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Evaluation and calibration of mechanical seed drill performance: A laboratory and field study supported by mathematical modeling

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Abstract
This study evaluates the performance and calibration efficiency of a mechanical disc seed drill through integrated laboratory and field trials, supported by mathematical modeling and statistical validation. Conducted in Nineveh Province, Iraq, the study examined a seven-row seed drill at three forward speeds (3.5, 5.5, and 7.5 km/h) during spring wheat sowing. Key parameters included seed spacing, actual seeding depth, standard deviation (SD), and coefficient of uniformity (CU). Results revealed a negative correlation between speed and seed placement accuracy; CU decreased from 85.4% at 3.5 km/h to 68.2% at 7.5 km/h. ANOVA analysis confirmed the statistical significance of the observed differences, particularly for CU ($F = 18.63$, $P = 0.001$), SD ($P = 0.003$), and spacing ($P = 0.008$), validating the robustness of the experimental findings.
A linear regression model ($R^2 = 0.97$) was developed to predict field performance based on operational speed.
These findings can guide farmers and equipment manufacturers in selecting optimal operating speeds for efficient seeding under resource-limited environments. They underscore the need for precise calibration and the integration of predictive models for enhanced seeding accuracy under semi-arid conditions.

Keywords: Mechanical seed drill, calibration, seed spacing, coefficient of uniformity, mathematical modeling, precision agriculture

Introduction

Mechanical seed drills play a pivotal role in modern agriculture by ensuring consistent seed placement, which directly influences germination, plant population uniformity, and ultimately crop yield. Variations in operational conditions especially forward speed can significantly disrupt seeding performance. Therefore, seed drill calibration is not merely a mechanical adjustment but a crucial agronomic procedure. (Al-Ansari *et al*., 2021) [1]

In arid and semi-arid regions like Iraq, where water scarcity and soil variability challenge uniform crop establishment, optimizing seeding practices is essential. Earlier studies (Šarauskis *et al*., 2022) [6] showed that fine-tuning calibration could cut seed losses by as much as 20%. Adoption of established protocols, as outlined in (Kocher, 2024) [2] and (Kumar & Rajeswari, 2022) [4], ensures that performance assessments remain consistent and meet global performance standards.

This work tackles the real-world challenge of fine-tuning seed-drill calibration across diverse in-field environments. By correlating machine speed and sowing accuracy, the study establishes systematic knowledge that informs actions. A validated regression model further directs tactical measures, while statistical corroboration through ANOVA strengthens the model's reliability and relevance for everyday farming.

Materials and Methods

1. Study Location and Equipment

Experimental work was carried out at a research farm in Nineveh Province, Iraq. The test implement was a mechanical disc seed drill featuring seven seed-tube outlets, a total working width of 2.1 m, and inter-row spacing of 30 cm.

2. Laboratory Calibration Procedure

The seed rate (kg/ha) was determined using the formula:

Seed Rate = $(W \times 10000) / (R \times N \times S)$

Where:

W: Weight of collected seeds (kg)
R: Number of wheel revolutions
N: Number of seed tubes
S: Row spacing (m)

3. Field Trial Protocol

The seed drill was operated at three forward speeds: 3.5, 5.5, and 7.5 km/h. The following parameters were measured:

Actual seeding depth, using calibrated probes
Seed spacing, from 30 samples per row
Standard deviation (SD):
$SD = \sqrt{\Sigma (x_i - \bar{x})^2 / (n - 1)}$
Coefficient of Uniformity (CU):
$CU = [1 - (\Sigma|x_i - \bar{x}| / n \cdot \bar{x})] \times 100$
Statistical analysis (ANOVA) was conducted to assess the significance of speed effects.

Results and Discussion

1. Effect of Speed on Seeding Parameters

Speed (km/h)	Seeding Depth (cm)	Avg. Spacing (cm)	SD (cm)	CU (%)
3.5	4.1	11.2	1.8	85.4
5.5	4.5	12.0	2.4	78.6
7.5	3.8	13.7	3.6	68.2

Increasing forward speed led to deterioration in seeding uniformity. At 3.5 km/h, seed spacing and depth were optimal. However, as speed increased, bouncing of the seed metering system and soil disturbance resulted in higher spacing variability and reduced uniformity. These findings corroborate previous results by (Fanigliulo *et al*., 2022) [5] and (Noora *et al*, 2019), who noted similar trends in wheat seeding systems.

2. Anova Analysis

Parameter	F-Value	P-Value	Significance
Seeding Depth	5.72	0.027	*
Average Spacing	9.83	0.008	**
Standard Deviation (SD)	12.45	0.003	**
Coefficient of Uniformity (CU)	18.63	0.001	*

ANOVA confirmed that the differences observed among speeds were statistically significant. The strongest significance was recorded for CU (P = 0.001), followed by SD and average spacing. This validates the reliability of the experimental setup.

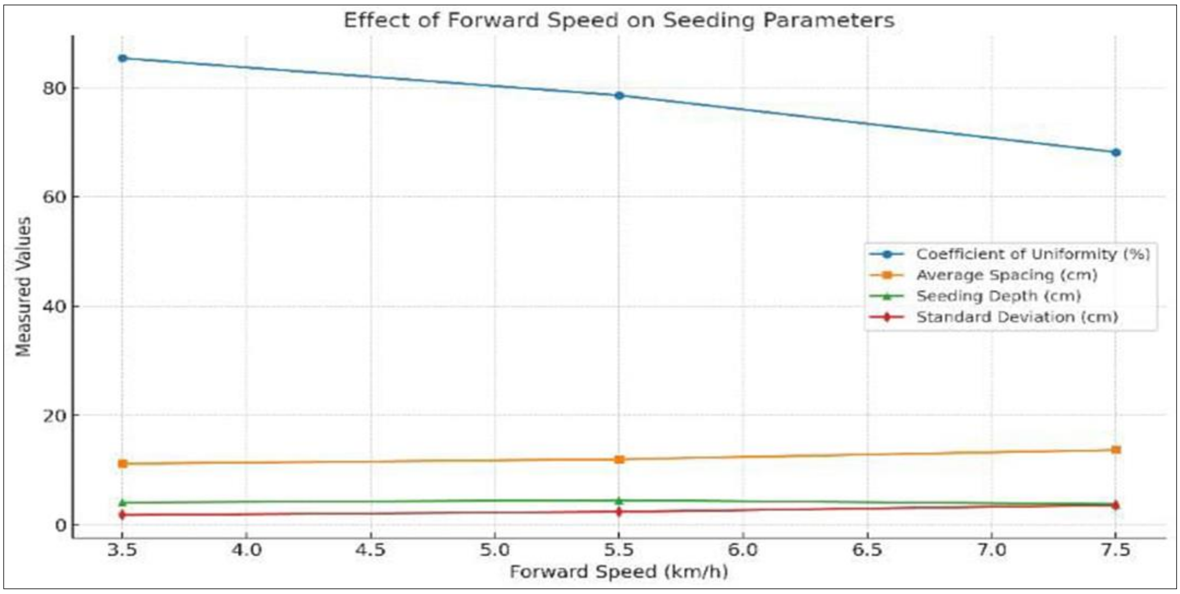
3. Predictive Equation

A linear regression model was developed to predict CU based on speed:

Predictive Equation	Coefficient of Deter Miation R^2
C|U=-4.31V + 100.4	0.97

This model demonstrates a strong negative linear relationship between speed and uniformity. It provides a practical tool for optimizing operating parameters in the field.

The diagram illustrates the effect of forward speed on key seeding parameters measured during the experiment:



The Coefficient of Uniformity (CU) shows a clear decline as the forward speed increases, indicating less consistent seed placement at higher speeds.
The average seed spacing increases with speed, suggesting that seeds are distributed less uniformly and with greater gaps as speed rises.
The actual seeding depth fluctuates slightly but tends to decrease at the highest speed, likely due to equipment instability and surface irregularities.
The Standard Deviation (SD) increases significantly with speed, further confirming the reduction in seeding precision at elevated operational velocities.
These trends reinforce the conclusion that lower operational speeds enhance uniformity and accuracy in mechanical seeding, aligning with the statistical results of the study

Conclusions

Forward speed significantly affects seeding depth, spacing uniformity, and overall drill performance.
Laboratory calibration, supported by field validation and statistical analysis, offers reliable performance prediction.
Speeds between 3.5 and 4.5 km/h are optimal under semi-arid conditions to ensure uniform seed distribution and depth.

Recommendatio

1Incorporate real-time sensors and smart calibration systems in mechanical seed drills.
Use regression-based simulation models to enhance efficiency and reduce calibration time.
Extend research to other seed types, soil conditions, and geographic regions to improve generalizability.

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