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CROP PRODUCTION

Seed sensor position on seeder performance at varying speeds

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ABSTRACT: The uniformity of seed distribution and sowing speed directly impact crop quality and productivity. This experiment assessed how the position of the sowing monitoring sensor influences the distribution of cotton seeds using a pneumatic meter at different operating speeds. The experiment employed a completely randomized two-factor factorial design on a static simulation bench. The first factor involved the sensor installation sites (upper, middle, and lower portions of the conductor tube and conveyor belt), while the second factor encompassed simulated speeds of 3.0, 5.0, 7.0, 9.0, and 11.0 km/h. Parameters such as frequency of double, flawed, and acceptable spacing, coefficient of variation, and precision index were measured based on five replications of 250 consecutive spacing. The results indicated that the sensor's placement significantly influences reading accuracy. Optimal results were observed when the sensor was positioned at the final portion of the conductor tube, providing more accurate seed deposition, and facilitating decision-making.
Key words: sowing uniformity, seeder, precision agriculture.

Influência da posição do sensor de sementes da semeadora em diferentes velocidades de trabalho

RESUMO: A uniformidade de distribuição de sementes no solo e a velocidade de semeadura estão diretamente relacionados à qualidade e produtividade da lavoura. O objetivo do experimento foi avaliar a influência da posição de instalação do sensor de monitoramento de semeadura, em relação a leitura realizada em bancada de ensaio, durante a distribuição de sementes de algodão com dosador pneumático, submetido a diferentes velocidades operacionais. O experimento foi conduzido em bancada estática de simulação, com delineamento inteiramente casualizado, fatorial duplo, sendo o primeiro fator o local de instalação do sensor (porção superior, média e inferior do tubo condutor e esteira condutora) e o segundo as velocidades simuladas de 3,0; 5,0; 7,0; 9,0 e 11,0 km h^{-1}. Os parâmetros mensurados para a avaliação da distribuição das sementes foram a frequência de espaçamentos duplos, falhos e aceitáveis, seu coeficiente de variação e índice de precisão, mensurados a partir de cinco repetições de 250 espaçamentos consecutivos. Os resultados obtidos foram que a posição de inserção do sensor de monitoramento interfere diretamente na eficiência da leitura, a qual tende a ser mais assertiva quando o sensor é posicionado na porção final do tubo condutor, demonstrando com maior acurácia a real deposição e assim facilitando a tomada de decisão.
Palavras-chave: uniformidade de semeadura, semeadora, agricultura de precisão.

INTRODUCTION

Seed distribution uniformity is crucial for assessing the efficiency of the sowing operation, measured by the spacing between consecutive seeds. Achieving proper seed deposition, both in quantity and uniformity, is vital for attaining high productivity levels. Homogeneous seed distribution allows plants to utilize available resources effectively, maximizing their genetic potential (TOURINO et al., 2002; HU et al., 2022).

Inadequate seed distribution has more significant negative effects on crops that are less adaptable, such as corn (*Zea mays* L.) and sunflower (*Helianthus annuus* L.). Conversely, crops with phenological plasticity, like rice (*Oryza sativa* L.), soybeans (*Glycine max* L.), and cotton (*Gossypium hirsutum* L.), show smaller effects due to their ability to adapt to variations through tillering or branching (PEREIRA & HALL, 2019).

The quality of the sowing operation and metering mechanism directly impact seed distribution per unit area in the field, with considerable variations in sowing rates (AL-MALLAHI & KATAOKA, 2013). Issues like excessive or imprecise seed deposition, system damage, and obstructions are undesirable and often go unnoticed by the operator (HE et al., 2017). Real-

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time feedback on the performance of deposition mechanisms, provided to the machine's telemetry system, can achieve the desired plant population and increased yields (KARIMI et al., 2019).

Detecting the exact positioning of seeds poses a significant challenge in automating sowing monitoring tests (OKOPNIK & FALATE, 2014). Therefore, evaluating seed deposition efficiency under laboratory conditions becomes necessary to isolate external factors' negative interference.

Various sensors, such as piezoelectric, capacitance, and photoelectric sensors (LV et al., 2018), can be used to detect seed flow rate, with the photoelectric detection unit being the most popular among seed sensing mechanisms (LIU et al., 2020). This type of sensor emits an infrared light beam, and when a seed interrupts the beam, the device counts the units by the sensor.

Proper sensor positioning in the conductor tube is essential for accurately detecting seed flow, ensuring higher precision in identifying dosed seeds (KARIMI et al., 2019). The distance between the infrared beams' emitting and receiving elements directly affects the mechanism's precision in identifying the passage of each seed. This factor becomes more critical for smaller seeds like soybean and sorghum seeds (DE SOUSA et al., 2017).

CAY et al. (2017) developed a reading system with an optoelectronic sensor for measuring seed spacing during laboratory tests of precision sowing mechanisms, using seeds from ten commercial crops with different physical properties. The system yielded satisfactory and precise results without the need for complex calibration and adjustment procedures, making it suitable for experimental bench tests.

Incorrect distribution occurs when there are higher rates of double or flawed seed spacings in the sowing furrow. Double spacing refers to consecutive seeds not reaching 0.5 times the desired spacing, while flawed spacing occurs when seeds are deposited above 1.5 times the desired spacing (ISO 7256/1, 1984).

Increasing the work regime leads to higher peripheral speeds of the metering discs, resulting in less regularity in the longitudinal distribution of seeds (NADIN et al., 2019). In this study, we evaluated the influence of the installation position of the sowing monitoring sensor on the reading taken during the distribution of cotton seeds using a pneumatic meter under different operating speeds.

MATERIALS AND METHODS

Characterization of the test bench

The static sowing bench described in SAVI et al. (2020), which allows the simulation of the distribution of seeds in the sowing furrow, was used to evaluate the influence of the positioning of the seed counting sensor. The seed metering mechanism is driven by a 0.25 kW gear reducer (Sew Eurodrive®), managed by a frequency inverter model CFW300 (WEG®).

The pneumatic metering mechanism used in the experiment consisted of the vSet model (Precision Planting®), equipped with a 32-hole Singulated High Rate® disk during seed distribution, with its corresponding singulator and ejector. The metering mechanism operated with a 4.98 kPa vacuum configuration, generated from a CR-3 IBRAM radial compressor (Brazilian Machinery Industry®), with a maximum flow capacity of 0.02 $m^3 s^{-1}$ and a vacuum of 12.75 kPa.

Figure 1 shows the electronic and structural components responsible for reading the seed distribution on the static sowing bench, which will be described below.

The evaluation of the singular seed distribution dynamics occurred through a measurement system using an E18-D80NK infrared proximity reflective optical sensor (OEM®), placed in the final portion of the conveyor belt. This device is separated into two components: an emitting unit, which is responsible for radiating the infrared light, and a receiving unit, responsible for capturing the light emitted by the receiver, creating a light beam. The reflection of light to the receiver and identification of the exact time of the event occur during the passage and complete interception of the infrared light beam by the seed (KUMAR & RAHEMAN, 2018). In addition, another infrared sensor was positioned on the 16-teeth gear present on the roller that drives the conveyor belt, measuring the simulated speed.

The optical position sensors PM 400 (Dickey John®) containing three LEDs as a light source and a photoelectric sensor operating on the photovoltaic cell principle controlled the reading width of the conductor tube. The signal from this sensor is then differentiated and converted into rectangular pulses initiated on the slope of a signal from the photoelectric element, and the strength of the measurement signal is automatically adjusted, according to the depth level. GIERZ (2015) compared different optical seed counting sensors and observed

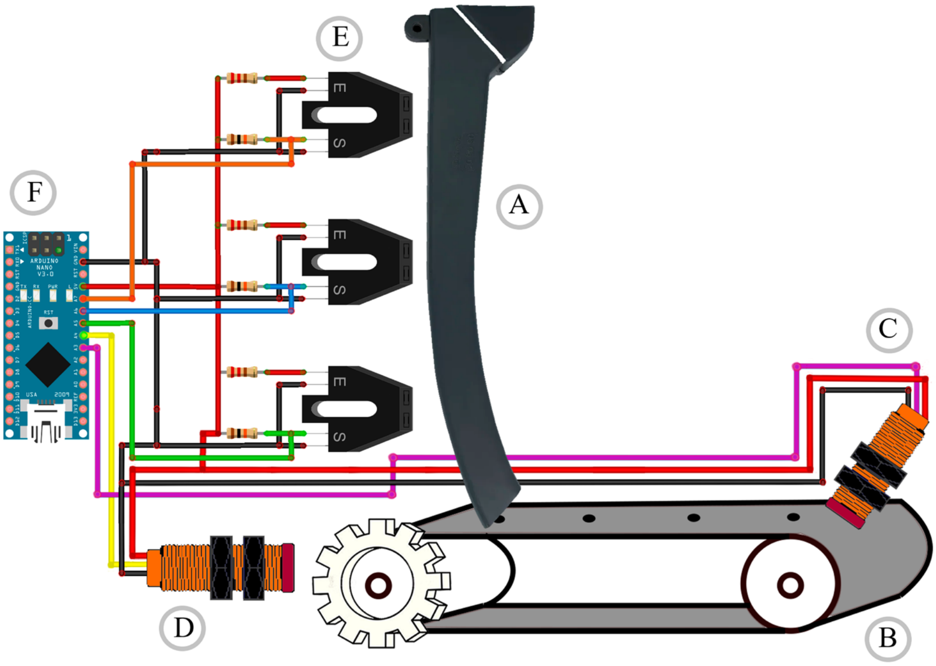


Figure 1 - Diagram of the reading components of the sowing bench: A – conductor tube; B – conveyor belt; C and D – infrared proximity reflective optical sensors; E – set of optical position sensors; F – data acquisition system.

that the sensor used in this experiment is highly efficient in identifying the exact moment of passage of each seed, corresponding to 99% precision in the number of distributed seeds.

The bench has a data acquisition system (DAS), with a printed circuit board designed in the software Proteus 8.1 (Labcenter Electronics®), built in an LPKF Protomat 93s milling machine. It is connected to an AT mega 328 microcontroller (Atmel®) with eight analog inputs and 14 software-programmed digital inputs/outputs, as well as a USB power/communication port, 16 MHz clock speed, and a 10-bit analog-to-digital converter. The acquisition frequency of one hertz was linked to the seed passage, measured by optical sensors connected to the DAS. The data were transferred and stored on hard disk.

Experimental arrangement and conduction of tests

The experiment was completely randomized in a two-factor factorial design. The first factor consisted of different positions of the plantability sensor (PPS) (upper, middle, and lower portion of the conductor tube and conveyor belt), while the second factor consisted of the distribution speeds (S) (3.0, 5.0, 7.0, 9.0, and 11.0 km h^{-1}). Each treatment corresponded to five replications of 250 consecutive spacing, totaling 5000 experimental units.

The duration of data collection corresponded to the deposition of two thousand seeds, each of which was repeated from the middle portion of the collection for subsequent statistical analysis. The reliability of these data is based on the number of observations and precision of the sensor, with a coefficient of determination (R^2) of 1.0.

The target sowing density was kept constant due to the adjustment of the deposition rate at the different simulated speeds, based on the change in the rotational speed of the metering disks. Calibration was performed by means of the correlation between the electrical frequency provided by the inverter and the number of seeds deposited per second, with an R^2 of 1.0, considering that the increment of one hertz promotes the deposition of 0.46 seeds per second.

The cotton seeds of the cultivar FM 954 GLT (BASF®), with purity and minimum germination rate of 98 and 85%, respectively, were distributed at a sowing density of 110,000 seeds ha^{-1}, spaced 0.20 m between plants and 0.45 m between rows.

Table 1 shows the physical characteristics of the cotton seeds used in this experiment. The dimensional characteristics (length, diameter, thickness, and sphericity) were measured following the methodology proposed by SOYOYE et al. (2018), evaluated from 100 sample units using a digital caliper (1×10^{-4} m precision). The thousand-grain mass was determined from three samples of 300 seeds on a BK-5002 semi-analytical balance (Gehaka®). The angle of repose of the seeds was established by the inverse tangent of the height relative to the distance of the mass deposited on a flat surface (AL-HASHEMI et al., 2018), measured after the addition of graphite at a dose of 4.0 g kg^{-1}.

Evaluated parameters

The parameters analyzed for the evaluation of distribution homogeneity were the percentage of acceptable (S_A), double (S_D), and flawed (S_F) spacings, according to ISO 7256/1 (1984), coefficient of variation (CV) (COELHO, 1996), and precision index (I_P). The performance indicators referring to the seeder were evaluated using the criteria shown in table 2.

According to CAY et al. (2018), I_P shows the distribution variability relative to the theoretical spacing (Eq. 1), disregarding S_D and S_F, meaning that higher I_P values present a higher unevenness of distribution relative to the desired spacing. It should not exceed the upper limit of 29%, suggested for precision seeders (NEJADI & RAOUFAT, 2013).

$$I_P = \left(\frac{\sigma}{X_{ideal}}\right) \times 100 \quad (1)$$

where I_P is the precision index (%), σ is the standard deviation of the acceptable spacings (m), and X_{ideal} is the expected spacing (m).

The collected data were subjected to analyses of normality and homogeneity of variances by the Shapiro-Wilk and Brown-Forsythe tests, respectively. The data were subjected to analysis of variance (ANOVA) once these assumptions were met and, if significant, the means were compared using the Tukey test ($P \leq 0.05$) for qualitative factors (sensor position) and regression analysis for quantitative factors (simulated speed and interaction), with models selected by the criterion of the highest R^2 and significance ($P \leq 0.05$) of the equation parameters, using software SigmaPlot 12 (Systat Software®).

RESULTS AND DISCUSSION

Table 3 shows the results of the synthesis of the evaluation analysis and Tukey's test, with no need to transform the means of all the variables, denoting normality (Shapiro-Wilk) and homogeneity of residuals of variance (Brown-Forsythe) for all variables. A significant effect of the isolated factors (PPS and S) was observed for all the analyzed variables and their interaction. Regarding efficiency during deposition, the uniformity corresponded to regular when analyzed at the upper and middle portions of the conductor tube and good at other positions (Table 2).

The analysis of the effect of the position of the monitoring sensor showed a higher uniformity at the final positions of the conductor tube and conveyor belt (Table 3). The higher frequency of S_A at the final position can be attributed to the more intimate contact of the seeds with the receptor element of the sensor due to the parabolic curvature of the conductor tube, improving the ability to identify the passage of consecutive seeds, corroborating the reading performed on the conveyor belt.

Regarding undesirable spacings, a higher occurrence of S_D was observed when measuring the distribution at the final portion of the conductor tube and conveyor belt, which is due to the change in seed positioning during the deposition route (SAVI et al., 2020). However, a reduction in the sensor efficiency was observed when allocated at the upper and middle portions due to the similar conditions of distribution between treatments, thus considering some of the seeds deposited consecutively.

The reduction in the monitoring sensor efficiency is evidenced when analyzing the frequency of flawed spacings, which overestimates the frequency of S_F in monitoring the upper and middle positions due to the non-identification of the passage of part of the deposited seeds (Table 3). This result

Table 1 - Physical characteristics of cotton seeds.

Length	Width	Thickness	Sphericity	1000-seed mass	Angle of repose
---(mm)---				---(g)---	---(°)---
8.59 ± 0.47	4.52 ± 0.47	3.99 ± 0.22	62.65 ± 2.66	76.26 ± 4.95	27.48 ± 0.70

Table 2 - Limiting values of the criteria for classifying the performance of precision sowing.

---Spacing (%)---			---Classification---
SA	SD	SF	
> 98.6	< 0.7	< 0.7	Excellent
> 90.4 to 98.6	≥ 0.7 to < 4.8	≥ 0.7 to < 4.8	Good
≥ 82.3 to ≤ 90.4	≥ 4.8 to ≤ 7.7	≥ 4.8 to ≤ 10.0	Regular
< 82.3	> 7.7	> 10.0	Unsatisfactory

Variables: acceptable spacing (S_A), double spacing (S_D), and flawed spacing (S_F). Source: AYKAS et al. (2013).

is due to the increased distance between the emitting and receiving elements of the equipment, which is directly related to its efficiency (CAY et al., 2017). Therefore, this effect is potentiated due to the small size of the cotton seeds.

However, the distribution carried out at the lower portion of the conductor tube was similar to that performed on the conveyor belt in all spacing classes (S_A, S_D, and S_F), which was constructed and validated experimentally through preliminary research (SAVI et al., 2020). It demonstrated that it is the appropriate site to insert the monitoring sensor, corroborating with KUMAR & RAHEMAN (2018), who described that the monitoring of efficiency factors in the distribution of seeds must be carried out at the lower portion of the conductor tube, thus representing results the closest to the actual distribution observed in the sowing furrow. Importantly, the seeds allocated at this portion of the conductor tube were already influenced by factors related to the processes of individualization, singulation, ejection, flow, and deposition, thus representing with higher accuracy the actual distribution of seeds in the sowing furrow.

The upper and middle portions presented the highest CV values than the other readings due to the higher heterogeneity between consecutive spacings, not differing from each other, followed by the reading performed on the felt belt and the lower portion of the

Table 3 - Summary of analysis of variance and test of means for cotton seed deposition.

Analysis	---Variable---				
	S_A	S_D	S_F	C_V	I_P
	---(%)---				
---Normality---					
SW	0.09	0.07	0.09	0.08	0.09
---Homogeneity---					
BF	0.66	0.63	0.08	0.40	0.06
---F-test---					
PPS	85.11^{**}	112.80^{**}	196.28^{**}	64.36^{**}	435.80^{**}
S	53.37^{**}	38.63^{**}	33.06^{**}	27.90^{**}	169.37^{**}
PPS x S	12.46^{**}	22.47^{**}	20.34^{**}	10.99^{**}	15.81^{**}
---CV (%)---					
	1.97	44.28	16.37	8.71	6.82
---Test of means – Sensor position---					
Initial	85.61 C	0.23 B	14.16 A	37.58 A	10.21 D
Intermediate	87.13 B	0.43 B	12.44 B	36.25 A	11.67 C
Final	91.89 A	2.30 A	05.81 C	28.40 C	14.87 B
Belt	90.72 A	2.44 A	06.84 C	31.43 B	18.26 A

Variables: sensor position (PPS), distribution speed (S), acceptable spacing (S_A), double spacing (S_D), flawed spacing (S_F), coefficient of variation (C_V), and precision index (I_P). Shapiro-Wilk normality test: SW < 0.05 – data abnormality; SW > 0.05 – data normality. Brown-Forsythe test for homogeneity of variance: BF < 0.05 – heterogeneous variances; BF > 0.05 – homogeneous variances. F-test of the analysis of variance (ANOVA): NS – not significant; * (P < 0.05) and ** (P < 0.01). CV (%) – coefficient of variation. Means followed by the same uppercase letter in each column for each factor do not differ from each other by the Tukey test (P < 0.05).

conductor tube (Table 3). The increase in CV observed on the conductor belt relative to the lower portion of the conductor tube is due to the formation of multiple paths during the seed fall (KOLLER et al., 2014) and the possible change in the positioning of seeds before being seized by the belt felt, which was also observed by movements in the equipment.

It can be measured and considered through the analysis of the final portion of the bench, minimizing this error and corroborating with the observation by JASPER et al. (2009), who indicated it as an efficient method for collecting and fixing seeds, with benefits in sampling compared to other methods, such as the use of grease. Despite the CV being higher on the conveyor belt, the isolated observations of S_A, S_D, and S_F without significant differences validated the use of sensors at the lower position of the conductor tube. Importantly, this process can be aggravated under field conditions due to the kinetic energy of the seeds when they collide against the surface of the sowing furrow, leading to a change at the seed deposition site related to possible bouncing and rolling (KARIMI et al., 2019).

Furthermore, there is a degradation of the accuracy of seed distribution along the deposition path, denoting the lowest I_P values at the upper position of the conductor tube, that is, right after its detachment from the metering disc, followed by the middle and lower portions and the reading performed on the conveyor belt (Table 3). This reduction in the uniformity of distribution occurs due to the sharp increase in the acceleration of larger seeds and the formation of multiple paths during the fall route (SAVI et al., 2020).

Therefore, the reading performed at the upper portion of the conductor tube refers to the efficiency of seed individualization by the metering mechanism and not the effective deposition due to the possibility of the formation of multiple paths at the remaining portions of the conductor or even the rolling of the seed on the sowing furrow or conductor belt. Moreover, changing the distance between the sensor components due to the constructive format of the conductor tube interferes with the optical coverage of the photodiodes and; consequently, the precision of identifying the passage of seeds (BESHARATI et al., 2019).

The behavior of the variables S_A, S_F, CV, and I_P as a function of the distribution speed (Figures 2A–E) shows a second-order polynomial trend and a determination factor higher than 65% can be observed for all cases.

The variable S_A (Figure 2A) had a non-linear trend of decreasing homogeneity of distribution with the increase in the distribution speed. Thus, the highest S_A levels corresponded to the distribution carried out at 3 km h^{-1}, not differing from the speeds of 5 and 7 km h^{-1}. However, according to the generated equation ($R^2 = 0.87$), the highest level of S_A is obtained at the distribution speed of 5 km h^{-1}.

The decrease in S_A levels with increasing speed is due to higher levels of undesirable spacing (S_F and S_D) (Figures 2B–C) when the metering mechanism operated at higher deposition rates. This reduction in distribution efficiency with increasing speed occurs due to the increase in the number of seeds dosed per minute, which is inversely related to the level of correctness in seed individualization (MANGUS et al., 2017). The frequency of S_F and S_D increased asymmetrically, demonstrating that speed not only reduced seed deposition uniformity but also interfered negatively with the singulation of the metering mechanism.

CV (Figure 2D) showed a non-linear increasing behavior to the detriment of the seed distribution speed, and its lowest value (31.88%) occurred at the speed of 4 km h^{-1} according to the generated equation. According to CAY et al. (2018), seed distribution uniformity is reduced with an increase in peripheral speed.

Regarding I_P (Figure 2E), an increase in speed provided higher variability on the observed spacing. However, I_P remained within the established limit of 29% for precision seeders at all distribution speeds (NEJADI & RAOUFAT, 2013).

This reduction in precision (CV) and accuracy (I_P) in seed distribution with increasing speed is explained by the increased centrifugal force of the seeds when entering the conductor tube, resulting in higher levels of collisions and jumps. In this sense, VIRK et al. (2020) reported a reduction in the uniformity levels of spacing between plants with increasing operating speed.

Equations capable of representing the slicing of the interaction between the variables S_A, S_F, CV, and I_P as a function of the distribution speed were generated (Figure 3). The equations generated for the acceptable spacing (Figure 3A) showed a trend of degradation of the distribution uniformity with an increase in the simulated speed, corroborating with the results obtained by MANGUS et al. (2017). However, this situation was equivalent in the readings taken at the lower position of the conductor tube and conveyor belt, demonstrating similarity between both reading points, differing from the readings taken at the upper and middle portion of the conductor tube. It is due to the inefficiency of the sensor in identifying the passage

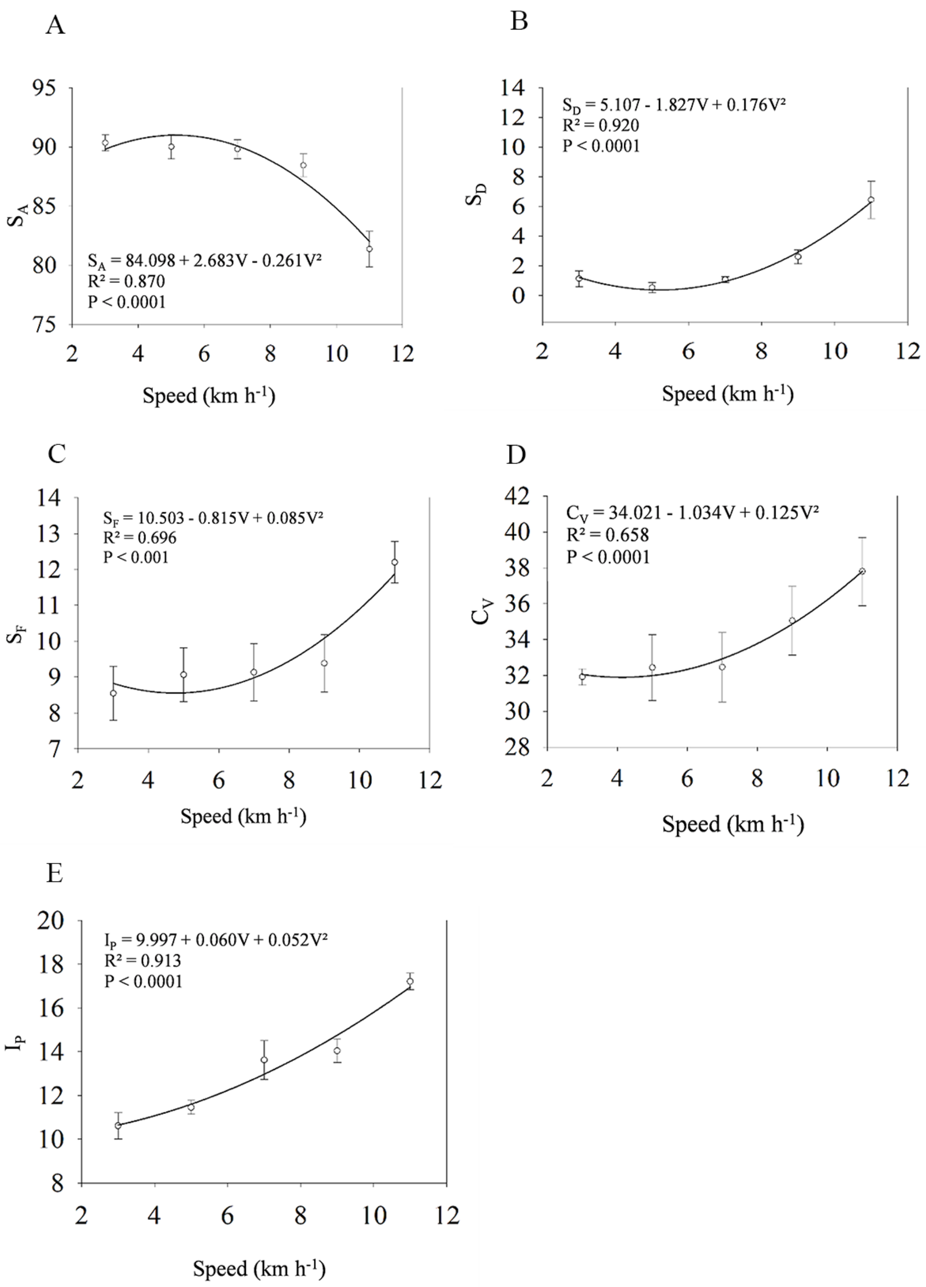
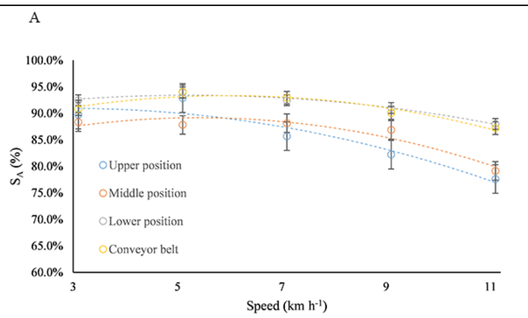


Figure 2 - Regression analysis for the isolated factor simulated speed in the variables acceptable spacing (S_A), double spacing (S_D), flawed spacing (S_F), coefficient of variation (C_V), and precision index (I_P).

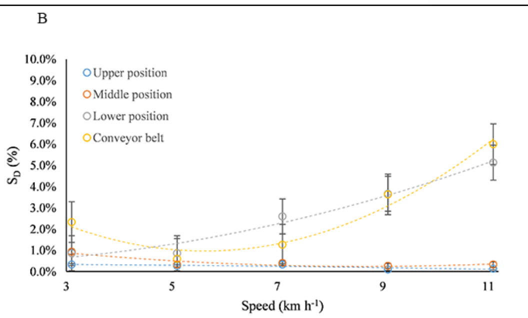
of the seed at the upper and middle positions of the conductor tube, underestimating the S_D values and overestimating the levels of flaws in the distribution.

The analysis of undesirable spacing (Figure 3B) showed that the sensor was not efficient in identifying nearby seeds with an increase in the simulated speed, resulting in minimum values of double spacing, which were confirmed by the readings carried out at the lower portion and conveyor belt. This reduction in reading efficiency is related to the higher proximity of the seeds when they are ejected by the metering disc with the increase in the distribution rate, A



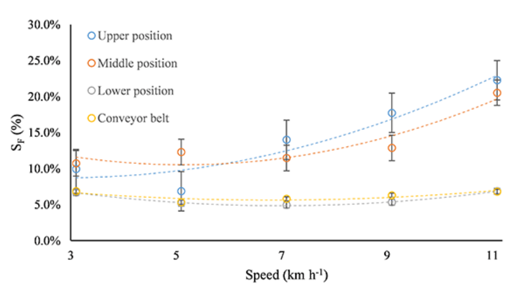
	ax²	bx	c	R²
Upper position	-0.0021	0.0119	0.8925	0.9066
Middle position	-0.0016	0.0164	0.8919	0.9763
Lower position	-0.0029	0.0303	0.811	0.9107
Conveyor Belt	-0.0025	0.0294	0.8468	0.9316

B



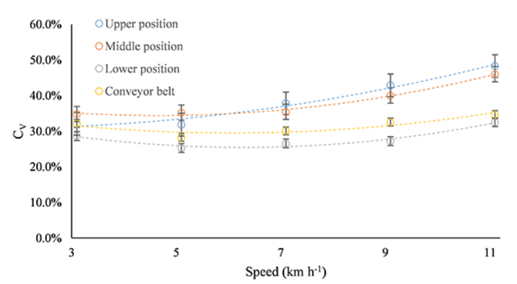
	ax²	bx	c	R²
Upper position	0.0018	-0.0196	0.0639	0.9678
Middle position	-0.0002	-0.0003	0.0036	0.6714
Lower position	0.0002	-0.0035	0.0173	0.8494
Conveyor Belt	0.0004	-0.0006	0.0032	0.9742

C



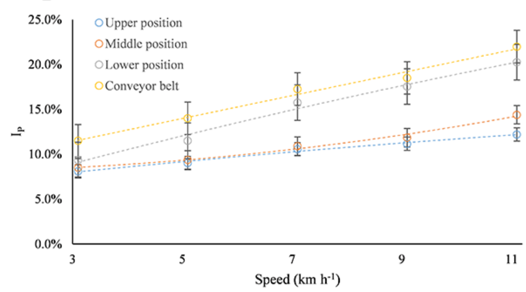
	ax²	bx	c	R²
Upper position	0.0012	-0.0164	0.1049	0.9954
Middle position	0.0021	-0.0117	0.1036	0.9107
Lower position	0.0026	-0.0260	0.1709	0.8808
Conveyor Belt	0.0007	-0.0098	0.0893	0.7369

D



	ax²	bx	c	R²
Upper position	0.0028	-0.0253	0.4017	0.9886
Middle position	0.0019	-0.0042	0.3093	0.9776
Lower position	0.0030	-0.0369	0.3683	0.9482
Conveyor Belt	0.0023	-0.0272	0.3759	0.8362

E



	ax²	bx	c	R²
Upper position	-0.0001	0.0070	0.0606	0.9883
Middle position	0.0005	0.0002	0.0803	0.9876
Lower position	-0.0002	0.0173	0.0413	0.9868
Conveyor Belt	-0.0006	0.0128	0.0770	0.9859

Figure 3 - Regression analysis for the interaction of factors in the variables acceptable spacing (S_A), double spacing (S_D), flawed spacing (S_F), coefficient of variation (C_V), and precision index (I_P).

thus moving away from each other in free fall (LIU et al., 2019). This reduction in reading efficiency at the time of passage of very close seeds results in the interpretation of a spacing considered flawed (Figure 3C), which did not occur because S_F was not identified by the reading performed at the lower portion and conveyor belt, as seed distribution occurred simultaneously among the four reading points.

Regarding the coefficient of variation (Figure 3D), uniformity degradation was also observed with increasing simulated speed. However, it was higher when the reading was performed in the upper and middle portions due to a reduction in the sensor efficiency at high deposition rates, as previously described.

A higher accuracy of the distribution is observed at the upper and middle portions because the precision index (Figure 3E) considers only the acceptable spacing, as the effect on changing the route of fall along the conductor tube was not expressive at these portions. In contrast, the portions later show a change in the deposition position (HE et al., 2017), thus reducing the accuracy in the distribution of cotton seeds.

The results showed that the position of insertion of the monitoring sensor interferes directly with the reading efficiency, generating distorted results of the actual distribution of seeds in the field. Thus, this constructive criterion interferes directly with the optimization of decision-making, which tends to be more assertive when the sensor is positioned at the final portion of the conductor tube, generating reliable information.

CONCLUSION

The increase in the simulated speed leads to an increase in the distribution rate, thus impairing the efficiency of the metering mechanism in individualizing and uniformly depositing the seeds.

The mounting position of the sowing monitoring sensor has different reading sensitivities, with the initial, upper, and middle portions resulting in a distortion of the real distribution, while the reading of the final portion of the conductor tube is more similar to the monitoring carried out in the conveyor belt.

The results of seed distribution and deposition carried out at the final portion of the conductor tube show a high correlation with the reading taken on the conductor belt, considered the actual seed deposition, proving to be the appropriate place for insertion of the sowing reading component.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The funding sponsors had no role in the study design; data collection, analysis, or interpretation; manuscript writing; or in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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