

Individual and population behavior of soybean plants grown in rows with different proportions of high- and low-vigor seeds

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Abstract

The objective of the present work was to evaluate the influence of high- and low-vigor soybean seeds on the agronomic characteristics, yield components and seed yield of individual plants and plant communities grown in rows containing different proportions of high- and low-vigor seedlings. The experiment was conducted in the county of Selbach-RS, Brazil, in the 2012/2013 crop year using the short-cycle soybean cultivar FPS Urano RR. The experimental design was completely randomized, with five replications. Seven different proportions of high and low seedling vigor distribution along the growing line were selected: T1 (100% HV); T2 (83.3% HV and 16.7% LV); T3 (66.6% HV and 33.3% LV); T4 (50% HV and 50% LV); T5 (33.3% HV and 66.6% LV); T6 (16.7% HV and 83.3% LV); and T7 (100% LV), where HV and LV indicate high and low vigor, respectively. Based on the results obtained, it was found that: plants originating from high-vigor seeds were taller than low-vigor plants at the V5 and R8 phenological stages; even when populations originated only from seeds with low vigor, yield levels did not reach those found for high-vigor seeds; values of thousand seed weight and number of pods per plant with one seed did not differ between high- and low-vigor seeds, individually; the yield components number of seeds and seeds per plant contributed most to increase yield for the vigor proportions studied; and populations formed only of seeds with high vigor exhibited a seed yield per area 21% (928 kg ha^{-1}) greater than that formed only by low-vigor seeds.

Keywords: *Glycine max* (L.) Merrill; physiological quality; seed yield; yield components.

Introduction

Brazil is one of the world's leading producers of soybeans, with current production approaching approximately 118 million tons (Conab, 2018). This figure is a reflection of advances in research and new technologies applied to production, highlighting the current cultivars' yield potential, which may or may not be expressed by the physiological quality of their seeds. Peske et al. (2012) have argued that seed improvement allows farmers to exploit the full potential of cultivars through increases in genetic, physical and physiological quality.

According to Popinigis (1977), physiological quality is defined as the ability to perform vital functions, as characterized by germination, vigor and longevity that directly affect the implantation of the culture in the field. For Marcos Filho (2002), high-quality seeds possess several attributes of which physiological parameters are most significant, particularly germination and vigor. Based on this, the manifestation of low physiological potential in batches of

seeds includes a low germination rate, higher sensibility of seeds and seedlings to stress during this process, as well as plants exhibiting slow growing, reduced, uneven and smaller root development (Marcos Filho, 2015; Szareski et al., 2018a). This lower emergence rate is due to the fact that low-vigor seeds, before initiating the growth of the embryonic axis, require more time for the restoration of organelles and damaged tissues (Villiers, 1973).

When batches of low-vigor seeds are used, yield normally goes down due to the uneven establishment of plants and population to below that recommended for the cultivar, thus impairing production. As a result, low-vigor seeds are associated with decreased and uneven emergence, decreased initial height in seedlings, as well as reduction in dry matter production, leaf area, use of reserves and culture growth rate (Khah et al., 1989; Schuch, 1999; Schuch et al., 2000; Machado, 2002; Hofs, 2003; Schuch et al., 2009; Henning et al., 2010; Scheeren et al., 2010; Mielezski and

Marcos Filho, 2012; Zimmer et al., 2016; Zanatta et al., 2018; Vargas et al., 2018). This in turn affects the establishment of the culture, potentially influencing its performance during the growth cycle and hence also its final yield. According to Carvalho and Toledo (1978), low-vigor seeds have reduced capability and conditions with which to restore their damaged tissues, with the emergence of these seedlings occurring later than those of high vigor. Similarly, Khah et al. (1989) observed that rapid emergence, associated with faster seedling growth arising from high quality seeds, provided better yields than those of plants originating from low-vigor seeds.

Tekrony and Egli (1991) stated that the physiological potential of seeds can not only have an indirect influence on field yield by affecting the speed of emergence and emergence rate of seedlings and initial stands, but can also directly impact grain yield through its influence on plant vigor. In Kolchinski et al.'s (2005) study of plant communities comprising different levels of seed quality combinations, the authors observed that plants arising from high quality seeds have a better grain yield. These results thus indicate that the use of more vigorous seeds provides larger seedlings and greater initial growth, and may also affect the development of the culture throughout its cycle (Marcos Filho, 2015; Szareski et al., 2018).

Scheeren (2002) noted that soybean plants grown from high physiologic quality seeds exhibited greater height 21 days after sowing than those grown from low quality seeds, with this initial advantage sufficient to result in a better grain yield. Similar results were found by Kolchinski (2003), who reported that the use of high-vigor seeds in the establishment of soybean plant communities provided an increase of more than 35% in seed yield, in relation to the use of low-vigor seeds. Elsewhere, Melo et al. (2006) and Mielezrski et al. (2008) observed that rice plants arising from high-vigor seeds had a higher yield than those arising from low-vigor seeds.

Considering the above, the present work aimed to evaluate the effects of high- and low-vigor seedlings, distributed in varying proportions along a crop row of one meter in length, on the yield components and yield of seeds per area, both individually and in terms of the overall performance of the communities formed.

Results and discussion

Morphological and seed yield characteristics in individual plants

High-vigor plants had a greater average height in all treatments when compared with plants of low vigor from the same population, at the V5 phenologic stage (Fig. 1-a). This result was repeated, at R8, in treatments up to those comprising 50% plants of each vigor quality, after which, i.e. with a decrease in high-vigor plants in the population, the average plant height was equal between the two vigor levels studied (Fig. 1-b). It should also be noted that whereas an increase in low-vigor plants in the population at V5 resulted in a decrease in the average height of plants, the same pattern was not observed for high-vigor plants at R8, a

difference in height potentially reflecting a higher seed yield (Scheeren et al., 2010; Gabriel et al., 2018). In oats, Machado (2002) evaluated the behavior of plants until 30 days after emergence, finding that plants arising from seeds of high physiological quality were taller than low quality plants throughout the study period. This suggests that, despite their better growth capability, the high-vigor plants increased in height only until reaching the point that they could outstrip the surrounding plants, or at least until reaching the same height as the low-vigor plants, thereby having an advantage in terms of solar radiation intake. In the present study, a comparison of high-vigor plants in treatments T1 (100% HV) and T6 (16.7% HV) reveals a significant decrease in average plant height. Vanzolini and Carvalho (2002) observed that batches of low physiological quality soybean seeds produced smaller plants at 18 and 38 days after sowing, compared with medium and high quality batches. According to the authors, their results reflect the speed of emergence of seedlings originating from low quality seeds, which was significantly lower than that of the other batches tested. According to Edje and Burris (1971), soybean seeds of low vigor emerge slowly and produce plants of a smaller initial size.

Analysis of stalk diameter and number of ramifications (Fig. 1-c and Fig. 1-d) revealed significant differences. Comparing high- and low-vigor plants both within and between treatments, high-vigor plants exhibited a larger stalk diameter, as well as a higher number of ramifications for all HV:LV ratios. Similar results were reported in the study conducted by Tavares et al. (2013), where high-vigor seeds produced soybean plants with greater height and stalk diameter, under periods of hydric stress during vegetative stages. Kolchinski et al. (2006) observed that soybean plants arising from seeds of greater vigor presented higher culture growth rates, as well as greater plant dry matter and leaf area at 30 days after emergence, in comparison to plants with lower vigor.

When comparing plants within the same treatment, it is apparent that those of higher vigor produced more seeds per plant (Fig. 2-d) than those of low vigor. This result is largely due to the number of pods with two seeds, which rose with an increase in high-vigor plants in the crop row. The same relationship between the proportion of high-vigor plants and number of seeds per plant was also observed for pods containing one or three seeds per plant, although a lower number of these two types of pod were produced (Fig. 2-a and Fig. 2-c). However, the difference in the number of pods with one or three seeds was not significant between the 100% HV and 100% LV treatments.

The number of seeds and pods per plant may also be related to the higher content of soluble proteins, starch and sugars in more vigorous seeds (Henning et al., 2010; Szareski et al., 2018b), which may produce taller plants and possibly a higher number of reproductive nodes per plant.

Similar results were found by Popinigis (1973), where soybean seeds of high physiological quality produced plants with a greater number of racemes and pods, resulting in a greater seed yield. Likewise, Kolchinski et al. (2005) reported that a higher seed yield was observed in plants grown from

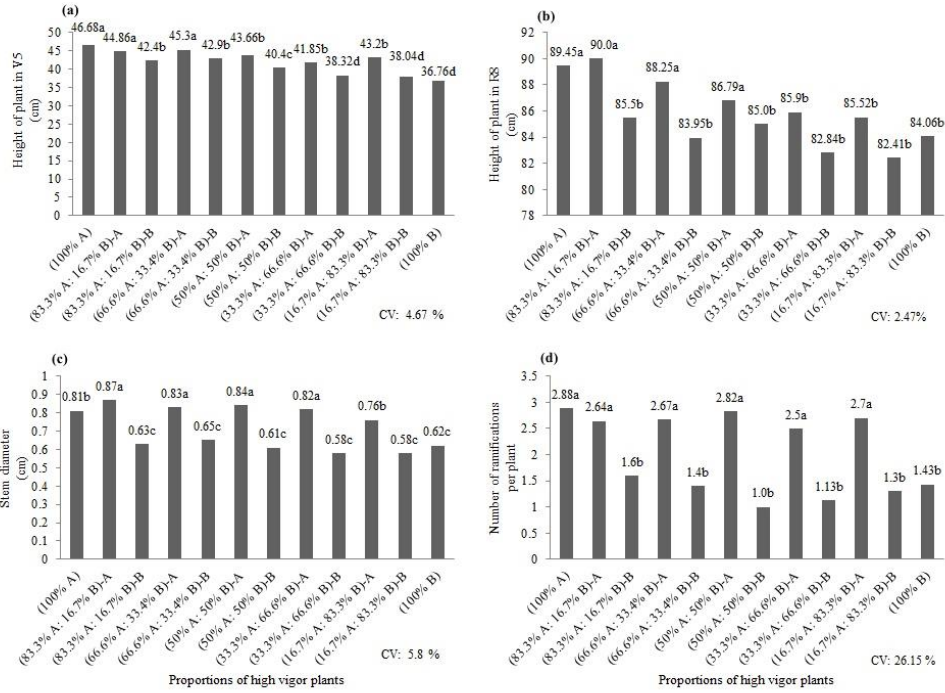


Fig 1. Individual height of soybean plants at the V5 (a) and R8 (b) phenological stages, stalk diameter (c) and number of ramifications per plant (d), in treatments consisting of different proportions of soybean plants with high and low vigor. Selbach-RS. A: high-vigor plants; B: low-vigor plants. T: treatment. T1 (100% A); T2 (83.3% A: 16.7% B)-A; T3 (66.6% A: 33.3% B)-A; T4 (50% A: 50% B)-A; T5 (33.3% A: 66.6% B)-A; T6 (16.7% A: 83.3% B)-A: high-vigor plants. T2 (83.3% A: 16.7% B)-B; T3 (66.6% A: 33.3% B)-B; T4 (50% A: 50% B)-B; T5 (33.3% A: 66.6% B)-B; T6 (16.7% A: 83.3% B)-B; T7 (100% B): low-vigor plants. ¹ Averages followed by the same letter do not differ according to the Scott-Knott test at the 5% significance level. CV: coefficient of variation.

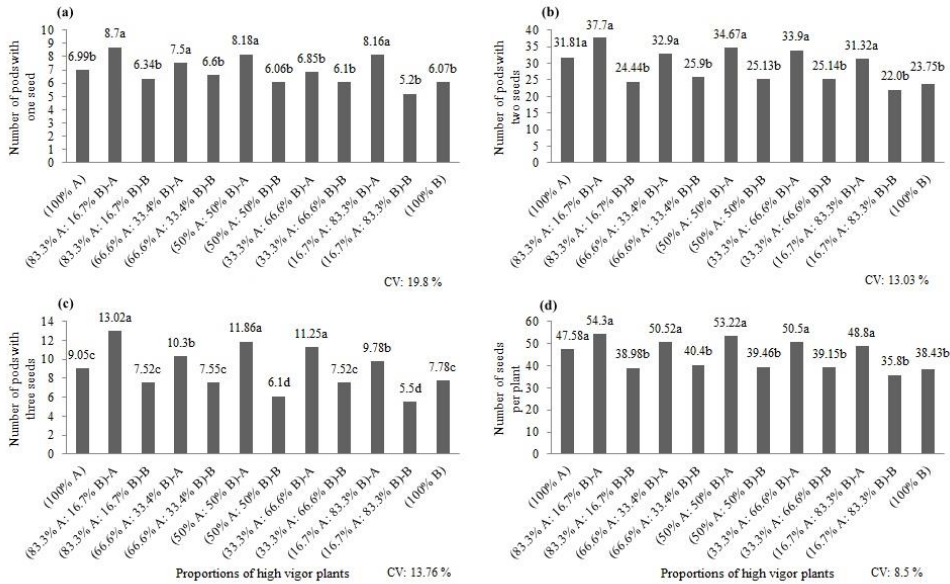


Fig 2. Number of pods with one seed (a), number of pods with two seeds (b), number of pods with three seeds (c), and total number of seeds per plant (d) in treatments consisting of different proportions of soybean plants of high and low vigor. Selbach-RS. A: high-vigor plants; B: low-vigor plants. T: treatment. T1 (100% A); T2 (83.3% A: 16.7% B)-A; T3 (66.6% A: 33.3% B)-A; T4 (50% A: 50% B)-A; T5 (33.3% A: 66.6% B)-A; T6 (16.7% A: 83.3% B)-A: high-vigor plants. T2 (83.3% A: 16.7% B)-B; T3 (66.6% A: 33.3% B)-B; T4 (50% A: 50% B)-B; T5 (33.3% A: 66.6% B)-B; T6 (16.7% A: 83.3% B)-B; T7 (100% B): low-vigor plants. ¹ Averages followed by the same letter do not differ according to the Scott-Knott test at the 5% significance level. CV: coefficient of variation.

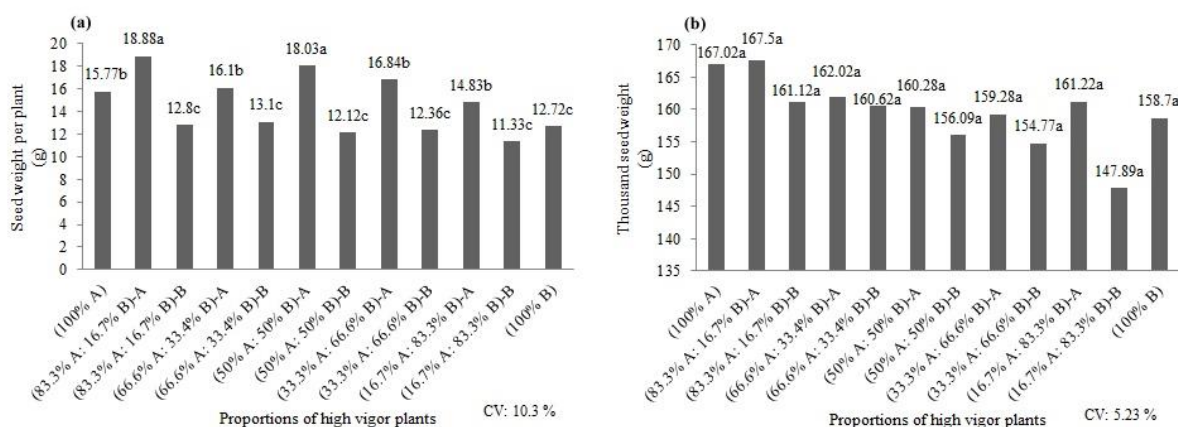


Fig 3. Weight of seeds per plant (a) and thousand seed weight (b) in treatments consisting of different proportions of soybean plants with high and low vigor. Selbach-RS. A: high-vigor plants; B: low-vigor plants. T: treatment. T1 (100% A); T2 (83.3% B)-A; T3 (66.6% A: 33.3% B)-A; T4 (50% A: 50% B)-A; T5 (33.3% A: 66.6% B)-A; T6 (16.7% A: 83.3% B)-A; high-vigor plants. T2 (83.3% A: 16.7% B)-B; T3 (66.6% A: 33.3% B)-B; T4 (50% A: 50% B)-B; T5 (33.3% A: 66.6% B)-B; T6 (16.7% A: 83.3% B)-B; T7 (100% B): low-vigor plants. ¹Averages followed by the same letter do not differ according to the Scott-Knott test at the 5% significance level. CV: coefficient of variation.

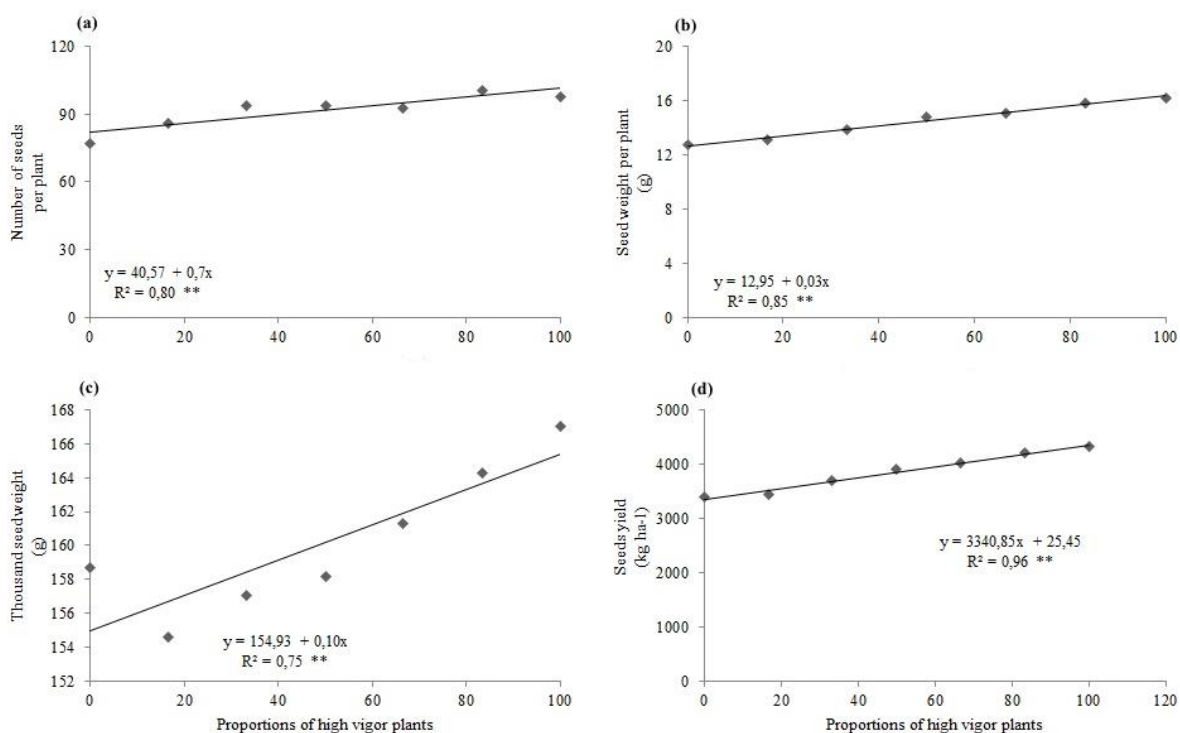


Fig 4. Variation in number of seeds per plant (a), weight of seeds per plant (b), thousand seed weight (c) and seed yield per area (kg ha⁻¹) (d) with an increasing proportion of high-vigor plants in the treatment population.

seeds of high vigor, mainly due to the number of pods per plant.

Because of the higher number of seeds, seed weight per plant (Fig. 3-a) also increased with an increasing proportion of high vigor plants in the crop row. In all treatments, seed weight in plants of high vigor was significantly higher than that in low-vigor plants. A small decrease in thousand seed weight (Fig. 3-b) was also observed with an increase in the proportion of low-vigor plants, although values were not statistically significantly different between low- and high-vigor plants in the same treatment, and between low-vigor plants in different treatments.

The larger mass of one thousand seeds recorded here for the plants obtained using high-vigor seeds may be related to the greater accumulation of reserves in these seeds (Henning et al., 2010; Szareski et al., 2018), a result previously observed in maize plants (Mondo et al., 2012).

Similar behavior was reported by Schuch et al. (2009) in isolated soybean plants, with no difference in thousand seed weight recorded between high- and low-vigor plants. This finding allowed the latter authors to confirm that the number of seeds per plant was the yield component that most influenced seed weight per plant. In an earlier study, Pinthus and Kimel (1979) observed that differences in plant yield according to the level of seed vigor were caused by variations in the number of pods per plant, and thus also in seed weight per plant.

In the present study, high-vigor plants generally exhibited a number of advantages over low-vigor plants, when compared both within and between treatments (Figs. 1, 2 and 3). An increase in the proportion of low-vigor plants resulted in a decrease in plant height, greater susceptibility to lodging due to a smaller stalk diameter, and a lower number of ramifications per plant. Furthermore, the number of seeds per plant also decreased as a consequence of a lower number of pods per plant, thereby reducing the weight of seeds per plant. The only yield component assessed for which no difference was observed between plants of high and low vigor was thousand seed weight, with values statistically similar both between plants and treatments. Mondo et al. (2012) reported that the use of batches of corn seeds of varying physiological quality resulted in increased intraspecific competition. Due to the lower competitive ability of the plants arising from low-vigor seeds, the latter were dominated by those grown from high-vigor seeds, as reflected in their reduced seed production. Considering the above findings, it is clear that high-vigor plants have a greater ability to establish themselves under field conditions. In the present study this characteristic resulted in their higher productivity in all treatments due to the better development of their yield components in comparison to that of the low-vigor plants.

Morphological and seed yield characteristics of plant communities

With an increase in the proportion of high-vigor plants in the population, the yield of seeds per area exhibited a linear rise (Fig. 4-d). Whereas the population formed only by low-vigor plants had a yield of 3319 kg ha⁻¹, that formed only by high-

vigor plants was 4319 kg ha⁻¹, an increase of 928 kg ha⁻¹ or 21%. A rise in the number of pods containing two or three seeds resulted in a similar linear increase of 19% in the number of seeds per plant (Fig. 4-a), from populations with a lower to a higher proportion of high-vigor plants in the crop row. Although the average thousand seed weight (Fig. 4-c) increased linearly by only 5% from treatment T7 (100% LV) to treatment T1 (100% HV), the total weight of seeds per plant (Fig. 4-b) increased by 21%.

This increase in plant yield is likely related to the homogeneity of the populations constituted only by high-vigor specimens (Schuch et al., 2009; Scheeren et al., 2010; Rigo et al., 2018), as these plants exhibit better mobilization and utilization of cotyledon reserve compounds (Corte et al., 2006; Carvalho et al., 2017) for both emergence (Mielezrski and Marcos Filho, 2012; Szareski et al., 2016; Ferrari et al., 2016) and initial growth of seedlings. Therefore, the use of high-vigor seeds is essential for obtaining high yields (Mondo et al., 2012).

In the present study, the number and weight of seeds per plant had the greatest impact on the increase in seed yield per area for the populations studied. Egli (1993) evaluated the effect of soybean vigor for seeds sown in an alternating pattern along the crop row. The latter author observed that more vigorous seedlings were able to gain a competitive advantage over later-emerging plants, resulting in a 9% increase in seed yield. Similarly, Schereen (2002) reported that plants arising from high quality soybean seeds exhibited better initial height and seed yield, while Cervieri Filho (2005) found that isolated soybean plants grown from seeds of high physiological quality outperformed those grown from low quality seeds, in terms of both number of pods per plant and seed yield. A close relationship between seed vigor and yield was also observed by França Neto et al. (1984), who reported an increase of 20% to 35% in grain yield from high-vigor seeds.

Materials and methods

Location, soil characteristics, fertilization and genotype

The experiment was conducted under field conditions during the 2012/2013 crop year in Selbach County, Rio Grande do Sul State – Brazil, at a site located at 28°39' South and 53°01' West, at 380 m a.s.l.

The regional soil is classified as a Dystrophic Red Typical Oxisol, based on the Brazilian Soil Classification System, Embrapa (2006). Soil analysis revealed the following properties: pH in water, 6.1; Ca, 7.1; Mg, 2.4; Al³⁺, 0.2 cmol_c dm⁻³; H+Al, 3.1; effective CTC, 10.6; AL⁺³ saturation, 2% and bases, 77%; SMP index, 6.3; organic matter level, 2.9%; clay level, 46%; texture, 2; P-Mehlich, 12.9 mg dm⁻³; CTC pH 7, 13.5 cmol_c dm⁻³ and K, 333 mg dm⁻³.

Fertilizer application was performed at time of sowing in the form of 300 kg ha⁻¹ of NPK 02-20-20 fertilizer, based on soil analysis and recommendations made by the Brazilian Commission of Fertilizing and Chemistry of Soil (Cqfs-RS/SC 2004).

The soybean seeds selected for use in the study were of the cultivar FPS Urano RR, short-cycle; the seeds were also of

certified commercial quality in order to accurately represent actual field conditions and outcomes experienced by farmers. Before sowing, all seeds were coated with fungicides (30 g active ingredient carbendazim + 70 g active ingredient tiram) and insecticides (150 g L⁻¹ imidacloprid + 450 g L⁻¹ tiodicarbe), at doses of 200 mL and 300 mL commercial product per 100 kg of seeds, respectively.

Experimental Design

The experiment was conducted using a completely randomized design comprising seven treatments and five replications. Treatments consisted of seven combinations of seeds of high and low vigor in the sowing line, classified as follows: T1- all twelve seedlings with high vigor (100% HV); T2- ten high-vigor seedlings and two low-vigor seedlings (83.3% HV and 16.7% LV); T3- eight high-vigor seedlings and four low-vigor seedlings (66.6% HV and 33.3% LV); T4- six high-vigor seedlings and six low-vigor seedlings (50% HV and 50% LV); T5- four high-vigor seedlings and eight low-vigor seedlings (33.3% HV and 66.6% LV); T6- two high-vigor seedlings and ten low-vigor seedlings (16.7% HV and 83.3% LV); and T7- all twelve seedlings with low vigor (100% LV), where HV and LV indicate high and low vigor, respectively.

In order to carry out the selection of seedlings originating from seeds of high and low vigor, a height criterion was used in which seedlings of 12 to 14 cm in height (from the ground to the higher end of the last trefoil leaf) were considered high-vigor seedlings, and those eight to ten cm in height (from the ground to the higher end of the last trefoil leaf) as low-vigor seedlings.

Sowing took place on November 30, 2012, using a no till seeder set to distribute 30 seeds per meter, at 3.0 cm depth and a distance of 0.45 m between crop rows. This high seeding rate enabled the selection, 21 days after sowing (DAS), of seedlings of high and low vigor based on the aforementioned height criterion. In this way, rows one meter in length containing 12 seedlings of interest were selected based on the treatment groups outlined above (266 thousand plants ha⁻¹).

Low-vigor seedlings were duly tagged with the aid of Kraft plastic tape, attached at the base of the hypocotyl. It is important to stress that in order to avoid competition, not only were seedlings equally spaced along the crop row, but were also roughed in lateral rows, thereby achieving twelve seedlings per meter in both directions.

The control of major weeds, pests and diseases found in soybeans was performed according to the technical recommendations of Embrapa (2012).

Plant evaluation and seed yield

In each plot (crop row) the following determinations were performed: height of plant at the V5 and R8 phenological stages (Fehr and Caviness, 1997); stalk diameter; number of ramifications per plant; and the yield components number of pods with, one, two and three seeds; number of seeds per plant; seed weight per plant; thousand seed weight; and yield of seeds per area.

Plants at the V5 stage of development were measured in terms of height only. At the R8 stage of development, plants arising from seeds of high and low vigor were harvested separately to determine the remaining yield components listed above, as well as plant height. Stalk diameter was measured at ground level using a caliper rule. The number of ramifications per plant was obtained by counting ramifications on the major stem. Number of pods with one, two and three seeds, and total seeds per plant were determined via simple counting. Seed weight per plant was determined with the aid of a precision scale to two decimal places.

Thousand seed weight was determined by weighing the seeds produced by each plant of high and low vigor, and corrected to that for one thousand seeds. The overall performance of thousand seed weight was obtained per arithmetic mean for all plants of high and low vigor, in each treatment. The seed yield per area was determined based on the weight of seeds produced by each plant in each repetition, and multiplying this figure by the population of plants present (266 thousand ha⁻¹), producing a final estimate of yield per hectare.

All assessments based on seed weight had their values corrected to the weight of seeds containing 13% moisture.

Statistical analysis

Experimental data were subjected to analysis of variance, with the behavior of individual plants (high and low vigor) assessed by grouping averages via the Scott-Knott (Scott and Knott 1974) test at 5% significance, and community performance analyzed via polynomial regression.

Conclusions

Plants of high and low vigor did not differ in terms of thousand seed weight and number of pods with one seed.

High-vigor seeds produced plants with greater height, stalk diameter, number of ramifications per plant, as well as a greater seed weight compared with that of low-vigor plants.

The seed yield per area of the population consisting only of high-vigor plants was 21% (928 kg ha⁻¹) higher than that consisting only of low-vigor plants.

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