

Performance, Adaptability and Stability of Soybean Cultivars Submitted to Different Environments Conditions

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Abstract

For the plant breeding, developing a single soybean cultivar that is adapted and stable to multiple production environments has been a major challenge. Therefore, integrating the individual analysis of cultivars to their average response when gathered in groups of relative maturity can be a smart alternative to minimize risks and maximize soybean productivity. Nine soybean cultivars were grouped into four distinct groups as to their relative maturity (from 4.8 to 6.4), and tested in three sowing times (September, October and December) and three growing seasons (2016/17, 2017/18 and 2018/19) as to their yield performance, adaptability and stability in southwest Paraná, Brazil, latitude 25°41'52 "S, longitude 53°03'94" W, altitude of 509 meters. Performance was evaluated by grouping means, using Scott Knott. For the adaptability and stability analysis, AMMI (Additive Main effect and Multiplicative Interaction), GGE Biplot and Centroid methods were used. The NS 5909 IPRO® and NS 6909 IPRO® cultivars, both close to GMR 6.0, presented superior average performance in most of the evaluated production environments, and the earliest cultivars, with GMR less than 5.4, were the ones that produced less, in general, in different environments. Specific adaptations stood out from the general broad adaptation for the evaluated cultivars. The adaptability of the genotypes was not accompanied by high stability, which contributes to the reduction of the average productivity of the cultivars when exposed to different environments.

Keywords: *Glycine max*, grain yield, relative maturity group, genotype-environment interaction

1. Introduction

In order to be successful with soybean cultivation in countries that have a wide diversity of edaphoclimatic conditions, it is necessary to conduct research by adaptation zones, testing more suitable sowing times for cultivars of different relative maturity groups (RMG). With this, it is possible to reduce the risks inherent to its cultivation throughout the crop years (Carvalho et al., 2010).

The soybean is a thermo-photoperiodic crop in which high temperatures and short photoperiod accelerate the development of plants influencing their size and cycle and, consequently, the productive potential of the crop (Braccini et al., 2004; Jiang et al., 2011). In this sense, the correct positioning of cultivars within the agricultural zoning for a given region is a decisive factor for high yields, as this strategy results in significant changes in the genotype x production environment relationship (Barros et al., 2010; Meotti et al., 2012; Peixoto et al., 2000; Zanon et al., 2018).

The significance of the G x E interaction is characterized as one of the biggest problems of breeding programs, as it limits the performance of some cultivars in specific environments. The procedures adopted to circumvent and minimize the magnitude of the interaction is the recommendation of cultivars with wide adaptability and high phenotypic stability (Barros et al., 2010). Therefore, studies on G x E interaction are of great importance, as they provide information about the behavior of each genotype in the face of environmental variations (Yokomizo & Santos, 2018; Barros, 2015).

One way of evaluating this interaction is the study of adaptability and stability of cultivars, by which it is possible to identify which ones have a predictable behavior and which respond positively to improvements in the environment, under specific or broad conditions (Cruz et al., 2012).

Cultivars with high genetic potential and stable when grown in different environments fits best farmer's demands and have a lower probability of yield frustration, making its positioning easier for different environments (Lemos et al., 2011; Vasconcelos et al., 2015).

Among the methods used to evaluate this pattern of behavior of soybean cultivars are AMMI (Additive Main effect and Multiplicative Interaction) (Gauch, 1992), GGE Biplot (Yan et al., 2000) and Centroid (Rocha et al., 2005).

The biplot methods AMMI and GGE are efficient in the analysis of the adaptability and stability of cultivars, when evaluated in different places, years and / or sowing times, since they facilitate the interpretation of the interaction in more than one dimension (Meotti et al., 2012).

In addition, the AMMI and GGE analysis allows the graphic representation of genotypes and environments in a multivariate dispersion diagram (Biplot). These diagrams provide information on phenotypic stability and adaptability and allow for agronomic zoning and the choice of specific environments for the evaluation and selection of cultivars (Meotti et al.,

2012; Yokomizo et al., 2013).

The Centroid method identifies the genotype of maximum general adaptability, maximum specific adaptability, to favorable or unfavorable environments, and genotypes with minimum adaptability (Rocha, 2005).

These analyzes can help to identify genotypes with high yield potential, well adapted and stable, for the purpose of recommending cultivars, or group of cultivars, for multiple or specific environments (Cruz et al., 2012; Yokomizo & Santos, 2018).

For the south of Brazil, the soybean cultivars of intermediate RMG are more adapted and stable than smaller and larger RMG cultivars. These latter are more exposed to environmental factors under different growing conditions, precisely because of their shorter and longer cycle.

The aim of the work was to evaluate the performance, adaptability and stability of soybean cultivars, from different maturation groups, sown at different periods and growing seasons, in southwest Paraná.

2. Material and Methods

2.1 Description of the Experiment Site

The Experiment was carried out in the southwest of Paraná, latitude 25°41'52" S, longitude 53°03'94" W, and altitude of 509 meters above the sea level, at the Experimental Station of the Universidade Tecnológica Federal do Paraná, Campus Dois Vizinhos. The soil of the experiment site is classified as a typical red Dystroferric Latosol (Embrapa, 2006).

Climate is classified as Cfa - Subtropical humid mesothermal climate, with no defined dry season and a mean annual rainfall of 2,000 mm. Annual average temperature is around 20 to 22°C. Summer is hot and frosts are uncommon in winter (Iapar, 2009).

2.2 Study Details

The experiment was carried out in field condition, forming four distinct groups of soybean cultivars depending on their cycle (Relative Maturity Group).

The nine cultivars tested were sown in three different times and in three growing seasons, according to Table 1, respecting the agricultural zoning for the adaptation region.

Table 1. Soybean cultivars and its respective relative maturity group (RMG).

Cultivars	RMG
NS 4823 RR®	4.8
95Y72 RR®	5.0
95Y52 RR®	5.2
NS 5445 IPRO®	5.4
NS 5959 IPRO®	5.9
NS 6909 IPRO®	6.0
BRS 284	6.3
LG 60163 IPRO®	6.3
M 6410 IPRO®	6.4

The sowing occurred near on September 20th (SEP); October 30th (OCT) and December 20th (DEC), in the three growing seasons (1: 2016/17; 2: 2017/18 and 3: 2018/19), ranging from one day to more or less.

Soybean soil fertilization was performed using a phosphorous source know as simple superfosphate (18% of P₂O₅) at a rate of 418 kg ha⁻¹. Potassium was broadcast at the V₃ soybean phenological stage using 130 kg of KCl ha⁻¹ (60% of K₂O). The management of weeds, pests and diseases was based on monitoring, applying products recommended for the protection crop, when justified.

2.3 Variables Analyzed

At harvest, five plants were randomly collected per experimental plot and subsequently evaluated for the following yield components: plant height (PH, cm), first pod insertion height (FPI, cm), number of pods per plant (NPP), number of grains per plant (NGP) and number of grains per pod (NGPP).

Soybean cultivar samples from the three central rows, each with 2 meters long (sample area 2.7 m² per point) per plot were manually harvested, threshed by a stationary combine harvester and cleaned.

Moisture content of the grains was evaluated using portable automatic equipment and thousand grain weight (TGW, g) and final yield (kg ha⁻¹) were adjusted to a moisture content of 12%. Additionally, the TGW was assessed by manual counting and weighing eight samples of 100 grains.

2.4 Statistical Analysis

The residues were subjected to the normality and homogeneity test, after which the analysis of variance was performed. Analysis of the yield components and final grain yield, grouping of averages were used and tested by Scott Knott, at 5% probability.

Analysis of adaptability and phenotypic stability of the genotypes, the mathematical models AMMI (Additive Main effect and Multiplicative Interaction) (Gauch, 1992), GGE Biplot (Yan et al., 2000) and Centroid (Rocha et al., 2005) were used.

The analyzes were performed with the aid of the statistical program Genes (Cruz, 2013).

3. Results and Discussion

The analysis of variance indicated an interaction between factors, cultivars and sowing periods (result in different production environments), for all variables analyzed (Table 2).

Table 2. Analysis of the variance of nine soybean cultivars traits grown at nine different environments

VF	GL	Medium square						
		PH	FPI	NPP	NGP	NGPP	TGW	GY
B/E	18	15.79	4.35	130.13	876.76	0.01	45.08	75133.38
C	8	6524.16**	550.20**	2296.40**	15179.74**	0.10*	5647.14**	915944.41ns
E	8	17149.97**	473.86**	2529.40**	23932.64**	1.11**	17015.48**	78934055.38**
CxE	64	501.56**	39.9**	263.64**	1178.61**	0.04**	598.68**	1741716.62**
CV %		6.59	13.55	23.08	20.45	4.06	4.19	9.32

** , * and ^{ns}, correspond, respectively, significant to 1% probability of error, significant to 5% probability of error and not significant. Variation factor (VF), block (B), cultivar (C), environment (E), coefficient of variation (CV), plant height (PH, cm), first pod insertion height (FPI, cm), number of pods per plant (NPP), number of grains per pod (NGP), number of grains per plant (NGPP), mass one thousand grains (TGW, g) and grain yield (GY, kg ha⁻¹).

Regarding to the plant height, comparing each cultivar within the production environments (sowing periods), it was noticed in general that soybean sowed in October showed taller plants than September or December sowing periods. Soybean cultivars sowed in September allowed better plant development resulting in taller soybean plants than December, for all three the crop years (Table 3).

Table 3. Results of the cluster analysis of means (Scott-Knott) for the interaction between cultivars x different environments

C/E	Plant Height (PH, cm)								
	SEPI*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	55.8eC	88.0dA	69.7bB	70.4Fb	94.0dA	25.8dE	55.7dC	60.7dC	42.5cD
95Y72	64.8dC	91.7dA	37.5dE	45.1gE	97.3cA	25.3dF	52.8dD	83.3bB	59.8bC
95Y52	66.3dB	90.3dA	36.3dD	71.9fB	87.1dA	30.1dD	45.6eC	71.0cB	43.1cC
5445	87.7cB	102.0cA	80.1aC	94.8Ea	99.5cA	29.9dF	66.9cD	73.1cD	47.3cE
5959	103.7bB	109.0cB	65.5bD	129.5Ba	104.3cB	54.8bE	85.9bC	91.4bC	35.3dF
6909	89.9cB	103.5cA	48.6cD	110.1Da	97.2cB	41.3cD	71.9cC	73.5cC	32.1dE
284	120.1aB	133.3aA	78.0aD	122.0Cb	132.7aA	73.7aD	72.1cD	96.5aC	73.0aD
60163	117.7aA	124.5bA	57.0cC	125.8bA	121.7bA	46.8cD	93.2aB	99.2aB	42.4cD
6410	124.7aB	135.5aA	52.7cF	140.3Aa	121.5bB	68.0aE	80.0bD	100.7aC	45.5cF
C/E	First Pod Insertion (FPI, cm)								
	SEPI*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	6.8eC	10.9eB	8.8dB	6.8dC	14.9cA	5.7cC	9.7dB	15.2dA	8.7bB
95Y72	7.2eC	11.1eB	12.0dB	7.7dC	16.0cA	8.2cC	10.0dB	15.2dA	10.8aB
95Y52	10.7dC	12.6eB	10.8dC	10.7cC	18.9cA	8.8cC	9.9dC	13.7dB	7.3bC
5445	18.9bB	17.8dB	14.7cC	13.5cC	30.5aA	10.8cC	11.4dC	17.7cB	11.3aC
5959	23.6aB	21.4cB	22.9aB	19.8bC	32.8aA	19.1aC	15.6bC	17.7cC	7.2bD
6909	17.5bB	21.1cA	11.7dC	12.0cC	23.6bA	9.7cC	14.3cC	19.9cB	5.9bD
284	14.7cA	9.5eB	17.6bA	19.4bA	17.3cA	14.8bA	17.7bA	16.3dA	11.7aB
60163	18.7bB	27.0bA	14.9cC	19.0bB	25.8bA	13.3bC	20.2aB	24.3bA	7.9bD
6410	22.8aC	31.9aA	13.8cE	26.7aB	31.7aA	17.7aD	22.3aC	31.5aA	10.5aE
C/E	Number of Pods per Plant (NPP)								
	SEPI*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	33.6bB	44.9bA	40.4bA	48.7bA	44.4bA	43.2cA	33.6aB	24.0bB	23.4bB
95Y72	45.0bA	55.7bA	42.5bA	50.7bA	42.9bA	29.1cB	35.7aB	33.2bB	26.9bB
95Y52	43.7bB	49.2bB	39.9bB	43.6bB	62.9aA	32.1cB	39.4aB	39.4bB	39.2aB
5445	37.1bB	49.4bA	36.3bB	53.0bA	46.6bA	32.6cB	42.3aA	34.9bB	22.7bB

5959	36.7bC	59.8bB	75.3aA	80.7aA	60.1aB	63.6aB	39.5aC	42.1bC	31.7bC
6909	44.7bC	53.7bB	62.3aB	77.9aA	59.1aB	52.2bB	34.1aC	41.9bC	34.3bC
284	62.0aB	76.4aA	67.9aA	86.4aA	70.6aA	72.6aA	48.0aB	50.7aB	55.9aB
60163	40.2bB	44.3bB	57.9aB	88.6aA	57.7aB	51.0bB	50.2aB	41.9bB	53.3aB
6410	41.5bB	57.2bA	37.7bB	72.5aA	69.3aA	47.3bB	42.7aB	58.1aA	44.3aB
Number of Grain per Plant (NGP)									
4823	71.9bB	106.7bA	80.2bB	119.5bA	110.8bA	91.6Ba	72.9aB	57.8aB	43.5bB
95Y72	93.5bB	125.1bA	85.8bB	125.6bA	114.7bA	58.6Bb	81.6aB	89.9aB	58.1bB
95Y52	94.3bB	113.1bB	81.1bB	108.1bB	151.9aA	65.5bB	91.2aB	99.4aB	77.5bB
5445	89.3bB	121.1bA	74.5bB	137.2bA	124.0bA	70.0bB	99.5aB	88.4aB	48.7bB
5959	100.6bC	146.7bB	149.6aB	204.7aA	155.1aB	126.6aC	99.3aC	108.1aC	65.3bD
6909	111.0bB	130.1bB	140.9aB	221.0aA	148.1aB	118.3aB	82.9aC	106.0aB	64.5bC
284	182.2aB	191.0aB	135.6aC	231.3aA	184.4aB	154.4aC	110.5aC	112.1aC	111.2aC
60163	99.0bB	107.3bB	135.9aB	227.6aA	140.6aB	119.9aB	120.3aB	102.3aB	105.8aB
6410	107.5bC	139.3bB	78.3bC	186.9aA	166.1aA	101.1aC	109.7aC	140aB	95.6aC

Means in the same row followed by different capital letters and in the column followed by lowercase letters differ by the Scott-Knott test at 5%. * Sep, Oct, Dec: sowing months; 1, 2 and 3: crop years 2016/2017, 2017/2018, 2018/2019, respectively; C: cultivar; E: environment.

At the third crop year (2018/19) soybean plants showed lower height compared to the two prior year, possible explained by two prolonged periods of water deficit, in November 2018 and in January 2019 (Figure 1), being the second more damaging, as it was longer than the first, significantly impacting the growth (plant height), especially in plants from December sowing (DEC3), which were in the vegetative phase.

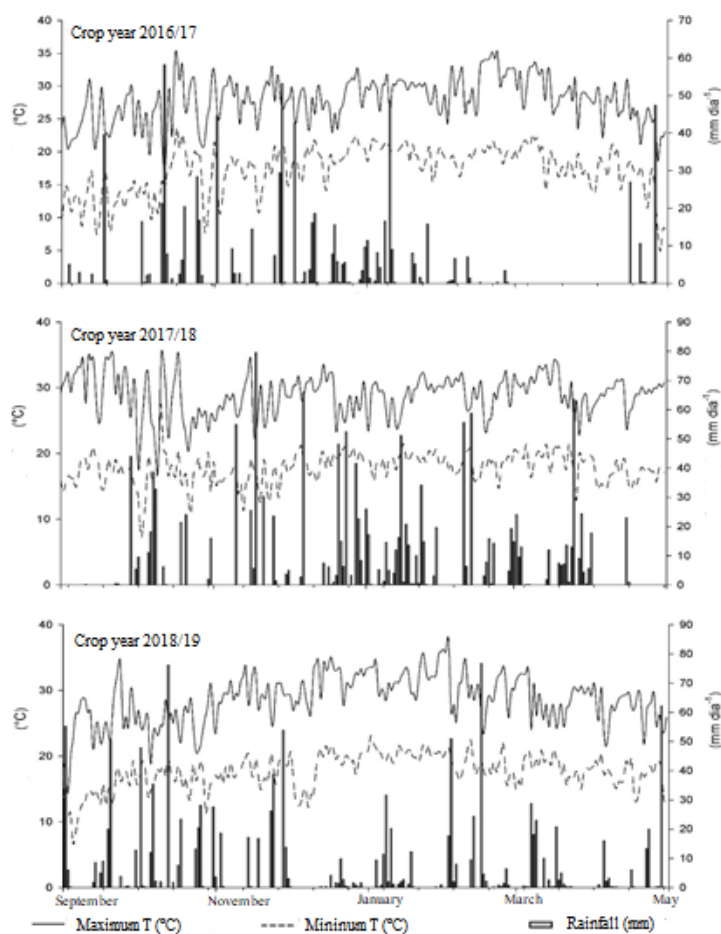


Figure 1. Maximum and minimum air temperature (°C) and rainfall (mm day⁻¹) along the experiment periods at the 2016/2017, 2017/2018 and 2018/2019 crop years. Dois Vizinhas - PR. (Inmet, 2019)

Soybean plant development behavior may be explained by both temperature and photoperiod effects. Lower or milder temperatures at September, with averages below 10 °C (Figure 1) may have affected soybean growth. Thus, daylight length increases from July to December and then decrease from December to July. In this way and according to Sediya et al. (2015), short daylight at September or at latter sowing periods (December) may stimulate earlier soybean flowering, resulting in shorter plants with less number of reproductive nodes, number of pods per plant and, consequently, lower grain yield.

According to Yokomizo & Santos (2018), the height of the soybean plant, at the point of harvest, must be at least 0.50 m to allow an adequate mechanized harvest, with less losses; with an upper limit of 0.76 m. For Silva et al. (2010), the ideal height of the soybean plant is 0.65 m. In the present study, at the DEC2 and DEC3 periods (December sowing and its environments), many of the genotypes showed main stem length lower than 0.50 m, which can be an aggravating factor in addition to adverse environmental conditions, resulting in even lower grain yield.

When analyzing the plant growth, among cultivars, for each environment, it was found that

plant grow taller as RMG increases with a tendency to decrease as the cycle of cultivar is reduced. This behavior was even more striking in the December sowing. Similar results were reported by Pires et al. (2012), at Tocantins (Brazil state), allowing the association sowing period with its cycle and the final plant size.

Similar to that observed for the PH, the FPI in the main stem was greater in environments with sowing at October, and lower at December environments. When the cultivars for each environment were compared, those with a longer cycle (>RMG) had a higher FPI compared to those with a shorter cycle (Table 3).

According to Almeida et al. (2011), FPI less than 0.10 m may result in losses at harvest, since the combine platform is not able to properly cut and collect the pods inserted near to the soil. When observing Table 3, the earliest cultivars, in practically all environments, presented lower FPI than that indicated by the researcher as ideal.

Moreover, the NPP is one of the yield components that most varies in relation to the environment conditions. NPP from most of the cultivars was higher in the SEP2 environment, followed by the OCT2 and OCT1 environments (Table 3).

However, the variation of this yield component was smaller between environments, for each cultivar, compared to PH and FPI, having been less impacted by the environmental conditions. Cultivars NS 5959 and NS 6909 showed the lowest values in the third growing season year, regardless of the sowing period, indicating that these cultivars are more susceptible to water deficit when it comes to fixing pods in the plant.

Although there is similarity for NPP between cultivars, for each specific environment, there was a predominance of a greater number of pods in the larger and intermediate RMG cultivars, compared to the smaller RMG cultivars. In this sense, cultivar BRS 284 stood out and presented superior results in all analyzed environments (Table 3).

Similar results were observed by Cruz et al. (2010), in a study evaluating the performance of soybean cultivars according to the sowing date in Bahia, Brazil. The authors reported lower variation in NPP between cultivars than between seasons in which the late seasons conditioned a smaller number of pods per plant corroborating with Peixoto et al. (2000).

The NGP showed a similar trend to that observed for the NPP. However, it suffered greater variation, especially in the third crop year, in which the number of grains was lower for most of the cultivars, compared to the other production environments. Possibly due to the prolonged water deficit that occurred during soybean ontogeny, with greater sensitivity of BRS 284, NS 6909 and NS 5959. Although such cultivars stand out positively in NGP compared to the first cultivars, they were the most affected by the water deficit when analyzing their individual behavior among the other environments.

In general, the NGPP, within environments, for each cultivar was higher at SEP2 (sowing in September, 2nd crop year), followed by OCT2 and OCT3 (sowing in October, 2nd and 3rd crop years). The lowest values of NGP were noticed at DEC1, DEC2 and DEC3 environments, all of them regarding to December sowing, indicating that factors such as shorter photoperiod,

more persistent water deficit and higher temperatures (Figure 1) are an undesirable combination for soybean, regardless of the RMG of the cultivar (Table 4).

Table 4. Number of grain per pods (NGPP), thousand grain weight (TGW) and grain yield (GY) of nine soybean cultivars grown at nine different environment

Cult	Number of grain per pods (NGPP)								
	SEP1*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	2.15Bb	2.37aA	1.98bC	2.47Ba	2.5Ba	2.13bB	2.18bB	2.43bA	1.85bC
95Y72	2.06Bd	2.24bC	2.02bD	2.47Bb	2.67aA	1.99cD	2.29bC	2.71aA	2.16aC
95Y52	2.15Bc	2.3bB	2.04bC	2.48Ba	2.43bA	2.01cC	2.32bB	2.51bA	2.01bC
5445	2.49Ab	2.47aB	2.04bC	2.58Ba	2.67aA	2.07cC	2.38bB	2.53bB	2.18aC
5959	2.56Aa	2.46aA	1.98bB	2.54bA	2.57aA	1.99cB	2.55aA	2.57bA	2.04bB
6909	2.49Ab	2.42aB	2.22aC	2.92aA	2.52bB	2.21bC	2.44aB	2.54bB	1.93bD
284	2.54Aa	2.50aA	1.97bC	2.68bA	2.64aA	2.17bB	2.28bB	2.19cB	2.00bC
60163	2.47Aa	2.41aA	2.35aA	2.54bA	2.44bA	2.33aA	2.42aA	2.44bA	2.01bB
6410	2.48Aa	2.43aA	2.08bC	2.56bA	2.31bB	2.14bC	2.57aA	2.41bA	2.17aC
Cult	Thousand grain weight (TGW, g)								
	SEP1*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	175.4Cb	186.8cA	167.5bC	184.7bA	188.0Ba	142.4cD	137.5bD	161.8aC	119.3bE
95Y72	183.2Cb	208.5bA	162.6bD	187.4bB	180.1Bb	171.3bC	145.0bE	164.8aD	137.3aE
95Y52	241.9Aa	219.1aB	188.9aD	199.2aC	205.3Ac	189.1aD	160.1aE	161.4aE	133.0Af
5445	205.3Ba	204.9bA	164.4bB	204.6aA	196.6Aa	163.7bB	155.1aB	139.7cC	121.6bD
5959	197.2Ba	183.6cB	155.3bD	180.5bB	182.2Bb	167.7bC	151.2aD	131.1dE	117.0bF
6909	205.6Ba	202.6bA	158.4bE	192.8aB	179.4Bc	169.7bD	144.8bF	124.0dG	104.2cH
284	164.2Da	150.1dB	138.5cB	149.1dB	159.5Ca	146.2cB	115.9cC	144.0cB	117.6bC
60163	199.7Ba	190.3cB	180.8aC	199.6aA	206.1Aa	192.4aB	160.9aD	127.0dE	115.5bF
6410	173.1Ca	159.4dB	124.3dD	160.9cB	143Dc	147.3cC	139.7bC	148.9bC	105.0cE
Cult	Grain yield (GY, kg ha ⁻¹)								
	SEP1*	OCT1	DEC1	SEP2	OCT2	DEC2	SEP3	OCT3	DEC3
4823	4052 eC	4480 dB	3471 bD	6670 bA	4705 Cb	1544 bF	3691 aD	2690 bE	980 cG
95Y72	4746 C	4885 cC	3071 cD	5840 cA	5254 Ab	1564 bE	3231 bD	3249 aD	1499 E
95Y52	5336cA	4881 cB	2993 cC	5741 cA	4946 Bb	2384 aD	2681 cC	2262 cD	1352 bE
5445	4420 dB	5200 cA	3067 cC	5487 cA	5363 Aa	1499 bE	3329 bC	2442 cD	1180 bE
5959	5772 bB	6325 aA	3117 cD	5542 cB	5659 Ab	2498 aE	3903 aC	2108 cE	757 cF
6909	5871 bB	6058 aB	2864 cE	7173 aA	5089 Bc	2313 aF	3663 aD	2069 cF	647 cG
284	5712 bB	5677 bB	2119 dE	7289 aA	4902 Bc	2674 aD	3044 bD	2218 cE	2728 aD
60163	5238 cB	4911 cB	3933 aC	6908 bA	4143 Dc	2716 aD	3958 aC	2181 cE	1105 bF
6410	6259 aA	5649 bB	2191 dE	5760 cB	4356 Dc	2688 aD	3144 bD	2866 bD	1339 bF

Means in the same row followed by different capital letters and in the column followed by lowercase letters differ by the Scott-Knott test at 5%. * Sep, Oct, Dec: sowing months; 1, 2 and 3: crop years 2016/2017, 2017/2018, 2018/2019, respectively; C: cultivar; E: environment.

When comparing NGPP within each production environment, among cultivars, it appears that it is highly variable, although there is a greater number of grains per pod for the larger and intermediate RMG cultivars with a greater (Table 4).

All December sowing periods resulted in lower TGW. Also, at the 3rd crop year, regardless of the sowing season, this variable was compromised due to water deficit (Table 4). The environments that most favored TGW were SEP1, followed by OCT1 and OCT2, and finally, SEP2, for most of the evaluated cultivars.

When analyzing the cultivars, in each environment, it is possible to verify that TGW is an

intrinsic trait of the genotype, with emphasis on the cultivar 95Y52, followed by 60163 and 5445, which presented greater mass in most production environments. The cultivars with the lowest TGW were BRS 284 and M6410 (Table 4).

These results corroborate with Cruz et al. (2010) and Dalchiavon & Carvalho (2012), in which both genetic and environmental influence was found for soybean TGW, however, the importance of genetics in this character was evidenced, mainly in favorable conditions.

Final GY in relation to the different environments, for each cultivar, was generally higher in SEP2 (Sowing in September, 2nd crop year) following the trend observed for the yield components (Table 4). Soybean is a very plasticity specie in a way that one yield component may be offset by other yield components aiming to maintain final yield potential. In these way, OCT1 (Sowing in October, 1st crop year) and SEP1 (Sowing in September, 1st crop year) environments were also favorable for higher yields and, in an intermediate way, the OCT2 environment (Sowing in October, 2nd crop year).

This result is accordance with those reported by Albrecht et al. (2008). The authors evaluated the GY of three soybean cultivars in five sowing seasons (09/15; 09/30; 10/15; 10/30 and 11/15), and concluded that the sowing dates of 09/30, 15/10 and 10/30 conferred the highest productivity.

The environments DEC1, DEC2, SEP3, OCT3 and DEC3 were unfavorable for GY. In the three crop years, the worst conditions were verified in December sowing, corroborating with Marques et al. (2011), in a study carried out in Minas Gerais state, to evaluate the performance of soybean genotypes according to the sowing date. Only in the last crop year that the unfavorable results occurred in the three seasons, SEP3, OCT3 and DEC3, due to the prolonged water deficit that occurred; but even so, the DEC3 environment was the most harmful for soybean GY (Table 4).

According to Meotti et al. (2012) and Jiang et al. (2011) in late sowing (short photoperiod), soybeans bloom early, have reduced size and cycle and, consequently, lower GY potential which is in accordance with what was verified in the present study. Therefore, the cultivation of soybeans in late sowing periods should adopt medium cycle cultivars with high height (Peixoto et al., 2000).

When comparing the cultivars, for each specific environment, it was possible to verify a range of responses among the materials. However, those close to RMG 6.0, represented by NS 5959 and NS 6909, were the cultivars that stood out in the greatest number of environments, with four observations, on average per cultivar (sum of observations with higher productivity for both cultivars, divided by the number of cultivars in the group).

Cultivars near to RMG 6.3 (BRS 284, LG 60163 and M6410) had, on average per cultivar, 2.7 positive observations for GY. In sequence, representatives of RMG 5.0 (NS 4823 and P95Y72, the earliest), stood out, on average per cultivar, in 1.5 observations. The cultivars that least stood out individually for grain productivity, in comparison of these, for each environment, were the representatives of RMG 5.3 (P95Y52 and NS 5445), with 1 observation each.

Regarding to the lowest GY, for each cultivar, representatives of RMG 5.0 had 3.5 observations; RMG 5.3, 3 observations; RMG 6.0, 2.5 observations; and, finally, those with the lowest number of negative results for cultivar were representatives of RMG 6.3, with 2.3 observations.

Thus, it was found that the cultivars representing RMG 6.0 were the ones that showed the highest productive balance in the average of the 81 observations made (nine environments x nine cultivars), being the RMG 5.3 the most volatile cultivars.

However, in very unfavorable environments, the cultivars most negatively impacted were NS 5959 and NS 6909 at the DEC3 (Table 4). Thus, the importance of knowing the individual response of soybean cultivars to specific environments is emphasized, in order to achieve a correct positioning of the cultivars, and sustainable productivity, even with variations in the production environment.

The cultivar that should be targeted for genetic improvement is the one that has a positive response to the improvement of the production environment, and low yield reduction in unfavorable environments, as reported by Freiria et al. (2018), with the BMX Potência RR, UEL 110, UEL 121 and UEL 123 genotypes.

The analyzes of adaptability and stability of cultivars in different environments, were carried out on GY, given the interest and main objective of the research. The results of the joint variance analysis indicated a significant interaction between the factors (Table 5), showing differentiated response of the genotypes according to the production environments, which suggests a more detailed analysis.

Table 5. Results of the AMMI analysis from the interaction among nine soybean cultivars grown in nine environments for the grain yield (kg ha^{-1}) variable

Variation Source	DF	Medium square	F	P>F
Cultivars (C)	8	305314.804	0.909641	0.514316
Environments (E)	8	26311351.8	78.39081	0.000
Interaction – C×E	64	335643.309	2.678571	0.000
IPCA1	15	536182.068	4.279	0.000001
IPCA2	13	406993.734	3.248	0.000195
IPCA3	11	406705.222	3.2457	0.000459
IPCA4	9	240676.05	1.9207	0.051565
IPCA5	7	151059.935	1.2055	0.301897
IPCA6	5	83161.314	0.6637	0.651461
IPCA7	3	9549.38	0.0762	0.972762
IPCA8	1	5806.035	0.0463	0.829875
Average error	180	125306.835		

In the result of the AMMI analysis, the three main components were significant by the F test, with explanation of the variation of the SQG x E 59.75% of the IPCA1. IPCA 2 explained 21.26% of the interaction, while IPCA 3 explained 21.17%. In this analysis, the ideal that the first two main components explain 70% or more of the total accumulated and explained variation of all components (Alcântara Neto et al., 2018). In the present study, it was 81.01%

for IPCA1 and IPCA2, in agreement with Silveira et al. (2018).

According to Gauch Jr. (2013), as the number of selected axes increases, the percentage of “noise” also increases, reducing the predictive power of the AMMI analysis, that is, the excessive inclusion of multiplicative terms can reduce the accuracy of the analysis. Therefore, in the present study, only the axes IPCA 1 and IPCA 2 were considered in the AMMI analysis.

The BRS 284, 6909 and 5959 cultivars presented above average yields, and the most stable cultivar was 95Y52, being able to be cultivated in all environments, indicating that the most productive cultivars were not, likewise, stable. The less productive cultivars, in addition to 95Y52, were 4823, 95Y72 and 5445 (Figure 2a), all of them are genotypes with a shorter cycle. In addition, cultivars 4823 and 6410 were the ones that most contributed to the G x E interaction, as they had the highest score range in the interaction axis, followed by 284 and 95Y72.

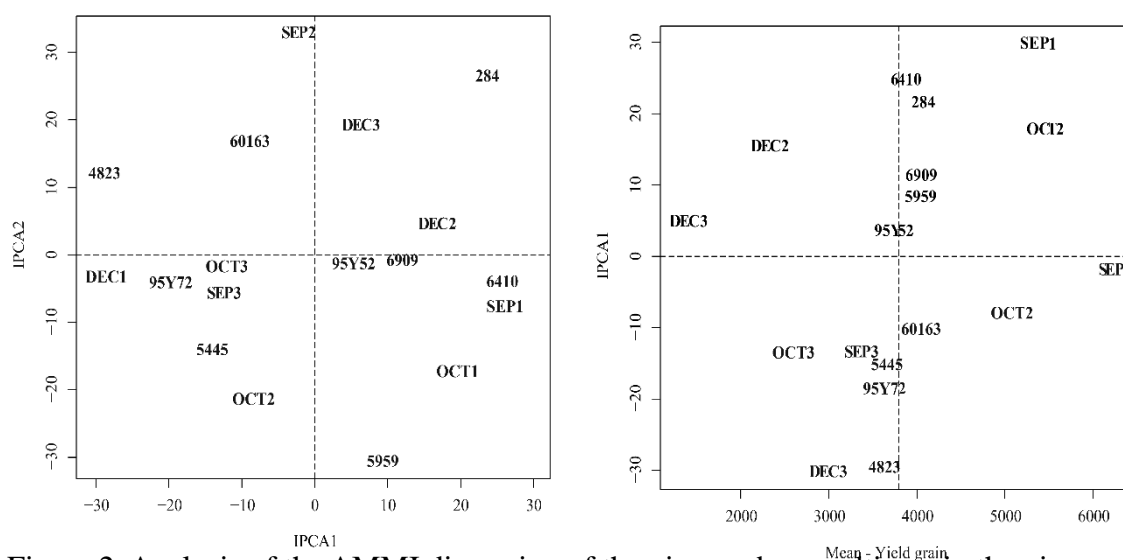


Figure 2. Analysis of the AMMI dispersion of the nine soybean cultivars in the nine cultivation environments for the grain yield variable (kg ha^{-1}). SEP1: 2016/17 crop year - season 1; OCT1: 2016/17 crop year - season 2; DEC1: 2016/17 crop year - season 3; SEP2: 2017/18 crop year - season 1; OCT2: 2017/18 crop year - season 2; DEC2: 2017/18 crop year - season 3; SEP3: 2018/19 crop year - season 1; OCT3: 2018/19 crop year - season 2; e DEC3: 2018/19 crop year - season 3

Silveira et al. (2016; 2018), using the AMMI methodology, reported that the earliest cultivar, SYN 1049, was the most unstable one compared to the cultivars of higher RMG. This occurred in the present study for NS 4823, with a RMG of 4.8, indicating that very early genotypes require greater attention for their cultivation, both in terms of management, as well as the prevailing edaphoclimatic conditions.

The most favorable environments for soybean productivity were SEP2 (Sowing in September, 1st crop year), followed by OCT1, DEC1 and OCT2. The most unfavorable environment was DEC3, (Sowing in December, 3rd crop year).

The use of an AMMI 2 biplot (IPCA 1 vs. IPCA 2) (Figure 2) allows the correction of

possible distortions in the analysis or interpretation produced using a single dimension (Yokomizo et al., 2013).

The adaptability of the genotypes in each cultivation site is interpreted from the score signs for genotypes and environments, and the genotypes and environments of the same sign (+, + or -, -) interact positively. On the other hand, when there are opposite signs (+, - or -, +) they present negative interaction (Duarte & Vencovsky, 1999), indicating in which environment the genotype should be cultivated preferentially.

The 95Y52 cultivar remained the most stable, corroborating with the AMMI1 biplot. It was also found that genetics related to higher productivity seems to be associated with specific adaptations. Example of cultivar 6410, with higher productive performance, and close to the SEP1 environment. Subsequently, BRS 284, however, of broader adaptation, with greater synergism to the DEC2 and DEC3 environments.

Similar to the AMMI1 biplot, but with greater amplitude, the cultivar 4823 proved to be one of the least productive. Regarding the contribution of the cultivar to the interaction, NS 5959 stood out in comparison to the others, followed by BRS 284.

All environments, in general, contributed to the interaction G x E, with emphasis on SEP1, DEC1 and SEP2. From the point of view of plant breeding, this situation increases the challenges for the recommendation of cultivars aiming at mega environments, conditioning the cultivar launch to more specific environments.

It was verified, by the GGE Biplot method, greater contribution of cultivars 5959 and 60163 with the interaction G x E, and environments SEP1 and SEP2 (sowing in September, 1st and 2nd crop years). As for environments with less collaboration for interaction, SEP3 and OCT3 stand out. Using this method, the 95Y52 cultivar was again more stable.

In the GGE method (Figure 3), smaller, greater and equal angles of 90 degrees indicate positive, negative and no association, respectively, between environments and cultivars.

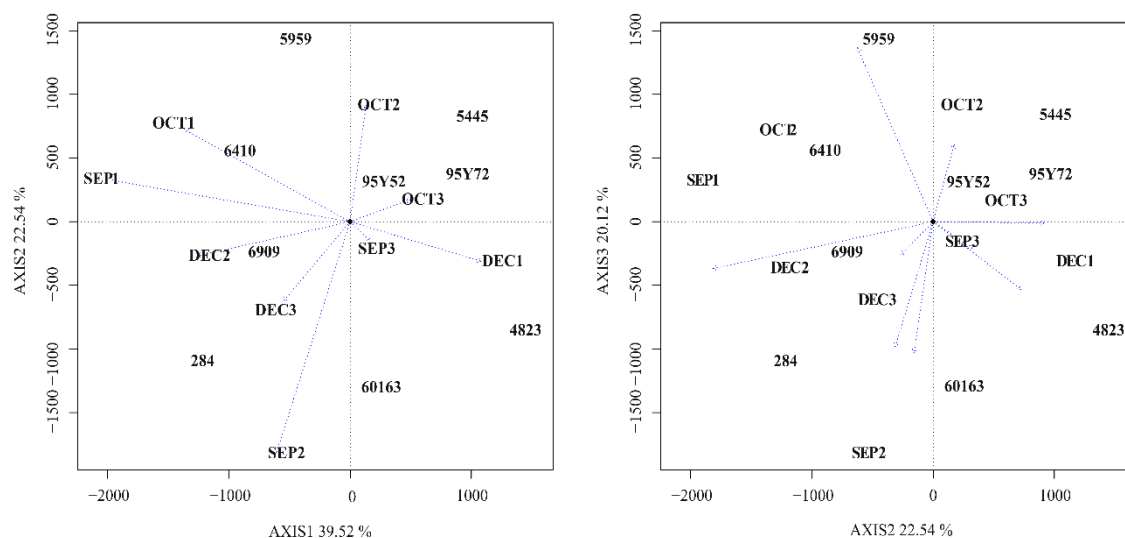


Figure 3. Analysis of the GGE Biplot dispersion of the nine soybean cultivars in the nine cultivation environments for the grain yield variable (kg ha^{-1}). SEP1: 2016/17 crop year - season 1; OCT1: 2016/17 crop year - season 2; DEC1: 2016/17 crop year - season 3; SEP2: 2017/18 crop year - season 1; OCT2: 2017/18 crop year - season 2; DEC2: 2017/18 crop year - season 3; SEP3: 2018/19 crop year - season 1; OCT3: 2018/19 crop year - season 2; e DEC3: 2018/19 crop year - season 3

The earliest cultivars (95Y72, 5445 and 95Y52) showed a positive association with the OCT2 and OCT3 environments; with greater interaction between the last two and OCT3; and 95Y72 with OCT2. NS 4823 cultivar was strongly associated with SEP3. The best performance of earlier cultivars can be seen in October sowing, but also in late September. These results are partially in agreement with Meotti et al. (2012), who attributed the favorable performance of the soybean cultivars tested to the conditions of temperature, solar radiation and photoperiod prevalent in October sowing.

The BRS 284 cultivar was positively associated with DEC2, 6909 with DEC2. The 6410 had a positive interaction with the OCT1. In a biplot, specific adaptations can be explored that can allow the breeder to make better use of his study materials both in the selection and in the recommendation of cultivars (Polizel et al., 2013).

The results of the analysis of the main components for the centroid method indicated that the two main components explained 63% of the total variation, being a value considered adequate for estimating the interaction of factors (Table 6).

Table 6. Results of the analysis of main components to estimate adaptability via the centroid method, average yield (kg ha^{-1}) and the classification of genotypes in one of the four groups characterized by the centroid and the probability associated with their classification of soybean genotypes

Root ¹	Root (%)	% Acum	Cultivar ²	Average	Classif.	Prob(I)	Prob(II)	Prob(III)	Prob(IV)
2.93	32.56	32.56	95Y52	3619.61	IV	0.202	0.241	0.240	0.317
2.76	30.66	63.22	5445	3554.18	IV	0.186	0.220	0.246	0.348
1.13	12.60	75.82	95Y72	3704.34	IV	0.209	0.217	0.277	0.297
0.99	11.01	86.83	4823	3587.06	IV	0.191	0.203	0.281	0.325
0.69	7.63	94.46	6410	3805.83	II	0.240	0.285	0.221	0.255
0.30	3.33	97.79	5959	3964.59	II	0.261	0.304	0.208	0.227
0.17	1.90	99.69	284	4040.33	I	0.300	0.285	0.210	0.205
0.02	0.26	99.95	60163	3899.24	III	0.254	0.222	0.284	0.241
0.00	0.05	100.00	6909	3971.77	II	0.240	0.402	0.163	0.195

¹ Analysis of main components; ² Analysis of adaptability via centroid for nine soybean cultivars. Overall average 3794.1. Ideotype I: High general adaptability. Ideotype II: Specific adaptability to favorable environments; Ideotype III: Specific adaptability to unfavorable environments and Ideotype IV: Little adapted.

The analysis of the graph of the main components, for the productive adaptability of the genotypes, by the centroid method, indicated that only the cultivar BRS 284 showed high general adaptability, since it was closer to ideotype I (Figure 4, Table 6), obtaining the highest

average productivity.

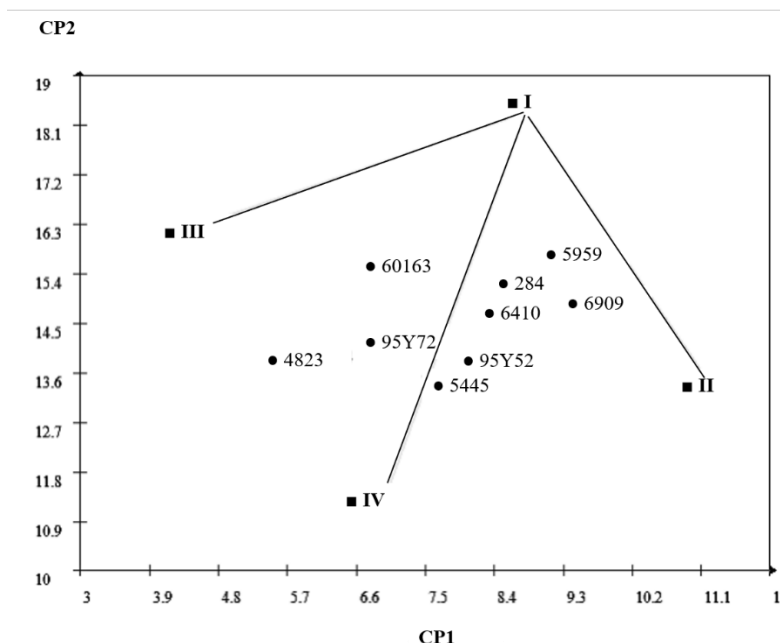


Figure 4. Graphical dispersion of the scores in relation to the first two main components obtained from the analysis of grain yield of nine soybean cultivars evaluated in nine environments. The four points numbered with Roman numerals represent the centroid

The 6410, 5959 and 6909 cultivars showed specific adaptation to favorable environments, since they were closer to ideotype II. The 60163 cultivar, on the other hand, showed specific adaptability to unfavorable environments, indicating that it is a promising genotype for more stressful conditions for soybean crops. In this method, the genotype of maximum specific adaptation is not the one that performs well in groups of favorable or unfavorable environments, but the genotype that shows maximum values for a given group of environments (favorable and unfavorable) and minimum for the other group (Pelúzio et al., 2010).

Shorter cycle cultivars (95Y52, 5445, 95Y72 and 4823) showed the lowest adaptation. These cultivar patterns are more susceptible to adverse conditions of environment and management, due to their reduced cycle, smaller size and, consequently, less phenotypic plasticity, in general, compared to cultivars with a longer cycle, requiring more caution in their recommendation.

Unfavorable environments are characterized by areas of cultivation whose technological index is low or regions with adverse edaphic and climatic conditions. Favorable environments are associated with regions with climatic and edaphic conditions appropriate to the suitability of the crop, or cultivation areas where high production technology is employed (Pelúzio et al., 2010).

As in our study, Vasconcelos et al. (2015) stratified soybean genotypes according to their adaptation in different environments by the centroid method, obtaining reliable results through this tool.

4. Conclusion

The NS 5909 IPRO® and NS 6909 IPRO® cultivars, both close to GMR 6.0, presented superior average performance in most of the evaluated production environments. The earliest cultivars, with GMR less than 5.4, were the ones that produced less, in general, in different environments.

Evaluated soybean cultivars specific adaptations stood out in relation to general adaptation, showing the importance of genotype environment interaction and the use of the right cultivar according to the environment.

The adaptability of the genotypes was not accompanied by high stability, which contributes to the reduction of the average productivity of the cultivars when exposed to different environments.

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