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Effect of pneumatic dosing mechanism angle on corn seed deposition[1]

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ABSTRACT - Maize sowing is crucial for farm production and food security. Technological advancements, such as electric-pneumatic seed metering and integrated software, have been developed to promote economic and environmental sustainability. However, a limited understanding of the physical processes involved in sowing may compromise the effectiveness and reliability of these mechanisms. Besides uneven terrains, slope conditions require scientific investigation to assess their impact on corn-sowing operations. This study aimed to examine corn seed deposition on longitudinal and transverse slopes using a pneumatic seed metering system. The experiment was conducted on a static sowing bench, simulating various inclination angles. Results indicated that longitudinal inclination did not affect seed spacing consistency, while transverse slopes led to a higher incidence of unsatisfactory spacing. The study concluded that longitudinal slopes decrease corn seed deposition precision, which can be mitigated by level cultivation. Conversely, transverse slopes negatively impacted acceptable, double, and missed seed spacing during sowing.

Key words: Precision index. Static bench. Slope.

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INTRODUCTION

The demand for increased agricultural efficiency has driven significant advancements in both economic and environmental sustainability (Abbasi, Martinez, and Ahmad, 2022). Corn-sowing is critical for ensuring food security and animal productivity. In this context, the effectiveness of corn sowing operations influences productivity by ensuring uniform seed distribution and proper depth placement within sowing rows (Moreno *et al*., 2023).

Technological advancements, particularly in electric pneumatic seed metering, have been instrumental in the success of precision agriculture, where resources are allocated and utilized more effectively (Ma *et al*., 2023). However, gaps remain in our understanding of the physical processes governing the interaction between external conditions and equipment used. These gaps can amplify the negative effects of various variables on technology, potentially leading to inefficiencies and compromising operational reliability (Zhao *et al*., 2020).

Irregularities in slope parameters are a common challenge in several agricultural regions of Brazil (Safanelli *et al*., 2023), justifying the need to investigate their impact on corn sowing. Corn is a highly significant crop throughout the country, with two annual harvests.

Ground slope affects soil degradation, contributing to issues such as surface sealing, erosion, and fertile layer losses. Erosion control methods, such as level cultivation with contour planting, are essential for mitigating these effects. Considering topography during sowing planning and prioritizing soil conservation is crucial (Telles *et al*., 2022).

Precision and accuracy are critical in sowing operations, as even minor errors in precision agriculture can significantly impact production profitability (Bai *et al*., 2022). While some studies have explored the effects of slope on sowing performance with crops like rapeseed and sorghum (Correia *et al*., 2016; Lei *et al*., 2022), there is limited research on corn seeds.

In this context, a static bench provides a controlled environment to evaluate metering devices without external interference (Savi *et al*., 2020). This study aimed to assess the effect of longitudinal and transverse inclinations of a pneumatic dosing mechanism on the precision and accuracy of an electronic and automated bench.

MATERIAL AND METHODS

The experiment was carried out in a laboratory using a static bench (Figure 1), as described by Savi *et al*. (2020), to simulate corn seed deposition at various longitudinal and transverse inclinations (-15º, -7.5º, 0º, 7.5º, and 15º). These slope angles were chosen to reflect field conditions more closely (Safanelli *et al*., 2023; Zimmermann *et al*., 2022).

The bench's articulated structure allows for adjustments in both longitudinal and transverse inclinations using threaded bars, which are sized to achieve the simulated angles (Figure 2).

Figure 1 - Isometric view of the bench: structure with joints (A), electric radial vacuum compressor (B), and pneumatic dosing mechanism with electric motor (C)

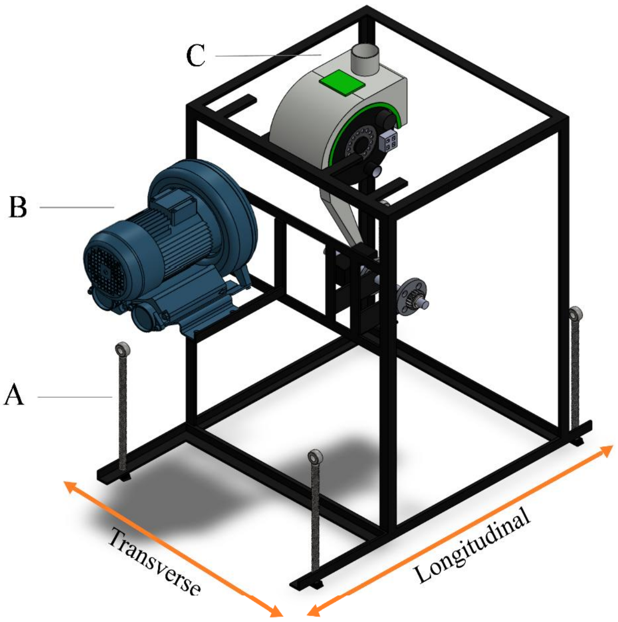
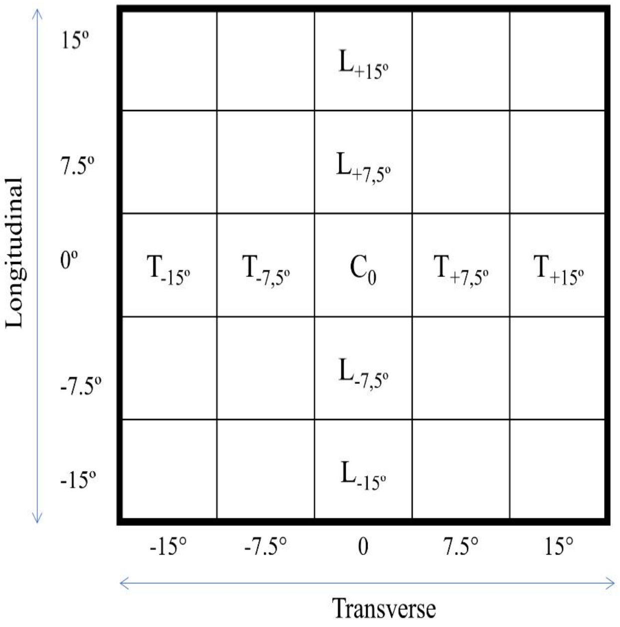


Figure 2 - Positional diagram of bench inclination angles. L – Longitudinal inclinations; T – Transverse inclinations; C – Centered



The experiment used a Selenium Electric pneumatic seed metering system (J. Assy™), powered by a 24-volt motor with a 62:1 transmission ratio. The setup included an Apollo disk with 28 holes (4.5 mm in diameter), along with its respective singulator. During operation, a vacuum of 4.98 kPa, generated by a CR-3 88 radial compressor (IBRAM ™), was adopted. This compressor has a maximum air-flow capacity of 0.022 $m^3 s^{-1}$ and a vacuum capacity of 12.75 kPa.

Seed deposition was monitored using a PM 400 optical position sensor (Dickey John™), positioned in the middle of the conductive tube. This sensor features three LED lamps as light sources and a photoelectric sensor atop a photovoltaic cell. The sensor's signal converts into rectangular pulses based on the reflection angle, with signal strength adjusted according to depth.

The static bench was equipped with a data acquisition system (DAS) and a printed circuit board (PCB) designed using the Proteus 8.1 software (Labcenter Electronics™), fabricated with an LPKF Protomat 93s™ milling machine. The DAS was connected to an ATmega328 microcontroller (Atmel™), operating at a 16 MHz clock speed with a 10-bit analog-to-digital converter. Data was acquired when seeds passed through the optical sensor, and the collected data were transferred and stored in an electronic spreadsheet.

The experiment followed a completely randomized design, evaluating nine longitudinal and transverse inclinations (-15º, -7.5º, 0º, 7.5º, 15º) at an operational speed of 5 km h^{-1}. Each treatment was repeated six times, with 250 consecutive spacings, totaling 13,500 experimental units. Data collection continued until 2,000 seeds were deposited, with each repetition's median used for subsequent statistical analysis.

The corn seed variety used was ANHEMBI, with a minimum purity of 98% and germination rate of 85%. Seeds were sown at a density of 90,036 seeds ha^{-1}, with a 0.25 m spacing between plants and 0.45 m between rows.

Dimensional measurements followed the method proposed by Soyoye *et al.* (2018), evaluating 100 sample units using a digital caliper (0.0001-m precision). One-thousand grain weight (TGW) was determined using a BK-5002 semi-analytical scale (Gehaka™), based on the average of three samples of 300 corn seeds. The angle of repose, measured after adding graphite at a dose of 4.0 g kg^{-1}, was calculated as the inverse tangent of the height relative to the distance deposited on a flat surface (Al-Hashemi & Al-Amoudi, 2018).

Corn seeds presented the following physical characteristics: 11.62 ± 1.07 mm in length, 7.49 ± 0.42 mm in width, 4.43 ± 0.66 mm in thickness, 62.80 ± 6.02% in sphericity (indicating the seed's shape resemblance to a sphere, where 100% represents an ideal sphere), 305 ± 3.63 g TGW, and 28.29 ± 0.70º repose angle. These values represent the mean measurements and coefficient of variation for each parameter.

Seed deposition quality was assessed using the following parameters: acceptable spacing (AS), double failure (DF), missing spacing (MS), coefficient of variation (CV), and precision index (PI) (Aykas *et al*., 2013).

The PI reflects the variability in seed distribution regarding the theoretical spacing (Eq. 1), excluding DF and MS. Higher PI values indicate greater non-uniformity in the target spacing (Cay *et al*., 2018).

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

P_I – precision index, %;

σ – acceptable spacing standard deviation, m; and,

X_{ideal} – ideal spacing, m.

The collected data were subjected to the Jarque-Bera normality test. Due to non-normality, the data were transformed: square root transformation for double and flawed spacing, and natural logarithm transformation for the coefficient of variation and precision index. After meeting the normality assumption, the data were subjected to analysis of variance (ANOVA). Statistically significant differences between means were compared using the Scott-Knott test at a significance level of $p \leq 0.05$.

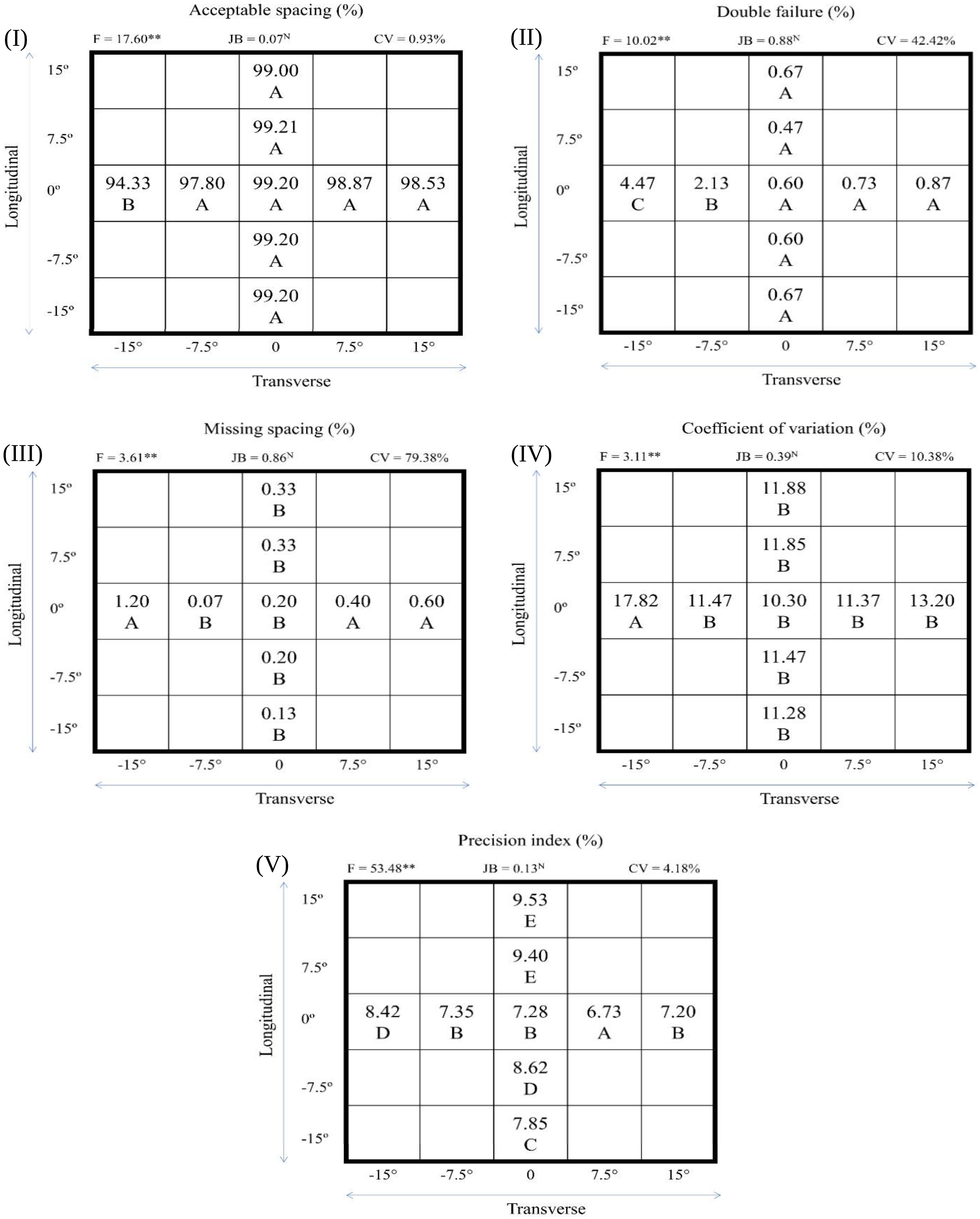
RESULTS AND DISCUSSION

The results show statistical significance in the F-test, as well as normality and homogeneity for the coefficient of variation across all analyzed parameters (Figure 3).

Regarding acceptable spacing (Figure 3A), no significant differences were observed between the longitudinal slopes. However, a lower occurrence of acceptable spacing was noted with transverse variations. This effect can be attributed to the position of the internal vacuum device within the metering mechanism, which influences seed capture on the disk. The working angle of the metering device likely however, when the seeds and the radial holes on the disk (Bai *et al*., 2022).

A similar pattern was observed for double failure (Figure 3B), where an increase was noted starting at $T_{-7.5^{\circ}}$ (-7.5º transverse inclination), with the highest occurrence at $T_{-15^{\circ}}$. This increase is related not only to the design of the metering system but also to the physical characteristics of corn seeds, such as sphericity and angle of repose (Ma *et al*., 2023). These factors make it more challenging for the device to acquire seeds (Moreno *et al*., 2023).

Figure 3 - Effects of transverse and longitudinal inclinations on sowing quality parameters. (I) Acceptable spacing. (II) Double failure. (III) Missing spacing. (IV) Coefficient of variation. (V) Precision index



(I) Acceptable spacing (%)

F = 17.60** JB = 0.07^{N} CV = 0.93%

Longitudinal	-15°	-7.5°	0	7.5°	15°
15°			99.00 A		
7.5°			99.21 A		
0°	94.33 B	97.80 A	99.20 A	98.87 A	98.53 A
-7.5°			99.20 A		
-15°			99.20 A		

Transverse

(II) Double failure (%)

F = 10.02** JB = 0.88^{N} CV = 42.42%

Longitudinal	-15°	-7.5°	0	7.5°	15°
15°			0.67 A		
7.5°			0.47 A		
0°	4.47 C	2.13 B	0.60 A	0.73 A	0.87 A
-7.5°			0.60 A		
-15°			0.67 A		

Transverse

(III) Missing spacing (%)

F = 3.61** JB = 0.86^{N} CV = 79.38%

Longitudinal	-15°	-7.5°	0	7.5°	15°
15°			0.33 B		
7.5°			0.33 B		
0°	1.20 A	0.07 B	0.20 B	0.40 A	0.60 A
-7.5°			0.20 B		
-15°			0.13 B		

Transverse

(IV) Coefficient of variation (%)

F = 3.11** JB = 0.39^{N} CV = 10.38%

Longitudinal	-15°	-7.5°	0	7.5°	15°
15°			11.88 B		
7.5°			11.85 B		
0°	17.82 A	11.47 B	10.30 B	11.37 B	13.20 B
-7.5°			11.47 B		
-15°			11.28 B		

Transverse

(V) Precision index (%)

F = 53.48** JB = 0.13^{N} CV = 4.18%

Longitudinal	-15°	-7.5°	0	7.5°	15°
15°			9.53 E		
7.5°			9.40 E		
0°	8.42 D	7.35 B	7.28 B	6.73 A	7.20 B
-7.5°			8.62 D		
-15°			7.85 C		

Transverse

The F test is significant at $p \leq 0.01$. Jarque-Bera Normality Test (JB): JB ≤ 0.05 – Data non-normality; JB ≥ 0.05 – Data normality. Means followed by the same letter do not differ from each other by the Scott-Knott test ($p \leq 0.05$)

Missing spacing (Figure 3C) was also affected by the design of the dosing mechanism and the physical characteristics of seeds, with a higher incidence at T_{-15^o}. Additionally, an increase in missing spacing was observed at $T_{7.5^o}$ and T_{15^o}, likely due to seed accumulation in the collection chamber, which interferes with seed acquisition by the disk (Li *et al.*, 2022).

In line with these observations, the coefficient of variation (Figure 3D) reached the highest value at T_{-15^o}, although it did not significantly differ from the other slopes studied. However, when examining the precision index (Figure 3E), longitudinal variations had a lesser impact on equipment accuracy, resulting in more stable seed depositions with spacing closer to the ideal (Khadatkar *et al.*, 2021).

In summary, transverse variations in working angles directly impact operational precision, leading to an increase in double and faulty spacing and reducing acceptable spacing. However, when considering the precision index, longitudinal inclinations had a more pronounced effect on operational accuracy, which is desirable in sowing as it minimizes errors. This highlights the importance of level cultivation, which not only promotes soil conservation but also enhances the performance of the equipment used.

CONCLUSIONS

1. Sowing under longitudinal inclination decreases the accuracy of corn seed deposition, but this can be mitigated by level cultivation;
2. Transverse slopes affect acceptable, double, and gap spacing parameters during sowing;
3. Seed metering efficiency is most significantly compromised at a -15º inclination.

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