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Fertilizer deposition as a function of angular velocity and inclination of the helical dosing mechanism[1]

Deposição de fertilizante em função da velocidade angular e inclinação do mecanismo de dosagem helicoidal

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HIGHLIGHTS:

The addition of speed in the helical overflow meter provides more homogeneity in the fertilizer deposition flow.
The influence of the granular fertilizer flow on homogeneity was more expressive on longitudinal slopes +7.5 and +15°.
Statistical process control proved to be an innovative alternative to the current evaluation method.

ABSTRACT: The establishment of grain crops in Brazil is an important industrial process in the agricultural chain, requiring the correct deposition of granular fertilizer over the sowing furrow and more efficient, precise, and sustainable assessments in the operation, which can be achieved with the statistical process control. This study aimed to assess the effect of the angular velocity on different inclinations of the helical metering mechanism on the granular fertilizer deposition. An automated electronic bench was used to assess the deposition quality of granular fertilizers considering different angular velocities (1.11, 1.94, and 2.77 m s^{-1}) and longitudinal and transverse inclinations (+15, +7.5, 0, −7.5, and −15°), with the helical doser by overflow. Flow data were collected and submitted to descriptive statistics and statistical process control. The metering mechanism showed expected variations, with acceptable performance under process control. The values of the flow rates of the granular fertilizer increased as velocity increased, standing out longitudinal inclinations of +7.5 and +15°, providing higher fertilizer depositions.

Key words: automated electronic bench, agricultural chain, statistical control

RESUMO: O estabelecimento de lavouras de grãos no Brasil é um importante processo industrial na cadeia agrícola, exigindo a correta deposição do fertilizante granulado no sulco de semeadura e avaliações mais eficientes, precisas e sustentáveis na operação, que podem ser obtidas com o controle estatístico do processo. Este estudo foi realizado com o objetivo de avaliar o efeito da velocidade angular em diferentes inclinações do mecanismo de dosagem helicoidal sobre a deposição de fertilizante granulado. Uma bancada eletrônica automatizada foi usada para avaliar a qualidade de deposição de fertilizantes granulados considerando diferentes velocidades angulares (1,11, 1,94 e 2,77 m s^{-1}) e inclinações longitudinais e transversais (+15, +7,5, 0, −7,5 e −15°), com dosador helicoidal por transbordamento. Os dados de fluxo foram coletados e submetidos à estatística descritiva e ao controle estatístico do processo. O mecanismo de medição apresentou variações esperadas, com desempenho aceitável sob controle de processo. Os valores de vazão do fertilizante granulado aumentaram com o aumento da velocidade, destacando-se inclinações longitudinais de +7,5 e + 15°, proporcionando maior deposição de fertilizante.

Palavras-chave: bancada eletrônica automatizada, cadeia agrícola, controle estatístico

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Introduction

Demands for maximizing crop efficiency have emerged as contemporary agriculture advances, aiming to meet the requirements imposed by the demographic growth projected for the coming decades (Hickey et al., 2019). In this scenario, agriculture undergoes profound technological and sustainable transformations that identify it as an industrial production process (Zilli et al., 2020) to meet the increasingly restricted windows of cultivars with short-cycle agronomic characteristics, dimensioning the logistics of mechanized assemblies, demand for quality and food security, and the international commodity market (OCDE, 2018).

The establishment of grain crops through mechanized sowing-fertilization operations is part of this industrial chain. Sowing and fertilization are primordial stages of the industrial process of establishment of grain crops in Brazil, which are carried out concurrently, that is, high genetic quality seeds distributed by highly efficient metering mechanisms (Xing et al., 2020) and more sophisticated fertilizers (Dimkpa et al., 2020), which requires the correct deposition along the sowing furrow to maximize crop productivity. It can only be achieved with efficient metering mechanisms, with high quality in their manufacturing process, which is directly related to their principles of operation (Silva et al., 2010a; Garcia et al., 2012; Franck et al., 2015).

Given the options offered in the markets, the available models of metering mechanisms present different types of architecture, standing out single and double helical mechanisms, which have a continuous thread system, and corrugated rollers, consisting of flutes (Ning et al., 2015; Zeng et al., 2020).

The current technological package involved in the manufacturing of metering mechanisms requires new methods of validating the distribution of granular fertilizers compared to the current ISO (1984) standard methodology, which may not meet the assessment of distribution as a step in the industrial process. Several studies carried out with this method have shown differences regarding the velocity and inclination of the metering mechanisms (Franck et al., 2015; Reynaldo & Gamero, 2015; Dalacort & Stevan Junior, 2018; Spagnolo et al., 2021), in addition to new assessment methodologies (Rosa et al., 2019).

The automation performed on static distribution simulation benches emerges as an alternative to meet this demand, allowing the assessment of the metering mechanisms used for seed (Savi et al., 2020) and fertilizer distribution (Zimmermann et al., 2020) at different velocities and inclinations, with no interference from external factors. A more efficient assessment can be carried out using a data acquisition system customized according to the test requirements (Jasper et al., 2016), generating an almost infinite amount of data and enabling precise and accurate detection of the deposition of a single fertilizer granule.

Rosa et al. (2019) developed a new methodology to assess the operation of a helical meter under laboratory and field conditions and observed that the ISO (1984) standard does not present accurate data due to the variations correlated with the distribution pulses, and the collection period favors different dosage fluctuations.

The demand for efficient, accurate, and sustainable assessments, such as the statistical process control method, arises due to the large number of data collected in this process (Duran-Villalobos et al., 2020). This tool, developed for industries and also used in agriculture, aims to develop and apply statistical methods as a strategic part of error prevention, improvements in quality and productivity, and cost reduction, with emphasis on research related to agricultural inputs, such as granular fertilizers (Zimmermann et al., 2020). This assessment is carried out by quality control charts, which facilitate the rapid detection of the causes of common or special variations in the test (Mehmood et al., 2020).

In this context, this study aimed to assess the effect of the angular velocity on different inclinations of the helical doser by overflow on the granular fertilizer deposition using an automated electronic bench.

Material and Methods

The experiment was carried out in Curitiba, Paraná State, Brazil, and assessed the quality of granular fertilizer (GF) flows using an automated electronic bench, considering different angular velocities (1.11, 1.94, and 2.77 m s^{-1}) and longitudinal and transverse inclinations (+15, +7.5, 0, −7.5, and −15°), with seven replicates, totaling 15 treatments. The angles were determined according to the need for greater representativeness of slope conditions, in addition to allowing a higher number of data quantifications relative to the standard method.

Figure 1 shows the automated electronic bench developed in the laboratory, with the electrical control (A), transmission (B) and articulation set (C), reservoirs (D), metering mechanism (E), and the data acquisition system (F).

The electrical control through a frequency inverter allowed a precise adjustment of the gearmotor rotation of 0.25 kW, which activated the metering mechanism axis through a symmetrical transmission ratio by pulley and chain. Angular velocities were determined based on the granular fertilizer application of 300 kg ha^{-1}, considering a sowing inter-row spacing of 0.50 m, resulting in 15 g m^{-1}.

The simulation of angular velocities was based on the conversion of actual values into Hertz (Hz) in the frequency inverter, that is, 1.11 m s^{-1} to 20.35 Hz, 1.94 m s^{-1} to 35.61 Hz, and 2.77 m s^{-1} to 50.88 Hz. The set was parameterized to operate at the frequency from 1 to 60 Hz, driven by a linear

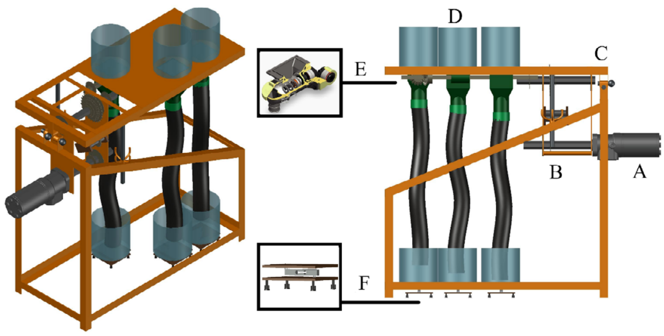


Figure 1. Diagonal and lateral top projection of the automated electronic bench

potentiometer of 5 KΩ, which allowed varying the angular velocity of the metering mechanism.

The bench architecture allows electrical velocity adjustment and variations on longitudinal and transverse inclination angles of +15, +7.5, 0, −7.5, and −15° through threaded bars dimensioned to meet the simulated inclinations. The GF reservoirs located at the top end of the bench are connected to the helical dosing by overflow with a 1” step and level regulating system with a transverse cover, which has the function of canceling the pulsating effect of the endless cycle and controlling the dose.

The granular fertilizer distribution was measured by a data acquisition system with a printed circuit board and frequency of data acquisition of 1 Hertz, connected to a hard disk for later tabulation in automated analysis spreadsheets. The set collected the granular fertilizer flow for 300 s, ignoring the initial and final 30 s to ensure the flow stabilization for each control chart, which totaled 8,100 collected information.

The data acquisition system was connected to a scale composed of a load cell (single point) with a precision of 1.1 mg per pulse, quantifying the granular fertilizer mass. The calibration was performed by determining 12 increasing masses on a semi-analytical scale, transferred to the container placed on the scale, and the pulses were read in the data acquisition system for each mass. The initial and final 30 s intervals were disregarded to stabilize the flow and the collection was interrupted before the reservoir content reached the final third. Thus, the pulses for each scale were averaged and, subsequently, the information was correlated, generating a linear equation with $R^2 = 1$, according to Figure 2.

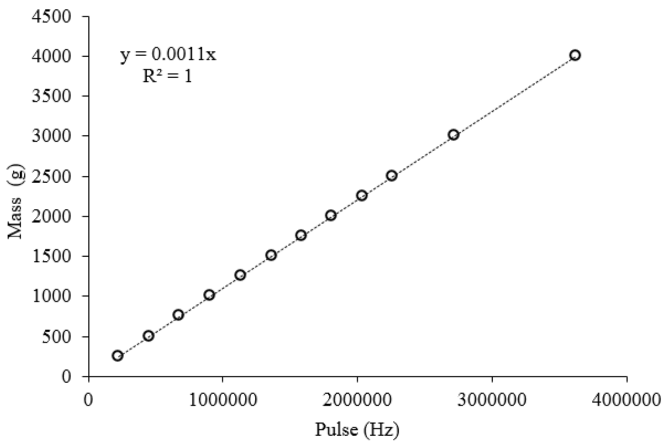


Figure 2. Calibration curve for scale

The granular fertilizer NPK 04-14-08 was used in the assessment. It has a density of 970 kg m^{-3}, angle of repose of 32.55°, moisture content of 0.03 kg kg^{-1}, and retention of 3.50, 81.38, 14.87, and 0.25% on 4.0 (ABNT no. 05), 2.0 (ABNT no. 10), 1.0 (ABNT no. 18), and 0.5 mm mesh openings (ABNT no. 35), respectively (MAPA, 2017).

The data obtained from different longitudinal and transverse working conditions were subjected to descriptive statistics using the software Minitab®, which allowed the calculation of the measures of central tendency (arithmetic mean, median, and mode) and dispersion (amplitude, standard deviation, and coefficient of variation), skewness, and kurtosis (Lee, 2020). The Jarque-Bera test of normality was also performed (Wijekularathna et al., 2019).

Subsequently, the flow data were subjected to analysis of the coefficient of variation and statistical process control aiming to generate Shewhart statistical control charts for the means of the metering mechanism used at each velocity and inclination, allowing examining the level and variation from the upper (UCL) and lower control limits (LCL) (Noronha et al., 2011). The control limits were established considering the data variation due to uncontrolled causes in the process (special causes), being calculated based on the standard deviation of the variables, according to Eqs. 1 and 2.

$$UCL = \bar{X} + 3\sigma \quad (1)$$

$$LCL = \bar{X} - 3\sigma \quad (2)$$

where:

UCL - upper control limit;

X - overall mean of the variable;

σ - standard deviation; and,

LCL - lower control limit.

Results and Discussion

Table 1 shows the results of the descriptive statistics of the granular fertilizer flows for an angular velocity of 1.11 m s^{-1}, considering different longitudinal and transverse inclinations. There was no need to transform the means of the studied variables due to the normality (Jarque-Bera) of residuals of variances for longitudinal angles of −15, −7.5, and +15°, 0°, and transverse angles of +15, and + 7.5°.

Table 1. Descriptive statistics of the granular fertilizer flow for longitudinal and transverse inclinations assessed at a velocity of 1.11 m s^{-1}

Parameter[1]	Longitudinal					Transverse			
	−15°	−7.5°	+7.5°	+15°	0°	+15°	+7.5°	−7.5°	−15°
Mean	15.71	14.50	17.30	19.66	16.46	16.03	16.00	16.57	16.32
Median	15.63	14.46	17.18	19.54	16.36	16.00	15.93	16.42	16.22
Mode	15.18	15.63	17.82	18.89	15.89	15.03	16.30	15.77	17.60
SD	1.08	0.85	1.02	1.17	0.98	0.99	0.98	1.11	1.35
Amplitude	6.50	4.85	6.74	5.97	5.20	6.75	4.71	8.22	8.59
CV (%)	6.85	5.87	5.89	5.94	5.95	6.22	6.16	6.71	8.28
Skewness	−0.01	0.01	−0.10	0.07	0.32	0.03	0.10	0.30	0.34
Kurtosis	−0.11	−0.39	0.72	−0.44	−0.22	0.20	-0.53	0.70	0.80
JB	0.16^N	1.92^N	7.12^A	2.73^N	5.86^N	0.55^N	4.07^N	10.85^A	14.22^A

[1]SD - Standard deviation; CV - Coefficient of variation; JB - Jarque-Bera test of normality (N: normal distribution; A: non-normal distribution at p ≤ 0.05; AA: non-normal distribution at p ≤ 0.01)

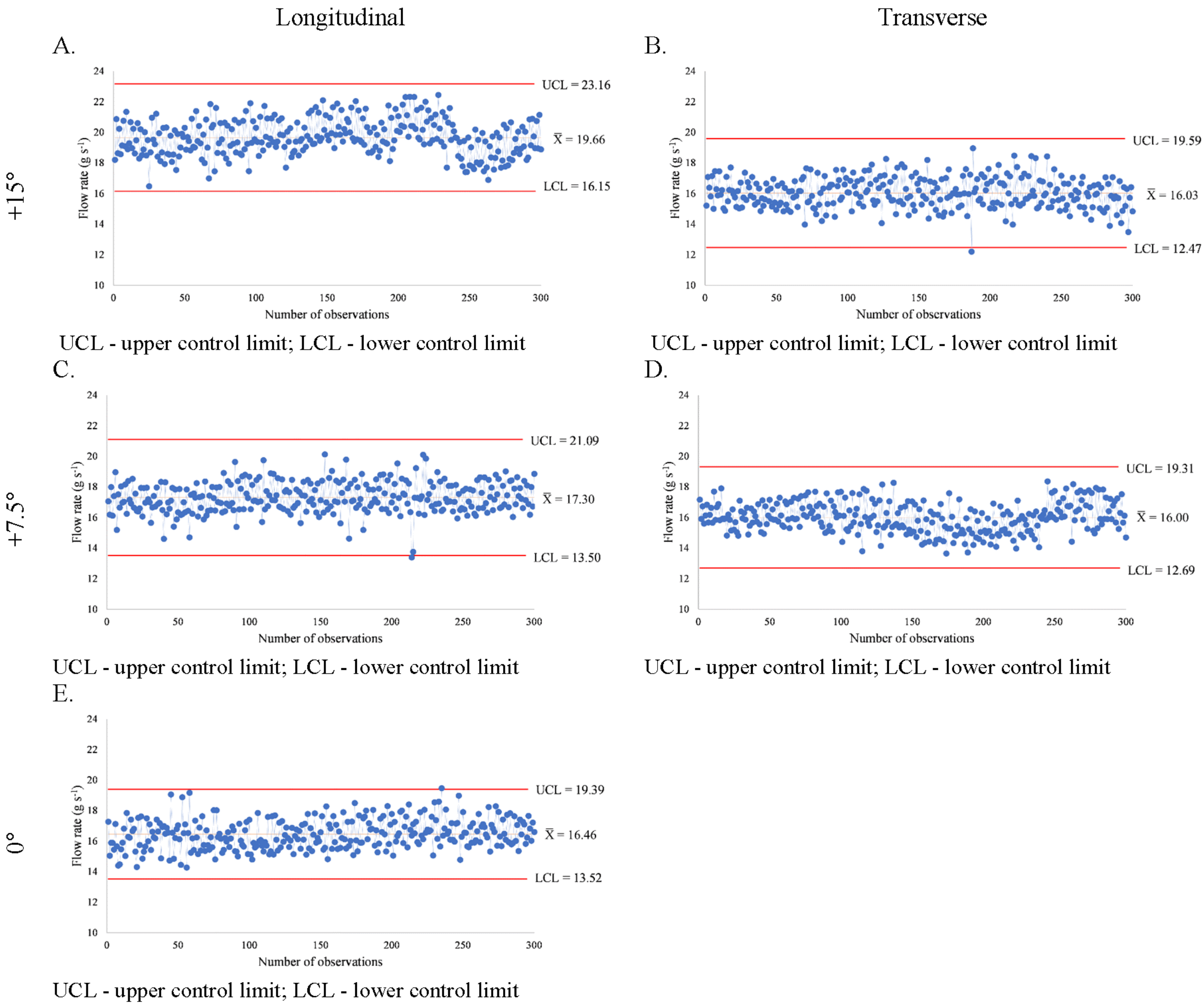
The results of the measures of central tendency were different for the studied inclinations, with higher mean, median, and mode values on the longitudinal angle of +15°. Transverse inclinations of −7.5 and −15° showed skewness values between 0.30 and 0.34, suggesting that their curve sinuosity is higher on the right side, confirming their medians to be lower than the mean. Skewness values for longitudinal angles of +7.5 and −15° were negative (−0.10 and −0.01, respectively), indicating a left-skewed distribution.

The dispersion showed values considered homogeneous, with a low scattering of the data (CV < 10%). This result differs from Rosa et al. (2019), who found a higher coefficient of variation values, justified by amplitude peaks, explaining the low coefficient of variation values in this experiment and stable behavior of the standard deviation and amplitude. The dispersion parameters of descriptive statistics can be explained by kurtosis. Longitudinal inclinations of −15, −7.5, and +15°, 0°, and the transverse inclination of +7.5° showed a leptokurtic data distribution, corroborating the higher concentration of flow values around the center (Silva et al., 2010b). However, kurtosis had a platykurtic shape for the longitudinal angle of +7.5° and transverse angles of +15, −7.5, and −15°.

The means of flows were presented in control charts, aiming at better monitoring of the process (Figure 3). The single helical metering mechanism at a velocity of 1.11 m s^{-1} on longitudinal inclinations of +7.5 and −15° and transverse inclinations of +15, −7.5, and −15° presented points out of the control limits, clearly identified by the first rule (ISO, 2013), suggesting the occurrence of a special cause in the process. This special cause identifies subgroups that are atypical when compared to other subgroups, which may be due to errors in the collection process, but not reducing the process capability.

The longitudinal inclination of +15° and the transverse inclination of −15° showed the approximation of points in the lower and upper control limits, while the reference of 0° showed a trend of points closer to the upper control limit. It indicates the occurrence of a special cause, but with no problems in the process capability.

The transverse inclination of +15° showed a trending behavior, denoted by the distribution of collection points forming similar curves at time intervals with analogous amplitudes. It can be explained by the presence of seven or more consecutive points in continuous upward or downward movements, causing deviations in quality standards (Khan et



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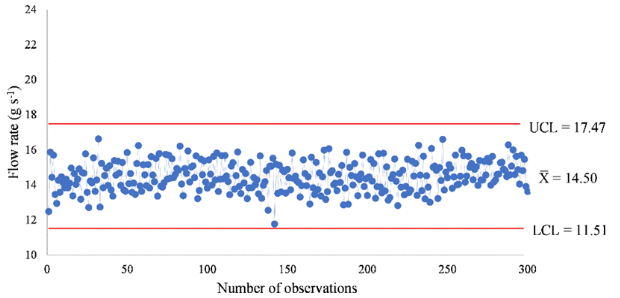
Continuation of Figure 3

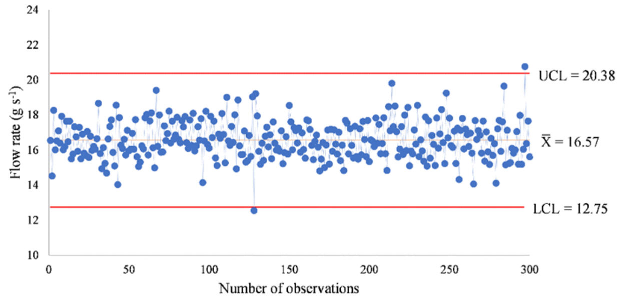
F.

−7.5°



UCL - upper control limit; LCL - lower control limit

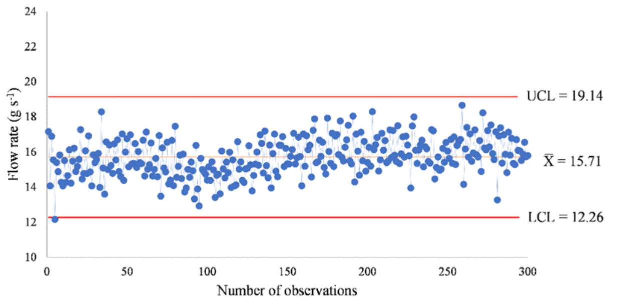
G.



UCL - upper control limit; LCL - lower control limit

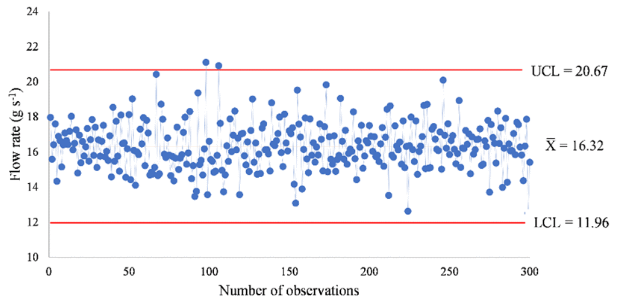
H.

−15°



UCL - upper control limit; LCL - lower control limit

I.



UCL - upper control limit; LCL - lower control limit

Figure 3. Flow rate control charts at the velocity of 1.11 m s^{-1} on inclinations ranging from +15° to -15°

al., 2018). However, the presence of a temporary change in the means of longitudinal angles of −15 and + 15° indicates fluctuations in the environmental or electronic parameters during the data collection period, which were not significant for the change in series (Shamsuzzaman et al., 2016).

The low variability in the distribution of points observed on longitudinal inclinations of +7.5 and −7.5° and the transverse inclination of −7.5° is denoted by the presence of 15 consecutive points in the zone close to the mean and above and below the control line, respectively. It is a behavior different from that shown by the transverse angle of +7.5°, which showed a trend in the data distribution and can be explained by seven or more consecutive points presenting continuous upward or downward movement. It also indicates that the process will naturally leave the specification means if nothing is changed (Celano et al., 2016).

The results of the descriptive statistics of the granular fertilizer flows for an angular velocity of 1.94 m s^{-1} due to different longitudinal and transverse inclinations are shown in Table 2. There was no need to transform the means for the studied variables, denoting the normality (Jarque-Bera) of residuals of variances for longitudinal inclinations of −15 and −7.5°, 0°, and transverse inclinations of +7.5 and −7.5°.

The mean, median, and mode values were higher on the longitudinal angle of +15°, a result similar to that observed at a velocity of 1.11 m s^{-1}. Longitudinal inclinations of +7.5, −7.5, and −15° had negative skewness values (−0.96, −0.10, and −0.03), indicating a left-skewed curve. However, transverse inclinations of +7.5, −7.5, and −15° presented skewness values of 0.12, 0.06, and 0.46, respectively, suggesting that the tail of the curve is larger on the right, assuming median values lower than the mean.

The dispersion can be explained by kurtosis. The 0° angle had a kurtosis value of −0.35 (leptokurtic), which represents the highest concentration of flow values around the mean, that is, higher homogeneity in the distribution. However, longitudinal inclinations of +15 and +7.5° presented a platykurtic kurtosis, agreeing weakly with the flow values around the distribution center. Low data dispersion (CV < 10%) and stable behavior of the standard deviation and amplitude were observed.

Table 2. Descriptive statistics of the granular fertilizer flow for longitudinal and transverse inclinations assessed at a velocity of 1.94 m s^{-1}

Parameter[1]	Longitudinal					Transverse			
	−15°	−7.5°	+7.5°	+15°	0°	+15°	+7.5°	−7.5°	−15°
Mean	25.29	27.53	32.10	35.82	29.92	28.63	30.16	30.38	28.80
Median	25.10	27.37	31.77	35.47	29.77	28.56	29.66	30.13	28.69
Mode	25.02	26.72	33.53	34.19	30.29	28.85	29.61	30.15	28.01
SD	1.60	1.66	2.14	2.18	1.86	1.84	1.80	1.91	2.02
Amplitude	8.60	10.55	17.62	19.06	10.55	15.92	10.10	11.79	12.52
CV (%)	6.35	6.04	6.68	6.09	6.23	6.45	5.97	6.30	7.04
Skewness	-0.03	-0.10	-0.96	0.19	0.04	-0.01	0.12	0.06	0.46
Kurtosis	-0.20	0.15	4.68	1.31	-0.35	1.30	-0.19	-0.06	0.69
JB	0.57^{N}	0.86^{N}	336.6^{A}	23.57^{A}	1.69^{N}	21.46^{A}	1.28^{N}	0.28^{N}	16.92^{A}

[1]SD - Standard deviation; CV - Coefficient of variation; JB - Jarque-Bera test of normality (N: normal distribution; A: non-normal distribution at p ≤ 0.05; AA: non-normal distribution at p ≤ 0.01)

The means of flows were presented in control charts aiming at better monitoring of the process (Figure 4). The helical dosing by overflow at a velocity of 1.94 m s^{-1} on longitudinal inclinations of +15 and +7.5° and transverse inclinations of

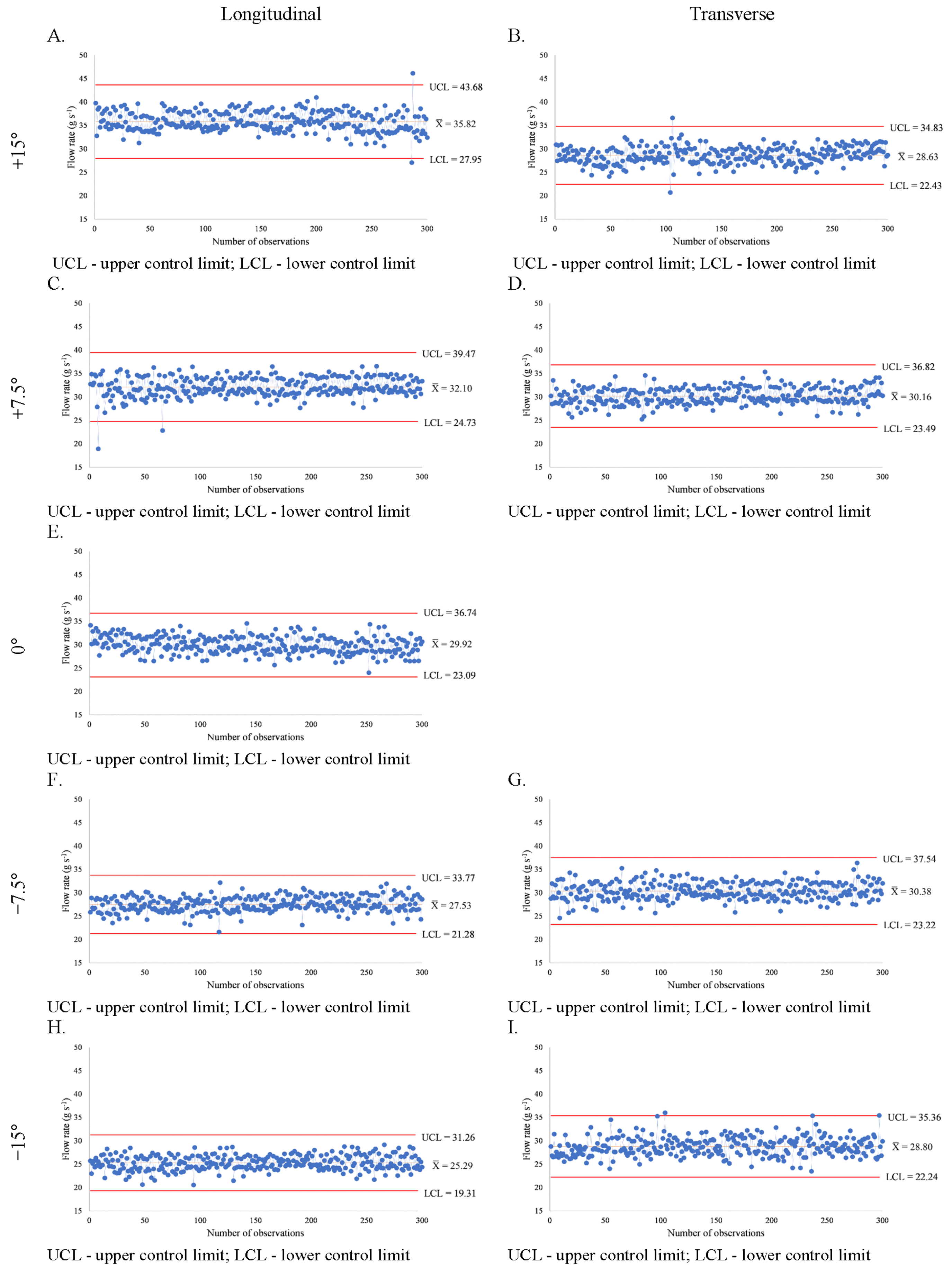


Figure 4. Flow rate control charts at the velocity of 1.94 m s^{-1} on inclinations ranging from +15° to -15°

+15 and −15° had at least one point out of the control limits, a behavior identified by the first test (ISO, 2013), suggesting the presence of atypical subgroups.

Longitudinal inclinations of +7.5 and −15° and the transverse inclination of +7.5° showed low variability in the distribution of points, different behavior from that shown by the longitudinal angle of +15°, the transverse angle of −7.5°, and 0°, which provided a trend in the data distribution related to seven or more consecutive points showing continuous upward or downward movement (Fu et al., 2017).

The approach behavior of the distribution points at the upper and lower control limits can be observed on the longitudinal angle of −7.5° and the transverse angle of −15°, indicating the presence of special causes in the process, but with no problems in the capability. These causes are derived from errors in the data collection period and the data will appear out of the desired specifications if nothing is done and other variations occur, but not causing persistent inconvenience. However, the presence of a temporary change in the mean of the transverse inclination of +15° suggests that some parameter that has little effect on the behavior of the series was changed (Shamsuzzaman et al., 2016).

Table 3 shows the descriptive statistics of the granular fertilizer flows for an angular velocity of 2.77 m s^{-1} due to different longitudinal and transverse inclinations. There was no need to transform the means for the studied variables, as at the previous velocities, denoting the normality (Jarque-Bera) of residuals of variances for longitudinal angles of −15 and +15°, 0°, and transverse angles of +15, −7.5, and −15°.

The mean, median, and mode values were higher on the longitudinal angle of +15°, a result similar to that observed at the previous velocities. Most of the longitudinal inclination angles had a positive skewness, suggesting that the tail of the curve is longer on the right, assuming that its median values are lower than the mean. However, longitudinal slopes of +7.5 and −7.5° showed negative skewness values, indicating a left-skewed distribution.

Kurtosis presented a platykurtic shape for longitudinal inclinations of +7.5 and −7.5°, agreeing weakly with the flow rate values around the distribution center. Kurtosis values of −0.40, −0.38, −0.11, and −0.40 for transverse angles of +7.5, −7.5, and −15° and 0°, respectively, represent that the flow rate are strongly concentrated around the center. However, a low data dispersion (CV < 10%) and stable behavior of the standard deviation and amplitude were observed.

The means of flow rates were presented in control charts, aiming at better monitoring of the process (Figure 5). The helical dosing by overflow at a velocity of 2.77 m s^{-1} presented points out of the control limits only on longitudinal slopes of +7.5 and −7.5°, a behavior identified by the first test (ISO, 2013), suggesting the existence of atypical subgroups.

The longitudinal inclination of +15° and transverse inclinations of -7.5 and +15° had a trend of high oscillation, as indicated by the distribution of seven or more consecutive points in an increasing and decreasing direction alternately. In this case, the process will naturally leave the specification means if nothing is changed (Fu et al., 2017).

The longitudinal inclination of −15° and transverse inclinations of −15 and −7.5° presented a behavior of seasonality, denoted by the distribution of collection points, which formed similar curves at comparable time intervals of amplitude. It can be explained by the behavioral alternation of the operation, anthropogenic and electronic factors, and the environmental condition (Khan et al., 2018).

The lack of variability in the distribution of points on the longitudinal angle of −7.5° is denoted by the presence of 15 consecutive points in the zone close to the mean and above and below the control line. This behavior is different from that shown by the longitudinal inclination of +7.5° and 0°, which showed a temporary change in the mean, suggesting that some parameter that has little effect on the behavior of the series was changed (Fu et al., 2017).

The helical dosing by overflow at the three angular velocities showed expected variations at doses and performance for each inclination, as found by Ferreira et al. (2010) when applying another type of test, which allowed demonstrating the significance or not of the means. However, the control charts enabled the study of the indicator variability as a function of factors and their relationship with the metering performance and not only the significance of variation between the means.

Granular fertilizer distribution at the reference of 0° was acceptable at all studied velocities, which is an expected result because the granular fertilizer under these conditions does not present mechanical resistance relative to gravity. It can be explained by the higher variation rate at the extremities compared to that of the central region, evidencing a higher flow gradient with an increase in inclinations (Spagnolo et al., 2021).

Although variations of 10% in the flow homogeneity of the granular fertilizer are considered admissible, they can exceed 40% in the field (Rosa et al., 2019). In this sense, the lack of

Table 3. Descriptive statistics of the granular fertilizer flow for longitudinal and transverse inclinations assessed at a velocity of 2.77 m s^{-1}

Parameter[1]	Longitudinal					Transverse			
	−15°	−7.5°	+7.5°	+15°	0°	+15°	+7.5°	−7.5°	−15°
Mean	37.91	38.27	45.48	49.29	43.57	43.84	44.99	43.40	41.83
Median	37.38	38.43	44.95	48.82	43.40	43.23	44.52	43.03	41.58
Mode	34.75	39.64	44.44	50.99	40.85	43.19	48.91	42.03	39.77
SD	2.22	3.64	2.89	3.16	2.69	2.85	2.63	2.75	2.60
Amplitude	10.95	35.84	20.63	20.16	13.52	17.51	14.62	15.25	13.58
CV (%)	5.88	9.52	6.36	6.42	6.17	6.51	5.85	6.33	6.23
Skewness	0.15	−2.67	−0.52	0.07	0.09	0.09	0.33	0.26	0.03
Kurtosis	−0.48	17.21	1.95	0.176	−0.40	0.14	−0.38	−0.11	−0.40
JB	4.08[N]	4063[A]	61.34[A]	0.66[N]	2.54[N]	0.72[N]	7.30[A]	3.57[N]	2.12[N]

[1]SD - Standard deviation; CV - Coefficient of variation; JB - Jarque-Bera test of normality (N: normal distribution; A: non-normal distribution at p ≤ 0.05; AA: non-normal distribution at p ≤ 0.01)

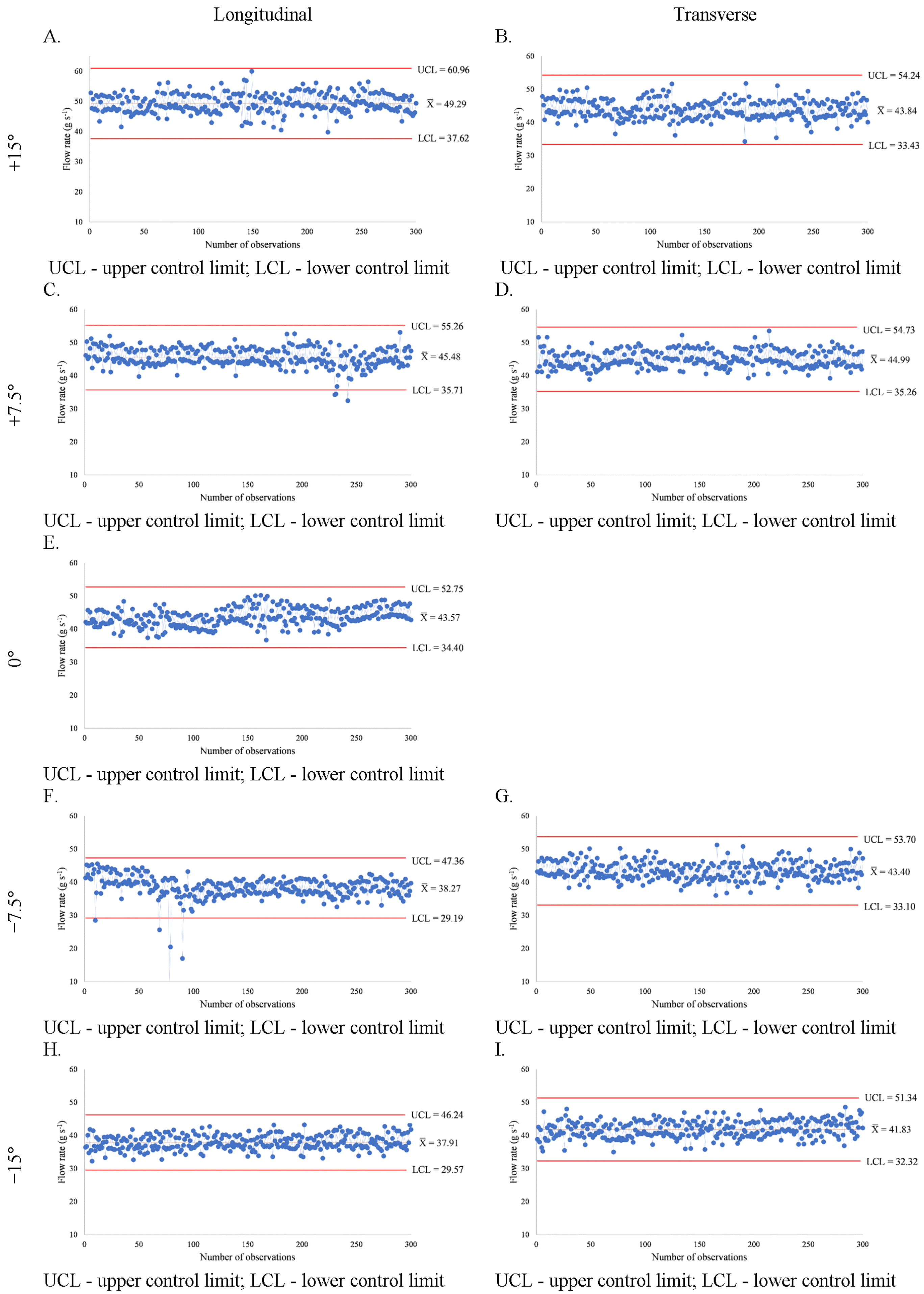


Figure 5. Flow rate control charts at the velocity of 2.77 m s^{-1} on inclinations ranging from +15° to -15°

fertilizer can reduce the agronomic yield (Weirich Neto et al., 2013), while its excess increases environmental risks (Serrano et al., 2014).

However, increases in flow rate values were observed on longitudinal inclinations of +7.5 and +15° with an increase in velocity, which can be represented in the operational condition. In addition, the helical thread component rotates to push the fertilizer downwards when the metering mechanism set is in an uphill direction, implying higher fluidity (Reynaldo & Gamero, 2015).

Conclusions

1. The single helical metering mechanism at the different studied angular velocities and inclinations presented acceptable performance under process control.

2. The increase in the flow rates of the granular fertilizer, provided by the increase in the angular velocity, is enhanced on longitudinal slopes of +7.5 and +15°, favoring fertilizer deposition in the seed furrow.

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