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SOIL SCIENCE

Distribution of granulated fertilizers in dispensers mounted with single and double helicoidal

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ABSTRACT: The high dependence of agriculture on fertilizers demands an improvement in the processes involved, with the purpose of environmental and economic sustainability. The objective was to compare the performance of helical dosing mechanisms with two formulations of granulated NPK fertilizers at three operating speeds. During the experiment, we used an electronic and automated bench to evaluate the performance of the single helical and double helical dosing mechanisms, in a completely randomized design. This bench measured the overflow of the two formulations of granulated NPK fertilizers (04-14-08 and 04-30-10) under different angular velocities (1.11; 1.94; and 2.77 m s^{-1}). On the tests, we collected flow data and submitted them to descriptive statistics, frequency histograms, and statistical process control. The single helical feeder, as the speed increased, exhibited greater homogeneity of granulated NPK fertilizer deposition, with 611 flaws ha^{-1} compared to 3763 flaws ha^{-1} in the double screw. Although, the speeds of 7.0 and 10.0 km h-1 generated an increase in the flow of both granular fertilizers, as expected, the 04-30-10 fertilizer obtained the most uniform distribution at the lowest speed.
Key words: application rate, dosing fertilizers, helical dispenser.

Distribuição de fertilizantes granulados em dosadores montados com helicoidal simples e duplo

RESUMO: A alta dependência da agricultura por fertilizantes demanda um aprimoramento nos processos envolvidos, tendo como propósito a sustentabilidade ambiental e econômica. Objetivou-se comparar o desempenho de mecanismos dosadores helicoidais, com duas formulações de fertilizantes granulados em três velocidades operacionais. Na realização do experimento, utilizou-se bancada eletrônica e automatizada, com a qual se avaliou o desempenho dos mecanismos dosadores helicoidal simples e helicoidal duplo por transbordo, em um delineamento inteiramente casualizado, com duas formulações de fertilizantes NPK granulados (04-14-08 e 04-30-10), em razão de diferentes velocidades angulares (1.11, 1.94, e 2.77 m s^{-1}). Durante os testes, coletaram-se dados de vazão que foram submetidos à estatística descritiva, histogramas de frequência e ao controle estatístico de processo. O dosador helicoidal simples, conforme o aumento da velocidade, exibiu maior homogeneidade de deposição de fertilizante granulado, com 611 falhas ha^{-1} em relação a 3.763 falhas ha^{-1} do helicoidal duplo. Apesar de que as velocidades de 7,0 e 10,0 km h^{-1} geraram um aumento da vazão de ambos os fertilizantes granulados, conforme esperado, o fertilizante 04-30-10 obteve a distribuição mais uniforme na menor velocidade.
Palavras-chave: taxa de aplicação, dosagem de fertilizantes, dosador helicoidal.

INTRODUCTION

Establishing grain crops with seeder-fertilizers is part of a contemporary agricultural production process (ZILLI et al., 2020). In Brazil, one of the primary steps of this agriculture process is sowing and fertilization, executed concomitantly, using seeds with high genetic quality (XING et al., 2020) and efficient fertilizers (DIMKPA et al., 2020). These raw materials require the correct deposition along the sowing furrow to maximize yield productivity. And that's possible with high-performance dosing mechanisms that are reliable.

The main models of fertilizer dosing mechanisms have different architectures, the most popular being the single and double screw continuous feeders (NING et al., 2015; WANG et al., 2017). However, the current technological package for manufacturing dosing mechanisms requires new methods of validating the distribution of granulated fertilizers, as proposed by ROSA (2019), then the ISO 5690/2 (1984) methodology, which may not satisfy the assessment of distribution as an industrial process (ZIMMERMANN et al., 2022).

To address this problem, automation performed in static simulation benches appears as an alternative, allowing the evaluation of fertilizer dosing mechanisms under different working conditions (ZIMMERMANN et al., 2020).

Due to the large number of data collected in this process, there is a demand for more efficient

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and accurate assessments through statistical process control (DURAN-VILLALOBOS et al., 2020). In addition to this tool, the elaborated histogram represents the fertilizer deposition samples in class intervals and evaluates their behavior based on the arrangement of events (MELO et al., 2019), according to SPAGNOLO (2020).

The objective was to compare the performance of single and double helical dispensers with two formulations of granulated NPK fertilizers using three operating velocities.

MATERIALS AND METHODS

The experiment was conducted within a controlled laboratory environment, involving an assessment of the dispersion pattern of granulated NPK fertilizer using a stationary simulation platform equipped with an automated electronic data collection system, as described by ZIMMERMANN et al. (2020). This platform facilitated the quantification of excess material resulting from the application of two distinct formulations of granulated NPK fertilizer (04-14-08 and 04-30-10), while subjecting them to varying angular velocities (1.11, 1.94, and 2.77 m/s), resulting in a total of 12 distinct treatment conditions, in a completely randomized design.

Figure 1 shows the automated electronic bench developed in the laboratory, its electrical control (A), transmission set (B), articulation (C), reservatory (D), helical dispensers (E) simple screw (I), and double screw (II) and the data acquisition system (F).

The electrical control provided by a frequency inverter allowed us to adjust the 0.25 kW geared motor's speed, which drove the dosing mechanism shaft through a symmetrical transmission ratio by gear and chain. We determined the angular velocity based on the application of 300 kg ha^{-1} of granulated fertilizer, considering the sowing spacing between rows of 0.50 m, resulting in 15 g m^{-1}. Despite the differences in the working principle of the dispensers, it was considered the characteristics of the test bench.

It was adopted the simulation of angular velocities based on the conversion of values to hertz (Hz) of the frequency inverter, with 1.11 m s^{-1} (4 km h^{-1}) for 20.35 Hz, 1.94 m s^{-1} (7 km h^{-1}) for 35.61 Hz and 2.77 m s^{-1} (10 km h^{-1}) for 50.88 Hz. We parameterized the set to operate under a varying frequency from 1 to 60 Hz, driven by a linear potentiometer. It allowed us to alter the angular speed of the dosing mechanisms. It was tested both helical dispensers simultaneously on the experimental bench with the same drive rotation, and the flow rate of the double helical dispenser was higher than the single helical.

The granulated fertilizer (FG) reservoirs are above the dosing mechanisms. The single helical dispenser (D_1) and double helical dispenser(D_2)

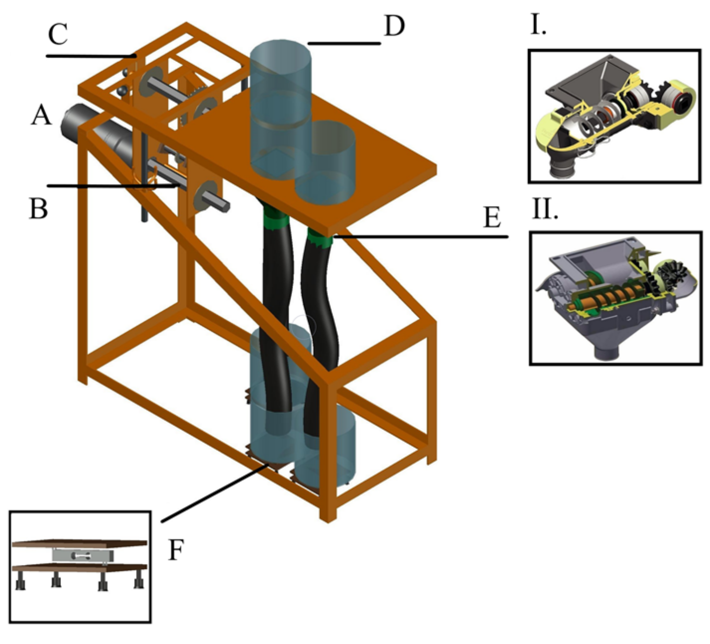

Figure 1 - Diagonal projection of the electronic and automated bench.

operated with a pitch of 1” and ½” respectively. They had a transverse cap level regulating system, which annuls the pulsating effect of the continuous motion and controls the applied dose.

We measured the granulated fertilizer distribution using a data acquisition system (SAD) with a printed circuit board and a frequency of one hertz. It is connected to a hard disk for later tabulation in spreadsheets and automated analysis. The set collected the granulated fertilizers flow for 420 seconds, totalizing 5040 information.

We connected the SAD to a scale composed of a load cell (single point) with an accuracy of 1.1 mg per pulse, quantifying the mass of granulated fertilizer. For calibration, we determined 12 samples on a semi-analytical scale, transferred them to the container allocated on the load-cell scale and measured their pulses using the data acquisition system for each mass. We disregarded the initial and final 30 seconds of the intervals to stabilize the flow, and we interrupted the collection before the reservatory content reached its last third part. Thus, we calculated and correlated the pulses, generating a linear equation with $R^2 = 1$, according to figure 2.

During the evaluations, we used NPK granulated fertilizers 04-14-08 (FG_1) and 04-30-10 (FG_2), with densities of 970 and 950 kg m^{-3}. They had a resting angle of 32.55º and 33.69º, water content 0.03 kg kg^{-1} for both fertilizers, with 2.50; 72.75; 24.25 and 0.50% and 4.50; 90.00; 5.50 and 0.00% retained in 4.8 mm meshes (ABNT nº 04); 2.0 mm (ABNT nº 10); 1.0 mm (ABNT No. 18); 0.5 mm, respectively (MAPA, 2017).

We adopted a completely randomized design with seven replications. We submitted the acquired flow values of the granulated fertilizers to descriptive statistics (Minitab®) and measures of central tendency (arithmetic mean, median, and mode), dispersion (amplitude, standard deviation, and coefficient of variation), asymmetry, and kurtosis (LEE, 2020). We also performed the Jarque-Bera normality test (WIJEKULARATHNA et al., 2019).

We applied statistical quality control to the obtained information, which allowed us to determine the capability index (Cp and Cpk), through an analysis of process capability according to SAMOHYL (2009). To determine the upper and lower specification limits we adopted 20% of the uniformity variation values of longitudinal fertilizer distribution. We adapted it from the ISO 5690/1 standards (1982) and ASAE S341.2 (1995), using the coefficient of variation to determine the transverse width.

Then we used the data to create a histogram, considering the frequencies distributed in the class intervals. We used Sturges’ Rule (Eq. 1) to define the number of classes, and the class range (Eq. 2) is the ratio of the total amplitude to the number of groups (FERREIRA, 2018).

$$k=1+3,32\log N \quad (1)$$

Where,

N - total number of observations.

$$h=\frac{A_t}{k} \quad (2)$$

Where,

At - total range of data.

We adopted the following reference values for asymmetrical coefficient distribution: Cs>0, asymmetrical to the right; Cs<0, asymmetrical to the left; and Cs=0, symmetric (CORREA, 2003). As for

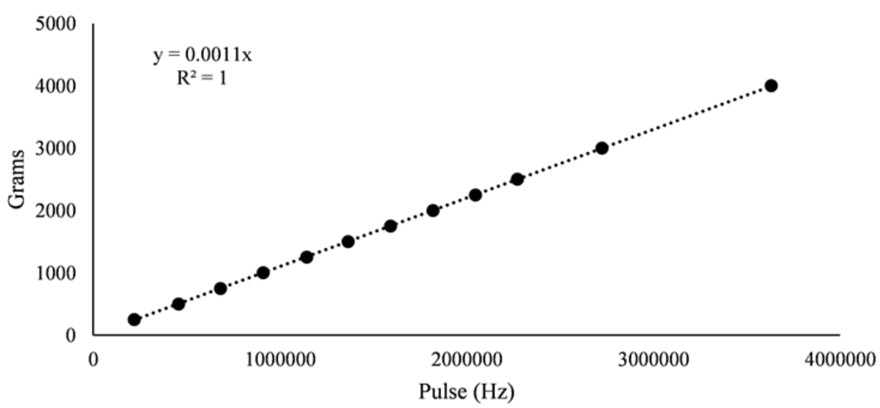

Figure 2 - Calibration curve for scale.

the kurtosis coefficient, they were: Ck>0, leptokurtic distribution; Ck<0, platykurtic distribution, and Ck=0 mesokurtic distribution (SAMOHYL, 2009).

RESULTS AND DISCUSSION

Table 1 shows the results of the descriptive statistics of the granulated fertilizer flow rates for the single and double helical dispensers due to the different velocities evaluated. There was no need to transform the means for all the studied variables, denoting the normality (Jarque-Bera) of the variance residues for most of the variables, except for the simple screw (using FG_2 at 7 km h^{-1}) and both feeders in FG_2 at 10 km h^{-1}, respectively.

The results of the central tendency parameters were different for the granulated fertilizer flow rates in the dosing mechanisms studied. The dispersion presented homogeneous values, with low data scattering (CV < 10%), in addition to the stable behavior of the standard deviation and amplitude, according to the LEE (2020).

The D_1 dosing mechanism presented asymmetry values between 0.09 and 1.41, suggesting that its curve sinuosity is greater on the right side, confirming that its medians are lower than the average. As for D_2, the asymmetry values indicate 50% asymmetrical distribution on the left, 16.67% symmetrical, and 33.33% asymmetrical on the right.

The plastic means of kurtosis explain the dispersion parameters of descriptive statistics. The kurtosis values of the dosing mechanisms D_1 (-0.40; -0.27; -0.01) and D_2 (-0.38; -0.29; -0.25; -0.16; -0, 10) showed an open curve data distribution behavior (platykurtic), corroborating the lower concentration of flow values around the center (SILVA et al., 2010). However, for D_1 (0.04; 2.47; 5.47) and D_2 (0.37), kurtosis presented a leptokurtic form, a greater concentration of data around the center.

The values of Cp and Cpk differ according to the capacity indices results. It means that the process is off-center, and the average does not coincide with the nominal value of the specifications. Thus, we will adopt Cpk values for discussing the results, as it considers the distance from the mean with the specification limits.

Analyzing the set's behavior at the studied velocities, we observed a decrease in Cpk values between the dosing mechanisms in both granulated fertilizers. The greater work homogeneity of the simple helical dispenser explains it, since the increase in the capacity index results in minor variation in the process' rejection rate (MELO et al., 2019). Table 2 and figure 3 show the Cpk results related to the rejection rate.

According to table 2, the Cpk values exceed the control limits specified by the industry. As a consequence, the process is incapable (Cpk < 1). In agriculture, these indices are good once it doesn't have

Table 1 - Descriptive statistics of the granulated fertilizer flow for the single and double helical metering mechanisms due to the different speeds evaluated.

	-----------------4 km h^{-1}--------------------				---------------7 km h^{-1}-----------------				-------------10 km h^{-1}--------------			
parameters	---------FG_1----------		--------F FG_2------		--------FG_1--------		------FG_2-------		------FG_1------		------FG_2------	
	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
Mean	16.51	18.48	15.70	15.31	29.71	32.37	28.08	26.15	43.98	47.50	39.15	36.70
median	16.43	18.42	15.60	15.30	29.47	32.45	27.55	26.20	43.75	47.64	38.57	36.86
mode	17.17	17.99	14.63	15.22	27.92	31.08	27.96	24.18	40.85	44.30	36.92	34.90
Minimum limits	13.33	13.33	13.33	13.33	23.33	23.33	23.33	23.33	33.33	33.33	33.33	33.33
Maximum limits	20.00	20.00	20.00	20.00	35.00	35.00	35.00	35.00	50.00	50.00	50.00	50.00
Standard deviation	0.97	1.40	1.04	1.06	1.85	2.42	2.05	1.67	2.79	3.41	2.54	2.44
Amplitude	5.69	7.52	6.42	6.19	10.55	14.32	17.08	10.81	18.28	19.27	19.42	16.49
CV (%)	5.87	7.60	6.66	6.92	6.23	7.46	7.29	6.40	6.35	7.18	6.48	6.67
Asymmetry	0.21	0.05	0.10	0.00	0.13	-0.09	1.41	-0.10	0.09	0.02	0.91	-0.25
kurtosis	-0.27	-0.10	0.04	-0.25	-0.40	-0.16	5.47	-0.29	-0.01	-0.38	2.47	0.37
JB	4.46^{N}	0.36^{N}	0.74^{N}	1.08^{N}	3.97^{N}	1.11^{N}	664^{A}	2.31^{N}	0.59^{N}	2.56^{N}	164^{A}	0.03^{A}
Cp	0.98	0.72	0.88	0.84	0.86	0.64	0.86	0.85	0.88	0.72	0.94	0.85
Cpk	0.93	0.33	0.63	0.50	0.78	0.29	0.70	0.41	0.63	0.22	0.66	0.34

CV (%) - Coefficient of variation; JB - Jarque-Bera Normality Test (N: Normal Distribution; A: Non-Normal Distribution (P < 0.05); AA Non-Normal Distribution (P < 0.01)). Cp: potential capacity index; Cpk: performance index.

Table 2 - Relationship between Cpk and rejection rate.

	4 km h^{-1}				7 km h^{-1}				10 km h^{-1}			
parameters	FG_1		FG_2		FG_1		FG_2		FG_1		FG_2	
	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
Cpk	0.93	0.33	0.63	0.50	0.78	0.29	0.70	0.41	0.63	0.22	0.66	0.34
Rejection rate (flaws/ha)	236	6346	1550	3628	357	3992	476	2895	620	3242	428	2474

the same control as industrial processes, in which many conditions and factors are controlled (MELO et al., 2016). In this case, the influences of granulometry, density, and the fertilizers resting angles can be special causes.

Figure 4 shows the graphs containing the flow rates of the single and double helical dispensers, arranged in ten grade intervals using the two fertilizers at three speeds.

For the speed of 4 km h^{-1} (FG_1), the D_1 dosing mechanism presented regular distribution, with 21% of the data in the fourth-class interval, 23% in the fifth, and 18% in the sixth interval. In addition, it showed greater sinuosity on the curve to the right, as discussed in table 1. When analyzing the metering mechanisms in FG_2, we can see a difference of 9% between D_1 and D_2 in the fifth class, although they become equal in the posterior classes (six and seven). This means that, at 4 km h^{-1}, the simple helical dispenser with the FG_2 deposed the fertilizer supply uniformly (ZIMMERMANN et al., 2020). For the cumulative frequency (FG_1) of the first and tenth classes, the fertilizer flow rates were below 2.5%, and the in range of third to eighth classes D_1 showed superiority over D_2. However, in FG_2 the helical dispensers inverted their behavior, especially between the third and fourth classes, showing the impact of the physical differences of granulated fertilizers.

At the speed of 7 km h^{-1}, both dosing mechanisms presented regular distribution (FG_1), with a higher flow concentration in the central classes, corroborating the proximity tendency of the accumulated frequency curves. The inverse feeder behavior occurs in FG_2, with the D_1 depositing a flow rate of 44% in the third class and decreasing to 2% in the sixth interval, resulting in the absence of flow in the final ones. It can be explained by inadequate supply to the helical dispenser, not filling it, leading to deposition failure (COSTA et al., 2022). In addition, the characteristics of density and granulometry of FG_2 can influence the depositions.

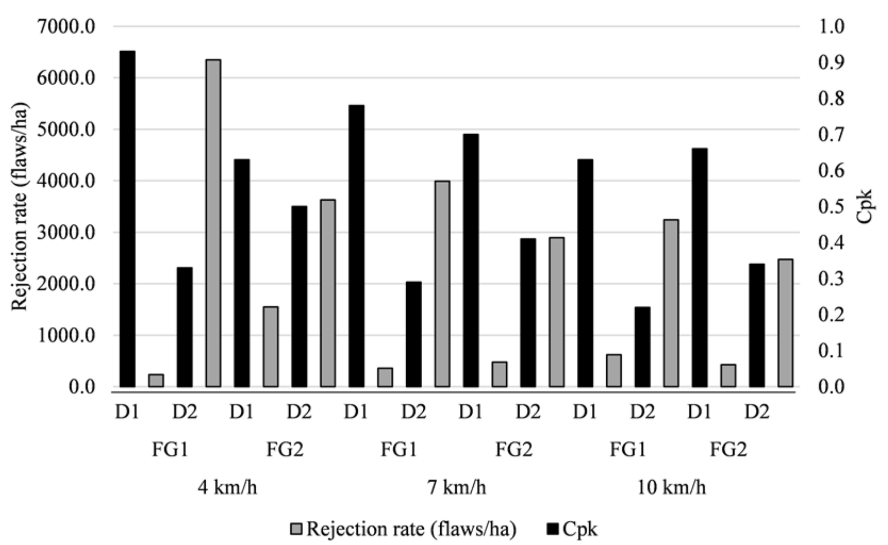

Figure 3 - Graphical analysis of the relationship between Cpk and rejection rate.

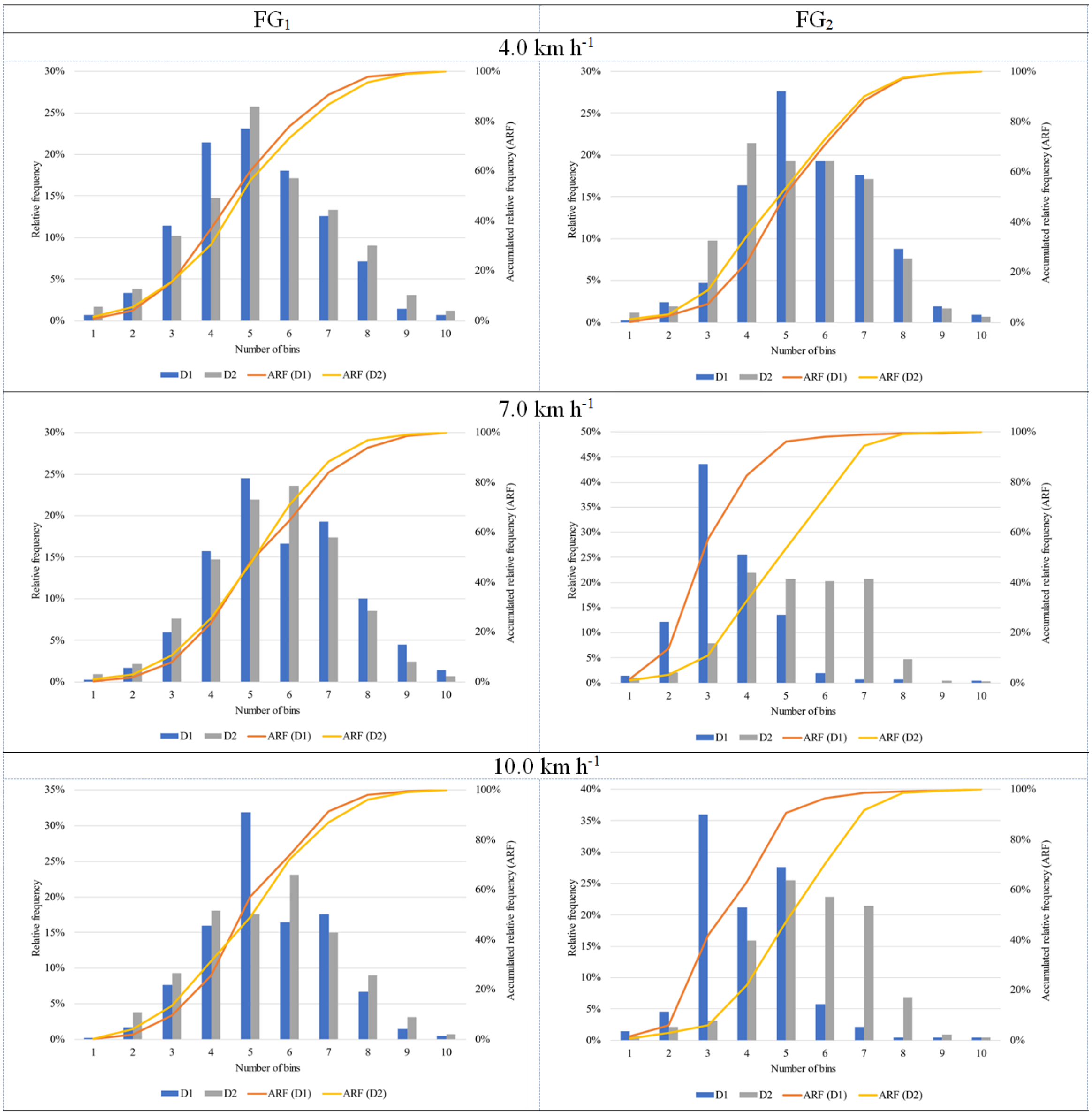

Figure 4 - Frequency Histogram.

Lastly, at a speed of 10 km h^{-1}, feeders D_1 and D_2 exhibited deposition below 1% at the histogram extremities (FG_1), with central classes five and six accumulating the highest flow mean. In the arrangement of the cumulative frequency curves, the intersection between the fourth and fifth classes is observed with the value growth, followed by divergence from D_1 in the subsequent intervals. In the FG_2 fertilizer, the feeders (D_1 and D_2) exhibited similar flow concentrations in the curves' sinuosities (ZIMMERMANN et al., 2022), with flow irregularities in the eighth, ninth, and tenth classes. Thus, the dosing mechanisms presented lower performance when operated with FG_2, resembling the 7 km h^{-1} velocity, resulting in recurrent fertilizer deposition failures.

Quality control is a crucial tool in agricultural operations, enabling decision-making that increases activity results. It does so once correcting flaws and minimizing waste provide cost reduction and consequent productivity rise, with numerous advantages for field competitiveness (CHIODEROLI et al., 2012).

The methodology addressed in this experiment contributes to assessing industrially granulated fertilizer doses and identifying the most effective configuration to achieve high process control.

CONCLUSION

The dosing mechanisms presented the anticipated variations, with acceptable performance under process control. The single helical dispenser, with velocity increase, exhibited greater homogeneity of granulated fertilizer deposition, with 611 ha^{-1} failures compared to 3763 of the double screw. The velocities of 7.0 and 10.0 km h^{-1} created a flow rate increase for both granulated fertilizers, but the 04-30-10 fertilizer, which has the bigger granule, obtained the most uniform distribution at 4.0 km h^{-1}.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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