

Performance Evaluation of Straight and Parabolic Seed Tubes on Longitudinal Seed Distribution under Varying Sowing Speeds and Lateral Inclination Angles

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Abstract: *The uniform distribution of seeds during sowing is essential for maximizing agricultural productivity. Seed tubes play a crucial role in this process, as they directly influence the longitudinal distribution of seeds. This study evaluated the performance of two seed tubes, one with a straight profile and the other with a parabolic profile, under different sowing speeds and lateral inclination angles of the seed meter. A mechanical horizontal disc plate meter was employed. Three experimental factors were examined: seed tube profile (straight and parabolic), lateral inclination angle of the metering unit at four levels (11°, 1°, 0°, and -11°), and sowing speed at three levels (5, 7, and 9 km·h⁻¹). A significant triple interaction was identified among tube profile, travel speed, and lateral inclination angle of the metering unit with respect to single, double, and missing seed spacings. The parabolic profile tube yielded a higher percentage of single spacings and lower percentages of double and missing spacings than the straight tube, with the best results observed at 5 km·h⁻¹ and a leveled inclination angle (0°). These findings provide a useful reference for optimizing seed tube design and sowing parameters.*

Keywords: Seed Tube, Straight Profile, Parabolic Profile, Sowing Speed, Lateral Inclination Angle, Longitudinal Seed Distribution, Seed Meter, Single Seed Spacing, Agricultural Productivity.

1. INTRODUCTION

The interaction between the seed metering device and the seed tube is crucial to ensuring sowing quality, directly influencing the uniformity of seed distribution and, consequently, crop productivity. Uniformity in seed distribution and proper stand establishment are determining factors for crop success (Carpes et al., 2017; Carpes, 2014).

Additionally, other factors, such as the disc's angular speed and the equipment's inclination relative to the ground, significantly impact seeding quality. Increasing speed while keeping seeding density constant can reduce the percentage of acceptable spacing due to longitudinal inclinations (Andrade, 2022; Garcia, 2022; Alonço et al., 2014). This phenomenon occurs because higher travel speed causes less filling of the metering disc's cells, resulting in fewer seeds distributed per meter and, consequently, lower averages of acceptable spacing.

Since seed speed and trajectory affect longitudinal distribution, the configuration of the delivery tube, including its length, angle of inclination, and diameter, can increase the effectiveness of this interface (Carpes et al., 2017; Teixeira, 2009). Evaluating the effect of the seed delivery tube at different peripheral speeds of the metering disc, Carpes (2014) found that delivery tubes with a parabolic profile and a discharge curvature of approximately 30° provided better longitudinal distribution quality, regardless of the metering mechanism used, a phenomenon also observed by (Garcia, 2022).

Furthermore, the equipment's transverse inclination interferes with the performance of metering mechanisms. Right angles cause greater "bouncing" of seeds when they hit the ground, creating double or missing spacing. The length of the delivery tubes can alter seed trajectory, affecting distribution uniformity (Andrade, 2022; Carpes, 2014).

Given the importance of the tube in minimizing adverse impacts on seed distribution, Carpes et al. (2017) argue that the delivery tube should be as short as possible with a parabolic profile to reduce the horizontal component of the seeds' falling speed and ensure greater uniformity in their distribution.

In this context, the objective of this study was to evaluate the influence of two delivery tubes with different configurations regarding profile, length, and seed inlet dimensions, combined with a horizontal disc mechanical metering device, at three seeding speeds and three lateral inclination angles of the metering device.

2. MATERIALS AND METHODS

Seed metering and deposition were simulated in the laboratory using a test bench according to ABNT (1994), with a horizontal disc metering device mounted to represent the terrain slope at three lateral inclination angles of the metering device, as shown in Figure 1.



Figure 1: Side tilt angles of the horizontal disc dispenser (11%, 0° and -11°).

For the conduction of the trial, two types of seed delivery tubes were used. The first with a straight profile (tube 1) has a length of 47.5 cm, a seed entry angle of 0°, a seed exit angle of 33,98°, seed entry dimensions of 75 x 51 mm, and seed exit dimensions of 44 x 19 mm. The second tube with a parabolic profile (tube 2), with a length of 53 cm, a seed entry angle of 0°, a seed exit angle of 36,56°, seed entry dimensions of 56 x 35 mm, and seed exit dimensions of 36 x 15 mm, as shown in Figure 2. Both tubes were coupled to a horizontal disc mechanical metering device of the J. ASSY® brand, model TITANIUM.



Figure 2: Side view of the straight and parabolic seed delivery tubes.

The experiment was conducted using soybean seeds of the 96Y90IPRO cultivar, of indeterminate growth habit from Pioneer® company, simulating a population density of two hundred and fifty thousand seeds per hectare, with sowing spaced at 0.45 meters and a sowing density of 11.3 seeds per meter. The experimental design adopted was completely randomized in a factorial scheme 2 x 3 x 3 with four replications. The treatments were the combination of two seed drop tubes (straight and parabolic), three lateral inclination angles of the metering device

(11°, 0°e -11°); and three sowing speeds (5km h⁻¹, 7km h⁻¹e9km h⁻¹) totaling 18 treatments.

To calculate the faulty, acceptable, and multiple spacings as a function of each speed, a reference time (Tref) was established, corresponding to the time taken for the seeds to pass through the delivery tube. The reference times defined for each speed in milliseconds (ms) were: V1=60ms, V2=43ms and V3=33ms. For counting the number of seeds and the relative time between the passage of consecutive seeds, an internal timer with a resolution of $\pm 0,001s$ was used, along with a sensor based on a microprocessed system that continuously communicates the readings made by an optical sensor instrumented for signal adjustment and arranged in a tested geometry, with the computer via a serial monitor using the RS-232 protocol. At the end of each experiment, the system provides a file containing information on the temporal spacing between seeds (Andrade, 2022).

The data were collected and recorded in a file using RcomSerial v. 1.2 software for subsequent analysis in an electronic spreadsheet. Next, the collected data were grouped into means for acceptable, double, and missing spacings, and then subjected to analysis of variance (ANOVA). When the factors showed significance by the F-test, the means were compared using the Tukey test, considering a 5% probability of error ($\alpha \leq 0,05$).

3. RESULTS AND DISCUSSIONS

There was a significant effect in the F-test for all variables analyzed as a function of the treatment factors. The Shapiro-Wilk test, with a 5% probability of error ($\alpha \leq 0,05$), demonstrated the normality of the errors, making data transformation unnecessary. The results of the statistical analysis showed that the acceptable spacings were influenced by the increase in speed, the inclination of the metering device, and the type of seed delivery tube.

The increase in speed caused a significant difference for this variable at all inclination angles. A more detailed analysis reveals that, depending on the delivery tube, the regularity of the percentage of acceptable spacings occurs only at speeds of 5km h⁻¹ and 7km h⁻¹ at inclinations of 0° and 11° to the right. A possible explanation for this behavior is that, although the straight-profile delivery tube has a shorter length compared to the parabolic-profile one, the increase in speed caused greater bouncing of the seeds, resulting in uneven distribution, as noted by (Carpes et al., 2017).

The percentage of acceptable spacings was lower when the straight-profile delivery tube was tested, as shown in Table 1.

Table 1: Acceptable soybean seed spacings (%) in simulated bench seeding with a horizontal disc metering device as a function of different drop tubes, lateral inclination angles of the metering device (11° to the right; 0°e; 11° to the left), and seeding speed (5; 7; e; 9km h⁻¹)

Speed (km h ⁻¹)	Doser											
	Tube 1						Tube 2					
	Angle						Angle					
	11° to the left		0°		11° to the right		11° to the left		0°		11° to the right	
5	1b2B3β	58,7	cAβ	66,0	bCβ	53,0	aBα	84,3	aAα	98,5	aCa	73,3
7	aBα	84,7	aAβ	94,2	cCβ	44,4	bBβ	76,2	aAα	96,4	bCa	66,0
9	bBα	60,0	bAα	90,1	aBα	59,2	bBβ	75,6	bAα	91,7	cCa	59,2

1 Lowercase letters compare the percentage of acceptable spacing (%) of soybeans as a function of speed, in the column, by Tukey's test ($\alpha \leq 0,05$). 2 Uppercase letters compare the percentage of acceptable spacing as a function of angle, in the row, by Tukey's test ($\alpha \leq 0,05$). 3 Lowercase Greek letters compare the percentage of acceptable spacing as a function of the type of metering tube used, by Tukey's test ($\alpha \leq 0,05$).

For the parabolic profile seed tube, it was observed that as the speed of the seed metering disc increased, the average percentage of acceptable spacing decreased. The highest percentage of acceptable spacing across all treatments was observed at speeds of 5km h⁻¹ and 7km h⁻¹ in the level position. This result was favored by the profile of the seed tube (Carpes et al., 2017). Additionally, it is believed that the inclination angle of the metering device in the level position contributed to the regularity in the distribution of acceptable spacing. Alonço et al. (2014) consider that speeds of up to 10 km h⁻¹ are favorable for the average of acceptable spacing at the inclination angle in this position.

The seed tube positively influenced the percentage of acceptable spacing at inclinations of 11° to the right and level. However, when subjected to an inclination of 11° to the left, there was considerable percentage variability in this variable. These results were expected according to Alonço et al. (2014), who found that the combination of the seed tube and the inclination angle in the level position (00) positively interferes with the regularity of the

longitudinal distribution of seeds in the sowing row, resulting in a greater number of acceptable spacing.

In parabolic profile tubes, the level position favors an increase in the number of acceptable spacing even with increased speed. This supports the conclusions of Carpes et al. (2017), who, evaluating different seed tubes in the longitudinal distribution of corn seeds, observed that the seed tube with a parabolic profile showed the best performance in terms of longitudinal seed distribution, regardless of the type of seed metering disc used.

Finally, it can be observed in Table 1 that, regardless of the seed tube and simulated speed, the highest averages of acceptable spacing were obtained with the level metering device (0°), demonstrating the deleterious effect of transverse inclination on the sowing quality of soybean seeds under the tested conditions.

The results in Table 2 indicate that the double spacing variable showed significance with tube profile, speed, and inclination.

Table 2: Double spacing of soybean seeds (%) in simulated bench sowing with a horizontal disc metering device as a function of different drop tubes, lateral inclination angles of the metering device (11° to the right; 0° ; 11° to the left), and sowing speed (5; 7; and 9 km h^{-1}).

Speed (km h^{-1})	Doser											
	Tube 1						Tube 2					
	Angle						Angle					
	11° to the left		0°		11° to the right		11° a esquerda		0°		11° to the right	
5	1a2A3a	3,3	aAa	2,3	aAa	3,3	aAa	3,0	aBa	0,7	bBb	1,4
7	aBa	2,2	bBa	1,4	aAa	5,2	aAa	2,6	aBa	1,0	abABb	2,3
9	aABa	3,0	bBa	1,3	aBa	3,6	aAa	2,0	aAa	1,6	aAa	3,6

1 Lowercase letters compare the percentage of double spacings (%) of soybeans as a function of speed, in the column, by Tukey's test ($\alpha \leq 0,05$). 2 Uppercase letters compare the percentage of double spacings as a function of angle, in the row, by Tukey's test ($\alpha \leq 0,05$). 3 Lowercase Greek letters compare the percentage of double spacings as a function of the type of metering tube used, by Tukey's test ($\alpha \leq 0,05$).

The highest percentage of variation in faulty spacings was observed in tube 1, with inclinations of 11° to the left and in the level position. There was no group change in the 11° inclination to the right in relation to faulty spacings. Although there was a decrease in faulty spacings with increasing speed in the level position (0°), this factor did not influence faulty spacings in other treatments. Correia et al. (2020) observed that increasing sowing speed does not interfere with double and faulty spacings, except at speeds above 8.7 km h^{-1} , which justifies the insignificance observed in this study.

Analyzing the double spacing indices in tube 2, it was found that the gradual increase in the speed of the seeder resulted in an increase in the percentage of faulty spacings at the inclination angles of 0° and 11° to the right. The level position (0°) obtained the lowest percentage of faulty spacings at all angles, resulting in a higher number of acceptable spacings. For the 11° inclination to the left, speed caused a decrease in the percentage of faulty spacings, a fact that explains the higher percentage of acceptable spacings at this inclination angle. A possible explanation for this phenomenon is that the conducting system causes vibrations that increase seed friction, delaying the falling flow and resulting in a high number of faults. This finding was also made by (Reynaldo 2016; Carpes et al., 2017).

There is an inverse relationship between the percentage of faulty and acceptable spacings, that is, an increase in the number of faulty spacings results in a decrease in acceptable ones. This suggests that the interaction between the conducting tube, inclination angles, and sowing speed influences the longitudinal distribution of seeds.

Data analysis showed that there was a significant interaction between all evaluated factors (speed, inclination angle, and tube profile) for the variable, faulty spacings (Table 3).

Table 3. Faulty spacings of soybean seeds (%) in simulated sowing on a bench with a horizontal disc metering device as a function of different drop tubes, lateral inclination angles of the metering device (11° to the right; 0° ; 11° to the left), and sowing speed (5; 7; e; 9 km h^{-1}).

Speed (km h^{-1})	Doser											
	Tube 1						Tube 2					
	Angle						Angle					
	11° to the left		0°		11° to the right		11° to the left		0°		11° to the right	
5	1a2B3a	38,0	aCa	31,7	bAa	43,7	bBa	12,7	bCa	0,8	cAa	25,4
7	bBb	13,0	cCa	4,3	aAa	50,4	aBa	21,2	abCB	2,6	bAa	31,7
9	aAa	37,0	bBa	8,6	cAa	37,2	aBb	22,4	aCa	6,6	aAa	37,2

1 Lowercase letters compare the percentage of failed spacing (%) of soybeans as a function of speed, in the column, by Tukey's test ($\alpha \leq 0,05$).

2 Uppercase letters compare the percentage of failed spacing as a function of angle, in the row, by Tukey's test ($\alpha \leq 0,05$). 3 Lowercase Greek letters compare the percentage of failed spacing as a function of the type of metering tube used, by Tukey's test ($\alpha \leq 0,05$).

An irregular behavior was observed in tube 1, where increasing the speed from 5 km h^{-1} to 7 km h^{-1} decreased the percentage of failures. However, when the speed increased from 7 km h^{-1} to 9 km h^{-1} , the percentage of failures increased. This behavior was observed only at the inclination angles of 11° to the left and in the level position (0°). At the 11° inclination angle to the right, the percentage of failed spacing was not influenced by the inclination angle nor by the tube profile.

The irregularity in the longitudinal distribution of seeds, expressed by the percentage of failed spacing as a function of variations in sowing speed, is explained by the profile of the delivery tube. In straight-profile tubes, increasing speed causes higher percentages of failures (Carpes et al., 2017). Lopes (2018) reported that lower percentages of acceptable spacing result in a higher number of failures, corroborating the results of this study.

Tube 2 showed a significant influence on the percentage of failed spacing with increasing speed. There was an increase in the percentage of failures at all inclination angles. The level position (0°) presented the lowest number of failures and the highest number of acceptable spacing throughout the experiment. This result was followed by the 11° inclination to the left and, finally, by the 11° inclination to the right. It was observed that the lowest results of failed spacing were obtained as a function of speed and the type of seed delivery tube, with the inclination factor having a reduced impact on this variable.

Alonço et al. (2014) evaluated the influence of the transverse inclination angle on the performance of three metering devices subjected to different speeds. The authors observed that variation in inclination does not have a significant influence on the percentage of failed and acceptable spacing. However, tests with metering devices in a level position responded better to speed variations of up to 10 km h^{-1} , justifying the results obtained in this study.

These results highlight that the choice of delivery tube, lateral inclination, and sowing speed are fundamental to optimize operational efficiency and the distribution of soybean seeds.

4. CONCLUSION

According to the methodology and results of this work, we can conclude: At a right slope of 11° , the use of a parabolic-profile delivery tube minimizes seed bounce and improves seed distribution efficiency. For this slope, the seeding speed should be reduced to 5 km h^{-1} to maintain seeding at acceptable distribution levels.

At a left slope of 11° , the parabolic-profile delivery tube allows the seeding speed to be increased up to 7 km h^{-1} without compromising seeding quality. In contrast, the straight-profile tube may reduce efficiency at this slope as speed increases.

Level position (0°): In this configuration, the parabolic-profile delivery tube demonstrated better seed distribution and a reduction in the percentage of doubles and misses. Increasing the seeding speed in this position, when combined with the parabolic tube, provides a more uniform distribution. The straight-profile tube, on the other hand, showed less effectiveness in maintaining distribution uniformity at higher speeds.

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