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Productive performance of soybean plants originated from seed lots with increasing vigor levels[1]

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ABSTRACT – The objective of this work was to evaluate the productive performance of soybean crops, in response to the use of seeds from lots with increasing vigor levels. The study was developed during the 2014/2015 and 2015/2016crops. In the first period, 14 treatments were evaluated, consisting of two factors, two genotypes (Syn 1059RR and NK7059RR), and seven seed lots. In the second seven treatments were considered, involving one genotype (Syn 1158RR) and seven seed lots. In both crop years, seed lots had vigor levels of 65, 70, 75, 80, 85, 90 and 95%, as determined by the accelerated aging test. The experiment was performed in a randomized block design, with a factorial scheme and five replications. Plant height, yield components, and grain yield were assessed throughout the culture cycle. The reflex of seed vigor in crop performance depended on the genotype employed. Also, there was an increase in both vegetative and reproductive performances of the crop as a function of seed vigor level. In this sense, every percentage point augmented in the vigor level of the lots resulted in a grain yield expansion of up to 28 kg.ha^{-1}.

Index terms: *Glycine max*, grain yield, physiological quality.

Desempenho produtivo de plantas de soja originadas de lotes de sementes com níveis crescentes de vigor

RESUMO – O objetivo do trabalho foi avaliar o desempenho produtivo da cultura de soja em resposta à utilização de lotes de sementes com níveis de vigor crescentes, avaliados pelo teste de envelhecimento acelerado. O trabalho foi desenvolvido durante as safras agrícolas de 2014/2015 e 2015/2016. Na primeira safra, o experimento foi composto de 14 tratamentos, envolvendo dois fatores, sendo dois genótipos (Syn 1059RR e NK7059RR), e sete lotes de sementes. Na segunda safra foi conduzido com sete tratamentos, envolvendo um genótipo (Syn 1158RR) e sete lotes de sementes. Em ambos os experimentos, os lotes possuíam níveis de 65, 70, 75, 80, 85, 90 e 95% de vigor, conforme determinado pelo teste de envelhecimento acelerado. O delineamento experimental foi o de blocos casualizados, em esquema fatorial com cinco repetições. Determinou-se a altura das plantas ao longo do ciclo da cultura, além dos componentes do rendimento e produtividade de grãos. A expressão do vigor das sementes no desempenho da cultura é dependente do genótipo utilizado. Ocorre incremento no desempenho vegetativo e reprodutivo da cultura em função do nível de vigor das sementes, sendo que cada ponto porcentual de aumento no nível de vigor dos lotes pode resultar num acréscimo de até 28 kg.ha^{-1}no rendimento de grãos.

Termos para indexação: *Glycine max*, rendimento de grãos, qualidade fisiológica.

Introduction

The physiological quality of seeds is a widely discussed theme due to its uttermost importance in agriculture. The effects of physiological quality on various aspects, such as initial growth, performance, plant uniformity, and grain yield have been extensively studied (Panozzo et al., 2009; Schuch et al., 2009; Scheeren et al., 2010; Silva et al., 2013; Tavares et al., 2013;Cantarelli et al., 2015).

Employing seed lots with low physiological quality results

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inconsiderable losses, perceivable during crop implementation already, once the establishment of an adequate plant stand is often impaired (Scheeren et al., 2010). Also, the initial growth of soybean plants from such seed lots tends to be inferior, as there is less dry mass formation. Moreover, the leaf area generally remains underdeveloped 30 days after emergence (Kolchinski et al., 2006). Another point of concern is the low uniformity of the plants, which may reduce the effectiveness of crop practices (Cantarelli et al., 2015).

Soybean grain yield is assembled throughout the crop cycle, as the components directly related to productivity are formed at different phases (Dalchiavon and Carvalho, 2012; Glier et al., 2015).On top of that, the usage of seeds with high physiological quality reflects positively not only on individual plants, but on the community as a whole, as verified by Panozzo et al. (2009), Schuch et al. (2009), Schereen et al. (2010), Silva et al. (2013), and Tavares et al. (2013).

The identification of seed lots with superior vigor level via laboratory tests is a crucial strategy, which has been extensively practiced by seed industries. The goal is to commercialize lots that can help to establish the plant population and also promote high productivity. In this sense, the accelerated aging test has shown consistent results in identifying lots that germinate alike but perform differently during storage and in field conditions (Santorum et al., 2013). Thus, it ultimately places it among the most useful and employed ones (Santos et al., 2011).

Despite that, until today, works relating seed lot quality to crop performance remain scarce. Therefore, the present research aimed at evaluating the productive performance of soybean cultures, in response to the use of seed lots with increasing vigor levels, as assessed by the accelerated aging test.

Material and Methods

The fieldwork took place in 2014/2015 and 2015/2016 crops. In the first year, it was carried out in *Iruña*, department of Alto Paraná—Paraguay. This city is located 373 m high, at the geographical coordinates of 26°10'59.08"S and 55°07'27.31" W. The local soil has clay texture, and it is sorted as Alfisol, according to the American classification (Soil Taxonomy) adopted in the country (López et al., 1995). Its chemical characteristics are the following: pH ($CaCl_2$) 5.6, P ($mg.dm^{-3}$) 11.8,Al^{+3} ($cmol_c.dm^{-3}$) 0.0, Ca^{+2} ($cmol_c.dm^{-3}$) 5.4, Mg^{+2} ($cmol_c.dm^{-3}$) 1.3; K^+ ($cmol_c.dm^{-3}$) 0.52, and V % 71.4. The fertilization was effectuated together with sowing, by using 250 $kg.ha^{-1}$ of a fertilizer composed of N-P_2O_5-K_2O, at the proportion 0:20:10.

In the second crop year, the research was moved to *Medianeira*, the western region of the Brazilian state of *Paraná*. The city is located 361 m above sea level, at the geographical coordinates 25°24'36.71"S and 54°00'11.95"W. The soil is equally of clay-type and classified as Eutrophic Red latosol (Embrapa, 2006). Its chemical characteristics are the following: pH ($CaCl_2$) 5.7, P ($mg.dm^{-3}$) 38.4, Al^{+3} ($cmol_c.dm^{-3}$) 0.0, Ca^{+2} ($cmol_c.dm^{-3}$) 7.8; Mg^{+2} ($cmol_c.dm^{-3}$) 3.0; K^+ ($cmol_c.dm^{-3}$) 0.33, and V % 76.5. Fertilization was performed simultaneously to the sowing process, through 200 $kg.ha^{-1}$ of a mixture N-P_2O_5-K_2O, formulated at the proportion of 04:30:10.

The prevailing climate in both sites is classified, according to Köppen (1936), as Cfa humid subtropical, mesothermic, with hot summers and winters with occasional frost. Rainfalls are more frequent in the spring and summer, and there is no distinct dry season.

In the first year, the experiment was composed of 14 treatments, having two genotypes (Syn 1059 RR and NK 7059 RR) as factors, and seven seed lot vigor levels. In their turn, the second-year experiments were conducted with seven treatments, covering seven vigor levels, and one genotype (Syn 1158 RR).

The experiment adopted a randomized block design, with a five-replication factorial scheme. In both crop years, the vigor levels of the seed lots were of 65, 70, 75, 80, 85, 90, and 95%, as estimated by the accelerated aging test. Seed lots of different cultivars with the desired vigor levels were selected among several lots produced by commercial seed companies.

The selection of lots relied on the accelerated aging test. It was conducted inside gerboxes containing a metal screen fixed horizontally at the mid-section. An amount of 40 mL of distilled water was added to the bottom of each box, and the seeds of each replication were distributed over the screen in a single layer, as to cover all the surface. Next, the boxes were covered and incubated in a BOD chamber, set at 41 ºC, for 48 h (Marcos-Filho, 1999).

After incubation, the seeds were subjected to germination analyses. For every experimental unit, four subsamples, with 50 seeds each, were placed in a germitest-paper substrate, which had been previously moistened with distilled water in a proportion of 2.5 times the dry paper weight. Subsequently, these sets were kept at 25 ºC. The evaluations were performed on the fifth day after sowing, as proposed in Rules for Seed Testing (Brasil, 2009), and the results were expressed in percentage of normal seedlings.

After selecting the lots, each one was sampled five times, corresponding to the experimental replications. All seed lots had been standardized by using round-hole perforated sieves, with a diameter of 6.0 mm, and an amplitude of 1.00 mm between them.

For the field experiment setup, mechanized sowing was conducted in experimental unities dimensioned 5.0 m long, with five lines spaced 0.45 m from one another, totalizing 11.25 m^2. The border effect was controlled by assuming the three central lines as the useful area, disregarding 0.5 m from their extremities, which totalizes an area of 5.4 m^2.

Seeds were previously treated with a fungicide (10 $g.L^{-1}$) based on Metalaxyl-M (10 $g.L^{-1}$) and Fludioxonil (25 $g.L^{-1}$), at the dose of 1.0 mL of the commercial product Maxim XL® per kilogram of seeds. A Fipronil-based insecticide (250 $g.L^{-1}$) was also administered, by using 1.0 mL of the commercial product Standak® per kilogram of seeds. Lastly, the seeds were inoculated with *Bradyrhizobium japonicum* (6,0x10^9 $UFC.mL^{-1}$) at 4.0 mL of the commercial product Master Fix per kilogram of seeds.

Seeds were sowed on October, 2nd 2014 (first crop year), over a wheat-straw bed, and on October, 8th 2015 (second crop year), over corn straw. They were sown in areas free from weeds, which had been previously dried.

At both locations, thirty seeds were distributed per linear meter. Twelve days after sowing, a manual pruning was carried out, aided by a millimeter rule, in order to even the initial population of all lots at 12.5 plants per linear meter (one individual every 8.0 cm). The selection criteria adopted in this procedure was to guarantee the best plant distribution over the area. The goal was to prevent a possible interference of the population effect, as lower emergence rates were expected in lots sown with low-vigor seeds. Throughout the crop cycle, the agricultural practices employed followed the technical recommendations for soybean production in the region, so that to protect the plants against diseases, plagues, and weeds, which otherwise would affect the proper development of the culture.

Plant height was measured 15, 30, 45, and 60 days after emergence (DAE). A millimeter rule was used for the inspection, which considered the distance between the soil surface and the primary stem apex. Overall, twenty sequential plants in the central sowing line of the lot were appraised.

Right after being harvested, plants were assessed for their final height, number of pods and seeds per plant, mass of one thousand seeds, and grain yield. The number of pods (NPP) and seeds (NSP) per plant were established as the mean of each of these units, gathered sequentially in 20 plants in the central line of the useful area of the lot. The mass of one thousand seeds (MTS) was determined by weighing eight subsamples of 100 seeds from the useful area of the lot, and then calculated according to the methodology described in Rules for Seed Testing (Brasil, 2009). Lastly, the productivity of each lot was obtained through the manual harvest of the pods within the useful area, followed by mechanical threshing. The results gauged in kilograms of seeds per lot had the moisture content adjusted to 13% wet basis, and were then converted to $kg.ha^{-1}$.

Once the presumptions fulfilled, the analysis of variation was executed at a 5% probability level. The F-test was applied to the qualitative factor (cultivar), whereas a regression analysis was used for the quantitative one (levels of vigor). In the latter, the testing for both crop years continued until a grade-six polynomial. All statistical procedures were handled by the software R, version 3.1.1, input with the databank "expdes.pt" (Ferreira et al., 2013; R Core Team, 2016).

Results and Discussion

In the first year of the experiment, the vigor level of the seed lots significantly affected plant growth, regardless of the cultivar or evaluation period (Figure 1). At early development stages, more precisely 15 DAE, the plants from both genotypes had an augment in height, as a response to the increase of vigor levels (Figure 1A). For the genotype NK 7059 RR, the increment was noticeable throughout all the vigor levels studied; whereas for the genotype Syn 1059 RR, it intensified only from 75%.

The plant height increase, as evaluated 30, 45, and 60 DAE, showed that both genotypes responded linearly to progressively higher vigor levels. Nonetheless, the genotype Syn 1059 RR exhibited a more significant enlargement when compared to NK 7059 RR. For every ten percentage points (pp) raised in seed lot vigor, there was a gain in height of 5.2 and 3.7 cm, in the genotypes Syn 1059 RR and NK 7059 RR, respectively.

Regarding the final plant height (Figure 1E), the gains were reduced and stabilized as from a vigor level equal to or surpassing 85%. Nevertheless, it is worth remarking that augmenting the vigor level resulted in general plant growth in all vigor intervals considered. During this evaluation period, plants of the genotype Syn 1059 RR presented less height gain, in vigor levels inferior to 75%. Above this value, however, no difference was noticed between the genotypes.

The second-year results of plant height of the genotype Syn 1158 RR are depicted in Figure 2. This genotype showed a linear increasing behavior in response to the usage of seed lots with higher vigor, as analyzed at 15, 30, and 60 DAE. However, at the aforementioned evaluation periods, the growth exhibited by the genotype Syn 1158 RR was less expressive than that of Syn 1059 RR and NK 7059 RR. This observation evidences that the influence of seed lot vigor depends on the interaction genotype-environment, which affects plant growth to different extents. At the evaluation carried out 45 DAE (Figure 2C), the behavior of plant height due to increasing seed lot vigor had a cubic fit, according to which, the feature plant height augmented more significantly within the vigor interval from 75 to 90%.

Disregarding the genotype, in both years there was a general increment in plant height throughout the whole culture cycle, due to an increase in seed vigor. Despite the year, genotype, and moment of evaluation, the plant community formed from seeds with the highest vigor level (95%) exhibited a growth 23% higher than that of plants from seeds with the lowest vigor level (65%). A similar outcome was reached by Scheeren et al. (2010), who observed that soybean plants developed from high-vigor seeds had more prominent initial structures and produced higher grain yield.

These findings can be explained by the great capacity of

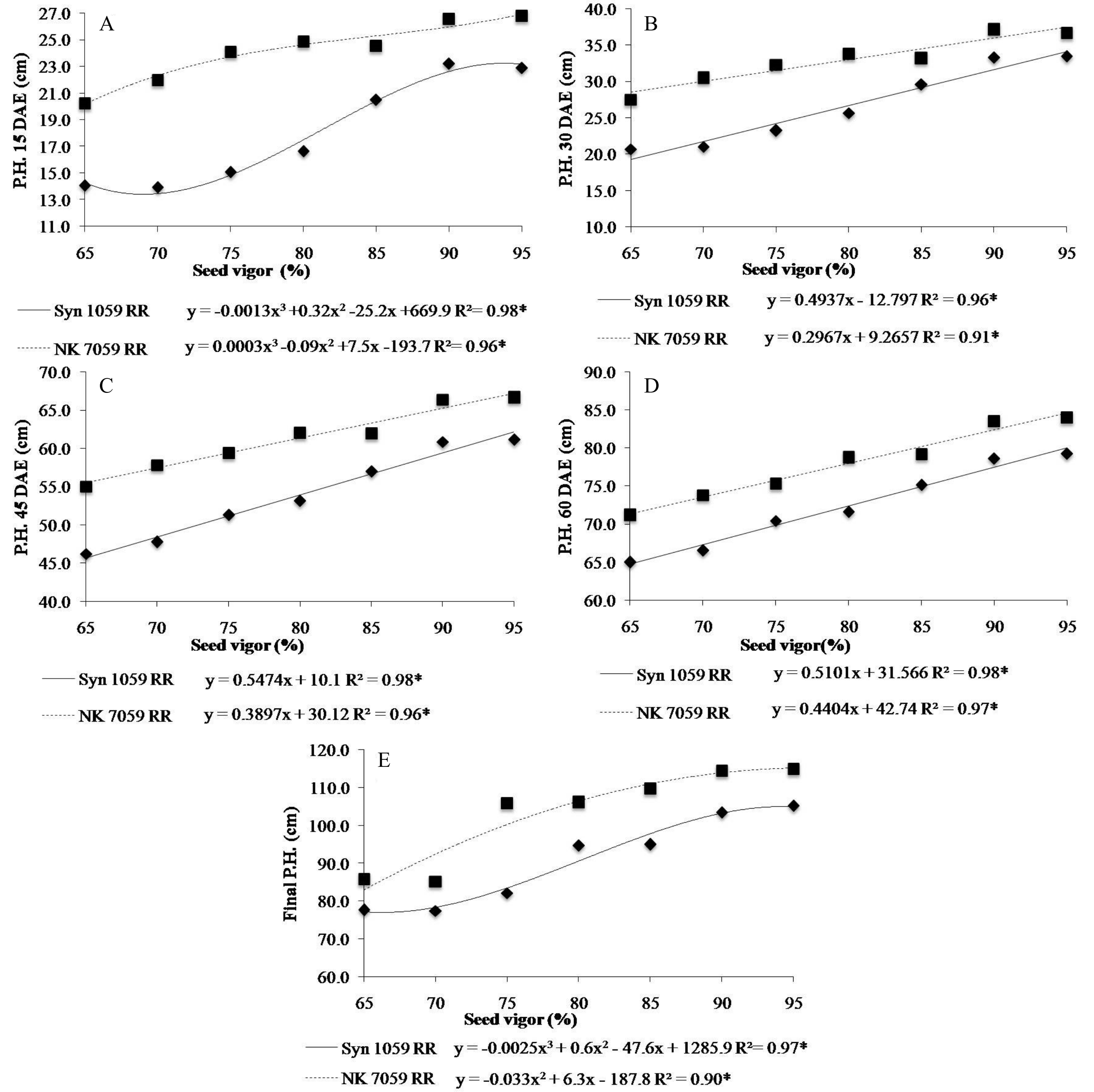

Figure 1. Height (PH)—gauged 15 (A), 30 (B), 45 (C), and 60 (D) days after emergence (DAE)— and final height (E) of soybean plants grown from seed lots of two genotype with increasing vigor levels, as determined by the accelerated aging test. Crop 2014/2015.

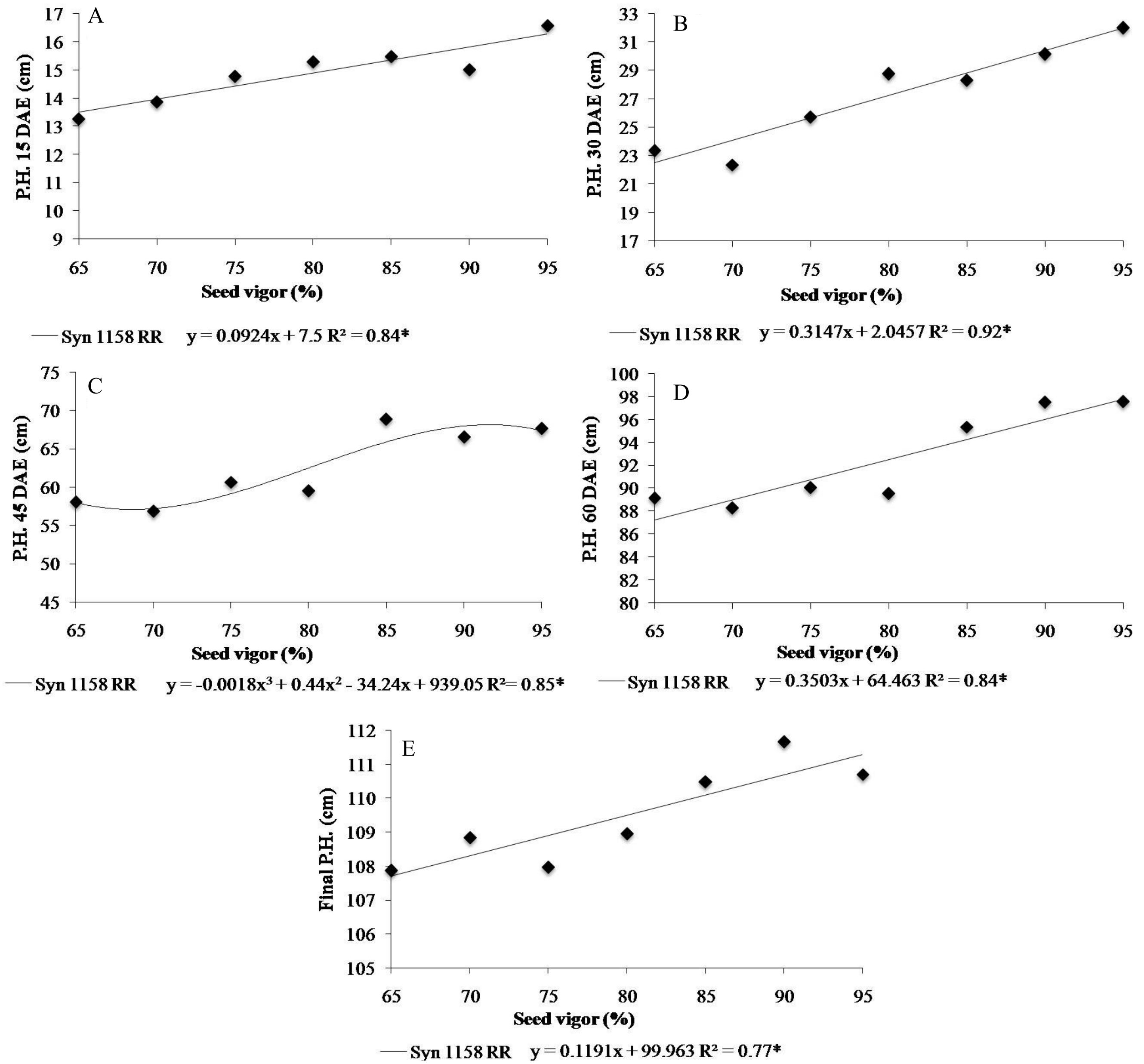

Figure 2. Height (PH)—gauged 15 (A), 30 (B), 45 (C), and 60 (D) days after emergence (DAE)— and final height (E) of soybean plants grown from seed lots of the genotype Syn 1158 RR, with increasing vigor levels, as determined by the accelerated aging test. Crop 2015/2016.

high-vigor seeds in generating high-performance plants. Such individuals tend to have more significant growth rates, better production structures, and a deeper root system. Therefore, they produce more pods and seeds, which leads to more substantial grain yield (França-Neto et al., 2016). In general, these plants form larger photosynthetic areas early on, and produce more dry matter than plants originated from low-vigor seeds. Kolchinski et al. (2005), Kolchinski et al. (2006), and Tavares et al. (2013) reported that this aspect is probably linked to the fact that plants grown from high-vigor seeds, by the 30thDAE, already have a leaf index that is 56% higher than that of plants originated from low-vigor seeds. During flowering, such difference expands to 67%. Such results attest that the vigor of soybean seeds used for sowing can heavily alter the vegetative growth of the plant community, during the entire production cycle.

Positive vigor-related effects on plant height were already reported in several studies (Panozzo et al., 2009; Schuch et al., 2009; Scheeren et al., 2010; Silva et al., 2013). However, up until now, no papers had connected plant growth throughout the crop cycle to the employment of seed lots with increasing vigor levels.

The quantitative enhancement in the formation of leaf area, dry mass, and height, owing to seed vigor, can also considerably impact productive and yield components, as they are defined at different physiological stages (Dalchiavon and Carvalho, 2012). Figures 3 and 4 show how these features were significantly influenced by the vigor of the soybean lots, in both crop years assessed in this research.

Regarding the number of pods per plant (NPP), the genotypes responded linearly to the augment of the vigor levels, in both crop years considered. The NPP is a key yield component, which was deemed by some authors as the central aspect related to the expansion of grain yield (Dalchiavon and Carvalho, 2012; Nico et al., 2015; Nunes et al., 2016).

The mean of the three genotypes revealed that, for every 10% rise in seed lot vigor, there was an average increase of 10.1 pods.plant^{-1}. Thus, in theory, for the population of 12.5 plants m.linear^{-1} used in this study, there would be an upsurge of 13.8 pods m.linear^{-1}, which represents an increment of about 305.000 pods.ha^{-1}.

According to Kolchinski et al. (2005), the production of more pods per plant can be explained by the fact that individuals coming from high-vigor seeds have a larger leaf area at the moment of flowering. In these plants, the leaf area index was 67% higher than that of plants originated from low-vigor seeds. Tavares et al. (2013) and Glier et al. (2015) add that the leaf area of soybean plants at the moment of flowering is directly related to high assimilation of carbon dioxide, which will help to build up reserves for the further podding phase. Tavares et al. (2013) also remarked that plants formed from high-vigor seeds produced more grains than those from a low-vigor origin, regardless of the soil hydric condition. This difference could account for an increase of 15% in productivity of the culture.

As a consequence of more pods being formed due to the use of more vigorous lots, there was a linear gain in the amount of seeds produced per plant (NSP) in all genotypes evaluated, in both crop years. Taking into account the average

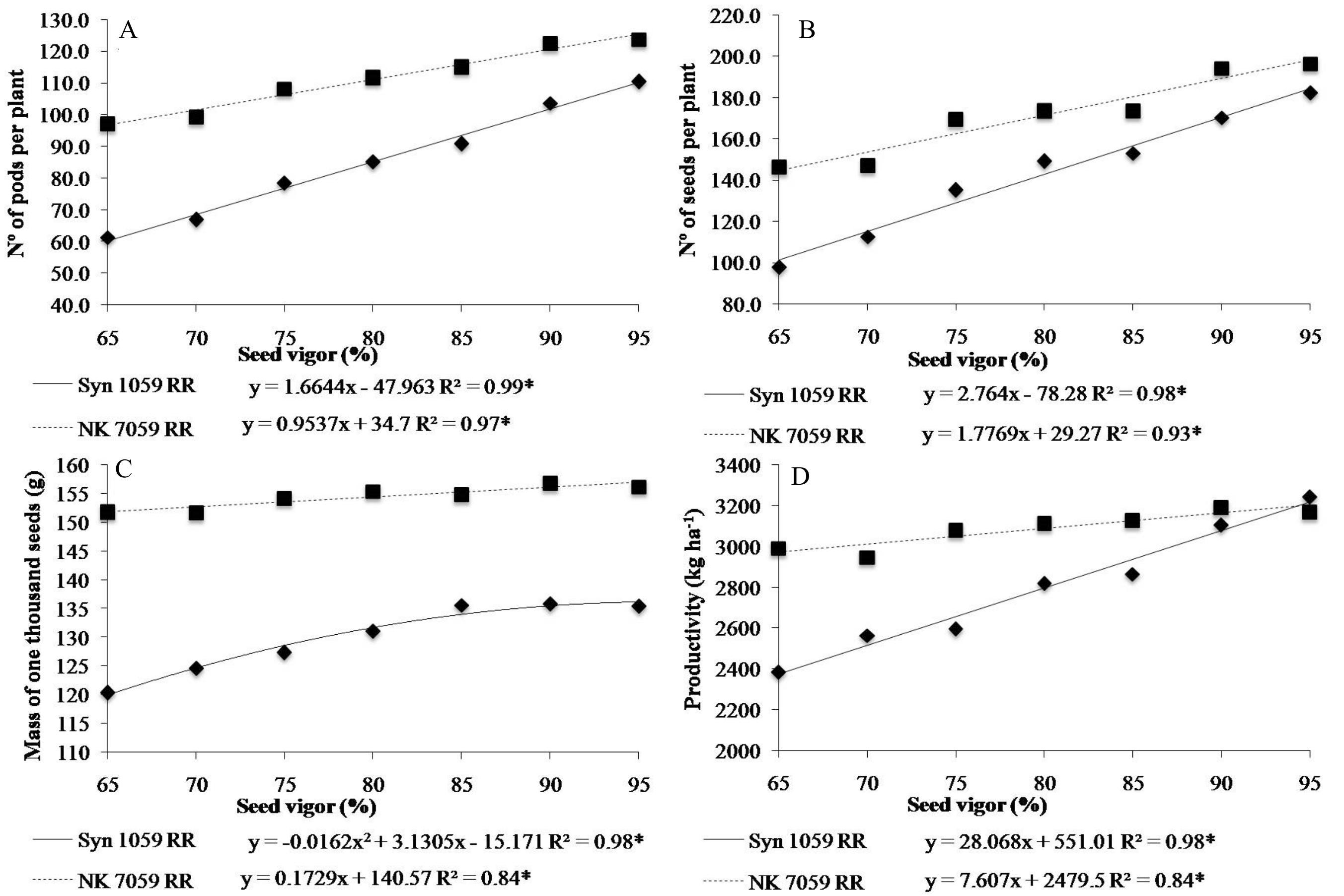

Figure 3. Number of pods per plant (A), number of seeds per plant (B), mass of one thousand seeds (C), and productivity (D) of soybean plants grown from seed lots of two genotype, with increasing vigor levels, as assessed by the accelerated aging test. Crop 2014/2015.

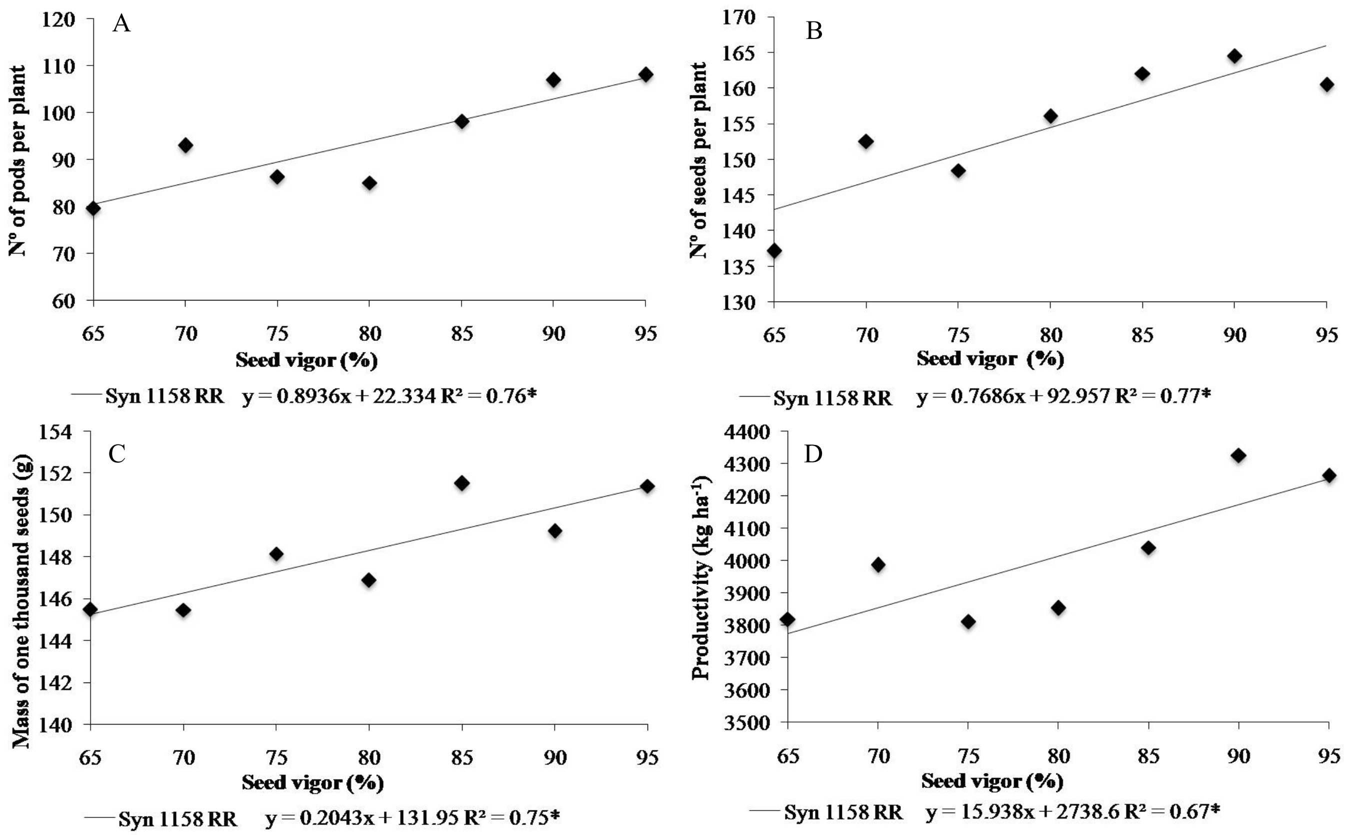

Figure 4. Number of pods per plant (A), number of seeds per plant (B), mass of one thousand seeds (C), and productivity (D) of soybean plants grown from seed lots of the genotype Syn 1158RR, with increasing vigor levels, as assessed by the accelerated aging test. Crop 2015/2016.

outcome of the genotypes Syn 1059 RR and NK 7059 RR, an augmentation of 10% in seed lot vigor level incremented the production by 20.3 seeds per plant. In its turn, the second-year testing with the cultivar Syn 1158 RR (Figure 4B) showed that a 10% addition in seed vigor inspired an increase of 8.0 seeds per plant. The genotype most affected, as for NSP, was the Syn 1059 RR, to which seed lots 10% more vigorous produced 28.0 more seeds per plant.

The employment of seed lots with increasing vigor levels also promoted rising rates in the mass of one thousand seeds (MTS), for all genotypes assessed, in both crop years. In the first year of experiment, the genotype NK 7059 RR responded linearly, with an addition of 1.7 g in the MTS for every 10% increase in seed lot vigor level. As for the genotype Syn 1059 RR, the response for this situation was quadratic. The distinct behavior noticed in the first year may have possibly occurred due to the genotype-related photosynthetic capacity, which reflects on the grain growth. That is, the difference between the genotypes promoted alterations in the response curve of the MTS during the accumulation of photo assimilates in grains at the R5 stage.

At the lowest vigor levels, as the vigor percentage rose, the greater were the gains in terms of MTS. Nonetheless, when seed lots with vigor levels above 80% were employed, the increments reduced. In the second crop year, the genotype Syn 1158 RR also responded linearly to the elevation of vigor. In this case, 2.0 g was added to the MTS for every 10% increase in seed vigor level.

Soybean MTS is intimately related to the leaf area at the reproductive stage (Glier et al., 2015). Plants originated from high-vigor seed lots generally present a more substantial growth, forming a larger leaf area during the vegetative phase. This fact results in individuals with greater photo synthetics simulation capacity during the reproductive period, therefore prone to better form and nourish seed, which ultimately increases the MTS (Kolchinski et al., 2005; Tavares et al., 2013; Glier et al., 2015).

Data on soybean crop productivity are presented in Figure 4. The use of seed lots with increasing vigor levels prompted linear gains in this aspect, regardless of the genotype or year of the experiment. The genotype Syn 1059 RR manifested the most conspicuous response to the raise of seed vigor, characterized by a greater increment in production. In this case, for every percentage point added to the vigor level of lots, there was an approximate addition of 28.0 $kg.ha^{-1}$ to final productivity. With regards to the genotype NK 7059 RR, every vigor percentage point raised productivity by 8.0 $kg.ha^{-1}$. In the second-year trials for the genotype Syn 1158 RR, each vigor percentage point implied in an elevation of productivity by 6.0 $kg.ha^{-1}$.

The genotype Syn 1059 RR displayed the strongest reactions to the rise of seed vigor levels in the following variables: plant height, number of pods per plant, number of seeds per plants, mass of one thousand seeds, and crop productivity. Differential genotype responses are connected to intrinsic characteristics. In this sense, the growth and productivity of Syn 1059 RR were more influenced by seed vigor than the corresponding features of the other genotypes. That difference should be considered on field genotype trials, once the genotype NK 7059 RR had a performance significantly superior to that of Syn 1059 RR when low-vigor seeds were used. However, at the highest vigor levels, the genotypes behaved alike in all variables studied. On that account, the genotype Syn 1059 RR can be regarded as the most reliant on seed technologies to express its full productive potential.

The literature encloses some reports relating the productivity increase to the use of seeds of high physiological quality.

França-Neto et al. (1983) observed that the use of high-vigor soybean seeds incremented grain yield by up to 24%, in contrast to the low-vigor ones. Scheeren et al. (2010) noticed not only a 9% increase in soybean crop productivity, but also a gain in the initial plant height, associated with the use of high-vigor seeds. Kolchinski et al. (2005) realized that plants coming from high-vigor seeds had high leaf area index, dry mass production, and additions to the yield of more than 35%. In their work, Tavares et al. (2013) verified that high-vigor seeds raised the yield by more than 15%. Finally, according to França-Neto et al. (2018) for commercial soybean crops, high-vigor seeds assured the establishment of high-performance plants, which represented an elevation in productivity of up to 10%.

Studies relating the increase in the vigor of soybean seed lots, as estimated via the accelerated aging test, with vegetative growth and crop productivity remain scarce. The present work showed that, despite genotype or crop year, there was an average gain of 14.0 $kg.ha^{-1}$for each percentage point added to the vigor level. This outcome states the importance of utilizing seed lots of high physiological quality, in order to accomplish cultures with elevated yield potential. The use of high-level lots often leads to substantial productivity once these seeds tend to generate more uniform plants, with high growth rate. These characteristics reflect on a large leaf area, which expands the capacity of absorbing light and assimilating carbon dioxide to be used for forming flowers, pods, and large heavy seeds. Therefore, all these factors combined result in a high grain productivity per unit of area (Kolchinski et al., 2005; Tavares et al., 2013; Silva et al., 2013; Cantarelli et al., 2015; França-Neto et al., 2018).

Conclusions

Soybean seed lots with high vigor level form plant communities with high growth rate, resulting in a better structure by the end of the crop cycle.

Productive performance of soybean plants augments as the vigor of the lots of seeds sown increases.

For every percentage point increase in the vigor level of a soybean seed lot (as assessed by the accelerated aging test), grain yield could expand by 28.0 kg per hectare.

The impact of seed vigor on the physiological performance potential of a soybean culture depends on the plant genotype.

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