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Physiological quality of soybean seeds produced under different spatial arrangements of plants

Caio Sippel Dörr[1], Tainan Lopes de Almeida[1], Victor Mouzinho Spinelli[2], Deivid Araújo Magano[3*], Luciano Carlos da Maia[1], Luis Eduardo Panozzo[1]

[1]Universidade Federal de Pelotas/UFPEL, Departamento de Fitotecnia, Pelotas, RS, 96.160-000, Brazil
[2]Universidade Federal de Rondônia/UNIR, Departamento de Biologia, Porto Velho, RO, 76801-059, Brazil
[3]Universidade Regional do Noroeste do Estado do Rio Grande do Sul/Unijuí, Departamento de Estudos Agrários/ Deag, Ijuí, RS 97800-800, Brazil

***Corresponding author: maganodeivid@gmail.com**

Abstract

The present study aimed to evaluate the physiological effect of seeds on soybean genotypes in the southern region of Rio Grande do Sul. The test was developed in the field, in two agricultural crops, on a farm located in the District of Monte Bonito - Pelotas (RS, Brazil), in eutrophic haplic planosol soil, with geographic coordinates 31° 40' 27"S and 52°23' 28 "W. The experiment consisted of twelve treatments involving two factors: factor A - 3 soybean genotypes (NA 5909 RR (super early, growth indeterminate and maturation group A), NS 6006 IPRO (high grain weight, growth indeterminate and maturation group B 5.9), and NS 5959 IPRO (precocity, indeterminate growth and maturation group C) and factor B - 4 line spacing (0.17; 0.30; 0.45 and 0.60 meters). The experimental design used was randomized blocks in a factorial scheme (3x4) with four blocks. The plant population used was 330.000 plants ha-1. The evaluations of the physiological performance of seeds were germination, first germination count, length and dry matter of aerial part, root, and a total of seedlings, accelerated aging, and emergence in the field. Soybean plants better distributed in the cultivation area, in spacings of 0.17 and 0.30 meters, present greater plant height, stem diameter, and productive performance.the only genotype that presented a reduction in germination as the row spacing increased was 'NS 6006 IPRO', resulting in seeds with lower germination in the spacings of 0.45 and 0.60 m compared to the other genotypes under study. The reduction in the spacings, 0.17 and 0.30 meters, produced seeds with better physiological quality, evidenced in years with rain preceding the harvest.

Keywords: *Glycine max*. Productivity. Physiological quality of seeds.

Introduction

Soybean seed producers in Brazil are thirstier for new technologies to provide the market with a competitive product of the highest quality. Among the rules of seed quality, the physiological attributes involve seed metabolism to express its full potential, which is quantified and evaluated through germination and vigor analysis (Peske et al., 2012).

The use of soybean seeds of high physiological quality, that is, with high germination and vigor, is the starting point in a crop to obtain the highest levels of productivity, allowing the genotype to express its full productive potential (Rossi et al., 2017; Dörr et al., 2018; Bagateli et al., 2019). Seeds of high physiological quality provide faster and more uniform formation of the desired plant stand (Scheeren et al., 2010), with better initial plant growth (Kolchinski et al., 2006), resulting in higher grain yield at the end of the cycle (Rossi et al., 2017; Dörr et al., 2018; Bagateli et al., 2019). However, soybean seed production of high physiological quality is a challenge to overcome for producers. The physiological quality of seeds is affected by several factors in the field, mainly climatic, nutritional, and phytosanitary (França-Neto et al., 2018). Soybean seed production in the southern region of Rio Grande do Sul has special peculiarities, mainly due to its soil conditions with frequent periods of flooding, associated with high relative humidity and high temperatures (Ludwig et al., 2015). Therefore, new technologies need to be developed and enable the production of soybean seeds with high germination and vigor in this region. Changes in water and nutrient availability and the interception of solar radiation can be interesting strategies to produce seeds of superior physiological quality (Carvalho et al., 2015; Zambiazzi et al., 2017; Marin et al., 2015). Based on this, the distribution of plants in a soybean seed production field can be an interesting tool since soybean plants grown under different arrangements in the space with kind conditions promotes the production of seeds with changes in the nutritional constitution, including differences related to stachyose and raffinose content (Silva et al., 2013; Ragin et al., 2014; Bellaloui et al., 2015, Matsuo et al., 2017). Therefore, this study aims to evaluate the physiological performance of seeds of soybean genotypes produced under different arrays of plant distribution.

Results

Exploratory analysis for the effect of row spacing

According to the results of the different evaluations carried out, arrays of plants influence the physiological quality of the seeds produced. Seeds produced under different spacing between plants in the field showed significant differences in germination, first germination count, accelerated aging, field emergence, seedling length, and dry matter results dependent on the production environment (crops). In the 2015/16 crop, in the period preceding the harvest, slightly higher temperatures of 35 °C and frequent rain caused deterioration in the field and affected the physiological quality of the seeds produced (Figure 2, Table 1). In this crop, it was also possible to observe the effects of the different arrangements between plants studied when compared to the 2016/17 crop, in which the environment was more conducive to the production of seeds of high physiological quality.

The germination results of the seeds produced in the 2015/16 harvest show no interaction between the factors under study due to isolated effect of the genotype and row spacing (Table 1). Regarding the spacing between the crop lines, a linear reduction was observed in the average of all genotypes as the spacing increased within the studied range of 0.17 to 0.60 meters (Figure 2B). Seeds produced under 0.60 m spacing showed, on average, a 15% reduction in germination potential compared to seeds produced using 0.17 m spacing. The germination average of each genotype, the NS 5959 IPRO, and NA 5909 RR genotypes are similar and present superior germination than the NS 6006 IPRO genotype.

As for the seeds produced in the 2016/17 harvest, seed germination showed an interaction between the factors under study. In this season, the germination of seeds showed higher rates, regardless of spacing and genotypes, possibly due to climatic conditions. In this sense, the only genotype that showed reduced germination as the spacing between rows increased was NS 6006 IPRO (Figure 2), resulting in seeds with lower germination in the spacings of 0.45 and 0.60 m compared to the other genotypes under study (Table 2).

Relative contribution of seed physiological performance variables and genotype

In the first germination count for the season 2015/16, there was an interaction between the factors under study (Table 3 and Figure 4). For the NS 6006 IPRO genotype, if we observe the averages in the graph, it is possible to verify that exists a reduction in the first germination count as the spacing between the lines increased. However, there was no adjustment for a trend line. For the other genotypes, a quadratic trend of response to the increase in spacing was observed. The NS 5959 IPRO genotype showed a quadratic tendency to increase in the first germination count, and the NA 5909 RR presented a quadratic tendency to reduce as the spacing between the sowing lines increased. These results did not reflect on the germination potential. Data from the first germination count, collected in the 2016/17 crop, did not show any interaction between the factors under study (Table 3). It was also not possible to identify the effect of the spacing between the crop lines. Only the genotype effect NA 5909 RR genotype showed a higher first germination count than the NS 6006 IPRO genotype, and the NS 5909 IPRO genotype presented itself intermediately, not differing from the others (Table 3).

According to the accelerated aging data (Table 1), in the 2015/16 harvest isn't possible to identify the interaction between the factors under study, only isolated effects of the spacing between lines and the genotypes. The NS 6006 IPRO genotype presented a lower performance than the others. Regarding the spacing between lines, we checked that the average genotypes in the different spacings showed a linear tendency to reduce, like in the germination test. However, in accelerated aging, the degree of declination of the line is higher. Seeds produced at 0.60 m spacing showed 19% lower performance than seeds cultivated at 0.17 m spacing.

In the 2016/17 harvest, we did not observe significant interaction. Nonetheless, some factors changed to accelerate aging results. These results are like those observed in the germination and first germination count tests. The emergence in the field showed a significant effect on the spacing between rows in the 2015/16 season. In this sense, whenever we increase the spacing between rows, we observe that the productivity of seeds decreases.

Regarding the qualitative effect of the genotypes, in the 2015/16 season, the cultivars NS 5959 IPRO and NA 5909 RG were superior, and in the 2016/17 season, cultivar NS 6006 IPRO presented higher field emergence than further.

Therefore, in an environment of high oxidative stress, that is, frequent rains after physiological maturity associated with high temperatures, similar to what occurred in the first crop of the experiment, seeds produced under reduced spacing may present a greater capacity to withstand these problems in the pre-harvest, as they were done by plants that make better use of the resources available in the environment, resulting in the production of seeds with greater vigor.

Regarding the growth of seedlings in the lab, the effects of row spacing in the 2015/16 season compared to 2016/17 were observed. In the 2015/16 season, there is an effect of the spacing between the crop rows on the total length of seedlings and their roots as the spacing between rows increases; there is a quadratic tendency to reduce the performance of the seedlings in the average of all the genotypes. However, if we analyze the dry matter of the roots, it is observed that as the spacing between rows increased, there was a linear tendency to increase the dry matter, but the slope angle was quite low, in such a way that it did not impact the total dry matter of the seedling.

In the season 2016/17, the effect of row spacing in total length and shoot dry mass on the average of all genotypes. As the spacing between rows increases, small increments are observed with a quadratic trend to response in the total length of the seedlings. For seedling shoot dry matter, a quadratic response trend where initially at the spacings of 0.17 and 0.30 m there is a rapid increase, and later stabilization of the increase in dry matter followed by a slight decrease to 0.60 m spacing.

Regarding the genotypes studied, it is worth noting that, in the 2015/16 crop, for the variables total dry mass and shoots of seedlings, there was an interaction between the factors, which means that depending on the spacing in which the seeds were produced, a different genotype showed high seedling growth. On the other hand, for the 2016/17 harvest, only the root dry mass variable showed an interaction between the factors under study. The results of seedling growth obtained in this 2015/16 season demonstrated seed vigor. The reduction in spacing

Table 1. Germination, first germination count, accelerated aging and field emergence of seed samples of soybean genotypes produced under different row spacing, in two agricultural harvests, Pelotas-RS, 2020.

E. L. (m)	Plant genotype					
	A	B	C	A	B	C
Germination (%)						
	Harvest 2015/16			Harvest 2016/17		
0.17	86.0	71.0	89.0	99.0 a	96.0 a	98.0 a
0.30	81.0	61.0	95.0	96.0 a	96.0 a	97.0 a
0.45	78.0	67.0	89.0	97.0 ab	95.0 b	99.0 a
0.60	90.0	45.0	76.0	97.0 a	91.0 b	98.0 a
Média	84.0 a	61.0 b	87.0 a	97.0	94.0	98.0
C.V. (%)		19.4			2.0	
First Germination Count (%)						
	Harvest 2015/16			Harvest 2016/17		
0.17	70.0 ab	56.0 b	80.0 a	97.0	95.0	96.0
0.30	61.0 b	35.0 c	84.0 a	95.0	93.0	95.0
0.45	62.0 b	38.0 c	83.0 a	94.0	94.0	97.0
0.60	78.0 a	29.0 b	66.0 a	94.0	89.0	97.0
Média	68.0	40.0	78.0	95.0 ab	93.0 b	96.0 a
C.V. (%)		17.8			2.6	
Accelerated Aging (%)						
	Harvest 2015/16			Harvest 2016/17		
0.17	81.0	53.0	85.0	91.0^{ns}	93.0	91.0
0.30	75.0	35.0	90.0	91.0	94.0	92.4
0.45	68.0	43.0	85.0	89.0	92.0	92.0
0.60	85.0	27.0	65.0	88.0	90.0	91.0
Média	77.0 a	40.0 b	82.0 a	90.0	92.0	91.0
C.V. (%)		22.9			3.8	
Field emergency (%)						
	Harvest 2015/16			Harvest 2016/17		
0.17	73.0	62.0	78.0	92.0	92.0	92.0
0.30	77.0	46.0	88.0	92.0	96.0	91.0
0.45	70.0	52.0	85.0	90.0	96.0	92.0
0.60	81.0	39.0	67.0	91.0	98.0	93.0
Média	76.0 a	50.0 b	80.0 a	92.0 b	96.0 a	92.0 b
C.V. (%)		19.8			3.1	

*Means followed by the same lowercase letter on the line, within each season studied, do not differ by Tukey's test at 5% probability of error. (A - NS 5959 IPRO; B - NS 6006 IPRO; C - NA 5909 RG; E.L. - spacing between lines; C.V. - coefficient of variation)

Table 2. Total length of shoots and roots of seedlings from seed samples of soybean genotypes produced under different row spacing, in two agricultural seasons, Pelotas-RS, 2020.

E. L. (m)	Plant genotype					
	A	B	C	A	B	C
Total Seedling Length (mm)						
	Harvest 2015/16			Harvest 2016/17		
0.17	156.0	144.0	171.0	175.0	172.0	195.0
0.30	154.0	134.0	185.0	165.0	186.0	184.0
0.45	162.0	126.0	170.0	171.0	183.0	187.0
0.60	152.0	112.0	166.0	164.0	220.0	173.0
Média	156.0 b	129.0 c	173.0 a	169.0 b	190.0 a	185.0 ab
C.V. (%)		8.7			13.4	
Aerial part length of seedlings (mm)						
	Harvest 2015/16			Harvest 2016/17		
0.17	74.0	67.0	75.0	72.0	80.0	91.0
0.30	74.0	64.0	89.0	73.0	74.0	91.0
0.45	76.0	63.0	84.0	73.0	84.0	89.0
0.60	71.0	56.0	83.0	71.0	79.0	87.0
Média	73.0 b	62.0 c	83.0 a	71.0 c	79.0 b	88.0 a
C.V. (%)		8.7			7.0	
Root Length (mm)						
	Harvest 2015/16			Harvest 2016/17		
0.17	83.0	77.0	88.0	108.0^{ns}	92.0	97.0
0.30	80.0	70.0	96.0	90.0	113.0	94.0
0.45	87.0	63.0	86.0	98.0	99.0	101.0
0.60	81.0	56.0	83.0	93.0	141.0	87.0
Média	83.0 a	67.0 b	88.0 a	97.0	111.0	95.0
C.V. (%)		12.3			22.4	

* Means followed by the same lowercase letter on the line, within each season studied, do not differ by Tukey's test at 5% probability of error. (A - NS 5959 IPRO; B - NS 6006 IPRO; C - NA 5909 RG; E.L. - spacing between lines; C.V. - coefficient of variation)

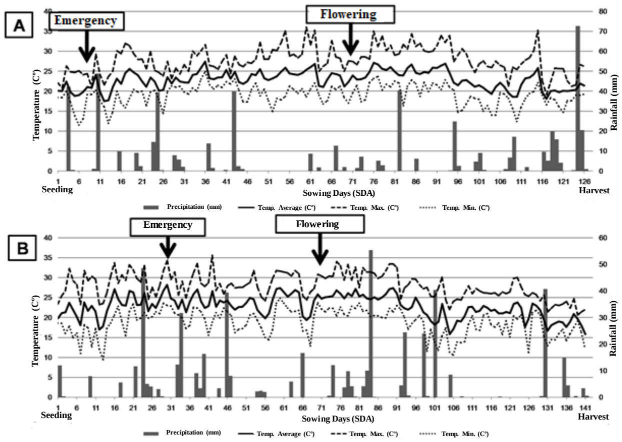

Fig. 1 Maximum temperature (Max Temp), minimum temperature (Min Temp), average temperature (Average Temp of the years) and Average temperature during the B. 2016/2017 harvest period, Pelotas – RS. Source: Pelotas Agroclimatological Station (EMBRAPA/UFPel).

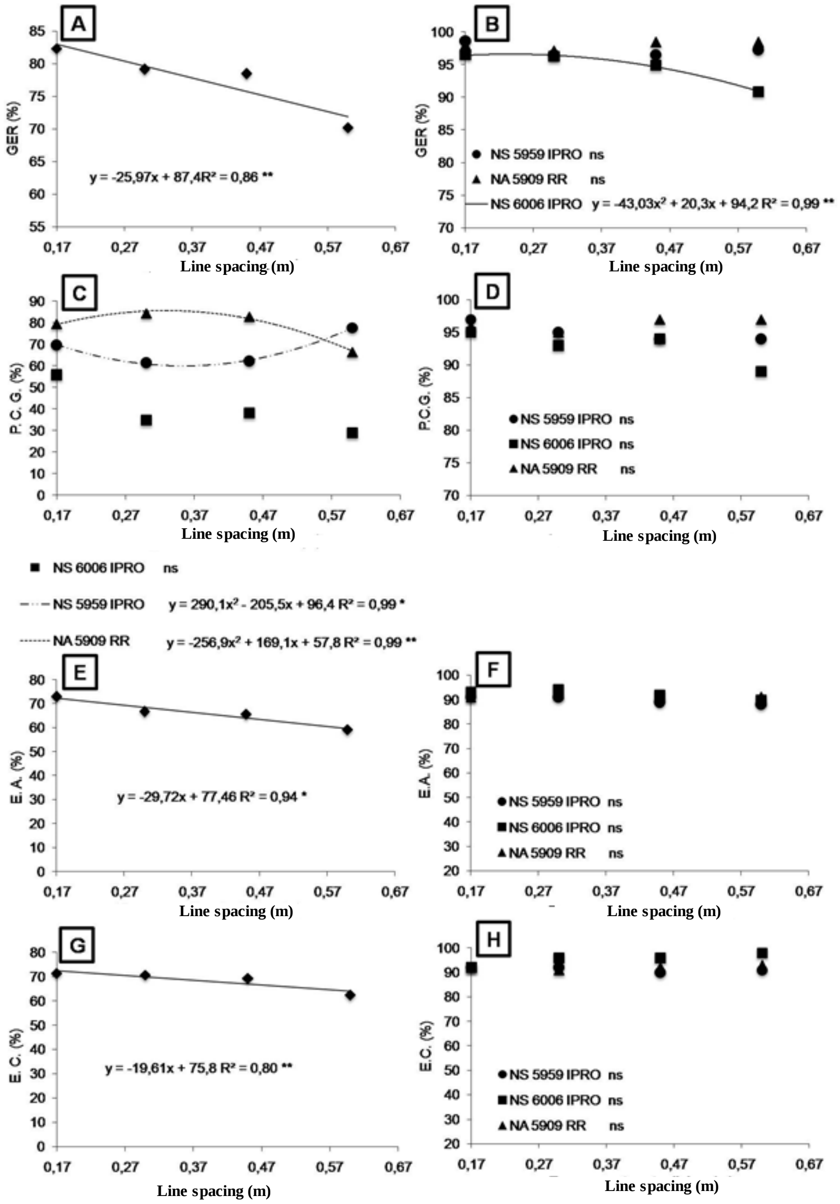

Fig. 2 Germination (GER, A-2015/16, B-2016/17), first germination count (P.C.G., C- 2015/16, D-2016/17), accelerated aging (E.A., E-2015/16 , F-2016/17) and field emergence (EC, G-2015/16, H-2016/17) of seeds of three soybean genotypes produced under different row spacing, in two agricultural seasons, Pelotas-RS, 2020.

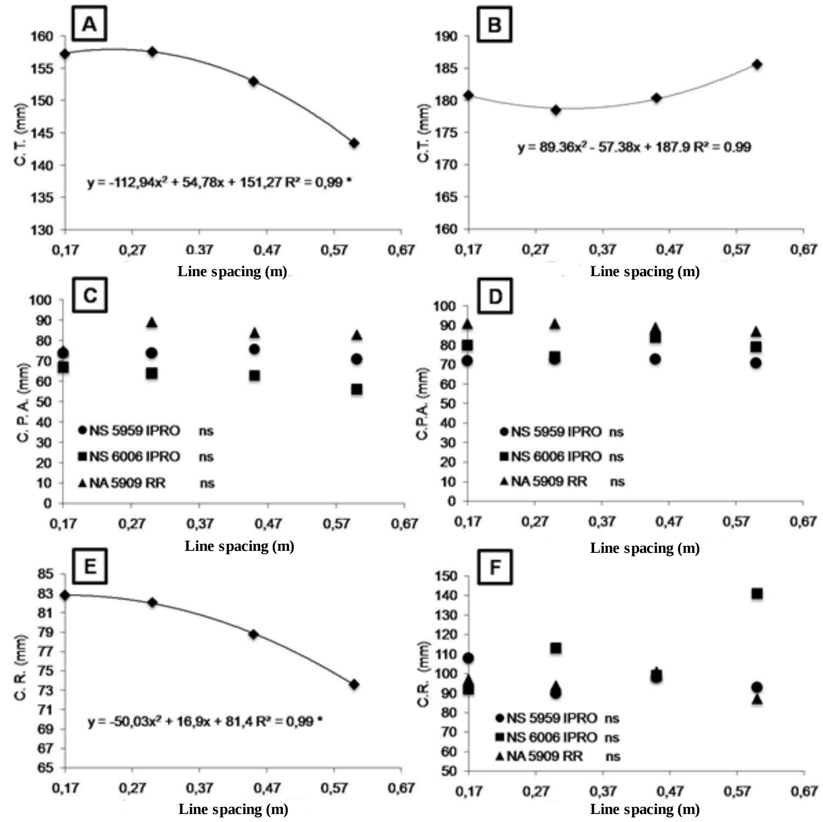

Fig. 3 Total length (C.T., A-2015/16, B-2016/17), shoot (C.P.A., C-2015/16, D-2016/17) and root (C.R., E-2015/16, F-2016/17) of seedlings from seeds of three soybean genotypes produced under different row spacing, in two agricultural harvests, Pelotas-RS, 2020.

Table 3. Total dry mass of shoots and roots of seedlings from seed samples of soybean genotypes produced under different spacing between rows, in two agricultural seasons, Pelotas-RS, 2020.

E. L. (m)	Plant genotype					
	A	B	C	A	B	C
Total dry mass of seedlings (mg)						
	Harvest 2015/16			Harvest 2016/17		
0.17	31.1 a	30.8 a	25.1 a	32.1	31.4	30.3
0.30	30.6 a	32.7 a	28.2 a	30.2	32.0	32.0
0.45	33.5 a	25.4 b	28.0 ab	31.0	33.2	31.4
0.60	31.8 a	23.8 b	27.0 ab	30.3	33.4	29.9
Média	31.7	28.2	27.1	30.9 b	32.5 a	30.9 b
C.V. (%)		11.9			5.4	
Seedling aerial part dry mass (mg)						
	Harvest 2015/16			Harvest 2016/17		
0.17	21.2 a	20.4 a	19.4 a	22.4	23.1	23.0
0.30	20.2 b	25.0 a	20.0 a	21.7	23.9	24.7
0.45	22.1 a	18.5 a	19.5 a	21.9	24.7	24.0
0.60	20.4 a	17.7 a	19.3 a	22.2	24.4	22.8
Média	21.0	20.4	19.5	22.1 b	24.0 a	23.6 a
C.V. (%)		12.5			6.4	
Root dry mass (mg)						
	Harvest 2015/16			Harvest 2016/17		
0.17	9.8	10.4	7.3	9.7 a	8.3 b	7.3 c
0.30	10.4	8.2	8.2	8.5 a	8.0 ab	7.3 b
0.45	11.4	9.4	8.5	9.1 a	8.5 a	7.4 b
0.60	13.0	9.3	7.8	8.2 ab	9.0 a	7.3 b
Média	11.1 a	9.3 b	7.9 c	8.9	8.4	7.3
C.V. (%)	14.4		6.6			

*Means followed by the same lowercase letter on the line, within each season studied, do not differ by Tukey's test at 5% probability of error. (A - NS 5959 IPRO; B - NS 6006 IPRO; C - NA 5909 RG; E.L. - spacing between lines; C.V. - coefficient of variation)

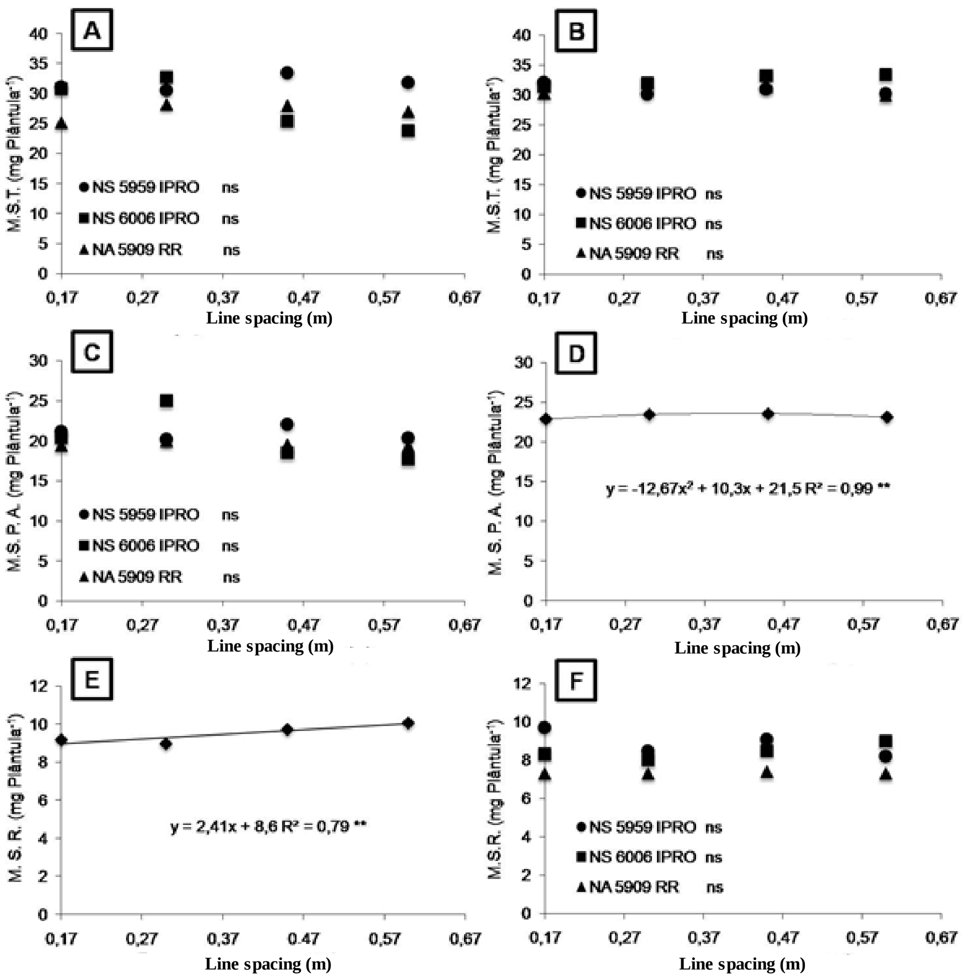

Fig. 4 Total dry mass (M.S.T., A-2015/16, B-2016/17), shoot (M.S.P.A., C-2015/16, D-2016/17) and root (M.S.R., E-2015/16) , F-2016/17) of seedlings from seeds of three soybean genotypes produced under different row spacing, in two agricultural seasons, Pelotas-RS,2020.

promoted the production of more vigorous seeds. The environmental conditions during the 2016/17 season allowed the production of high-performance seeds and effects concerning the spacing between crop rows. In general, according to the study conditions, the use of reduced spacing in soybean cultivation favors the production of seeds with higher physiological quality than those produced in larger spacings. However, if the production occurs in an environment favorable, that is, dry and with mild temperatures, the effect of spacing between crop rows reduces.

Discussion

In general, for the variable's germination, the first germination count accelerated aging and field emergence in the first harvest of the experiment, so it was possible to identify significant effects of the spacing between sowing lines on the performance of the seeds for these analyses. These results may be related to the action of the environment, which in the first harvest showed frequent rains during maturation, causing high levels of deterioration in the pre-harvest, and in the second harvest, there was an environment with less frequent rains and mild temperatures, that, an environment more favorable to seed production, causing less deterioration in the field (Bueso et al., 2017).

Soybean plants grown under reduced spacing show better use of mineral nutrients and water in the soil, and better use of available solar radiation, resulting in the production of

seeds with higher levels of soluble oligosaccharides, the so-called cell protectors, mainly stachyose and raffinose (Silva et al., 2013; Ragin et al., 2014; Bellaloui et al., 2015, Matsuo et al., 2017).

The mechanisms that reduce the deterioration of seeds in the field are still not understood. (Bueso et al., 2017), reinforces that structural characteristic of the tegument or molecular alterations related to genetic mutations, alterations in the cellular protection and repair systems, and even hormonal concentrations in the seed. In this sense, Bellaloui et al. (2015) observed that soybean seeds produced under reduced spacing had higher concentrations of stachyose and raffinose. These soluble oligosaccharides are protector cell membranes during the process of seed dehydration through their stabilization (Peske et al., 2012). Nonetheless, the higher concentration of these sugars in the seeds does not necessarily result in seeds with higher germination and vigor (Dierking & Bilyeu, 2009). Therefore, possibly, only in years with an environment that favors the deterioration process of seeds in the field, the better distribution of plants in the area affects the seed's physiological quality. In years with favorable environments to produce seeds of high physiological quality, these differences are not observed since the higher concentration of soluble sugars alone does not necessarily promote germination and seed vigor. Only in years with an environment that favors the deterioration process of seeds in the field, the better distribution of plants in the area has a favorable effect on the seed's physiological quality.

In general, with the results of the physiological quality of seeds during the two years of the experiment, it can be inferred that the genotype NS 6006 IPRO presents greater sensitivity to the cultivation and environmental conditions for the physiological quality of seeds. In the first harvest, the genotype NS 6006 IPRO presented the lowest physiological quality of seeds. The second harvest showed an effect in the germination between the different spacings between the lines studied. For seed production of high quality, the genotype effect is significant. However, the interaction between genotype and environment was decisive, which means that in different years we can have differential responses for each genotype under study (Bornhofen et al., 2015).

These results show that plants grown in reduced spacing produce seeds with higher content of stachyose and raffinose, oligosaccharides, that act in their acclimatization so that after physiological maturity withstand the stresses of the natural dehydration process (Bellaloui et al., 2015, Peske et al., 2012). In this analysis, plants grown under reduced spacing present a better use of radiation due to greater light entrance in the plant canopy (Silva et al., 2013; Matsuo et al., 2017), granting faster drying of pods/seeds after rain. Another aspect is that plants growing under reduced spacing showed higher use of the nutrients made available obtained by fertilization, resulting in higher productivity (Jardim Rosa et al., 2016) and possibly in seeds with adequate mineral composition. The chemical composition of kernels considering macro and micronutrients, maybe influence the physiological performance (Zambiazzi et al., 2017; Rigo et al., 2018).

Materials and methods

Plant material and experimental setup and climatic data monitoring

The study was conducted in the Graduate Program in Seed Science and Technology at the Federal University of Pelotas, and the experiment was carried out in the field in two crops (2015/2016 harvest and 2016/2017 harvest), in the District of Monte Bonito - Pelotas (RS-Brazil), with the geographic coordinates 31° 40' 27" S and 52°23' 28" W. The daily climatic data of precipitation and maximum, average, and minimum daily temperature, referring to the duration of the tests, were collected at the EMBRAPA/UFPel meteorological station and are illustrated in Figure 1.

Experimental design and treatments

The experiment consisted of twelve treatments involving two factors: factor A – 3 soybean genotypes (NA 5909 RR, NS 5959 IPRO, NS 6006 IPRO) and factor B – 4 line spacing (0.17; 0.30; 0 .45 and 0.60 meters). The experimental design used was randomized blocks in a 3x4 factorial scheme with four blocks. Each plot had a dimension of 2.4 meters wide and 4 meters long. for the evaluations, 0.6 meters were discarded on each side of the plots and 0.5 meters on each end to serve as a border. The area was prepared with plowing and two tilling to reduce the presence of clods of earth and impediment barriers to avoid losses to the emergence of *seedlings*. Subsequently, in possession of the soil analysis, fertilization was carried out according to the recommendations of the CFQS RS/SC (Commission on Fertility and Soil Chemistry - RS/SC, 2016) for soybean cultivation, incorporating the nutrients into the soil in the soil. Sowing was carried out manually in furrows at a sowing density of 50 seeds per meter. Subsequently, the thinning of plants seeks to adjust the spacing between plants in the row according to the spacing between the rows of each plot, maintaining the same population of plants per area. The plant population used for the experiment was 330 thousand plants per hectare, thus seeking to meet the recommendation of the plant population of all genotypes. The cultural treatments and pest management followed the Technical Indications for Soybean Culture in Rio Grande do Sul and Santa Catarina. Plants reached the phenological stage of R8, seeds were harvested to evaluate their physiological quality through germination, first germination count, length, and matter tests. Shoot, roots and total seedling dryness accelerated aging and field emergence. Germination was done with four subsamples of 50 seeds for each experimental unit, placed in a substrate of germination paper "germitest" previously moistened in distilled water using 2.5 times the mass of dried paper in the proportion of water, and kept at a temperature of 25°C. The evaluations were carried out according to the Rules for Seed Analysis (Brasil, 2009), expressing the results in the percentage of normal seedlings.

Measurements of plant characteristics

The first germination count determined the percentual of normal seedlings five days after sowing and germination eight days after sowing. The roots, shoot, and total length was performed with four subsamples of 20 seeds per repetition, distributed in germitest paper rolls moistened with distilled water using 2.5 times the dry paper mass, and kept in a germinator at 25 °C for five days (Nakagawa, 1999). A line was drawn on the moistened paper towel in the upper third in the longitudinal direction, with the micropyle downwards. At the end of the fifth day, the length of the shoot, root, and ten seedlings was assessed as normal using a millimeter ruler. Subsequently, the measurements of the seedlings' length and the dry mass of the aerial part, root, and the total of the same ten seedlings were recorded. The methodology used to determine the dry matter of seedlings was that of an oven at 70°C, keeping the seedlings up to constant weight in an analytical balance. The accelerated aging test was done using boxes with horizontal wire mesh fixed in the middle position and added to 40 mL of distilled water to the bottom of each box. In each repetition, the seeds were evenly distributed on the screen, forming a single layer to cover its surface. Subsequently, boxes with seeds were covered and placed inside a BOD-type incubator set at 41 ºC, where they were kept for 48 hours (Marcos Filho, 1999). After this incubation period, the seeds underwent a germination test, and the counting did on the fifth day after sowing.

Statistical analysis

The field analysis of seedling emergence was carried out by sowing 100 seeds per experimental unit. These seeds were distributed into two furrows, each measuring 1.0 m in length and 3.0 cm in depth, with a spacing of 20 cm between furrows. The field conditions remained without irrigation during the experiment. Twenty-first day after sowing, the percentage of normally emerged seedlings was recorded, considering seedlings with fully expanded cotyledons above the soil surface.

Subsequently, the collected data were tabulated, and the assumptions for the analysis of variance were checked.

When applicable, the data underwent an analysis of variance and were tested using the F test at a significance level of 5%. For the qualitative factor (genotype), a Tukey means comparison test was applied at a 5% significance level. In the case of the quantitative factor (spacing), a polynomial regression analysis was conducted at a 5% significance level. All statistical analyses were performed using the R software (2014).

Conclusions

In conclusion, our study demonstrates that the distribution of plants within the seed production field plays a crucial role in determining the physiological performance of seeds. Notably, utilizing reduced spacing of 0.17 and 0.30 meters proves to be a promising approach, as it yields seeds with enhanced physiological quality. This positive outcome is pronounced during years marked by the presence of rain and high temperatures in the period preceding the harvest. These findings shed light on the importance of thoughtful plant distribution strategies to optimize seed quality and ultimately enhance agricultural productivity in relevant climatic conditions.

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