reliability in the classification and recommendation of soybean cultivars to certain environments. Teixeira Júnior et al. (2015) agreed with this strategy including the use of the Centroid method (Rocha et al., 2005).

CONCLUSIONS

The G x E interaction for grain yield in soybean was of complex nature in the analysis of 28 conventional early maturity genotypes grown in 15 localities in five Brazilian states. Annicchiarico and Lin and Binns, modified by Carneiro analyses were similar in the classification of genotypes that stood out regarding wide and specific adaptability to favorable and unfavorable environments.

Wricke, Eberhart and Russel, and AMMI methods identified the lines UFU 21 and UFU 22 as being the most stable, both showing grain yield standards superior to 3,800 kg.ha^{-1}. UFU 06 line gave an average of grain yield higher than 4,000 kg.ha^{-1} and showed wide adaptability by the Annicchiarico and Lin and Binns method, modified by Carneiro, and the Centroid method.

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REFERENCES

Alcântara Neto F, et al. (2012). Desempenho agronômico de cultivares de soja em duas épocas de semeadura no cerrrado piauiense. *Com. Sci.* 3: 215-219.

Annicchiarico P (1992). Cultivar adaptation and recommendation from alfafa trials in Northern Italy. *J. Genet. Breed.* 46: 269-278.

Barros HB, Sediyama T, Melo AV, Fidelis RR, et al. (2012). Adaptabilidade e estabilidade de genótipos de soja por meio de métodos uni e multivariado. *J. Biol. Biotech.* 3: 49-58.

Barros HB, Sediyama T, Texeira RC, Fidelis RR, et al. (2010). Adaptabilidade e estabilidade de genótipos de soja avaliados no estado do Mato Grosso. *Rev. Ceres.* 57: 359-366.

Carneiro PCS (1998). Novas metodologias de análise da adaptabilidade e estabilidade de comportamento. Doctoral Dissertation. Doutorado em Genética e Melhoramento – Universidade Federal de Viçosa.

Carvalho EV, et al. (2013). Adaptabilidade e estabilidade de genótipos de soja em Tocantins. *R. Agro@mbiente.* 7: 162-169.

Céleres (2016/17). Adoção de Biotecnologia. Inf. Biotecnologia. IB16.03. 09 dez. 2016. Available at < http://www.celeres.com.br/2o-levantamento-de-adocao-da-biotecnologia- agricola-no-brasil-safra-201617/>. Accessed 13 fev. 2017.

Companhia Nacional de Abastecimento - Conab (2017). Acompanhamento da safra brasileira: grãos– v.4 – SAFRA 2016/17–N.4– Quarto levantamento. Brasília: Conab, janeiro 2017, 162p. Available at: <http://www.conab.gov.br/OlalaCMS/uploads/arquivos /17_01_11_11_30_39_boletim_graos_janeiro_2017.pdf>. Accessed 14 jan. 2017.

Companhia Nacional De Abastecimento- Conab (2016). Evolução dos custos de produção de soja no Brasil. Compendio de estudos Conab. ISSN: 2448-3710, v.2, 2016. Available at: <http://www.conab.gov.br/OlalaCMS/uploads/arquivos/16_09_14_15_10_40_compendio_de_estudos_conab__volume_2, _2016.pdf>. Accessed: 10 fev. 2017.

Cruz CD (2016). Genes Software – extended and integrated with the R, Matlab and Selegen. *Acta Sci-Agron.* 38: 547-552.

Cruz CD, Regazzi AJ and Carneiro PCS (2012). Modelos biométricos aplicados ao melhoramento genético. Viçosa, MG: UFV.

Cruz CD and Castoldi FL (1991). Decomposição da interação genótipo x ambiente em parte simples e complexa. *Rev. Ceres. Viçosa.* 38: 422-430.

Eberhart AS and Russel WA (1996). Stability parameters for comparing varieties. *Crop Sci* 6: 36-40.

Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (2013). Tecnologias de produção de soja – Região Central do Brasil 2014. - Londrina: Embrapa Soja.

Fehr WR and Caviness CE (1977). Stages of soybean development. Ames: Iowa State University. Special Report, 80, Cooperative Extensive Service, Iowa. Available at: <https://www.agencia.cnptia.embrapa.br/Repositorio/STAGES.+FEHR_000g50w2l4s02wx5ok0dkla0sik2sqav.pdf>. Accessed: 7 jan. 2017.

Ferreira Júnior JÁ, Unêda-Trevisoli SH, Espindola SMCG, Vianna VF, et al. (2015). Diversidade genética em linhagens avançadas de soja oriundas de cruzamentos biparentais, quádruplos e óctuplos. *Rev. Cien. Agron.* 46: 339-351. Available at <http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/3768/1180>. Accessed: 21 jan. 2017.

Ferreira DF (2002). Programa Estabilidade. Available at: <www.dex.ufla.br>. Accessed: 15 fev. 2017.

Gonçalves ECP, Mauro AO and Cargnelutti-Filho A (2007). Adaptabilidade e estabilidade de genótipos de soja conduzidos em duas épocas de semeadura, na região de Jaboticabal –SP. *Rev. Científica.* 35: 61 – 70.

Hamawaki RL, Hamawaki OT, Nogueira APO, Hamawaki CDL, et al. (2015). Adaptabilityand stability analysis of soybean genotypes using toler and centroid methods. *American J. Plant Sci.* 6: 1509-1518.

Lin CS and Binns MR (1988). A method of analyzing cultivar x location x year experiment: a new stability parameter. *Theor. Appl. Genet.* 76: 425-430.

Marques MC, Hamawaki OT, Sediyama T, Bueno MR, et al. (2011). Adaptabilidade e estabilidade de genótipos de soja em diferentes épocas de semeadura. *Biosci. J.* 27: 56-69.

Meotti GV, Benin B, Silva RR, Beche E, et al. (2012). Épocas de semeadura e desempenho agronômico de cultivares de soja. *Pesq. Agropec. Bras.* 47: 14‑21.

Nogueira APO, Sediyama T and Gomes JD (2015). Avanços no melhoramento genético da cultura da soja nas ultimas décadas. In: LEMES, E; CASTRO, L.; ASSIS, R. (Org.) Doenças da soja: Melhoramento Genético e Técnicas de Manejo. Millennium Editora, Campinas.

Peluzio JM, Afférri F, Monteiro FJF, Melo AV, et al. (2010). Adaptabilidade e estabilidade de cultivares de soja em várzea irrigada no Tocantins. *Rev. Ciênc. Agron.* 41: 427-434.

Pimentel-Gomes F (2009). Curso de estatística experimental. 15ª ed. Piracicaba, FEALQ.

PMSOJA (2017). Programa de Melhoramento de Soja da Universidade Federal de Uberlândia. Site. Available at <http://www.pmsoja.iciag.ufu.br/>. Accessed 7 jan. 2016.

Ramalho MAP, Abreu AFB, Santos JBD and Nunes JAR (2012). Aplicações da genética quantitativa no melhoramento de plantas autógamas. Lavras: UFLA.

Rocha RB, Muro-Abad JI, Araújo EF and Cruz CD (2005). Avaliação do método centroide para estudo de adaptabilidade ao ambiente de clones de Eucalyptus grandis. *Cienc. Florest. Santa Maria.* 15: 255-266.

Romanato FN, et al. (2016). Análises paramétricas e não paramétricas para determinação da adaptabilidade e estabilidade de genótipos de soja em três épocas de semeadura. *Biosci. J.* 32: 574-580.

Silva AF, Sediyama T, Borém A and Silva FCS (2015). Cultivares. In: Sediyama, T.; Silva, F.; Borém, A.; (Eds). Soja do plantio à colheita. Viçosa: UFV.

Sousa LB, Hamawaki OT, Nogueira APO, Batista RO, et al. (2015). Evaluation of soybean lines and environmental stratification using the AMMI, GGE biplot, and factor analysis methods. *Genet. Mol. Res.* 14: 12660-12674.

Soares IO, et al. (2015). Adaptability of soybean cultivars in different crop years. *Genet. Mol. Res.* 14: 8995-9003. Available at <http://www.funpecrp.com.br/gmr/year2015/vol14-3/pdf/gmr5354.pdf>. Accessed May 21, 2016.

Teixeira Júnior T, et al. (2015). Correlação entre metodologias de adaptabilidade e estabilidade para genótipos de soja em regiões de áreas degradadas. *Rev. Agro@mbiente.* 9: 35- 41.

Torres FE, Silva EC and Teodoro PE (2014). Desempenho de genótipos de soja nas condições edafoclimáticas do ecótono Cerrado-Pantanal. *Interações.* 15: 71-78.

Unêda-Trevisoli SH, et al. (2010). Avaliação de cultivares de soja precoces para cultivo em áreas de reforma de cana-de-açúcar. *Cien. e Tecn.* 1: 50-57.

Vasconcelos ES, et al. (2015). Produtividade de grãos, adaptabilidade e estabilidade de genótipos de soja de ciclos precoce e médio. *Semin. Cienc. Agrar*. 36: 1203-1214.

Wricke G (1965). Zur berechning der okovalenz bei sommerweizen und hofer. *Pflanzenzuchturg.* 52: 127-138.

Zobel RW, Wright MJ and Gauch HG (1988). Statistical analysis of a yield trial. *Agron J. Madison.* 80: 388-393.