ADAPTABILITY AND STABILITY OF SOYBEAN CULTIVARS IN FOUR SOWING SEASONS

ADAPTABILIDADE E ESTABILIDADE DE CULTIVARES DE SOJA EM QUATRO ÉPOCAS DE SEMEADURA

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ABSTRACT: In recent decades, the expansion of soybean production in Brazil has been observed. This advance was motivated by the search of environments with better cultivation conditions, as well as the development of genotypes with wide adaptation. The diversity of "environments" hinders the process of selection and recommendation of cultivars, since the productive potential of a cultivar is given as a function of the sum of the genotype effect, the environment and the interaction between the latter two (G x E). In the case of this G x E interaction, regional studies are necessary in order to detail the differential behavior of the cultivars. Thus, the objective of this work was to evaluate the genotype interaction by environments, adaptability and phenotypic stability for grain yield, of fifteen soybean cultivars, in four sowing seasons, in order to identify cultivars that combine high productive potential, predictability of behavior and adaptation to the edaphoclimatic conditions of Uberlândia-MG. The trials were conducted at the Experimental Farm Capim Branco, in Uberlândia-MG. Fifteen soybean cultivars were evaluated in four sowing seasons (October 23, 2016, November 19, 2016, December 10, 2016 and January 14, 2017), in relation to grain yield. The experimental design was of randomized complete blocks, with three replications, in each season. Data were submitted to individual and joint analyzes. The G x E interaction was decomposed by the method proposed by Cruz and Castoldi (1991). The differential behavior of the genotypes was detailed by the adaptability and phenotypic stability by the methods of Eberhart and Russell (1966), Lin and Binns (1988) modified by Carneiro (1998), AMMI and Centroid. By the analysis of joint variance, it was observed the existence of the cultivar interaction by sowing times (C x E), for the grain yield trait, at the 5 % probability level by the F test. The C x E was predominantly complex in nature. The cultivar CD 2737 RR presented satisfactory results for the four sowing seasons in Uberlândia-MG, with high grain yield and predictability of behavior, by the evaluated methods. The cultivar NS 6909 IPRO was classified into favorable environments by the methods of Eberhart and Russell (1966) and Lin and Binns (1988) modified by Carneiro (1998). Considering Lin and Binns (1988) modified by Carneiro (1998) and Centroid the cultivar that is also classified for this cultivation condition is UFUS 8301. By AMMI, UFUS 7415, CD 2737 RR and UFUS Milionária are considered stable and adaptable.

KEYWORDS: *Glycine max*. Interaction cultivars x sowing season. Adaptation and predictability of behavior.

INTRODUCTION

In the last decades, it has been observed in Brazil the agricultural expansion of soybeans, ranging from the states of Rio Grande do Sul to Roraima. This progress was motivated by the genetic improvement of plants and the search for environments with better cultivation conditions, such as: soil fertility, pluviometric regime, topography (BEZERRA et al., 2015).

The state of Minas Gerais is the highlight in the production of soybeans, in the Southeast region, representing around 62%, equivalent to 5046.8 tons, in the 2016/2017 harvest (CONAB, 2017). The Triângulo Mineiro/Alto Paranaíba is located in the soybean Macroregion 3 (MR3), together with anothers localities in the states of Mato Grosso do Sul (Centro-Norte), Góias (Southwest, South, Southeast and East), São Paulo (North), besides the Vale do Rio Grande, in Minas Gerais (EMBRAPA, 2018). The city of Uberlândia-MG is very promising in the agricultural scenario, since it presents a regional and national infrastructure of services and telecommunications (BERNARDES; FERREIRA,

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2013), as well as favorable conditions of cultivation for this legume, such as: regular rainfall distribution, with low declivity and soil fertility that can be corrected chemically (PRADO et al., 2016).

Considering the mesoregion Triângulo Mineiro/Alto Paranaíba, the period in which there is a low restriction, according to the history of water conditions and possible impacts in the soybean development phases, occurs between the months of October and November. However, this sowing recommendation can be anticipated or extended, according to the genetic constitution of the cultivar (CONAB, 2017).

The expression of the phenotype of a given cultivar is a result of the genotype effect, the environment and the interaction between them. The genotypes by environments interaction refers to the differential behavior of the genotypes in relation to the phenotype, with the environmental oscillation. Thus, regional studies are necessary to determine the agronomic performance, in order to guide the choice of the appropriate sowing period and to identify stable genotypes adapted to the specific conditions of cultivation (PACHECO et al., 2017).

Adaptability and stability studies allow us to detail the inconstant behavior due to the environmental variation. Adaptability refers to the ability of genotypes to respond favorably to environmental stimulus, while stability may be related to the principle of invariance or predictability of behavior (CRUZ et al., 2014).

There are different definitions for "environment", there are authors who defend the relationship with the edaphoclimatic conditions of cultivation (BORÉM; MIRANDA, 2013) and others argue that this is the result of biophysical components such as sowing times and cultural practices responsible for growth and culture development (SILVA et al., 2011). The time of soybean sowing influences the success of the crop, because there are variations, such as temperature, humidity, solar radiation, photoperiod, precipitation, that cause fluctuations in grain yield (JIANG et al., 2011).

The objective of this study was to evaluate the genotype interaction by environments, adaptability and phenotypic stability for the grain yield trait of 15 soybean cultivars in four sowing seasons, in order to identify cultivars that combine high productive potential, predictability of behavior and adaptation to the edaphoclimatic conditions of Uberlândia-MG.

MATERIAL AND METHODS

The experiments were conducted at the Capim Branco Experimental Farm, belonging to the Federal University of Uberlândia - UFU, located in the city of Uberlândia-MG (latitude 18º 53' 19" S, longitude 48º 20' 57" W and 843 m altitude). The climate, according to the classification of Köppen (1948), is tropical, with dry season (*Aw*). The local climatological data, during the period of the experiments, were obtained at the Laboratory of Climatology and Environmental Meteorology of UFU (Figure 1).

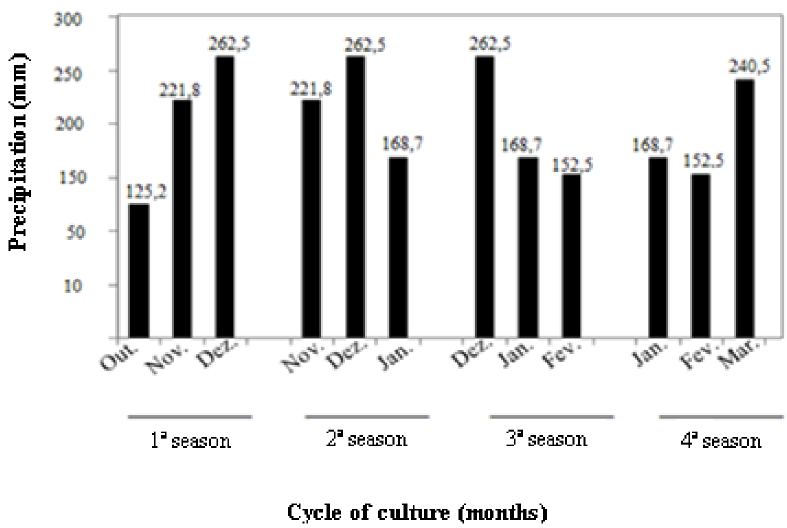

Figure 1. Monthly accumulated precipitation during the execution of the experiments, agricultural year 2016/2017, in four sowing seasons, in Uberlândia-MG. Source: Laboratory of Climatology and Environmental Meteorology of UFU.

The soybean cultivars evaluated in this study were: UFUS Xavante, UFUS 7910, UFUS 7801, UFUS Impacta, UFUS 8301, UFUS 6901, UFUS 7401, UFUS Milionária, UFUS 7415, BRS 7270 IPRO, TMG 2158 IPRO, TMG 7062 IPRO, CD 2737 RR, NA 5909 RG and NS 6909 IPRO, manually sown in October 23, 2016, November 19, 2016, December 10, 2016, and January 14, 2017.

The experimental design was of randomized complete blocks, with three replications, in each season. The experimental unit consisted of four soybeans lines with 5.0 m of length, spaced apart at 0.5 m.

The soil was prepared by a plowing and two gradations, the last one being carried out on the eve of the grooving and fertilization of sowing. This was done using the NPK formulation 2-28-18 and zinc sulfate at the doses of 400 kg ha^{-1} and 1.2 kg ha^{-1}, respectively.

Seed treatment with the fungicide Methylbenzimidazol-2-ylcarbamate and Tetramethylthiuram disulfide was carried out prior to sowing and subsequently inoculated with *Bradyrhizobium japonicum* at a ratio of 7×10^8 mL^{-1} cells. For weed control was applied the S-Metolachlor herbicide at sowing, and Haloxifope-P-Methyl after 20 days, and when necessary, manual weeding was applied until the crop harvest.

The fungicides Trifloxystrobin/Prothioconazole and Fluxapyroxad/Pyraclostrobin, in the dosage of 0.4 L ha^{-1}, were intercalated for control of Asian soybean rust and Powdery mildew. The insecticides with active principle Thiamethoxam/Lambda-cyhalothrin (30 mL in 20 L), Acephate (0.5 kg ha^{-1}) Acetamiprid and Alpha-cypermethrin (0.4 L ha^{-1}) were applied to control soybean looper (*Pseudoplusia includen*), red-banded stink bug (*Piezodorus guildinii*) and brown stink bug (*Euschistus heros*).

The plants were harvested manually and processed by a soybean harvesting machine. The grain yield was determined in the useful plot, with was formed by two central lines of soy plants with 4 m of length, spaced of 0.5 m between the lines. In order to estimate the yield of grains, the weight of grains of the useful plot, obtained in grams, and extrapolated to kg ha^{-1} were evaluated. Lastly, the humidity was corrected to 13%, according to the equation:

$$PF = PI \times \frac{100 - UI}{100 - UF}$$

Which:
PF: Final corrected sample weight;
PI: Initial weight of the sample;
UI: Sample initial humidity;
UF: Sample final humidity (13 %).

The fixed effect to cultivate and to sowing time was adopted in the individual analyzes, considering that Cruz et al. (2012) stated that this type of effect allows conclusions inherent to the study material and not a sample of the population. Afterwards, the homogeneity of the residual variances, given by the ratio between the largest mean square of the residue and the smallest mean square of the residue was evaluated, considering the limit value of 7 (RAMALHO et al., 2012). As the ratio was 11.73, the degree of freedom correction was performed, according to Cruz et al. (2014).

For the joint analysis, the following model was adopted:

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

μ: overall average;
G_i: effect of genotype *i*;
E_j: effect of environment *j*;
GE_{ij}: effect of the interaction between genotype *i* and environment *j*;
B/E_{jk}: effect of the block *k* within the environment *j*;
ε_{ijk}: random error.

Once the cultivar interaction was detected by sowing times (C x E), the decomposition was performed by Cruz and Castoldi (1991), according to the estimator, for a complex part.

$$C = (1- r)^3 (Q_1Q_2)^{½}$$

Which:
Q1 and Q2: correspond to the average squares of genotypes in environments 1 and 2, respectively.
r: correlation between the means of the genotypes in the two environments.

The differential behavior of the cultivars in the four sowing seasons was detailed by the methods of adaptability and stability proposed by Eberhart and Russell (1966), Lin and Binns (1988) modified by Carneiro (1998), AMMI (Additive Main Effects and Multiplicative Interaction Analysis) (DUARTE; VENCOVSKY, 1999) and Centroid (ROCHA et al., 2005).

The method of Eberhart and Russell (1966) is based on simple linear regression, in which the axes are formed by the average of each genotype in each environment as a function of an environmental index. The linear regression coefficient and the regression deviation provide estimates of adaptability and stability parameters, respectively.

The ideal genotype by this method, is one that has a high grain yield average, a regression coefficient equal to one unit (wide adaptability) and a non-significant (stability) regression deviation. The mathematical model is given by:

$$Y_{ij} = B_{0i} + B_{1i} I_j + \delta_{ij} + \dot{\varepsilon}_{ij}$$

Which:
Y_{ij}: mean of genotype *i* in the environment *j*;
B_{0i}: mean of genotype *i* considering all the environments;
B_{1i}: coefficient of linear regression for genotype *i*;
I_j: environmental index *j*;
δ_{ij}: regression deviation for genotype *i* in environment *j*;
$\dot{\varepsilon}_{ij}$: average experimental error.

The method of Lin and Binns (1988) modified by Carneiro (1998) having as an estimator the value of Pi, with smaller values of this parameter being desirable. The mathematical model is given by:

$$P_i = \sum^{n}_{j=1} \frac{(X_{ij} - M_j)^2}{2n}$$

Which:
P_i: estimate of the stability parameter of the *i-th* genotype;
X_{ij}: productivity of the *i-th* genotype in the *j-th* environment;
M_j: maximum observed response among all genotypes in the *j-th* environment;
n: number of environments.

P*i* for favorable environments (P_{if}):

$$P_{if} = \sum^{n}_{j=1} \frac{(X_{ij} - M_j)^2}{2f}$$

Which:
f: number of favorable environments;
X_{ij}: productivity of the *i-th* genotype in the *j-th* environment;
M_j: maximum observed response among all genotypes in the *j-th* environment.

And for unfavorable environments (P_{id}):

$$P_{id} = \sum^{n}_{j=1} \frac{(X_{ij} - M_j)^2}{2d}$$

Which:
d: number of unfavorable environments.

AMMI combines main effects (additive components of genotypes and environments) and multiplicative components for G x E interaction. By the graphic interpretation, the genotypes and environments that are closer to the origin of the biplot are considered as more stable; and those that are furthest from the intercept of the axes contribute to the G x E interaction. In addition, genotypes or environments close to each other have similar patterns of behavior for G x E interaction and environments and genotypes in the same quadrant enhance the effect of this interaction. The mathematical model is given by:

$$\bar{Y}_{ij} = \mu + g_i + a_j + \sum^{q}_{c=1} (\lambda_c)^{1/2} a_{ic} \gamma_{jc} + \delta_{ij} + \bar{e}_{ij}$$

Which:
$\bar{Y}_{ij}$: mean observed for the response variable of genotype *i* in environment *j*;
μ: overall mean;
g_i: fixed effect of genotype *i*:
a_j: fixed effect of the environment *j*;
λ_c: eigenvalue of the c-major main component related to the G x E interaction;
a_{ic}: eigenvalue of the c-th major component related to genotype *i*;
γ_{jc}: eigenvalue of the c-th major component related to environment *j*;
δ_{ij}: residue or noise not explained by the main components;
$\bar{e}_{ij}$: mean experimental error.

The Centroid method expresses the Cartesian distance of the genotype performance in function of pre-established ideotypes, as a function of the main components. The interesting point of this method is that it allows the classification of genotypes as a function of environmental variation, without depending on several parameters, such as regression-based methods, and there is no duplicity of interpretation, such as the method of Lin and Binns (1988).

The established references were: I- general high adaptability (Maxf, Maxd); II - specific adaptability to favorable environments (Maxf, Mind); III - specific adaptability to unfavorable environments (Minf, Maxd); IV- Little adapted (Minf, Mind); V- high general adaptability (Medf, Medd); VI- specific adaptability to favorable environments (Maxf, Medd); VII - specific adaptability to unfavorable environments (Medf, Maxd).

Statistical and biometric analyzes were performed by Genes Program (CRUZ, 2016) and the AMMI Anaysis by the Stability Program (FERREIRA, 2000).

RESULTS AND DISCUSSION

The coefficients of variation (CV) of the individual analyzes ranged from 17.66 % to 26.13 % for the grain yield in soybean in the four sowing seasons (Table 1). According to Carvalho et al. (2003), the acceptable CV limit for this trait is up to 16 %. However, the values found resemble those verified by several studies conducted in the field, with this legume, in which they presented a CV greater than 20 % (SOUZA et al., 2013; TORRES et al., 2015; BATISTA et al., 2015; OLIVEIRA et al., 2017). It is also worth mentioning that it is a trait that has high environmental influence and phenotypic manifestation governed by several genes (BALDISSERA et al., 2014; LEITE et al., 2015).

Table 1. Estimates of variance, coefficient of variation and coefficient of genotypic determination for grain yield, in four sowing seasons, agricultural year 2016/2017.

Sowing Times	QMC	QMR	CV (%)
October	2239060.19*	898829.14	21.23
November	142861.81*	25631.84	17.66
December	1467782.16**	285227.39	22.24
January	383782.63**	76652.23	26.13

** and *: significant at 1 % and 5 % probability, respectively, by the F test; QMC: mean square of cultivars; QMR: mean square of residue; CV: coefficient of variation.

By the analysis of joint variance, it was observed the existence of the cultivars interaction by sowing times (C x E) for the grain yield trait, at the 5% probability level by the F test (Table 2). There are reports of this interaction in several studies (ROMANATO et al., 2016; TESSELE et al., 2016; RAMOS JÚNIOR et al., 2017).

Table 2. Summary of the joint variance analysis for grain yield of 15 soybean cultivars at four sowing dates in the agricultural year 2016/2017.

Sources of Variation	Degrees of Freedom	Mean Square
Block/Sowing season	08	2050728.08
Cultivar (C)	14	2653193.96**
Sowing season (E)	03	100738670.62**
Cultivar x Sowing season (C x E)	31	1165293.54*
Residual	74	638074.82
CV (%)	27.50	

** and *: significant at 1 % and 5 % probability, respectively, by the F test; CV: coefficient of variation.

Due to the significant interaction, there is a differential behavior of the cultivars in relation to sowing times. Thus, the C x E interaction was decomposed into simple and complex parts, according to Cruz and Castoldi (1991). The nature of this interaction was classified, predominantly, as complex, since the complex part estimates were higher than 50 % (Table 3). Several studies have been carried out to characterize the type of interaction G x E for agronomic traits, and it has been observed interaction of the complex type for productivity (CARVALHO et al., 2013; CANTELLI et al., 2016; SILVA et al., 2017). The occurrence of this type of interaction implies genetically that there is the possibility of a genotype to stand out in one environment and not in another, thus having an effect under the gain of selection and recommendation of cultivars (CRUZ et al., 2014).

Table 3. Decomposition of the cultivar interaction by sowing season (C x E) for grain yield of 15 soybean cultivars at four sowing times, proposed by Cruz and Castoldi (1991).

Sowing season		C (%)	Classification
October/2016	November/2016	67.85	Complex
October/2016	December/2016	67.53	Complex
October/2016	January/2017	50.29	Complex
November/2016	December/2016	91.80	Complex
November/2016	January/2017	83.32	Complex
December/2016	January/2017	28.89	Simple

C (%): complex part of G x E interaction.

The Eberhart and Russell method (1966) allows the classification of environments as favorable or unfavorable, by estimating the environmental indexes, determined by the difference between the averages of the genotypes in each place in relation to the general average. Positive indexes indicate favorable environments and negative indicate unfavorable. In this sense, the sowing season of October and November were considered environments that have favorable cultivation conditions (Table 3), corroborating with the recommendation of Conab (2017) for obtaining high yields in Triângulo Mineiro/Alto Paranaíba.

The sowing in January and December were considered unfavorable (Table 4), because despite having total precipitation recommended for the soybean crop, which is between 450 and 800 mm per cycle (EMBRAPA, 2013), there was an irregular distribution of rainfall, especially in flowering and filling the beans.

Table 4. Classification of the environments, according to Eberhart and Russell (1966), for grain yield of 15 soybean cultivars, in four sowing seasons, agricultural year 2016/2017.

Sowing seasons	Mean	Index (I_j)	Classification
October	4465.57	1560.53	Favorable
November	3693.42	788.37	Favorable
December	2401.60	-503.45	Unfavorable
January	1059.60	-1845.45	Unfavorable

I_j: environmental index.

The adaptability and stability study proposed by Eberhart and Russell (1966) is based on linear regression, in which the adaptability parameter is β_{1i} and stability is σ^2_{di}. According to this method, the ideal genotype should ally high grain yield, productive stability (σ^2_{di} not significant) and wide adaptation (β_{1i} = 1), towards environmental variations. In addition, it should be noted that the coefficient of determination (R^2) must be higher than 70 %, since this descriptive measure demonstrates how much the model was able to explain the data collected (BANZATTO; KRONKA, 2013).

The stable cultivars with wide adaptation were: UFUS 6901, UFUS 7415, UFUS 7401, UFUS Xavante, CD 2737, BRS 7270 IPRO, NA 5909 RG, UFUS Milionária, UFUS Impacta and UFUS 7801, deserving prominence CD 2737 RR, UFUS 6901 and UFUS 7415 because they presented high average grain yields, being in the order of 3208.26 kg ha^{-1}, 3092.94 kg ha^{-1} and 3078.87 kg ha^{-1}, respectively (Table 5). This classification for cultivars UFUS Xavante and UFUS Milionária was also verified by Romanato et al. (2016), in a study with 25 pure lines of soybeans, in Campo Alegre-GO. It should be noted that the values found for grain yield were close to the national average (3072.00 kg ha^{-1}), from the State of Minas Gerais (3200.00 kg ha^{-1}) (CONAB, 2017).

Table 5. Estimation of coefficients β_{1i}, σ^2_{di} and R^2 by the method of Eberhart and Russell (1966), for the study of adaptability and stability of fifteen soybean cultivars, regarding grain yield (kg ha^{-1}), in four sowing seasons, agricultural year 2016/2017.

Cultivars	Productivity	β_{1i}	σ^2_{di}	R^2 (%)
UFUS 6901	3092.94	0.83^{ns}	8.44^{ns}	86.67
UFUS 7415	3078.87	1.05^{ns}	100.00^{ns}	98.77
UFUS 7401	2920.63	0.96^{ns}	18.07^{ns}	92.68
UFUS Xavante	2337.90	0.75^{ns}	7.00^{ns}	82.95
UFUS 7910	2288.84	0.57^{**}	100.00^{ns}	98.04
TMG 7062 IPRO	3939.28	0.98^{ns}	3.98^{+}	87.23
CD 2737 RR	3208.26	1.17^{ns}	100.00^{ns}	98.05
BRS 7270 IPRO	2420.64	0.96^{ns}	5.14^{ns}	87.69
TMG 2158 IPRO	2854.08	1.32^{*}	100.00^{ns}	99.99
NA 5909 RG	3034.83	1.12^{ns}	16.31^{ns}	94.19
NS 6909 IPRO	3308.40	1.33^{*}	12.42^{ns}	95.19
UFUS 8301	3112.36	1.35^{**}	1.58^{+}	90.85
UFUS Milionária	2856.96	0.94^{ns}	100.00^{ns}	99.58
UFUS Impacta	2077.29	0.86^{ns}	21.24^{ns}	91.73
UFUS 7801	3044.43	0.78^{ns}	100.00^{ns}	96.38
Average	2905.05			

^{ns} Not significant, ** and * significant at the 1 % level and 5 % probability by the t test; $^{+}$ significant at the 1 % level probability by the F test; β_{1i} - Linear regression coefficient; σ^2_{di} - Regression deviation; R^2 - Coefficient of determination.

The cultivars TMG 2158 IPRO and NS 6909 IPRO were classified for favorable growing conditions, since they presented stability (non-significant regression deviation) and linear coefficient greater than one unit (β_{1i}>1). While the cultivar UFUS 7910 is only responsive in unfavorable cultivation condition (β_{1i}<1).

The method of Lin and Binns (1988) modified by Carneiro (1998), estimates the adaptability and stability by means of the parameter P_i, in which it is determined by the existing relation of the average square of the distance between the averages as a function of the maximum average answer obtained in the environment, with lower P_i values being desirable.

The cultivar TMG 7062 IPRO presented low values of P_i for general conditions, being a responsive cultivar in either favorable or unfavorable conditions (Table 6). Tessele et al. (2016), in Palotina-PR, using this same method, also verified general adaptation and predictability of behavior for this cultivar, despite the environmental diversity between these soybean farms.

Table 6. Estimates P_i for favorable and unfavorable general environment for grain yield (kg ha^{-1}) of 15 soybean cultivars, according to Lin and Binns (1988), modified by Carneiro (1998).

		Environments		
Cultivars	Productivity	General	Favorable	Unfavorable
UFUS 6901	3092.94	707059.97	1078351.88	335768.06
UFUS 7415	3078.87	602189.90	609137.23	595242.56
UFUS 7401	2920.63	825545.73	1047522.21	603569.25
UFUS Xavante	2337.90	1932290.85	2444586.46	1419995.25
UFUS 7910	2288.84	2007222.68	2992481.30	1021964.06
TMG 7062 IPRO	3939.28	84219.48	168438.96	0.00
CD 2737 RR	3208.26	463596.64	367239.73	559953.56
BRS 7270 IPRO	2420.64	1760891.08	1592857.16	1928925.00

TMG 2158 IPRO	2854.08	937934.10	437285.14	1438583.06
NA 5909 RG	3034.83	819041.85	435638.70	1202445.00
NS 6909 IPRO	3308.40	524942.11	251579.15	798305.06
UFUS 8301	3112.36	924336.58	176743.17	1671930.00
UFUS Milionária	2856.96	890482.58	1016081.61	764883.56
UFUS Impacta	2077.29	2338411.37	2567699.17	2109123.56
UFUS 7801	3044.43	731129.75	1055467.95	406791.56

The cultivars TMG 7062 IPRO, UFUS 8301, NS 6909 IPRO, and CD 2737 RR highlighted for favorable conditions, according to Lin and Binns (1988), modified by Carneiro (1998). The classification of NS 6909 IPRO reinforces the result already presented by the method of Eberhart and Russell (1966), in this study. According to Polizel et al. (2013), concordant and complementary methods increase the reliability of the soybean cultivar recommendation, since they obtained similar results, despite considering different biometric parameters.

The environment classified as "unfavorable" is one that may present factors that compromise the phenological development of the plants, such as: incidence of diseases, pests, irregular rainfall distribution (BORÉM, 2005). The cultivars TMG 7062 IPRO, UFUS 6901 and UFUS 7801, when cultivated under these conditions, presented productive stability, which means that they are productive even in these adverse conditions.

The AMMI method has been used in several adaptability and stability studies (MEOTTI et al., 2012; YOKOMIZO et al., 2013) and has the advantage of easy interpretation. However, its use requires that a high proportion of phenotypic variability be retained in the first components. In this study, the first two main components accounted for 94.89 % of the total variance of the original variables. The scores obtained in the discriminant analysis of the main components are shown in Figure 2. A study conducted by Meotti et al. (2012), with six soybean cultivars sown in four seasons, obtained 85 % and 94 % for the first two main components, in the 2008/2009 and 2009/2010 agricultural years, respectively.

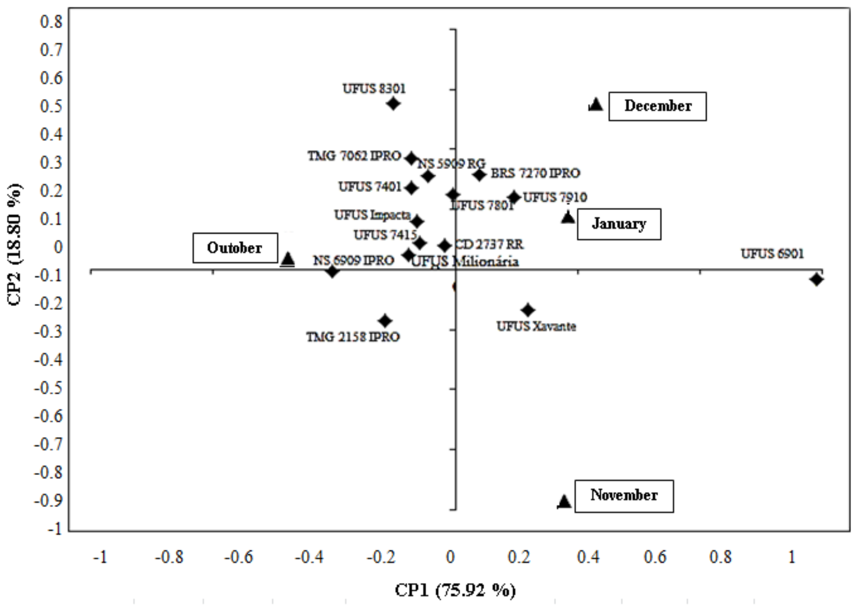

Figure 2. Plot of the scores of the first two main components regarding the association between sowing times and cultivars, agricultural year 2016/2017, according to the AMMI model, for grain yield of 15 soybean cultivars in four sowing seasons (October, November, December and January). CP1: main component 1; CP2: main component 2.

The interpretation of the AMMI allows identifying the magnitude and the signal of the genotype and environment scores for the axis of the G x E interaction, in which scores that are closer to the origin have less contribution to this interaction, that is, they are more stable genotypes. In addition, for the purpose of recommendation, it is also necessary to consider the desirable performance, especially grain yield (DUARTE; VENCOVSKY, 1999). Thus, the cultivars that stand out, combining grain yield and stability were CD 2737 RR, UFUS Millionária, UFUS 7415 (Figure 2).

According to Ramalho et al. (2012), environments that present scores closer to each other, in the graphic dispersion, belong to the same group. This similarity of cultivation conditions can be observed in December/2016 and January/2017. It was verified that, most of the cultivars presented stability of production, when sowed in October/2016.

The total precipitation was in sufficient quantity for the soybean crop, that is, between 450 and 800 mm (EMBRAPA, 2013). However, there was a poor distribution of rain in the months of February and March (Figure 1), during which flowering and grain filling occurred, which compromised grain yield for sowing in January.

Centroid is the projection of the performance of the cultivars in relation to ideal standards (ideotypes), in the Cartesian plane. This methodology considered the proximity of the genotype to each of the reference centroids (ROCHA et al., 2015). By this methodology, it was verified that 60 % of the genotypes showed high general adaptability, therefore, the cultivars UFUS 6901, UFUS 7415, CD 2737 RR, BRS 7270 IPRO, TMG 2158 IPRO, NA 5909 RG, UFUS Millionária, UFUS 7801 and UFUS 7401 belonging to class V (Medf, Medd) and TMG 7062 IPRO with the same classification, but designed in class I (Maxf, Maxd) (Figure 3). This predominance of genotypes with this classification was also observed by Barros et al. (2010).

This method of adaptability and stability study considered that UFUS cultivars Xavante, UFUS 7910 and UFUS Impacta are not very adapted to the four sowing dates in the city of Uberlândia-MG. The proportion of 20 % was also observed in an experiment carried out in the State of Tocantins by Pelúzio et al. (2010).

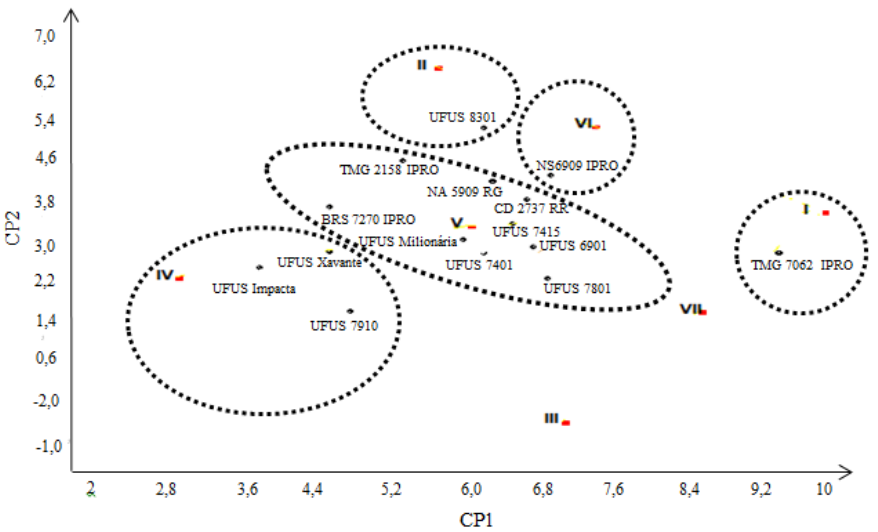

Figure 3. Graphic dispersion of the first two main components of the fifteen soybean cultivars, for grain yield, at four sowing times (October, November, December and January). The points numbered with Roman numerals represent the ideotypes, with I: general high adaptability (Maxf, Maxd); II: specific adaptability to favorable environments (Maxf, Mind); III: Specific adaptability to unfavorable environments (Minf, Maxd); IV: poorly adapted (Minf, Mind); V: high overall adaptability (Medf, Medd); VI: specific adaptability to favorable environments (Maxf, Medd); VII: Specific adaptability to unfavorable environments (Medf, Maxd). CP1: main component 1; CP2: main component 2.

When carrying out the concomitant analysis of all the methods it is possible to infer with greater reliability that the cultivar CD 2737 RR presented high grain yield, wide adaptation, that is to say, it was responsive in the four sowing seasons, and had predictability of productive behavior. By the method of Eberhart and Russell (1966) and Lin and Binns (1988), modified by Carneiro (1998), cultivar NS 6909 IPRO was classified for favorable environments. Considering Lin and Binns (1988), modified by Carneiro (1998) and Centroid, UFUS 8301 was also considered for favorable growing conditions. Through the AMMI, the cultivars that stand out with wide adaptation were CD 2737 RR, UFUS Milionária and UFUS 7415.

CONCLUSION

The interaction of cultivars by sowing times was predominantly complex, that is, the cultivars had different behavior at different times.

The cultivar CD 2737 RR presented satisfactory results for the four sowing times in Uberlândia-MG, with high grain yields and predictability of behavior by the evaluated methods. For favorable environments, considering the methods of Eberhart and Russell (1966) and Lin and Binns (1988) modified by Carneiro (1998), cultivar NS 6909 IPRO was thus classified, whereas, for these cultivation conditions, Lin and Binns (1988) modified by Carneiro (1998), and Centroid, identified UFUS 8301. For AMMI, UFUS 7415, CD 2737 RR and UFUS Milionária are considered to be stable and widely adapted.

RESUMO: Nas últimas décadas, observou-se a expansão da produção agrícola de soja no Brasil. Esse avanço foi motivado pela busca de ambientes com melhores condições de cultivo, bem como o desenvolvimento de genótipos com ampla adaptação. A diversidade de "ambientes" dificulta o processo de seleção e recomendação de cultivares, pois o potencial produtivo de uma cultivar é dado em função da somatória do efeito genotípico, do ambiente e da interação entre ambos (G x A). Caso haja essa interação G x A, fazem-se necessários estudos regionalizados a fim de pormenorizar o comportamento diferencial das cultivares. Assim, o objetivo deste trabalho foi avaliar a interação genótipos por ambientes, adaptabilidade e estabilidade fenotípica para produtividade de grãos de 15 cultivares de soja, em quatro épocas de semeadura, de modo a identificar cultivares que aliam alto potencial produtivo, previsibilidade de comportamento e adaptação às condições edafoclimáticas de Uberlândia-MG. Os ensaios foram conduzidos na Fazenda Experimental Capim Branco, em Uberlândia-MG. Foram avaliadas 15 cultivares de soja, em quatro épocas de semeadura (23 de outubro de 2016, 19 de novembro de 2016, 10 de dezembro de 2016 e 14 de janeiro de 2017), quanto a produtividade de grãos. O delineamento experimental foi de blocos completos casualizados, com três repetições, em cada época. Os dados obtidos foram submetidos a análises individuais e conjunta. A interação G x A foi decomposta pelo método proposto por Cruz e Castoldi (1991). O comportamento diferencial dos genótipos foi pormenorizado pela adaptabilidade e estabilidade fenotípica dos métodos de Eberhart e Russell (1966), Lin e Binns (1988) modificado por Carneiro (1998), AMMI e Centróide. Por meio da análise de variância conjunta observou-se a existência da interação cultivares por épocas de semeadura (C x E), para o caráter produtividade de grãos, ao nível de 5 % de probabilidade pelo teste F. Quanto a natureza C x E foi predominante complexa. A cultivar CD 2737 RR apresentou resultados satisfatórios para as quatro épocas de semeadura em Uberlândia-MG, com alta produtividade de grãos e previsibilidade de comportamento, pelos métodos avaliados. A cultivar NS 6909 IPRO foi classificada para ambientes favoráveis, pelos métodos de Eberhart e Russell (1966) e Lin e Binns (1988), modificado por Carneiro (1998). Considerando Lin e Binns (1988), modificado por Carneiro (1998), e Centróide a cultivar que é classificada também para essa condição de cultivo é UFUS 8301. Pelo o AMMI, UFUS 7415, CD 2737 RR e UFUS Milionária são tidas como estáveis e de ampla adaptação.

PALAVRAS-CHAVE: *Glycine max*. Interação cultivares x épocas de semeadura. Adaptação e previsibilidade de comportamento.

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