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Physiological quality of soybean seeds under different yield environments and plant density

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ABSTRACT

Yield potential of agricultural fields associated with plant spatial arrangement could determine the physiological quality of soybean (*Glycine max* L.) seeds. Thus, this study aimed to evaluate the physiological quality of soybean seeds from different yield environments and plant densities. Experiments were carried out in Boa Vista das Missões-RS, Brazil, during the 2014/2015 growing season. Yield environments were delineated by overlapping yield maps from the 2008, 2009/2010 and 2011/2012 growing seasons. The experimental design was a randomized complete block in a 2 x 5 factorial arrangement with two yield environments (low and high) and five plant densities, with four replicates. Two varieties were tested: Brasmax Ativa RR (10, 15, 20, 25 and 30 plants m^{-1}) and Nidera 5909 RR (5, 10, 15, 20 and 25 plants m^{-1}). After harvested, the seeds were analysed as following: first count index, germination, abnormal seedlings, dead seeds, electrical conductivity, accelerate aging test, root length, hypocotyl length and seedling length. The spatial variability of seed vigor in the production field could be reduced by adjusting plant density, but the adjustment should consider the variety. Harvest according to yield environment is a strategy to separate lots of seeds with higher vigor, originated from high-yield environments.

Palavras-chave:
Glycine max L.
vigor de sementes
mapas de colheita
otimização

Qualidade fisiológica de sementes de soja em diferentes ambientes de produtividade e densidade de plantas

RESUMO

O potencial produtivo das áreas agrícolas associados ao arranjo espacial de plantas pode determinar a qualidade fisiológica de sementes de soja (*Glycine max* L.). Neste sentido, o estudo teve por objetivo avaliar a qualidade fisiológica de sementes de soja oriundas de diferentes ambientes de produtividade e densidade de plantas. Os experimentos foram conduzidos em Boa Vista das Missões, RS, na safra 2014/2015. Ambientes de produtividade foram definidos através da sobreposição de mapas de colheita das safras 2008, 2009/2010 e 2011/2012. O delineamento experimental foi o de blocos ao acaso, em esquema fatorial 2 x 5, com dois ambientes de produtividade (baixa e alta) e cinco densidades de plantas, com quatro repetições. As cultivares utilizadas foram: Brasmax Ativa RR (10, 15, 20, 25 e 30 plantas m^{-1}) e Nidera 5909 RR (5, 10, 15, 20 e 25 plantas m^{-1}). As sementes colhidas foram submetidas às análises de primeira contagem, germinação, plântulas anormais, sementes mortas, condutividade elétrica, envelhecimento acelerado, comprimento de raiz, hipocótilo e plântulas. A variabilidade espacial do vigor pode ser reduzida no campo de produção ajustando-se a densidade de plantas, contudo o ajuste deve considerar a cultivar. A colheita otimizada pode permitir a separação de lotes com maior vigor, oriundos de ambientes de alta produtividade.

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INTRODUCTION

Using seeds with high physiological quality (PQ) is a key factor to obtain high yields in the soybean crop (Cantarelli et al., 2015; Gazolla Neto et al., 2015). Plants from seeds with superior PQ emerge earlier, have greater dry matter and leaf area, and are consequently more productive (Schuch et al., 2009; Scheeren et al., 2010). Studies have reported that, besides lower mortality in the field (Cantarelli et al., 2015), plants originated from seeds with high PQ were 9% (Scheeren et al., 2010) and 25% (Schuch et al., 2009) more productive in comparison to seeds with low PQ.

Factors related to the environment in which the crop grows (low or high yield potential) and plant arrangement, such as plant density (PD), can also determine seed PQ (Vazquez et al., 2008; Mondo et al., 2012). In a soybean seed production field, Mattioni et al. (2011, 2013) and Gazolla Neto et al. (2015) reported the presence of spatial variability in the vigor index. Similarly, studies have concluded that the organic matter content (Mondo et al., 2012), calcium content and soil $CEC_{effective}$ benefited the germination index (Mattioni et al., 2013). On the other hand, PD interferes with the intraspecific competition of plants, conditioning the individual yield (Luca & Hungría, 2014) and, therefore, possibly affecting PQ. Nonetheless, the effects of yield environments and PD on seed PQ have been little explored. These studies can benefit the field management, by equalizing PQ through the adjustment of PD, or even allow the separation of seed lots within the same field (Mattioni et al., 2011; Gazolla Neto et al., 2015).

In this context, this study aimed to evaluate the PQ of seeds of two soybean cultivars sown in environments with different yield potentials and plant densities.

MATERIAL AND METHODS

The experiments were carried out in a 32 ha irrigated agricultural field, located in the municipality of Boa Vista das Missões, RS, Brazil (27° 43' 21.69" S; 53° 20' 17.39" W). The characteristic relief of the region is gently undulating and the soil was classified as 'Latossolo Vermelho distrófico típico' (Santos et al., 2006). The local climate is humid-spring subtropical (Maluf, 2000). The field has been managed with no-tillage system for more than 20 years, following a plan of crop rotation with wheat (*Triticum aestivum* L.), black oat (*Avena strigosa* Schreb.) and white oat (*Avena sativa* L.) in the winter, and soybean or corn (*Zea mays* L.) in the summer.

As proposed by Santi et al. (2013), three yield maps were used to define the yield environments (YE): white oat (2008) and corn (2009/2010 and 2011/2012), selected due to the satisfactory rainfall during the seasons (Santi et al., 2013). The maps were obtained by a CASE® Axial-Flow 2399 combine equipped with yield and moisture sensors. The maps were filtered (Menegatti & Molin, 2004), relativized and overlapped for the same grid (30 x 30 m). Two YE were isolated according to the relative yield: low yield (LY, < 95%) and high yield (HY, > 105%), using the software QGIS (QGIS Development Team). Soil chemical characterization (Tedesco et al., 1995) in each YE is presented in Table 1.

In each YE, two traditional cultivars were tested in the 2014/2015 growing season. The experimental design was randomized blocks, in a 2 x 5 factorial scheme, with two YEs and five PDs in the sowing row, with four replicates. The cultivars were: Brasmax Ativa RR (determinate growth habit, maturity group 5.6, short size, low branching capacity, ideal PD of 20 plants m^{-1}), at PDs of 10, 15, 20, 25 and 30 plants m^{-1} (200, 300, 400, 500 and 600 thousand plants ha^{-1}, respectively), and Nidera 5909 RR (indeterminate growth habit, maturity group 5.9, medium size, high branching potential, ideal PD of 15 plants m^{-1}), at PDs of 5, 10, 15, 20 and 25 plants m^{-1} (100, 200, 300, 400 and 500 thousand plants ha^{-1}, respectively). Seeds were inoculated with *Bradyrhizobium japonicum* and treated with 25 g ha^{-1} of Mo and 3 g ha^{-1} of Co. The cultivars were manually sown on November 27, 2014, in plots with 4 x 5 m, using a row spacing of 0.50 m. Fertilization was performed using NPK fertilizer, 4.30.15 formulation, at dose of 350 kg ha^{-1}, applied in the sowing row. All other cultivation practices were performed uniformly in the experimental units and together with the farmer. The climatic conditions and irrigation used along the experiment are presented in Figure 1.

Experimental units were harvested on March 23, 2015 (cultivar Ativa) and on March 26, 2015 (cultivar 5909), in

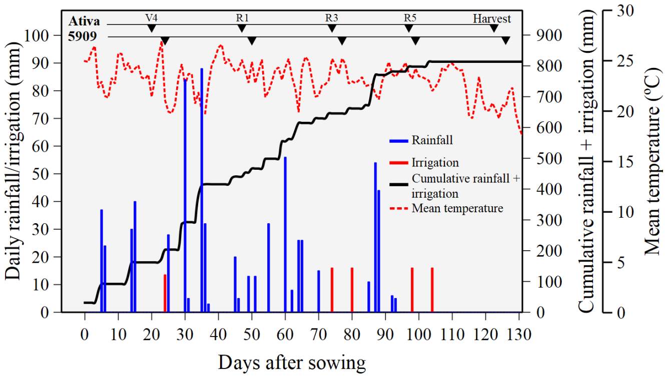

Figure 1. Daily rainfall, irrigation, total accumulated, and mean air temperature during the growing season

Table 1. Soil chemical properties before sowing in low-yield (LY) and high-yield (HY) environments (YE)

YE	Depth (m)	Clay	OM	V	pH water (1:1)	P	K	Al	Mg	Ca	CEC
			(%)			($mg\ dm^{-3}$)			($cmol_c\ dm^{-3}$)		
LY	0 - 0.05	67	3.5	66.4	5.6	25	120	0.3	3.5	6.9	16.1
	0.05 - 0.10	78	2.7	65.8	5.7	7.1	67	0.2	3.2	6.0	14.2
	0.10 - 0.15	80	2.4	69.3	5.8	3.3	33	0.2	3.4	6.0	13.7
	0.15 - 0.20	78	2.3	69.8	5.9	2.4	13	0.0	3.4	5.8	13.2
HY	0 - 0.05	47	4.2	65.7	5.4	50.1	150	0.4	3.1	7.4	16.6
	0.05 - 0.10	63	3.3	58.5	5.4	17.8	57	0.6	2.8	6.0	15.3
	0.10 - 0.15	68	3.0	60.1	5.4	12.0	23	0.8	2.8	5.9	14.6
	0.15 - 0.20	73	2.7	55.7	5.4	5.7	12	0.8	2.7	5.3	14.4

OM – Organic matter; V – Base saturation; $pH_{1:1}$; P – Phosphorus extracted by Mehlich-1; K – Potassium extracted by Mehlich-1; Al - Aluminum; Mg - Magnesium; Ca - Calcium, and CEC – Cation exchange capacity, pH 7.0

the five central rows, disregarding the borders. Plants were mechanically threshed, and seeds were placed in paper bags and stored in environment with controlled temperature and humidity. In September 2015, the following variables were determined: first count, germination, abnormal seedlings, dead seeds, electrical conductivity, accelerated aging and lengths of roots, hypocotyl and seedlings. Germination analysis used eight samples of 50 seeds from each experimental unit. Seeds were placed on Germitest paper moistened with distilled water and maintained in germination chamber (BOD) at 25 °C and under 12 h photoperiod. Counts were made at five (first count) and at eight days (germination, abnormal seedlings and dead seeds) (Brasil, 2009). Lengths of roots, hypocotyl and seedlings were determined manually.

Electrical conductivity (μS cm^{-1} g^{-1}) was analysed in four samples of 50 seeds. The seeds were weighed on analytical scale (0.001 g precision) and then each sample received 75 mL of deionized water. The samples were then maintained in germination chamber (BOD) at 25 °C for 24 h (Loeffler et al., 1988). Evaluations were taken in soaking solution, using a conductivity meter (Lutron CD-4303). For the aging test, four samples of 50 seeds were arranged on a stainless-steel screen, placed in plastic boxes (Gerbox) containing 40 mL of water (Krzyzanowski et al., 1991) and taken to the germination chamber (BOD) at 41 °C for 48 h. After this period, the seeds were subjected to the germination test, and normal seedlings were evaluated five days after sowing, with results expressed as vigor (%) (Brasil, 2009).

The evaluated parameters were subjected to normality test and then to analysis of variance (ANOVA) ($p \leq 0.05$). Given the difference between cultivars and between the PDs tested, the cultivars were considered as distinct experiments, while the YEs and PDs were treated as fixed effects. When the results were significant by F test, means of the parameters were compared by Tukey test ($\alpha = 0.05$). The data were analysed using the software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Cumulative rainfall along the experimental periods was 814 mm (Figure 1) and was considered as satisfactory to obtain high yields in the soybean (Zanon et al., 2016). There was no significant difference for dead seeds (Table 2) in the tested factors (YE and PD), and the mean values were 2.10% (cultivar Ativa) and 1.02% (cultivar 5909).

The highest percentages of first count were obtained at PDs of 30 and 25 plants m^{-1}, respectively, for the cultivar Ativa. For 5909, the first count was higher at PDs of 5, 10 and 25 plants m^{-1} (Table 3). Germination and abnormal seedlings differed only between the PDs and in both cultivars (Table 2). Mean values of germination were higher in the HY for the cultivar Ativa, and highest percentages were obtained at PDs of 30 and 25 plants m^{-1} for LY and HY, respectively (Table 3).

In comparison to the PD recommended for the cultivar Ativa (20 plants m^{-1}), the increment in PD to 30 plants m^{-1} increased germination by 6.7%. Similar results were observed

Table 2. Analysis of variance for first count (FC), germination (GE), abnormal seedlings (AS), dead seeds (DS), electrical conductivity (EC), accelerated aging (AA), root length (RL), hypocotyl length (HL) and seedling length (SL)

Cultivar	Factor	FC	GE	AS	DS	EC	AA	RL	HL	SL
						Pr > F				
Ativa	YE	0.453^{ns}	0.448^{ns}	0.156^{ns}	0.434^{ns}	0.168^{ns}	0.000***	0.003**	0.655^{ns}	0.007**
	PD	0.003**	0.002**	0.006**	0.114^{ns}	0.037*	0.000***	0.000***	0.034*	0.000***
	YE x PD	0.097^{ns}	0.196^{ns}	0.237^{ns}	0.216^{ns}	0.375^{ns}	0.005**	0.000***	0.004**	0.000***
	Mean	89.90	91.85	6.05	2.10	52.33	85.15	10.00	9.48	19.49
	CV (%)	6.59	5.10	61.27	108.29	10.16	5.41	31.54	21.23	16.02
5909	YE	0.422^{ns}	0.175^{ns}	0.418^{ns}	0.194^{ns}	0.001**	0.396^{ns}	0.043*	0.313^{ns}	0.192^{ns}
	PD	0.001**	0.009**	0.006**	0.850^{ns}	0.223^{ns}	0.011*	0.000***	0.016*	0.000***
	YE x PD	0.543^{ns}	0.153^{ns}	0.112^{ns}	0.552^{ns}	0.069^{ns}	0.021*	0.000***	0.001**	0.000***
	Mean	91.60	92.9	6.02	1.02	50.40	89.30	8.13	8.87	17.00
	CV (%)	4.23	3.51	50.04	149.71	12.07	4.93	35.50	20.64	17.99

*, **, ***Significant at 0.05; 0.01 and 0.001 probability levels, respectively, and ns – Not significant by F test;
YE – Yield environment; PD – Plant density; CV – Coefficient of variation

Table 3. Values of first count (FC), germination (GE), abnormal seedlings (AS), electrical conductivity (EC) in low-yield (LY) and high-yield (HY) environments at different plant densities (PD) in the sowing row

Cultivar	PD	FC (%)			GE (%)			AS (%)			EC (μS cm^{-1} g^{-1})		
		LY	HY	Mean	LY	HY	Mean	LY	HY	Mean	LY	HY	Mean
Ativa	10	89	89	89 ab	91	90	91 ab	6.8	7.8	7.3 ab	47	52	49 b
	15	89	88	89 ab	91	90	91 ab	6.8	6.5	6.7 ab	47	53	50 ab
	20	87	85	86 b	89	89	89 b	9.0	7.3	8.2 a	59	56	58 a
	25	88	96	92 a	91	97	94 a	6.8	2.0	4.4 b	51	54	53 ab
	30	94	94	94 a	95	95	95 a	4.0	3.8	3.9 b	53	52	53 ab
	Mean	90	90		91	92		6.7	5.5		51	53	
5909	5	94	93	94 a	96	93	95 a	3.5	5.3	4.4 b	49	54	52
	10	93	92	93 a	93	94	94 ab	6.5	4.8	5.7 ab	49	59	54
	15	87	89	88 b	90	92	91 b	9.3	7.5	8.4 a	42	58	50
	20	91	90	91 ab	94	92	93 ab	5.3	7.5	6.4 ab	44	52	48
	25	95	92	94 a	96	93	95 a	4.3	6.5	5.4 b	50	47	49
	Mean	92	91		94	93		5.8	6.3		47 B	54 A	

*Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ by Tukey test ($\alpha = 0.05$)

by Crusciol et al. (2002), who also found increment in seed PQ when PD was increased. PDs of 25 and 30 plants m^{-1} also led to the lowest percentages of abnormal seedlings in the cultivar Ativa, with values of 4.4 and 3.9%, respectively. Increments in germination and reduction of abnormal seedlings for the cultivar Ativa may be related to the high seed weight, but this parameter was not measured in the present study. Higher PDs led to higher intraspecific competition, causing reduction in the size of the seeds and reduction in the mechanical damage at harvest (Marcos Filho, 2005). Mechanical damages are common in soybean seeds, especially under unfavorable conditions of harvest, since the embryo axis is located under a not much thick integument (Marcos Filho, 2005). Santos et al. (2005) found lower values of germination in larger seeds.

For the cultivar 5909, germination showed higher variability between the PDs. On average, the PD of 15 plants m^{-1} led to the lowest percentages, whereas the other PDs did not differ from one another (Table 3). PD also led to variable results of abnormal seedlings, since the lowest values were found with PD of 5 plants m^{-1}, without differing from 10, 20 and 25 plants m^{-1}. Lowest electrical conductivity values were found at the lowest PD in the cultivar Ativa, without differing from 5909. Electrical conductivity is related to the quantity of ions leached in the soaking solution and, therefore, it indirectly evaluates seed deterioration as a function of the structure of its cell membranes (Vieira & Krzyzanowski, 1999). The mean values obtained indicate that, regardless of PD, seeds showed satisfactory PQ for this variable (Vieira & Krzyzanowski, 1999).

Significant interaction was observed between YE and PD for accelerated aging, root length, hypocotyl length and seedling length in both cultivars (Table 2). For the cultivar Ativa, in the LY, vigor percentage after the aging test showed the lowest values at PD of 15 plants m^{-1}, not differing in the other PDs. In the HY, the PDs did not differ (Table 4).

For the cultivar 5909, seed vigor was higher at PDs of 5 and 15 plants m^{-1}, in LY and HY, respectively. These results differ from those reported by Vazquez et al. (2008), who observed no influence of PD on vigor after the aging test. Considering the obtained values, the variable-rate seeding could be used to equalize the vigor in the production field, but differently for each cultivar. In general, for the cultivar Ativa, PDs > 20 plants m^{-1} could be recommended for LY, whereas lower PDs would be recommended for HY, because they did not differ (Table 4). For the cultivar 5909, due to the high branching potential, the PD of 5 plants m^{-1} could be recommended for LY, whereas maintenance of standard PD (15 plants m^{-1}) could be recommended for HY. Carvalho et al. (2014) also concluded that seed PQ dynamics was related to the genotype evaluated. Considering the mean value of all PDs evaluated, the vigor after aging test was 7% (Ativa) and 1% (5909) higher in HY, compared with LY (Table 4).

In studies conducted by Pádua et al. (2010), the authors observed that seeds with higher vigor after the aging test also resulted in more productive plants. Hence, considering the obtained results, seeds originated in environments with high yield potential can be more tolerant to stress and lead to more uniform stands when sowing conditions are not favorable. In the studied field, although precision agriculture tools were adopted, including georeferenced soil sampling and variable-rate fertilizer application, the HY was characterized by higher OM contents, P contents and CEC in all layers evaluated, compared with LY (Table 1). Mondo et al. (2012) and Mattioni et al. (2013) observed positive relationship between seed PQ and soil fertility. According to Panozzo et al. (2009), plants originated from high-vigor seeds produce 17% more pods in comparison to those originated from low-vigor seeds. Likewise, Scheeren et al. (2010) concluded that high-vigor seeds led to taller plants until 75 days after sowing, besides higher yield. Therefore, in addition to variable-rate seeding, YE-optimized harvest is also an alternative, aiming to separate lots with different values of vigor in the same production field. Lots from HY can ensure an adequate plant stand in sites with unfavorable conditions of emergence at sowing. Root length showed high CV% (Table 2) and, as in hypocotyl length and seedling length, no trends were observed between YE and PDs for the cultivars evaluated, making it difficult to use these parameters as predictors for future recommendations (Table 4).

Variations in seed PQ as a function of YEs and PDs reveal the possibility of improvement in the management of seed production fields. Optimized harvest and separation of lots by YEs emerge as a new strategy, and variable-rate seeding becomes an option to reduce the spatial variability of vigor. For this latter, the response depends on the cultivar. Cultivars with low branching potential (Ativa) can be sown at higher PD in the LY, whereas for cultivars with high branching potential (5909), the PD can be reduced in the LY. The effects of both

Table 4. Accelerated aging (AA), root length (RL), hypocotyl length (HL) and seedling length (SL) in low-yield (LY) and high-yield (HY) environments at different plant densities (PD) in the sowing row

Cultivar	PD	AA (%)		RL (cm)		HL (cm)		SL (cm)	
		LY	HY	LY	HY	LY	HY	LY	HY
Ativa	10	80 aB*	87 aA	10.8 bA	9.1 bcB	10.1 aA	9.4 aA	20.9 bA	18.5 abB
	15	69 bB	88 aA	13.1 aA	9.8 abB	10.2 aA	9.4 aA	23.2 aA	19.2 bB
	20	85 aA	87 aA	9.8 bA	7.5 cB	8.6 bA	9.4 aA	18.4 cA	16.9 cB
	25	87 aA	90 aA	9.3 bB	11.4 aA	8.6 bB	9.8 aA	17.9 cB	21.2 aA
	30	89 aA	92 aA	9.5 bA	9.9 abA	9.8 abA	9.6 aA	19.2 bcA	19.5 abA
	Mean	82	89	10.5	9.5	9.5	9.5	19.9	19.1
5909	5	97 aA	89 abB	8.5 aB	11.9 aA	8.6 bcA	8.7 aA	17.1 aB	20.6 aA
	10	87 bA	91 abA	7.3 abA	8.1 bcA	9.3 abA	8.5 aB	16.6 aA	16.6 bcA
	15	88 abA	94 aA	6.4 bA	6.0 dA	8.0 cA	8.8 aA	14.4 bA	14.7 cA
	20	85 bA	84 bA	9.0 aA	9.0 bA	8.8 bcA	9.2 aA	17.8 aA	18.3 bA
	25	87 bA	92 abA	8.1 abA	7.1 cdA	10.0 aA	8.7 aB	18.1 aA	15.8 cB
	Mean	89	90	7.9	8.4	8.9	8.8	16.8	17.2

*Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ by Tukey test ($\alpha = 0.05$)

variable-rate seeding and separated harvest should be further investigated in future studies.

Conclusions

1. Seed vigor spatial variability can be reduced in the production field by adjusting plant density according to the yield environment.

2. For the cultivar with low branching potential, plant density can be increased in low-yield environments, whereas for the cultivar with high branching potential, plant density can be reduced, to increase vigor.

3. Optimized harvest and according to yield environment can allow the separation of seed lots with greater vigor, originated from high-yield environments.

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