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INFLUENCE OF THE USE OF GRAPHITE ON THE QUALITY OF SWEET CORN SOWING

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Abstract

The propagation process of sweet corn (*Zea mays* L. saccharata group) is carried out through seeding. For good quality in this process, the operating speed and graphite dosage must be assertive for a greater plant stand and seed distribution and depth. Given the above, this research aimed to analyze three different operating speeds and the influence of graphite dose to evaluate the effects on plantability in sweet corn. A John Deere 4 x 2 TDA tractor with a nominal power of 78 kW (106 hp) and a Netz model PDN 6000 seeder were used to carry out the sowing. The area was part of an 18-hectare central pivot. Three operating speeds (5.0, 7.7, and 10.7 km h^{-1}) and three amounts of graphite (4.0, 8.0, and 12.0 g for each kg of seed) used in mechanical seeders were evaluated. The experiment was carried out in a 3 x 3 factorial design in subdivided plots with 12 replications. The results were subjected to analysis of variance (ANOVA) using the “F” test, and subsequently, the means of the variables in the different treatments were analyzed using the Tukey test. Statistical process control was also analyzed using control charts with upper and lower limits drawn based on the ideal sowing spacing. In conclusion, the greatest uniformity of sowing was achieved with a speed of 5.0 km h^{-1}, and a graphite dose of 12.0 g kg^{-1} provided the greatest uniformity of sowing. Higher operating speeds and lower graphite doses resulted in a higher number of failed or double germinations. The lowest seed spacing VC was when there was a higher dosage of graphite and a lower operating speed.

Keywords: seed distribution; seed lubrication; plantability.

INFLUÊNCIA DO USO DE GRAFITE NA QUALIDADE DA SEMEADURA DE MILHO DOCE

Resumo

O processo de propagação do milho doce (*Zea mays* L. grupo saccharata) é realizado por meio de semeadura. Para uma boa qualidade nesse processo, a velocidade de operação e a dosagem de grafite devem ser assertivas para um maior estande de plantas e distribuição e profundidade das sementes. Diante do exposto, esta pesquisa teve como objetivo analisar três diferentes velocidades de operação e a influência da dosagem de grafite para avaliar os efeitos na plantabilidade do milho doce. Para realizar a semeadura, foi utilizado um trator John Deere 4 x 2 TDA com potência nominal de 78 kW (106 hp) e uma semeadora Netz modelo PDN 6000. A área fazia parte de um pivô central de 18 hectares. Foram avaliadas três velocidades de operação (5,0, 7,7 e 10,7 km h^{-1}) e três quantidades de grafite (4,0, 8,0 e 12,0 g para cada kg de semente) usadas em semeadoras mecânicas. O experimento foi realizado em um projeto fatorial 3 x 3 em parcelas subdivididas com 12 repetições. Os resultados foram submetidos à análise de variância (ANOVA) pelo teste “F” e, posteriormente, as médias das variáveis nos diferentes tratamentos foram analisadas pelo teste de Tukey. O controle estatístico do processo também foi analisado por meio de gráficos de controle com limites superior e inferior desenhados com base no espaçamento ideal de semeadura. Em conclusão, a maior uniformidade de semeadura foi obtida com uma velocidade de 5,0 km h^{-1}, e uma dose de grafite de 12,0 g kg^{-1} proporcionou a maior uniformidade de semeadura. Velocidades de operação mais altas e doses mais baixas de grafite resultaram em um número maior de germinações fracassadas ou duplas. O menor CV para o espaçamento de sementes ocorreu quando houve uma dose maior de grafite e uma velocidade de operação menor.

Palavras-chave: distribuição de sementes; lubrificação de sementes; plantabilidade.

Introduction

The annual world area harvested for sweet corn is 1,042,894.0 hectares, production is 8,858,138.9 tons, and productivity is 8,493.8 kg/ha. Currently, the largest producers of sweet corn are the United States (2,617,864.0 tons), Mexico (1,059,259.9 tons), Nigeria (775,989.6 tons), and Indonesia (653,821.9 tons) (Faostat, 2023).

Direct seeding is the most common process for sweet corn, in which the seeds are distributed directly on the ground. There are several seed-distributing mechanisms for mechanical and pneumatic seeders, each of which has characteristics that influence the performance of seeders in uniform longitudinal seed distribution (Barr *et al.*, 2019).

The quality of seeding processes includes various parameters to be assessed during the operation, including the speed of the mechanized unit, the dosage of graphite deposited in the seed reservoir, plant stand, plant spacing, and seed depth (Martins *et al.*, 2022).

Depending on the operating speed at the time of sowing, the seeds deposited in the soil can be unevenly spaced, damaging the establishment of the plant stand (Nandin *et al.*, 2019). The effects caused by heterogeneous longitudinal seed distribution are worse in crops that cannot compensate for this factor, such as corn (Sangoi *et al.*, 2019) and sunflower (Pereira; Hall, 2019).

Thus, Marafon and Assmann (2022) used the conventional system for speeds (4.0, 7.0, and 10.0 km h^{-1}) and concluded that at a speed of 4.0 km h^{-1}, the best performance is demonstrated by reduced percentages of misses and doubles, and increasing the speed reduces the acceptable spacing between plants.

To improve the filling of metering discs, graphite is used, which is an ideal natural dry lubricant that reduces friction between surfaces (Scremin *et al.*, 2022). The use of graphite added to seeds has been widely studied because, in dosing mechanisms, it helps to even out distribution, filling the disc and reducing gaps (Savi *et al.*, 2022). However, when added together with the seed treatment, graphite loses its lubricating power and affects seed distribution (Pereira *et al.*, 2021)

The use of graphite to aid the metering of large seeds has been widely studied. However, the efficiency of this technique during the distribution of tiny seeds still requires technical information (Sidhu *et al.*, 2017). According to Carpes *et al.* (2018), using a coating polymer on the seeds can provide the same effect as using a solid graphite lubricant, making them flow well inside the seed reservoir and facilitating their uptake by the cells of the metering disk.

Given the above, this study aimed to analyze the plantability of sweet corn under three different operating speeds and the influence of using different graphite doses on linear seed distribution to improve the seeding system for mechanical seeders.

Material and Methods

The study was carried out at the Morrinhos Campus of the Instituto Federal Goiano, located in the municipality of Morrinhos-GO, with coordinates of 17º 30' 20“ to 18º 05‘ 40” south latitude and 48º 41' 08“ to 49º 27’ 34” west longitude. The Morrinhos region has an average altitude of 771 m and a mild (tropical humid) climate.

According to Santos *et al.* (2018), the soil at the site was classified as a Red-Yellow Latosol with a clay texture in the Brazilian Soil Classification System. To carry out the sowing, a John Deere 4x2 TDA tractor with a nominal power of 78 kW (106 hp) and a Netz model PDN 6000 precision seeder with gravity-filled horizontal metering disks were used.

The crop used was sweet corn (*Zea mays* L. saccharata group), a tropical cultivar. Before the mechanized unit started, the seeder was calibrated to the number of seeds recommended by the supplier, 3.8 seeds m^{-1}, giving a total ideal stand of approximately 76,000 seeds ha^{-1} and a row spacing of 0.5 m. The seeds were deposited at a depth of 1.5 m and a depth of 1.5 m, respectively. The seeds were sown at an average depth of 3.5 cm. A thousand seeds weighed 129 grams, with 8.3, 7.1, and 3.3 mm seed length, width, and diameter, respectively.

The conditions for fitting the seeds into the disks and rings were checked to choose the metering disk. This check was based on the premise that only one seed should fit per hole and that part of the seed should not remain above the disk's surface. There is no specific sweet corn disk, so conventional corn was used instead. After these observations, the 28-hole, 13.5 x 9 mm, one-row disk was chosen.

Three operating speeds and three amounts of graphite used in mechanical seeders deposited in the seed reservoir were evaluated. Therefore, the design consisted of a 3 x 3 factorial scheme in subdivided plots, totaling nine treatments and twelve replications. Each plot had an area of 15 m² (5 x 3 m).

The operating speeds were based on the standard operating speed (approximately 5.0 km h^{-1}) and were defined using a combination of tractor gears and engine speed. They were obtained using a stopwatch to measure the time the mechanized unit took to cover a distance of 50 meters in 5 repetitions. After converting from m s^{-1} to km h^{-1}, the speeds were 5.0, 7.7 and 10.7 km h^{-1}.

The graphite doses used were 4, 8, and 12 g for each kg of seed. Therefore, before filling each sowing unit, scales were used to weigh the quantity of seeds and the proportional amount of graphite for each treatment.

The variables analyzed to determine the quality of the sowing were the linear distance and the type of spacing between the seeds. The linear distance between the seeds was measured using a 3-meter tape measure. After the mechanized unit had passed, the seeds were dug up in the sowing bed to measure the distance between them.

Costa *et al.* (2018) adopted the methodology to define the type of spacing between the seeds. These authors classified the linear distribution into three categories: double (when the distance between plants is less than 0.5 times their ideal distance), faulty (when the distance between plants is 1.5 times greater than the ideal distance), and acceptable (when the distance between plants is greater than 0.5 times and less than 1.5 times. The ideal spacing was based on the number of seeds per meter (3.8 seeds m^{-1}) and had a value of 0.26 m between seeds. The spacing was therefore defined as double ($x < 0.13$ m), acceptable ($0.13 \text{ m} < x \leq 0.39$ m), and failure ($x > 0.39$ m).

After testing the data's normality, the results were analyzed by analysis of variance (ANOVA) using the F-test at a 5% significance level. The p-values were presented to show whether or not there was significance between the variables' levels and their interaction. The means of the variables in the different treatments were analyzed using the Tukey test at a 5% significance level. The software used was Assistat version 7.7.

Control charts were then drawn for each operating speed concerning the disk used. The central line of the charts was the ideal spacing between seeds (0.26 m) and the Upper Control Limits (UCL) and Lower Control Limits (LCL), calculated based on the limit values for double and miss spacings using the methodology adopted by Costa *et al.* (2018).

Results and Discussion

Table 1 shows the Analysis of Variance (ANOVA) for operating speed and graphite dosage factors. The interaction between the factors did not provide statistical differences. Speed significantly influenced the average spacing, the number of seeds, and the percentage of failures. Graphite dosage significantly differed in the number of seeds and percentage of failures.

Table 1. Effect of operating speed, graphite amount, and their interaction with seed spacing, seed number, and seed accuracy.

		Spacing	**Seed number**	**Double**	**Acceptable**	**Failure**
	df	***p*-value**	***p*-value**	***p*-value**	***p*-value**	***p*-value**
Speed (S)	2	0.0032^{*}	0.0369^{*}	0.6072^{ns}	0.0797^{ns}	0.0208^{*}
Graphite (G)	2	0.0551^{ns}	0.0032^{*}	0.0969^{ns}	0.1165^{ns}	0.0458^{*}
S x G	4	0.1021^{ns}	0.6603^{ns}	0.5229^{ns}	0.5339^{ns}	0.8526^{ns}

Note: ANOVA test was used. * significant at 5% probability level ($0.01 \leq p < 0.05$); ^{ns} represens no significant value (α=0.05).

In addition, according to the results in Table 1, increasing the speed at which the mechanized unit moved led to a higher percentage of sowing failures due to the influence on seed distribution in the soil. Varying the dosage of graphite significantly influenced the number of seeds and the percentage of failures, so the amount of graphite used did not reduce the percentage of failures. However, it did influence the double and acceptable spacing.

Mühl *et al.* (2022) evaluated the operating speed performance in soybean cultivation and concluded that travel speed influenced grain yield, although the increase in travel speed had no significant effect.

Table 2 shows the average spacing between seeds, seed number, and the percentage of spacings with gaps. The 7.7 km h^{-1} speed provided the greatest average spacing (0.353 m) and, consequently, the lowest number of seeds (3.36 seeds m^{-1}) and the highest percentage of gaps compared to the other speeds. The 7.7 km h^{-1} speed is statistically different from the 5.0 km h^{-1} speed.

Table 2. Averages and VC (%) for average seed spacing (m), number of seeds (seeds m^{-1}), and percentage of failures (%) about the speeds evaluated (km h^{-1}).

Speed	Spacing	Seed number	Failure
5.0	0.270 b	3.77 a	23.53 b
7.7	0.353 a	3.36 b	35.90 a
10.7	0.324 ab	3.51 ab	33.74 ab
VC	34.91	20.29	71.49

Note: Averages followed by the same letter in the column do not differ statistically by the Tukey test at 5% probability.

At the lowest operating speed, there were lower values for average spacing and percentage of failures. The speed of 10.7 km h^{-1} did not differ from the other speeds, as it obtained statistically similar values to the other speeds for average spacing, number of seeds, and percentage of failures.

Savi *et al.* (2023) evaluated different dosing mechanisms, graphite doses, and operating speeds. They concluded that homogeneity was observed up to 5.0 km h^{-1}, demonstrating the greater spacing stability about the variation in operating speed when graphite was used at a dose of 4.0 g kg^{-1}, thus reducing the VC during the operation.

According to Ferreira *et al.* (2019), the increase in speed caused a variation in the trajectory of the seeds, causing them to “bounce” inside the conductor tube, delaying or anticipating the fall of the seed in the furrow, altering the spacing between the seeds in the row.

Corroborating the above studies, it can be said that even though the speed of 10.7 km h^{-1} did not differ from the others, it was observed that increasing the speed to 7.7 km h^{-1} influenced the sowing quality parameters evaluated.

Table 3 shows the averages for the number of seeds and the percentage of failed spacings for the amounts of graphite used. The 12.0 g kg^{-1} dose provided the highest number of seeds (3.77 seeds m^{-1}) and the lowest percentage of spacing gaps (24.29 seeds m^{-1}), which differed from the other doses.

Table 3. Means and VC (%) for the seed number (seeds m^{-1}) and the percentage of spacing gaps (%) for the different graphite doses (g kg^{-1}).

Graphite dose	Seed number	Failure
4.0	3.63 a	34.75 a
8.0	3.23 b	34.13 a
12.0	3.77 a	24.29 b
VC	20.29	71.49

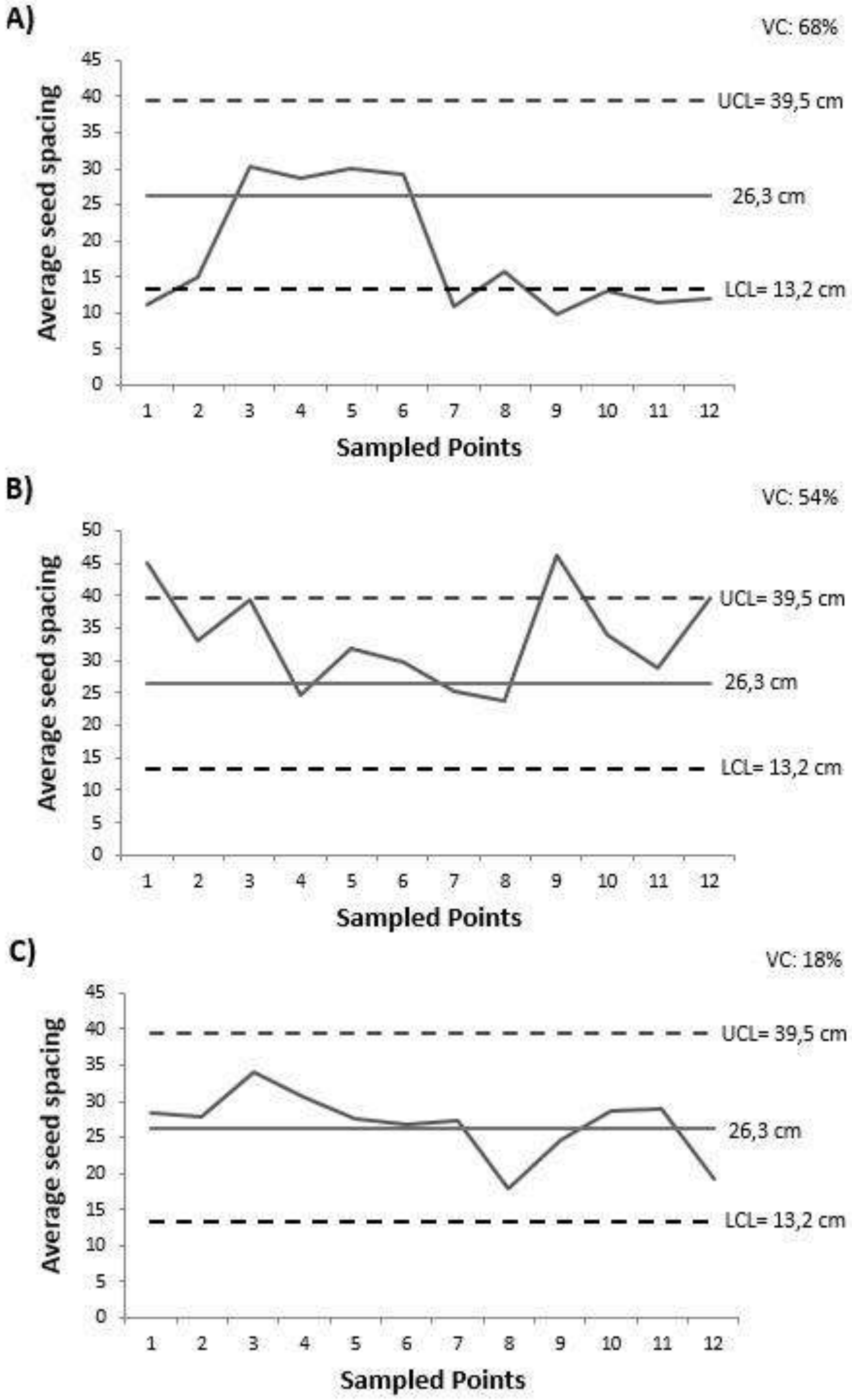
Note: Averages followed by the same letter in the column do not differ statistically by the Tukey test at 5% probability.

It can be seen that the lower graphite doses of 4.0 and 8.0 g kg^{-1} showed a higher percentage of failures and a lower percentage of failures for the 12.0 g kg^{-1} dose. There was a lower number of seeds m-1 when the graphite dose was 8.0 g kg^{-1} compared to the other graphite doses.

The results corroborate those of Badua *et al.* (2019), who determined that greater seed fluidity reduces double spacing and failures during seed distribution. Undesirable spacing directly affects the individual yield of each plant and per unit area, the degree of lodging, and the mass of the harvested grain, contributing to significant reductions in crop yields. Dalchiavon *et al.* (2020) also reached the same conclusions when studying the dosage of solid lubricant in sunflower cultivation, where the best doses were 8.0 to 12.0 g for each kg of seed.

Figure 1 shows the control chart for a speed of 5.0 km h^{-1} with different graphite doses on the seeds. In Figure 1 A, for a speed of 5.0 km h^{-1} with a graphite dose of 4.0 g kg^{-1}, according to the points sampled, there was an increase in observations 2 to 6, thus obtaining values close to the ideal spacing. Between observations 7 and 12, there was a trend towards regularity between spacings, with values close to the lower limit of 13.2 cm and a greater tendency for doubles. Even though all the observations were within the control, at this speed, there was greater variation in the data, with a VC of 68%, which may be due to the amount of graphite being less than indicated, thus demonstrating greater irregularity between the spacings.

Figure 1. Control charts for the speed of 5.0 km h^{-1} with different graphite doses: A) 4.0 g kg^{-1}; B) 8.0 g kg^{-1}; and C) 12.0 g kg^{-1}.



In Figure 1 B, at a dose of 8.0 g kg^{-1}, there was a tendency for the spacing to be uneven. The spacing was around 45 cm in observations 1 and 9, and close to ideal spacing was observed between observations 3 and 8. Even though most of the observations were within the control, values such as spacing considered to be failures were preponderant for a VC of 54%. Figure 1 C, showing values when the graphite dose was 12.0 g kg^{-1}, was the most regular among the dosages observed, whose spacings varied very close to the 26.3 cm average with a small increase at point 3 of 35 cm and a decrease at spacings 8 and 12 of 20 cm, where the VC was 18% lower than the others.

The importance of having less variation in the data is associated with the fact that, in addition to measuring the spacing, it is necessary to evaluate the dispersion concerning the average determined by the coefficient of variation (VC) and how closely the deposition varies depending on the theoretical distribution, expressed by the precision index (PI) (Cay *et al.*, 2018).

Reducing friction between the seeds by using graphite caused a marked reduction in the levels of undesirable spacing, regardless of speed. Badua *et al.* (2019) reported that the use of solid lubricants increased singularization during seed distribution, in addition to minimizing abrasion with the components of the metering mechanism, consequently reducing damage to the seeds and extending the useful life of the metering components. Studies by Correia *et al.* (2020) show that operating speed is directly proportional to planting quality, increasing the number of failed and double spacings and reducing acceptable spacings.

Figure 2 shows control charts for a speed of 7.7 km h^{-1} with different graphite doses used in the seeding process. In Figure 2 A, for a speed of 7.7 km h^{-1} with a graphite dose of 4.0 g kg^{-1}, the highest VC values were obtained, and most of the points were above the ideal spacing, with some even considered to be faulty spacings. In Figure 2 B, with a graphite dose of 8.0 g kg^{-1} for the observations sampled, it was found that this had the highest VC (66%) among the amounts of graphite evaluated at this speed, with some observations exceeding the upper control limit.

Figure 2. Control charts for the speed of 7.7 km h^{-1} with different graphite doses in the seeds: A) 4.0 g kg^{-1}; B) 8.0 g kg^{-1} and C) 12.0 g kg^{-1}.

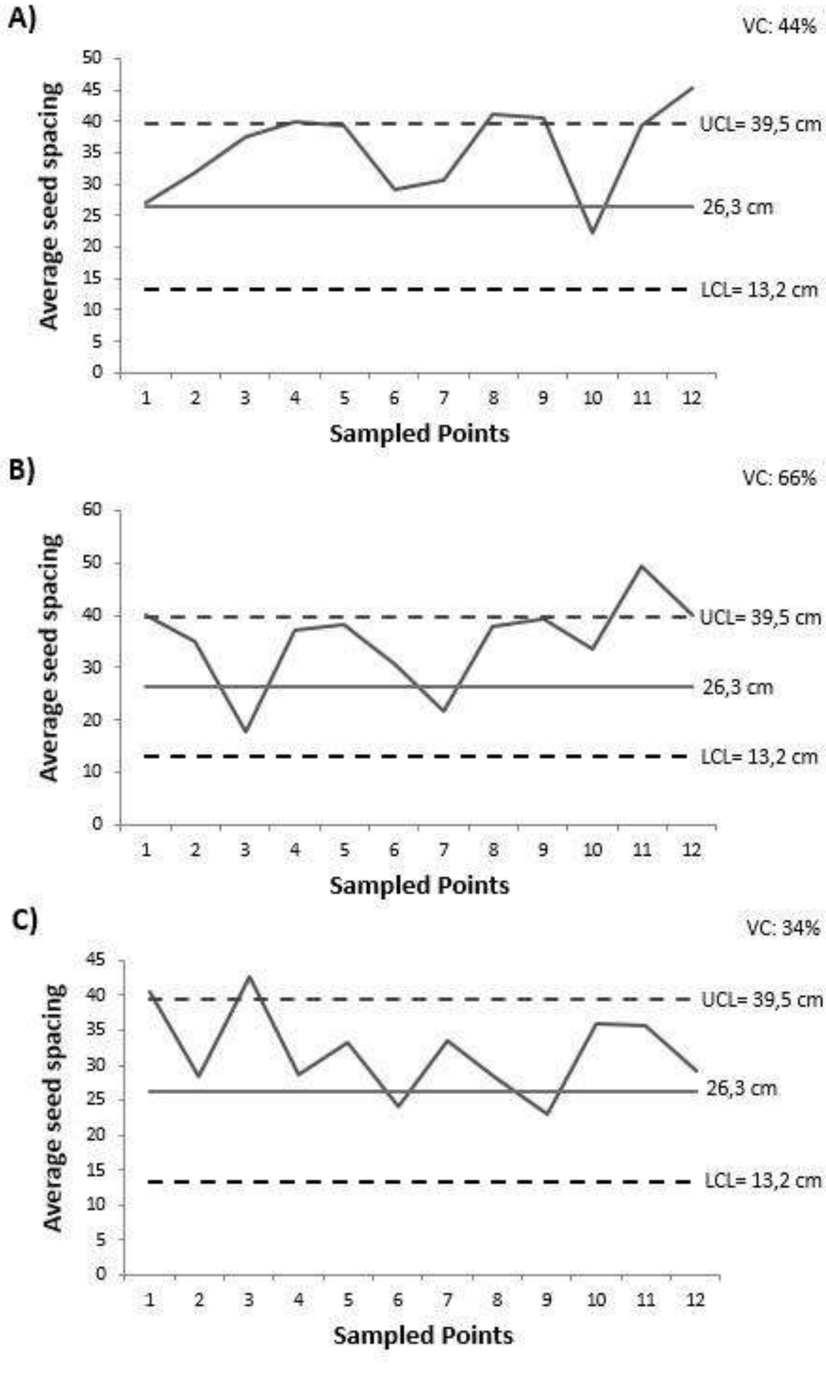


Figure 2 C shows the spacing between seeds in the sampled observations, where there was less variation in the space between seeds at a speed of 7.7 km h^{-1} and a dose of 12.0 g kg^{-1}. The VC was 34% due to the high graphite dose. As in Figure 1, using a higher graphite dose helped the seed spacing to be more homogeneous and close to the ideal spacing of 26.3 cm.

This can also be explained by the increased centrifugal force of the seeds when they enter the conductive tube, resulting in more frequent collisions and jumps (Virk *et al.*, 2020). In addition, this reduction in the efficiency of the metering disk with increasing distribution speed is due to the increase in the number of seeds metered per minute, which has an inverse effect on the level of correct deposition (Mangus *et al.*, 2017).

Figure 3 shows control charts for a speed of 10.7 km h^{-1} with different graphite doses in the seeding process. Figure 3 A, with the graphite dose of 4.0 g kg^{-1}, shows a high VC value (57%) in the observations presented, with most observations above the ideal spacing and even with some points outside the Upper Control Limit, showing faulty spacing.

Figure 3. Control charts for a speed of 10.7 km h^{-1} with different graphite doses on the seeds: A) 4.0 g kg^{-1}; B) 8.0 g kg^{-1} and C) 12.0 g kg^{-1}.

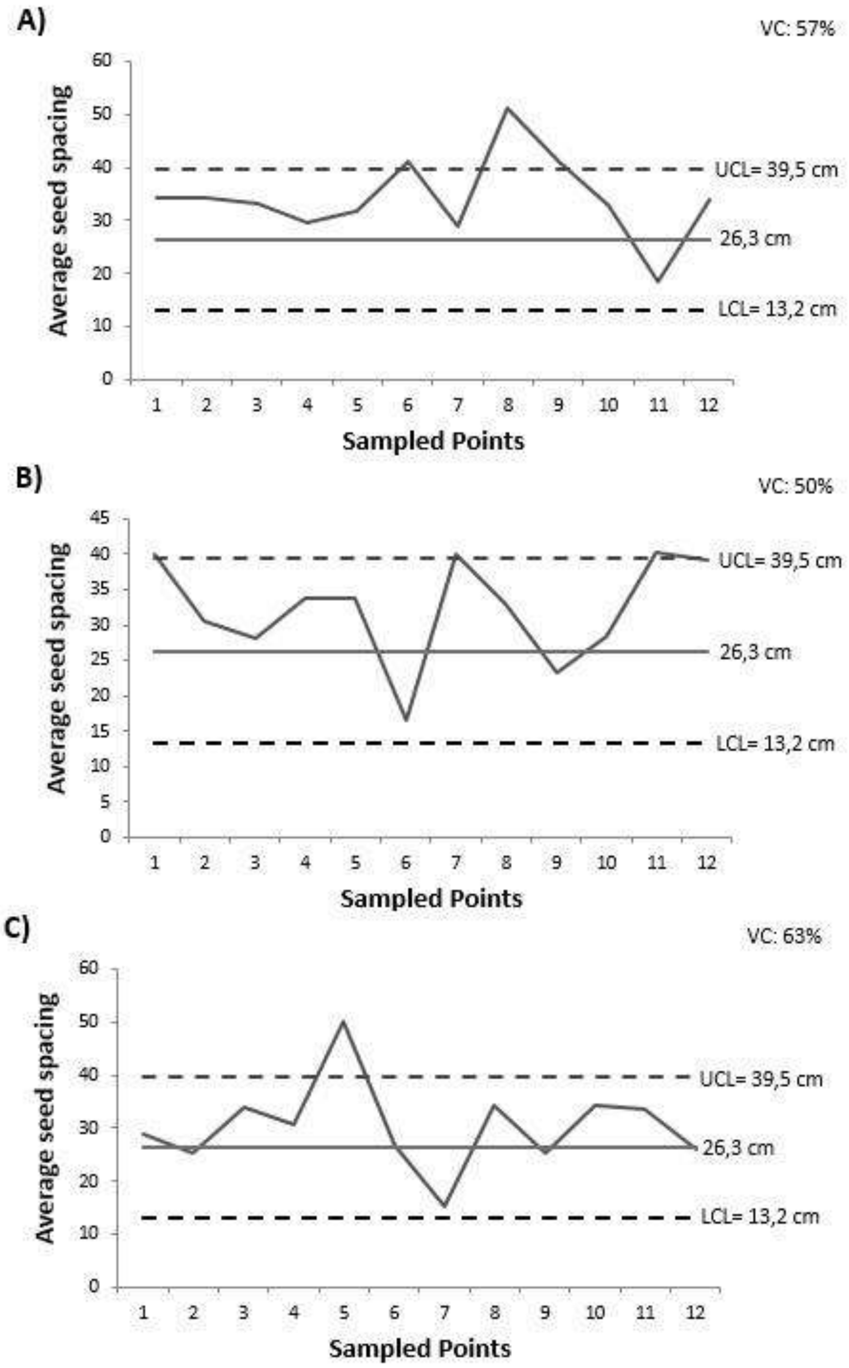


Figure 3 B, with 8.0 g kg^{-1} of graphite, showed the lowest coefficient of variation in seed spacing, with a value of 50%. Even at high speeds, this amount of graphite maintained the greatest uniformity in this condition.

With a graphite dose of 12.0 g kg^{-1} (Figure 3 C), there were high spacing values, which were classified as failures up to values close to double spacing. These values influenced the VC, which was 63%. Unlike the other speeds evaluated, the speed of 10.7 km h^{-1} obtained heterogeneous values even with the increase in graphite dosage, showing a greater speed influence in this process.

Traditional seed drills tend to increase the spatial variability of plant spacing in maize with an increase in planting speed and, likewise, the quantity of seeds, when there is an increase in speed or an increase in seeding rate, resulted in greater variation in the spacing between maize plants in planting speed ranges from 6.0 to 9.5 km h^{-1} (Virk *et al.*, 2020).

This study also corroborates the work carried out by Bortoli *et al.* (2021), who verified the seeding process in soybeans and concluded that the precision of seed deposition was reduced, with an increase in double spacings, and grain yield reduced as the speed increased to 9.0 km h^{-1} with a precision in-line seeder.

Therefore, this study shows that the ideal graphite dose can vary depending on the operating speed and that there was a better distribution of the seeds at low speeds and with a higher graphite dose.

Conclusion

In summary, it was concluded that there was greater seeding uniformity with a speed of 5.0 km h^{-1}. The graphite dose of 12.0 g kg^{-1} provided less variation in seed spacing. The influence of speed leads to a reduction in acceptable spacing and, consequently, an increase in the percentage of gaps and double spacing. Speed was more influential between spacings when above 10.7 km h^{-1}. Up to a speed of 7.7 km h^{-1}, a higher dosage of graphite was influential for more uniform spacings. In order to maintain sowing quality, the increase in speed can be compensated for by using graphite, thus allowing a gain in operational capacity.

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