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A method for verifying the uniformity in fertilizer dispenser flow

Metodologia para verificar a uniformidade de mecanismos dosadores de fertilizantes

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Highlights

Implementing a data acquisition system for operational measurement.
The NPK formulation 04-14-08 produced higher flows in both dispensers.
At a speed of 7 km/h, the NPK formulation 04-14-08 promoted the optimal flow.

Abstract

The success of crops is directly related to effective planting and fertilization, especially regarding yield factors like plants per area and final yield. Thorough evaluations are vital to understanding modern methods in these operations. Current regulations and their broaden scope highlight the need for more specific approaches. This study aimed to validate a new method for assessing the effectiveness of helical and fluted dosing mechanisms with two granulated fertilizer formulations (04-14-08 [GF1] and 04-30-10 [GF2]) at different speeds (4, 7, and 10 km/h) in a controlled setting. We collected flow data, organized it, checked for normality, and subjected it to variance analysis. The fluted dispenser showed better flow at 4 km/h and 7 km/h. The GF1 formulation produced higher flows in both dispensers, with the helical design outperforming. The flow for GF1 increased linearly with speed. For GF2, the best flow rate was at 7 km/h. In summary, our new method effectively evaluated the factors under study, offering insights into the function and potential improvements of the technologies used.

Key words: Dispenser mechanism. Static bench testing. Helical dosing. Fluted dosing.

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Resumo

A eficiência da operação de semeadura e adubação é determinante no sucesso de uma lavoura, estas exigem avaliações eficientes que possam favorecer o entendimento dos mecanismos empregados nas tecnologias contemporâneas. Contudo as normativas vigentes não apresentam acurácia compatível para avaliar as operações, evidenciando a necessidade de criação de metodologias mais adequadas. Assim, o objetivo do trabalho foi validar uma proposta de metodologia para a avaliação do desempenho de mecanismos dosadores helicoidal e acanalado com duas formulações de fertilizantes granulados (04-14-08 e 04-30-10), em razão de diferentes velocidades angulares (4; 7 e 10 km/h) realizado em bancada estática. Durante os testes, os valores de vazão foram adquiridos por um sistema de aquisição, posteriormente estes dados foram relativizados, em seguida submetidos ao teste de normalidade e posteriormente análise de variância. O dosador acanalado apresentou melhor desempenho nas vazões para as velocidades de 4 km/h e 7 km/h. O formulado 04-14-08 gerou vazões maiores em ambos os dosadores, com ênfase para o helicoidal. As velocidades ocasionaram um aumento linear da vazão no fertilizante 04-14-08. Com 7 km/h se observou o ponto ótimo para a vazão do fertilizante 04-30-10. A metodologia proposta demonstrou ser eficiente na avaliação dos parâmetros estudados bem como para facilitar o entendimento do funcionamento das tecnologias empregadas, assim como suas adequações.
Palavras-chave: Mecanismo dosador. Bancada estática. Helicoidal. Acanalado.

Introduction

Fertilizing and sowing operations are central to effective cultivation. Precision in fertilizer application rates ensures optimal crop yields (Yu et al., 2019). The key lies in using well-constructed dosing mechanisms and understanding the relationship between operational speed and input attributes (Zilli et al., 2020). When used correctly, these tools ensure the best fertilizer placement in the sowing furrow.

The fertilizer dosing mechanisms available in the domestic market vary in design. Helical mechanism operates with a continuous thread system, whereas fluted system adjusts fertilizer amounts through rotation speed and roller length (Zeng et al., 2020). These design variations address the diverse needs of the agricultural sector.

The emergence of an automated static test bench has revolutionized the evaluation of dosing mechanisms. It streamlines assessments under varied conditions (Zimmermann et al., 2020) and is aided by precise data acquisition systems. These ensure safe and accurate data storage, which is advantageous when managing extensive datasets.

Pearson's correlation coefficient is a recognized tool for analyzing parameter interactions (Ferreira, 2010). This statistical measure identifies similarities in the evolutionary trends of variables. However, its application in assessing fertilizer dosing mechanisms remains underexplored. This oversight signals a research gap in using the coefficient to determine metering flow precision across various variables (Šverko et al., 2022; Zhang et al., 2023).

Existing agricultural standards, such as ISO (International Standard Organization [ISO], 1984) and ISO 7256, may not fully cater to modern equipment's data needs. These standards dictate operational evaluations but might falter with today's data acquisition demands (Fountas et al., 2020). Revised parameters could better serve the evolving agricultural landscape.

This study aimed to validate a method to assess fluted and helical dosing mechanisms using specific granulated fertilizers at varied speeds. Based on regional availability, we used N-P_2O_5-K_2O granular fertilizer formulations, namely 04-14-08 (GF1) and 04-30-10 (GF2). The granular fertilizers underwent rigorous tests, including particle size determination through recommended sieves and density assessment via the Dalle Molle equipment. Preliminary results, such as the angle of repose and water content, shed light on the physical characteristics of the selected fertilizers.

Material and Methods

The study was conducted in a laboratory setting, using an automated electronic workbench to collect granular fertilizer distribution data, as described by Zimmermann et al. (2020). Both helical and fluted dosing mechanisms were assessed using two granulated fertilizer formulations (04-14-08 [GF1] and 04-30-10 [GF2]) at different angular speeds (1.11; 1.94; and 2.77 m/s). Each treatment underwent seven replications, yielding an average of 84 sample collections.

Figure 1 provides a visual of the automated workbench setup, highlighting the electrical control (A), transmission set (B), articulation (C), reservoirs (D), dosing mechanisms (E) — notably the simple helical (I), and fluted (II) — and the data acquisition system (F).

A 220-V 3-phase geared motor (SEW EURODRIVE™) with a power capacity of 0.25 kW and a 1.12 reduction ratio was incorporated into the workbench. Its speed was precisely regulated using a frequency inverter (CFW300 WEG™). Together with a symmetrical transmission ratio achieved by pulley and chain, the setup simulated distinct angular speeds. These were established based on granulated fertilizer application rates: 300 kg/ha for the helical dispenser and 250 kg/ha for the fluted mechanism. It ensured that both spreaders operated at congruent rotations, mirroring the consistent speed of a tractor-implement system, which is crucial for evaluating their operational efficiency (Zimmermann et al., 2020). Additionally, sowing row spacing was 0.50 m apart, correspondeding to application rates of 15 g/m and 12.5 g/m for the helical and fluted dispensers, respectively.

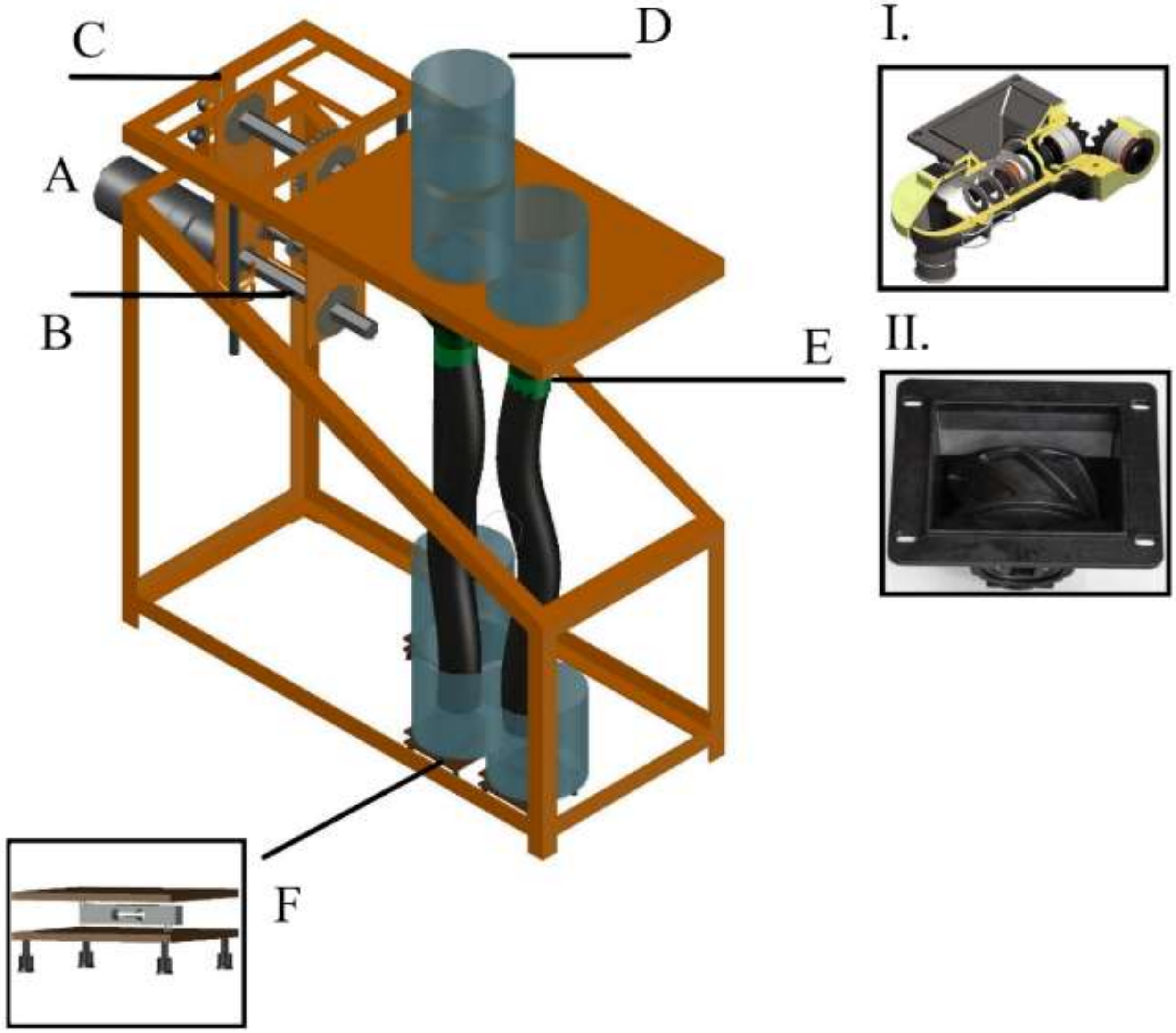

Figure 1. Diagonal projection of the electronic and automated static bench.
Electrical control (A), transmission set (B) and articulation (C), reservoirs (D), dosing mechanisms (E) simple helical (I) and fluted (II) and the data acquisition system (F).

For simulations, actual angular speeds were converted into Hertz (Hz) using the frequency inverter. Therefore, the speeds 4 km/h (1.11 m/s), 7 km/h (1.94 m/s), and 10 km/h (2.77 m/s) corresponded to frequencies of 20.35 Hz, 35.61 Hz, and 50.88 Hz, respectively. The system was set to work between 1 to 60 Hz, using a linear potentiometer to adjust the metering mechanism's angular speed. Both dosing mechanisms were assessed simultaneously on the experimental workbench.

The granulated fertilizer reservoirs were at the top of the bench and connected to the dosing mechanisms. The simple helical dosing mechanism (Auto-Lub AP model, FERTSYSTEM™) operated with a pitch of 2.54 cm. It incorporates a level-regulating system with a transverse lid to mitigate the pulsating effect inherent to continuous cycles, thereby controlling the dosage. The secondary, fluted dosing mechanism (Planter model, FERTIDISPENSER™) featured eight diagonally-arranged channels (6.9 cm³ each) to regulate fertilizer application.

The granular fertilizer flow was gauged using a data acquisition system equipped with a printed circuit board, operating at a data acquisition frequency of 1 Hertz. This system was linked to a hard disk, facilitating subsequent data tabulation in automated analysis spreadsheets. The system monitored the granular fertilizer flow for 420 seconds, resulting in 5,040 data measurements.

The data acquisition system (DAS) was linked to a scale featuring a single-point load cell, model SPL (IWM™), with a 2 mV/V resolution. This scale could manage a maximum load of 7.5 kg and operated effectively at 5 kg, delivering a precision of 1.1 mg per pulse when measuring granulated fertilizer mass. For calibration, 12 weights were assessed using a semi-analytical scale. The weights were then placed on the main scale and had their pulses recorded by the DAS. To ensure data collection stability, the first and final 30-s intervals were omitted, and data collection ceased before the reservoir was two-thirds empty. By averaging the pulses across all weights, a correlation was derived, culminating in a linear equation with an R2 value of 1 (Figure 2).

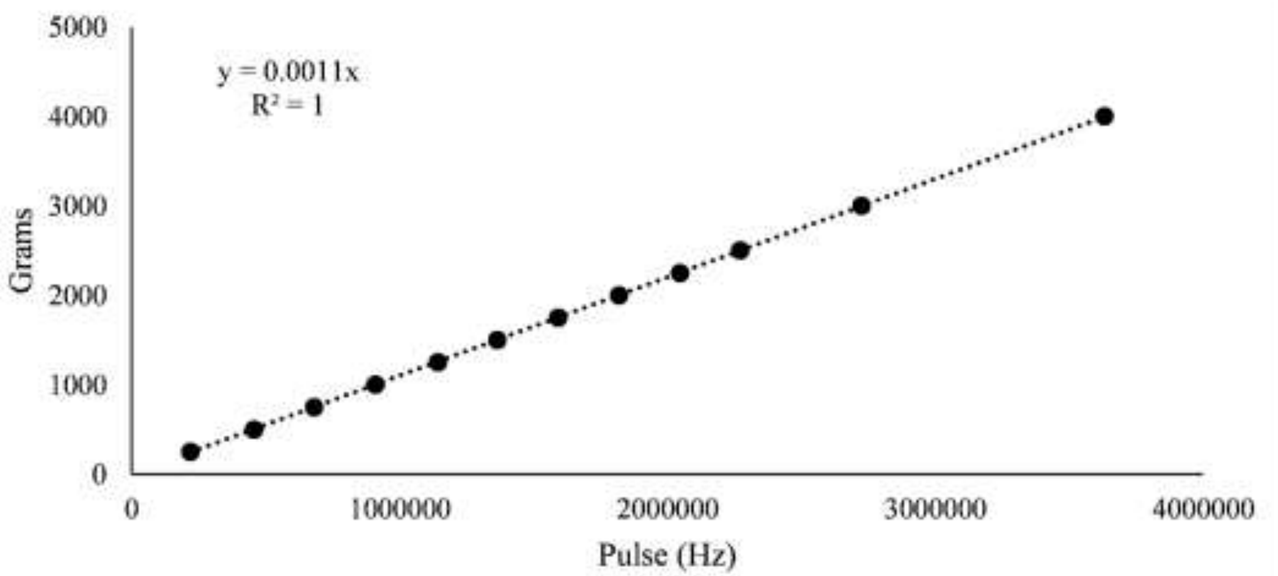

Figure 2. Scale calibration curve.

During the evaluations, GF1 and GF2 had densities of 970 and 950 kg m-3, angles of repose of 32.55° and 33.69°, and moisture contents of 0.03 kg/kg, respectively. For GF1, retention percentages were 2.50, 72.75, 24.25, and 0.50 on 4.0 mm (ABNT n° 05), 2.0 mm (ABNT n° 10), 1.0 mm (ABNT n° 18), and 0.5 mm meshes (ABNT n° 35). Conversely, GF2 had retention percentages of 4.50, 90.00, 5.50, and 0.00 on the same mesh sizes.

The collected flow values were adjusted based on Equation 1 to match the expected flow (as shown in Table 1), ensuring a more effective data normality analysis.

$$V_R = \left(\frac{V_{LET}}{V_{ESP}}\right) x\ 100 \qquad (1)$$

V_R = Relative flow, g/s;

V_{LET} = Read flow, g/s;

V_{ESP} = Expected flow, g/s.

Table 1
Summary of expected flow values for helical and fluted feeders

Dosador	Expected Flow (g/s)		
	4.0 km h^{-1}	7.0 km h^{-1}	10.0 km h^{-1}
Helical	16.67	29.17	41.67
Fluted	13.89	24.31	34.72

To assess the accuracy of the dispensers' relative flow across various variables, we used the Pearson test as outlined by Šverko et al. (2022). This approach supplied the essential parameters to define value intervals corresponding to specific precision classes (Table 2). Furthermore, associations were established between normalized flows and the targeted flow percentages.

Table 2
Interpretation of the precision in the flow of the dispenser s

Relative Flow (g/s)		Precision in the dispenser flow
Minimum	Maximum	
95	105	Excellent
85	115	Good
75	125	Regular
65	135	Bad
<45	>145	Terrible

For the experimental design, a completely randomized approach with seven replications was chosen. The collected data underwent the Montgomery test (2004). With the underlying assumptions confirmed, an analysis of variance (ANOVA) was executed to ascertain the influence of numerous factors and any potential interactions. This analysis was conducted using the SigmaPlot software (version 12; Systat Software Inc). If the F-test identified a significant difference with a probability value ($p \leq 0.05$), a post-hoc comparison of means was conducted using the Tukey test ($p \leq 0.05$).

Results and Discussion

Table 3 shows the synthesized data analysis results. There was no need to adjust the means for all studied variables, as the examined parameters exhibited a normal distribution. According to Montgomery (2004), this is deduced from the fact that if asymmetry and kurtosis coefficients lie between -2 and 2, the data can be deemed normal. The coefficient of variation was also stable, as per Ferreira's (2018) classification, indicating a consistent experimental process.

The F-test revealed significant differences for most of the assessed factors. The same was not observed for interactions among dispensers, speeds, and fertilizers. Upon analyzing the means test for the dosing mechanism, the fluted dispenser outperformed the helical by 0.92%, suggesting enhanced precision in granulated fertilizer deposition.

Table 3
Statistical synthesis of analysis of variance and test of means

Treatments	Test F
Dispenser	26.32**
Speed	17.52**
Fertilizer	892.28**
Dispenser x speed	98.60**
Dispenser x speed	129.57**
Speed x fertilizer	123.02**
Dispenser x speed x fertilizer	0.782^{NS}
Test of averages	
Dispenser	**Relative Flow (%)**
Helical	98.48 B
Fluted	99.40 A
Speed	
4.0 km h^{-1}	98.53 B
7.0 km h^{-1}	99.68 A
10.0 km h^{-1}	98.61B
Fertilizer (N-P-K)	
04-14-08	101.60 A
04-30-10	96.28 B

Analyses: Asymmetry 0.28, Kurtosis 0.35, Coefficient of variation 6.39%. Analysis of variance F test (ANOVA): NS – Not significant; * ($p < 0.05$) and ** ($p < 0.01$). In each column, for each factor, means followed by the same letter do not differ from each other by the "Tukey test" ($p < 0.05$).

Deposition rates (g/s) correlate directly with the flow accuracy of dispensers. When comparing the target flow with parameters (Table 2), Pearson's coefficients indicate that both dosing mechanisms were rated "Excellent" for all operational speeds, fertilizer formulations, and studied interactions. However, interactions between the helical mechanism with GF2 and a speed of 10 km/h were classified as "Good."

Tables 4, 5, and 6, below, elucidate the interactions, illustrating the means and statistical interpretations. They provide insights into relationships among Dispenser-Speed, Dispenser-Fertilizer, and Speed-Fertilizer, respectively.

Table 4
Statistical synthesis of the analysis of variance and the interaction means test

Dispenser	Speed		
	4 km h^{-1}	7 km h^{-1}	10 km h^{-1}
Helical	96.63 Bb	99.05 Ba	99.76 Aa
Fluted	100.42 Aa	100.32 Aa	97.45 Bb

Means followed by uppercase letters in columns and lowercase letters in rows do not differ from each other by the "Tukey test" ($p < 0.05$).

Regarding the Dispenser-Speed interaction, results suggest that increasing the speed beyond 10 km/h in the fluted mechanism leads to decreased operational precision. However, the helical mechanism performs optimally at 10 km/h. This phenomenon might be attributed to supply deficits (Benjamin et al., 2019) in the feeding chamber, resulting in fluted mechanism channel fill delays at elevated speeds. Consequently, the helical mechanism's flow precision appears more consistent, especially at higher speeds.

Table 5
Statistical synthesis of the analysis of variance and the interaction means test

Dispenser	Fertilizer (N-P-K)	
	04-14-08	04-30-10
Helical	102.16 Aa	94.81 Bb
Fluted	101.04 Ba	97.75 Ab

Means followed by uppercase letters in columns and lowercase letters in rows do not differ from each other by the "Tukey test" ($p < 0.05$).

Table 5 shows that using GF2 reduces the flow in both mechanisms when compared with GF1. With GF1, the helical had better flow precision, whereas, for GF2, the fluted mechanism excelled. This discrepancy is likely due to the increased powder content in GF1, wherein minute particles accompany granules through the mechanism, thus enhancing the flow and, subsequently, fertilizer distribution (Costa et al., 2022).

Table 6
Statistical synthesis of the analysis of variance and the interaction means test

Speed (km h^{-1})	Fertilizer (N-P-K)	
	04-14-08	04-30-10
4 km h^{-1}	100.06 Aa	96.99 Bb
7 km h^{-1}	101.51 Ba	97.86 Ab
10 km h^{-1}	103.24 Ca	93.97 Cb

Means followed by uppercase letters in columns and lowercase letters in rows do not differ from each other by the "Tukey test" ($p < 0.05$)

Concerning the interplay between fertilizers and operational speeds, GF1 displayed escalating flow rates with increased speed a trend not observed in GF2. For the latter, flow reduces beyond 10 km/h. While GF1's linearity is ascribed to particle density traits, GF2's attributes delineate an optimal balance between density and speed, pinpointed at 7 km/h. The observed superior flow at three speeds for GF1 stems from the inherent ingredient properties (Costa et al., 2022).

In conclusion, evolving methods, like the one proposed here, are pivotal for understanding fertilizer application equipment. Such advancements allow the industry to integrate the latest technologies effectively, ensuring innovation validation and accurate adaptation for both industry stakeholders and end consumers.

Conclusion

The proposed method effectively evaluated the studied parameters, streamlining the comprehension of the technologies in use and their respective adaptations.

The fluted dispenser outperformed at 4 km/h and 7 km/h.

The 04-14-08 formula resulted in higher flows in both dispensers, notably with the helical design.

For the 04-14-08 fertilizer, increasing speeds corresponded to a linear rise in flow.

The flow of the 04-30-10 fertilizer reached its peak performance at 7 km/h.

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