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.

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
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 (D₁) and double helical dispenser (D₂)
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, totaling 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 reservoiry 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).

$$k = 1 + 3.32 \log N$$

Where, 
$N$ - total number of observations.

$$A_t = \frac{A}{k}$$

Where, 
$A_t$ - 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
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 FG2 at 7 km h⁻¹) and both feeders residues for most of the variables, except for the simple screw (using FG2 at 7 km h⁻¹) and both feeders.

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 flow rates in the dosing mechanisms studied. The parameters were different for the granulated fertilizer in FG2 at 10 km h⁻¹, respectively. The D₁ 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 D₂, the asymmetry values indicate 50% asymmetrical distribution on the left, 16.67% symmetrical, and 33.33% asymmetrical on the right.

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>4 km h⁻¹</th>
<th>7 km h⁻¹</th>
<th>10 km h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>D₁</td>
<td>D₂</td>
<td>D₁</td>
</tr>
<tr>
<td></td>
<td>16.51</td>
<td>18.48</td>
<td>15.70</td>
</tr>
<tr>
<td>Median</td>
<td>16.43</td>
<td>18.42</td>
<td>15.60</td>
</tr>
<tr>
<td>Mode</td>
<td>17.17</td>
<td>17.99</td>
<td>14.63</td>
</tr>
<tr>
<td>Minimum limits</td>
<td>13.33</td>
<td>13.33</td>
<td>13.33</td>
</tr>
<tr>
<td>Maximum limits</td>
<td>20.00</td>
<td>20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.97</td>
<td>1.40</td>
<td>1.04</td>
</tr>
<tr>
<td>CV (%)</td>
<td>5.87</td>
<td>7.60</td>
<td>6.66</td>
</tr>
<tr>
<td>Asymmetry</td>
<td>0.21</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.27</td>
<td>-0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>JB</td>
<td>4.46N</td>
<td>0.36N</td>
<td>0.74N</td>
</tr>
<tr>
<td>Cp</td>
<td>0.98</td>
<td>0.72</td>
<td>0.88</td>
</tr>
<tr>
<td>Cpk</td>
<td>0.93</td>
<td>0.33</td>
<td>0.63</td>
</tr>
</tbody>
</table>

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.
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 (FG₁), the D₁ 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 FG₂, we can see a difference of 9% between D₁ and D₂ 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 FG₂ deposed the fertilizer supply uniformly (ZIMMERMANN et al., 2020). For the cumulative frequency (FG₁) of the first and tenth classes, the fertilizer flow rates were below 2.5%, and the in range of third to eighth classes D₁ showed superiority over D₂. However, in FG₁, 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 (FG₁), with a higher flow concentration in the central classes, corroborating the proximity tendency of the accumulated frequency curves. The inverse feeder behavior occurs in FG₂, with the D₁ 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 FG₂ can influence the depositions.

### Table 2 - Relationship between Cpk and rejection rate.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FG₁</th>
<th>FG₂</th>
<th>FG₁</th>
<th>FG₂</th>
<th>FG₁</th>
<th>FG₂</th>
<th>FG₁</th>
<th>FG₂</th>
<th>FG₁</th>
<th>FG₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₁ Cpk</td>
<td>0.93</td>
<td>0.33</td>
<td>0.63</td>
<td>0.50</td>
<td>0.78</td>
<td>0.29</td>
<td>0.70</td>
<td>0.41</td>
<td>0.63</td>
<td>0.22</td>
</tr>
<tr>
<td>D₂ Cpk</td>
<td>0.33</td>
<td>0.63</td>
<td>0.50</td>
<td>0.78</td>
<td>0.29</td>
<td>0.70</td>
<td>0.41</td>
<td>0.63</td>
<td>0.22</td>
<td>0.66</td>
</tr>
<tr>
<td>Rejection rate (flaws/ha)</td>
<td>236</td>
<td>6346</td>
<td>1580</td>
<td>3628</td>
<td>357</td>
<td>3992</td>
<td>476</td>
<td>2895</td>
<td>620</td>
<td>3242</td>
</tr>
<tr>
<td></td>
<td>4 km h⁻¹</td>
<td>7 km h⁻¹</td>
<td>10 km h⁻¹</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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

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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 most uniform distribution at 4.0 km h⁻¹.

fertilizer, which has the bigger granule, obtained the 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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