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Original Article

Effect of seeding speed and graphite lubricant on soybean plantability[1]

Efeito da velocidade de semeadura e do lubrificante à base de grafite na plantabilidade da soja

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HIGHLIGHTS:
Treatments with insecticides, herbicides, and fungicides hinder distribution by horizontal disks.
Solid graphite lubricant mitigates issues related to seed treatments, ensuring uniform distribution.
Adding graphite lubricant at 4 km h^{-1} optimized seed distribution.

ABSTRACT: This study aimed to assess the efficiency of soybean seed distribution in the soil, which directly influences crop yield, using graphite as a solid lubricant, a common practice to improve seed dosing fluidity. The effect of sowing speed and seed chemical treatment on distribution in the furrow, final plant population, and yield was investigated. The experiment used Federer´s augmented block design with 10 treatments, five sowing speeds (4, 6, 8, 10, and 12 km h^{-1}) and two seed treatments (with and without 4 g of graphite lubricant per kilogram of seeds). High sowing speeds increased uneven seed distribution, while graphite lubricant significantly improved plant spacing and crop yield. This study reinforces the importance of precise sowing speed adjustment and proper seed treatment to optimize soybean plant distribution in the field. Graphite lubricant proved to be effective at reducing spacing failures and increasing crop yield. These findings underscore the relevance of precision agriculture and the use of technology to ensure efficient and sustainable sowing operations.

Key words: *Glycine max*, sowing density, dosing mechanisms, longitudinal distribution, flowability

RESUMO: Este estudo teve como foco avaliar a eficiência na distribuição de sementes de soja no solo, influenciando diretamente a produtividade da lavoura utilizando o grafite como lubrificante sólido, uma prática comum para melhorar a fluidez na dosagem de sementes. Foi investigada a interação entre a velocidade de semeadura e o tratamento químico das sementes na distribuição no sulco, na população final de plantas e na produtividade. O experimento foi conduzido no delineamento de blocos aumentados de Federer, com 10 tratamentos, abrangendo cinco velocidades de semeadura (4, 6, 8, 10 e 12 km h^{-1}) e dois tratamentos de sementes (com e sem adição de 4 g de lubrificante grafitado por quilograma de sementes). Verificou-se que altas velocidades de semeadura aumentam a irregularidade na distribuição das sementes, enquanto o uso de lubrificante grafitado melhorou significativamente o espaçamento aceitável das plantas e aumentou o rendimento da cultura. O estudo reforça a importância do ajuste preciso da velocidade de semeadura e do tratamento adequado das sementes para otimizar a distribuição das plantas de soja no campo. A utilização de lubrificante grafitado mostrou-se uma prática eficaz para reduzir falhas na distribuição das sementes e aumentar a produtividade da cultura. Esses resultados destacam a relevância de práticas agrícolas precisas e do uso de tecnologias para garantir uma operação de semeadura eficiente e sustentável.

Palavras-chave: *Glycine max*, densidade de semeadura, mecanismos dosadores, distribuição longitudinal, escoabilidade

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Introduction

Soybean yield is highly dependent on plant density, row spacing, irrigation, and high-yielding cultivar selection (Graffitti et al., 2021). Silveira et al. (2021) and Bortoli et al. (2021) suggest precise sowing based on plantability to ensure uniform stands and proper row distribution.

Francetto et al. (2021a) emphasize that sowing requires meticulous planning, with precise equipment adjustments and careful speed selection. According to Fiss et al. (2018), uneven plant distribution can compromise resource efficiency, leading to yield losses. Effective seed distribution is crucial, especially in precision planters, although high sowing speeds or densities may hamper precision (Bottega et al., 2018).

Vanini et al. (2017) found that speeds up to 10 km h^{-1} resulted in a satisfactory emergence speed index, while Bortoli et al. (2021) caution against speeds over 4 km h^{-1}, which favor uneven distribution. Plant distribution controversy in Brazil is influenced by factors such as no-till systems, soil diversity, and seed metering mechanisms (Weirich Neto et al., 2012; Machado & Reynaldo, 2017).

Improving sowing efficiency depends directly on reducing friction between seeds, meters, and conductors, since excess friction can cause uneven spacing and mechanical damage (Pereira et al., 2021). The use of a solid graphite lubricant is an effective solution to mitigate this problem (Savi et al., 2022). In addition to ensuring more uniform seed distribution, it optimizes plant spacing and has the potential to significantly increase soybean yield when compared to untreated seeds, especially at faster sowing speeds.

Ensuring uniform graphite application during sowing is challenging and is therefore typically incorporated via on-farm seed treatment (Pereira et al., 2021). This study aimed to evaluate the efficiency of graphite lubricant in the soybean seed distribution as a function of sowing speed.

Material and Methods

The study was conducted in the experimental area of Faculdade Marechal Rondon (FARON) (12° 46' 15.32" S and 60° 05' 55.92" W, altitude of 593 m), in the municipality of Vilhena, Rondônia state (RO), Brazil (Figure 1). According to Alvares et al. (2013), the region has a humid tropical climate, with a rainy season from September to March (Amazonian winter) and dry season from April to August (Amazonian summer). Average annual temperature and total rainfall are approximately 25.8 °C and 2,200 mm, respectively.

The soybean cultivar used was 80I82 RSF IPRO (https://www.brasmaxgenetica.com.br/cultivar-regiao-cerrado/?produto=14243), characterized by minimum germination of 80%, 99% purity, and a target population of

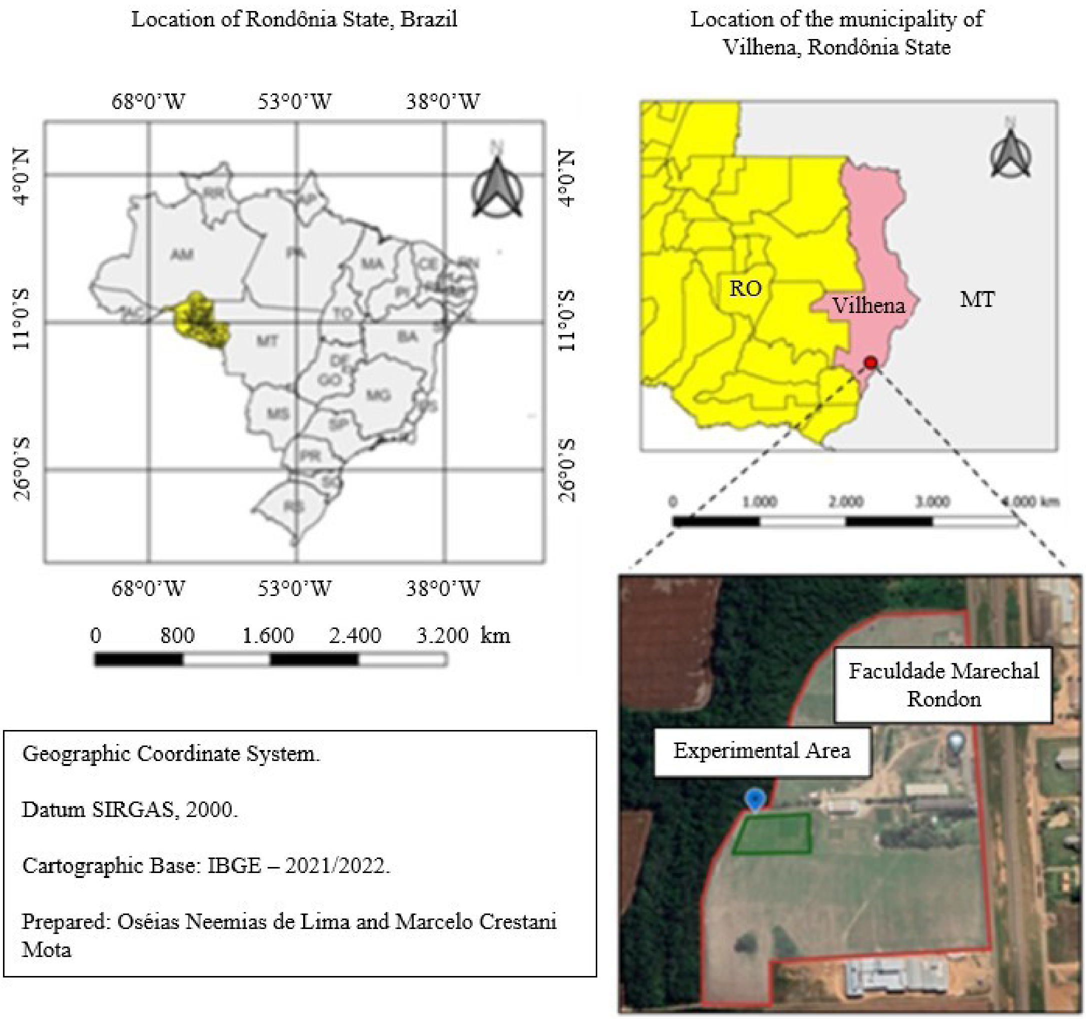


Figure 1. Location of the experimental area at Faculdade Marechal Rondon

300,000 plants per hectare (equivalent to 15 seeds per meter). Sowing was performed on November 24, 2022, using a Case 315 Magnum tractor and a 12-row pantographic fertilizer seeder, with row spacing of 0.5 m. The average soil water content in the 0 to 0.3 m layer at sowing was around 30 to 32%.

Soil pH was corrected by liming and fertilization to meet crop needs, based on the results of the soil chemical analysis in the 0 to 0.2 m layer of the experimental area (Table 1) and recommendations for clayey soils (Sousa & Lobato, 2004). Liming was performed manually 30 days before sowing, using 930 kg ha^{-1} of dolomitic limestone with a relative neutralizing power (RNP) of 90%, incorporated into the soil by harrowing. Recommended fertilization for soybean (Sousa & Lobato, 2004) is 20 kg ha^{-1} of N (source: urea), 120 kg ha^{-1} of P_2O_5 (single superphosphate), and 120 kg ha^{-1} of K_2O (source: KCl), applied in the furrow using a mechanical seeder-fertilizer. The seeder was adjusted to distribute seeds at a depth of 3 cm and fertilizer at 5 cm, alongside and below the seeds. The furrow was closed using a double-angled V-shaped wheel with a diameter of 0.31 m. The fertilizer and seed hoppers were filled to 50% of their maximum capacity of 1,215 and 1,645 liters, respectively.

The experiment was conducted using Federer's augmented block design, with split plots and five replicates. The sowing speeds tested were 4, 6, 8, 10, and 12 km h^{-1} and the graphite lubricant dose was 4.0 g per kilogram of seeds. The 10 treatments consisted of a combination of five sowing speeds and two lubrication conditions. Each experimental plot occupied an area of 150 m² (3 × 50 m), with the four center rows considered the study area, disregarding the two outer rows and 0.5 m at either end to reduce experimental error, totaling an area of 18 m² (Figure 2). Sowing speed was adjusted by gear shifting and monitored by a Garmin Etrex GPS device installed on the tractor.

Plant spacing was assessed 30 days after emergence (DAE), when population density was well-established, and included multiple, failed, and acceptable spacings, compared against agronomic recommendations for soybean seed spacing. The guidelines followed were in accordance with the Brazilian National Standard Organization (ABNT, 1994), which considers 0.5 to 1.5 times the expected average spacing acceptable. Spacings beyond these limits are categorized as failures (greater than 1.5 times) or multiples (less than 0.5 times). The analysis was based on a desired soybean population of 15 plants per linear meter, with 6.6 cm between plants considered acceptable. Distances between plants less than 50% of the correct spacing were deemed double spacing (< 6.6 cm between plants) and those exceeding 150% spacing failures (> 9.9 cm between plants).

The data were submitted to analysis of variance and polynomial regression, with statistical significance set at $p \leq 0.05$ and homoscedasticity of variances assessed using Hartley's test. Statistical analysis was performed using SISVAR v.5.6 software (Ferreira, 2019).

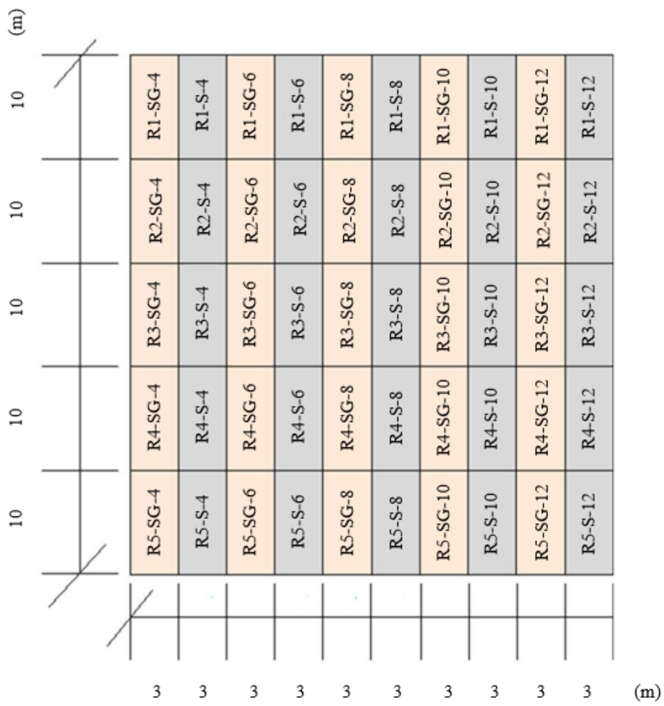


Figure 2. Layout of the experiment, where: R1, R2, R3, R4, and R5 are the blocks; SG soybean seeds treated with 4.0 g of graphite lubricant per kilogram of seeds; S untreated seeds without graphite lubricant; and 4, 6, 8, 10, and 12 represent sowing speeds in km h^{-1}

Results and Discussion

As shown in Table 2, the regression model that best fit the distribution of both treated and untreated seeds at the sowing speeds tested was the second-order polynomial. For spacings classified as failures, the data were significant at $p \leq 0.05$. The corresponding equation obtained coefficients of determination of 94 and 98.5%, for untreated and treated seeds, respectively. By contrast, the results indicate only a slight variation in double spacings both with and without graphite lubricant. For both lubricant conditions, acceptable spacings were best represented by a second-order polynomial equation, with coefficients of determination of 97 and 99.1% for untreated and treated seeds, respectively. Figures 3 and 4 provide greater detail on these equations and the variations and factors that led to seed distribution changes at different speeds.

Sowing without lubricant resulted in differences in the number of spacing failures at speeds close to 6 and 10 km h^{-1}. However, when the speed approached 12 km h^{-1}, there was a substantial increase in the number of failures, with the largest difference observed during the transition from 6 to 12 km h^{-1}. In

Table 1. Soil chemical attributes in the experimental area

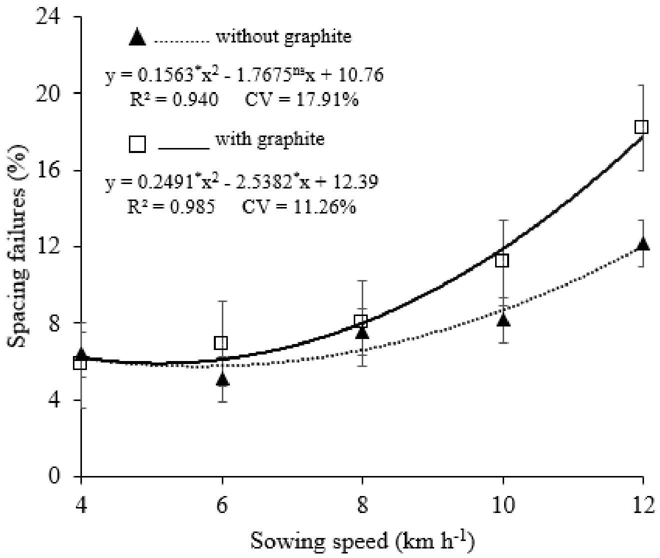
Depth (m)	Chemical attributes												
	pH	Ca^{+2}	Mg^{+2}	K^{+}	Zn	Fe	Mn	B	Cu	Al^{+3}	CEC	P	OM
	H_2O	(cmol$_c$ dm^{-3})										(mg dm^{-3})	(g kg^{-1})
0-0.2	6.1	2.3	0.7	0.07	1.7	42	3.6	0.35	0.6	0	5.6	1.5	24
0.2-0.4	6.1	2.9	0. 9	0.11	2.5	46	6.6	0.36	0.3	0	6.7	4.5	29

CEC - Cation exchange capacity; OM - Organic matter

Table 2. Regression analysis of failures, double, and acceptable spacings during soybean sowing at speeds of 4, 6, 8, 10, and 12 km h^{-1} using a tractor + seeder-fertilizer unit, with and without solid graphite lubricant

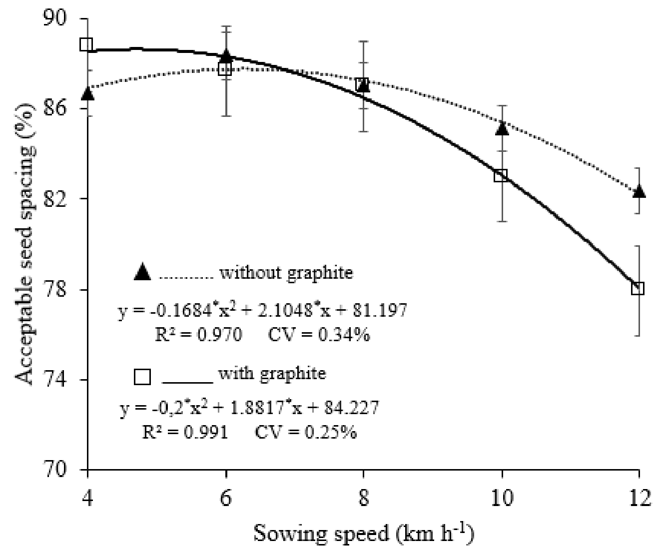
	Failures (%)			Doubles (%)			Acceptables (%)		
	GL	Pr > F	R^2	GL	Pr > F	R^2	GL	Pr > F	R^2
Spacing between seeds without graphite lubricant									
Linear	1	0.000*	0.749	1	0.081ns	0.372	1	0.001*	0.665
Polynomial 2	1	0.025*	0.940	1	0.685ns	0.391	1	0.010*	0.970
Polynomial 3	1	0.866ns	0.941	1	0.224ns	0.562	1	0.418ns	0.995
Deviation	1	0.188ns	—	1	0.061ns	—	1	0.703ns	—
Error	15	—	—	15	—	—	15	—	—
Spacing between seeds treated with graphite lubricant									
Linear	1	0.000*	0.845	1	0.0187*	0.295	1	0.000*	0.878
Polynomial 2	1	0.000*	0.985	1	0.120ns	0.533	1	0.000*	0.991
Polynomial 3	1	0.127ns	1	1	0.107ns	0.791	1	0.492ns	0.993
Deviation	1	0.960ns	—	1	0.144ns	—	1	0.278ns	—
Error	15	—	—	15	—	—	15	—	—

** Significant at $p \leq 0.01$; * Significant at $p \leq 0.05$; ns Not significant ($p \geq 0.05$). Spacings was classified into three categories according to the ABNT (1994): acceptable (0.5 to 1.5 times the reference mean spacing, Xref.), double (less than 0.5 times the Xref.), and failure (greater than 1.5 times the Xref.)



* - Significant at $p \leq 0.05$ according to the F-test. Error bars indicate the standard error of percentage of spacing failures.

Figure 3. Spacing failures as a function of sowing speed, without and with graphite lubricant



* - Significant at $p \leq 0.05$ according to the F-test. Error bars indicate the standard error of the percentage of acceptable spacings

Figure 4. Acceptable seed spacing as a function of sowing speed, without and with graphite lubricant

regard to double spacings, there was no statistically significant difference in the percentage of double spacings between speeds (Table 2). However, the highest average number of double spacings occurred near the lowest sowing speed of 4 km h^{-1}, reaching approximately 78 of a total 4,500 spacings, with most spacings (around 4,359) deemed acceptable.

For treated seeds, the largest number of spacing failures occurred near the highest sowing speed (12 km h^{-1}), indicating a 211% increase in failures compared to the lowest sowing speed. This did not occur for double spacings, where approximately 40 instances were observed at this speed. In other words, it cannot be inferred that an increase in speed is directly related to a reduction in double spacings, but rather to a decline in the total number of acceptable spacings, as identified in both seed treatment conditions (with and without lubricant) near speeds of 10 and 12 km h^{-1}.

For spacing failures classes (Figure 3), the second-order polynomial model exhibited coefficients of determination (R^2) of 0.940 and 0.985 for untreated and treated seeds, respectively, between speeds of 4 and 12 km h^{-1}. The model indicates that the average percentage of spacing failures remained practically constant between 4 and 8 km h^{-1}, with only a slight variation of approximately +1.8%. This demonstrates that the average number of failures in rows with untreated seeds at this speed varied by 17, considered low for a total of 4,500 spacings. This result is more precise than that reported by Naves et al. (2020) and Reynaldo et al. (2016), who found a minimum 4% variation in spacing failures at speeds up to 10 km h^{-1}, compared to 3.1% at 6 to 10 km h^{-1} in the present study.

For graphite-treated seeds, the number of spacing failures increased continuously (Figure 3) by 1.1, 1.08, 3.17, and 6.83% from 4 to 6, 6 to 8, 8 to 10, and 10 to 12 km h^{-1}, respectively. These variations were more evident at speeds above 8 km h^{-1}, corroborating the findings of Pereira et al. (2021), who reported that graphite improves seed flowability in the hopper, facilitating capture by the dosing disks. Additionally, the increase in sowing speeds causes greater turbulence inside the dispensing tube, increasing the total number of failures in the sowing lines, especially at speeds above 10 km h^{-1}, with failures reaching up to 18%.

It should be noted that the second-order polynomial model obtained a low coefficient of determination (see Table 2) of only

0.391 for the percentage of double spacings without graphite, which varied from 3.87 to 5.38%. This can be explained by the more pronounced deviations between 8 and 12 km h^{-1}. When seeds were treated with graphite, the percentage variation in double spacing declined from 8 to 12 km h^{-1}, considering the horizontal honeycomb disk system used in the present study. These findings are consistent with research by Castela Junior et al. (2014) and Furlani et al. (2010), but differ from those of Reynaldo et al. (2016) and Jasper et al. (2011).

Despite the small difference in the percentage of acceptable spacings in both treatments up to 6 km h^{-1}, a continuous and more pronounced difference was observed from 10 km h^{-1} onwards, reaching 82.4 and 78% without and with graphite lubricant, respectively, at 12 km h^{-1} (Figure 4). These results are similar to those obtained by Bertelli et al. (2016), who found that considering only the effect of increasing doses of graphite on the longitudinal distribution of seeds results in a greater percentage of acceptable spacings and a decline in failures and doubles. The authors reported that these patterns remained stable up to a dose of 8.0 g of graphite per kilogram of treated seeds.

Bertelli et al. (2016) examined the effects of faster sowing speed on spacing percentages and observed a decline in the number of acceptable spacings from 72 to 63% after 6 km h^{-1}, and an approximate 5% increase in the number of doubles at 10 km h^{-1}.

It is also important to underscore the higher percentage of double spacings at 6 km h^{-1}, which declined at faster speeds because the seeds had less time to properly fill the seed metering disks. This corroborates Pereira et al. (2021), who observed that high disk rotation speeds prevented seeds from completely filling the metering disks, resulting in failures in longitudinal distribution during sowing.

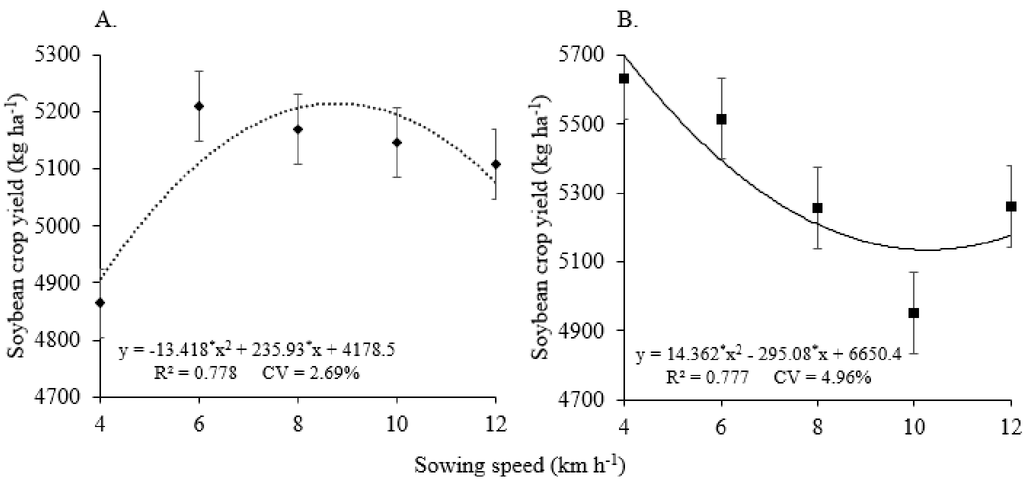
According to second-order polynomial regression (Figure 5A), soybean yield differed in the graphite-free treatment depending on sowing speed. Yield was lower and more pronounced at speeds below 6 km h^{-1}, varied only slightly between 8 and 10 km h^{-1}, and stabilized around 5,200 kg ha^{-1}, with an average variation of only 0.38%. From 10 km h^{-1} onwards, yield declined by an estimated 2.3% for every 2 km h^{-1} increase in sowing speed. These results indicate that, in the graphite-free treatment, yield is more sensitive to speed variations at both the lowest (under 6 km h^{-1}) and highest speeds (above 10 km h^{-1}). This can be attributed to the continuous increase in spacing failures from 6 km h^{-1} onwards and the reduction in double spacings, resulting in only a 4% variation in acceptable spacing, as shown in Figures 3 and 4.

These results are consistent with those of Cortez et al. (2021) and Lenhardt et al. (2022), namely, sowing speeds between 5 and 7 km h^{-1} for optimal soybean yields. Similarly, Jasper et al. (2011) found that sowing speed affects seed distribution, with slower speeds producing plant densities closer to the ideal. In the present study, the highest crop yield obtained at a sowing speed of 6 km h^{-1} was 4,100 kg ha^{-1}, which declined at higher speeds.

The second-order polynomial model demonstrated that the highest crop yield (5,700 kg ha^{-1}) in the graphite seed treatment (Figure 5B) occurred at the lowest speed (4 km h^{-1}). Yield declined by approximately 5.3% from 4 to 6 km h^{-1} and 3.7% from 6 to 8 km h^{-1}, stabilizing at around 5,150 kg ha^{-1} between 8 and 12 km h^{-1}, representing a reduction of about 8.8% in relation to the yield obtained at 4 km h^{-1}. Although Carpes et al. (2018) and Mantovani et al. (1999) found that adding graphite lubricant minimizes spacing differences (double and failures), because graphite is an inert material that reduces friction between seeds and facilitates flow and adaptation to the mechanical metering disks, this influence on soybean yield responses was not observed in the present study.

Although the effects of graphite on longitudinal seed distribution have been reported, decisions by agricultural managers to apply this lubricant in seed treatment should be based on factors such as seed quality (roughness level), density, and size, different graphite doses, the topography of cultivated areas, and seed distribution system (type of horizontal perforated or pneumatic disk), among others.

The main challenge during sowing is achieving an appropriate plant density, allowing the full expression of genetic potential and reducing competition between plants of the same and different species, with a view to achieving high yields. Factors such as soil characteristics, weather conditions, topography, cultivated variety, sowing speed, and components



* - Significant at $p \leq 0.05$ according to the F-test. Error bars indicate the mean standard error for soybean yields at sowing speeds of 4, 6, 8, 10, and 12 km h^{-1}.

Figure 5. Soybean yield as a function of sowing speed, without (A) and with graphite lubricant (B)

of the seeder-fertilizer play a crucial role in this process. This makes it imperative to collect and analyze information about these factors to minimize potential sowing errors and optimize operational efficiency. In order to determine the sowing window and seed density per hectare, it is vital to adapt to the specificities of each agricultural property, considering elements such as soil type, texture, precipitation, and light intensity. Variations between 200,000 and 500,000 soybean plants per hectare recommended by Seixas et al. (2020) can result in similar yields, but lower densities increase susceptibility to weeds and higher densities imply additional costs and greater competition between plants.

Careful seed selection is key to optimizing germination and robustness, reducing germination failures and ensuring uniform plant distribution. Aspects such as size, growth habit, resistance to agrochemicals, and yield expectations must be considered when choosing cultivars.

It is currently common practice to sow seeds treated with phytosanitary products, inoculants, and co-inoculants in order to protect seedlings in the early and vegetative stages. However, these treatments can affect the physical structure of seeds, impacting their distribution during sowing. As suggested by Mantovani (1999), the application of 4.0 g of solid graphite lubricant per kilogram of seed is an alternative to minimize these problems, improving seed flow and reducing impacts on dosing mechanisms. Additionally, polymer coating has emerged as a viable option, providing seed protection and uniform distribution during sowing, with studies indicating greater effectiveness when compared to graphite, as reported by Alonço (2018). It is important to carefully assess the available options and consider the specific needs of the property to ensure efficient and economically viable agricultural practices.

On steep terrain, the use of pneumatic seed dispensers may result in greater sowing failures, requiring careful analysis of the terrain and the use of strategies such as building contour lines to mitigate slope effects. The proper selection of dispensing tubes is essential in minimizing seed bounce. Curved dispensing tubes facing the rear of the seeder have shown better performance in soybean sowing, as reported by Carpes (Carpes et al., 2016).

Moreover, according to Becker (2014) and Francetto et al. (2021b), choosing the best devices for cutting crop residues and opening furrows, such as smooth, curved, or notched disks, is vital given their influence on fuel consumption, traction force, and soil mobilization. It is important to carefully assess whether bars or double disks are more suitable for furrow opening depending on soil characteristics, since bars are preferable in conventionally prepared soils with no crop residue and double disks are better suited to heavier soils with residue. Precise adjustment of depth-limiting wheels, as recommended by Seixas et al. (2020), is essential to ensure an adequate sowing depth (3 to 5 cm), which varies according to soil type, enabling soybean seeds to absorb 50% of their weight in water to ensure germination. Close attention should be paid to the compacting wheel to ensure that the furrow is closed and compacted laterally, preventing excess surface compaction, which could compromise seedling emergence and stand uniformity.

Conclusions

1. High sowing speeds, especially above 8 km h^{-1}, resulted in uneven seed distribution and, consequently, double spacing and failures in cultivated areas.

2. The use of graphite lubricant proved effective from 4 km h^{-1} onwards, providing a larger number of acceptable spacings and significantly reducing failures and double spacings.

3. Graphite lubricant improved soybean yield, which reached 5,632.2 kg ha^{-1}.

4. In the absence of graphite, the most effective responses for acceptable and double spacing, failures and crop yield were observed at 6 km h^{-1}.

Authors' contribution: Marcelo Crestani Mota: conceptualization, methodology, validation, formal analysis, data curation, writing – original draft preparation, writing – review and editing, visualization, supervision, and project administration. Oséias Neemias de Lima: conceptualization, methodology, validation, investigation, conducting the field experiment, data collection, drafting the first version of the manuscript, and manuscript corrections.

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