Models for predicting the performance of fertilizer metering in seed cum fertilizer drill[1]

Modelos de predição do desempenho de dosadores de fertilizantes de semeadoras-adubadoras agrícolas

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HIGHLIGHTS:
Longitudinal slope causes variations in fertilizer dosage.
Two helical measurements provide less variation in the applied dose per hectare when working on sloping terrain.
The action of gravity influences the high dosage variability, especially when using meterings with only one helicoid.

ABSTRACT: This study aimed to establish mathematical models that predict the performance of helical fertilizer metering according to the longitudinal and transverse inclinations, angular speed, and helical pitch. Laboratory tests were carried out with helical meterings with lateral and longitudinal discharge through overflow and with two helicoids, working at an angular speed of 16 and 46 rpm at the following longitudinal inclination angles: -20, -15, -10, -5, 0, +5, +10, +15, and +20° and on the transverse axis: -15, -10, -5, 0, +5, +10, and +15°. It was found that the variation of the transverse inclination has little effect on the dosage. When using fertilizer metering with a helicoid, the higher the longitudinal inclination, the greater the dosage in a linear manner, while the meterings with two helicoids provided less oscillation of the dosages according to the inclinations.

Key words: fertilizer dosage, longitudinal inclination, transverse inclination, helical pitch

RESUMO: Objetivou-se neste estudo estabelecer modelos matemáticos preditivos do desempenho de dosadores helicoidais de fertilizantes em função das inclinações longitudinal e transversal, velocidade angular e passo dos helicoides. Foram realizados testes em laboratório com dosadores helicoidais por transbordo lateral, longitudinal e com dois helicoides, trabalhando na velocidade angular de 16 e 46 rpm nos seguintes ângulos de inclinação longitudinal: -20, -15, -10, -5, 0, +5, +10, +15 e +20° e no eixo transversal: -15, -10, -5, 0, +5, +10 e +15°. Verificou-se que a variação da inclinação transversal pouco interfere na dosagem. Quando utilizados dosadores com um helicoide, quanto maior a inclinação longitudinal maior a dosagem de forma linear, enquanto o dosador com dois helicoides proporcionou menor oscilação das dosagens em função das inclinações testadas.

Palavras-chave: dosagem de fertilizante, inclinação longitudinal, inclinação transversal, passo do helicoide

Introduction

The correct dosage of fertilizers by the seed cum fertilizer drill is an essential step in the process of implanting any crop, contributing to its development and yield. Contextualizing this operation, in the Brazilian market, more than 94.4% of the seed drills are equipped with helical thread type fertilizer metering (Francetto et al., 2015). This mechanism is found in four models: helical by gravity, helical by lateral or longitudinal discharge through overflow, and two longitudinal helicoids.

Helical fertilizer meterings have dosage variations that can reach 70% (Reynaldo & Gamero, 2015; Garcia et al., 2017; Rosa et al., 2019). Size, profile, and rotation of the helicoid (Garcia et al., 2012; Galvão et al., 2018); the inclination of work, and fertilizer humidity and granulometry (Franck et al., 2015; Reynaldo & Gamero, 2015) are the main factors that influence the dosage variation.

There is little research comparing fertilizer meterings; also, the evaluations require a lot of work, when evaluating more than two factors. Data modeling is being increasingly requested for the generation of information in the field, as the technique allows to estimate the performance of equipment, they are useful in the planning of crop management actions, and they serve as an aid for the creation of innovative technologies. In this context, Franck et al. (2015) developed mathematical models that relate the rate of fertilizer application according to the type of metering. However, the proposed models do not predict the behavior of meterings with different helical pitch and, as well, meterings with two helicoids, a reality present in the market.

This study aimed to establish mathematical models for predicting performance of helical fertilizer meterings according to the longitudinal and transverse inclinations, angular speed, and helical pitch.

Material and Methods

The tests were performed at the Center for Engineering of the Federal University of Pelotas, on a test bench (Figure 1), driven by an electromechanical drive system for angular speed control, being arranged side by side, and driven together by the same axis, three fertilizer meterings of seed cum fertilizer drill.

A randomized block design in a 7 x 9 x 2 x 2 factorial scheme was used, in which the metering was blocked, as local control. The tested factors were transversal inclination (7),

longitudinal inclination (9), angular speed (2), and helical pitch (2), which will be detailed below.

Tests were performed with the meterings D1, D2, and D3, whose functional principles of discharge are detailed in Figures 1B, 1C, and 1D, considering the factors under study for modeling. As for the helical pitch, models available from manufacturers were used; 25.4 mm (1") and 50.8 mm (2") in the D1 and D3 meterings, and 15.9 (5/8") and 25.4 mm (1") in the D2 metering. The inclinations were in the longitudinal and transversal directions, -20, -15, -10, -5, 0, +5, +10, +15, and + 20° in the longitudinal axis and -15, -10, -5, 0, +5, +10, and + 15° on the transverse axis. Regarding the angular speed of the helicoids, two rotations (16 and 46 rpm) were used, within the angular speed range recommended by the manufacturers of the fertilizer meterings.

In the tests, NPK 05-20-20 granulated fertilizer was used, with a density of 1,063 kg m^{-3}, angle of rest of 33.49°, dry basis moisture content of 1.01%, with 2.28, 78.21, 99.31 and 99.97% retained and accumulated in sieves of 4.0, 2.0, 1.0, and 0.5 mm, respectively (ABNT, 2003).

The tests were carried out following the methodology proposed by the ISO standard (1984). Each test lasted 45 seconds, and in the first 15 seconds, no fertilizer was collected, so that the mass flow stabilized. The collection was carried out in polypropylene trays (200 x 150 x 200 mm), and the mass was measured with a precision scale (0.1 g).

Each plot was individualized by the exposure time (30 s) of the metering to the collection container, totaling 756 plots and four replications, that is, 3,024 experimental units.

An analysis was performed to verify the dosage behavior in each metering. This analysis did not allow the data to be adjusted to a surface, since there are more than two predictors, which constitutes a hyperplane; however, it allows to establish estimates of model validity. In the second analysis, the levels, angular speed, and helical pitch, were fixed for each metering, remaining two independent variables, longitudinal and transverse inclination. These were considered as variables (x and y) and the dosage value as the variable (z).

For statistical evaluation, the results were submitted to analysis of variance and F-test ($p \leq 0.05$). Subsequently, multiple regression was performed, with the model adjustment analyzed with the aid of the coefficient of determination (R^2). Dosing model, longitudinal and transverse inclination, angular speed, and helical pitch were considered as independent variables, also called predictors. In this way, a response surface was obtained, Eq. 1.

$$z = \beta_0 + \beta_1 x_1^2 + \beta_2 y_1^2 + x_1 y_1 + \beta_3 x_1 + \beta_4 y_2 + ... + \beta_k x_k + \varepsilon \quad (1)$$

where:
  z - response variable;
  $x_1, y_1...x_k, y_k$ - predictors;
  $\beta_0, \beta_1,...\beta_k$ - parameters; and,
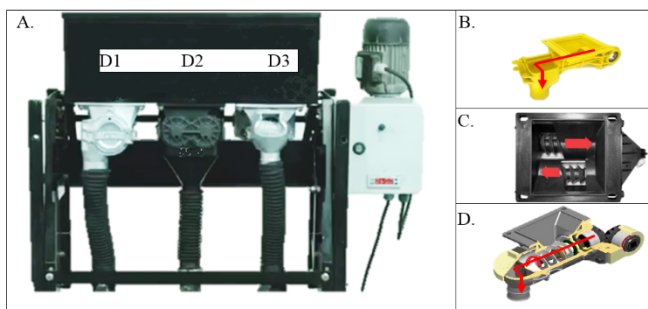 ε - error.

Figure 1. Test bench for helical fertilizer meterings (A), type: helical by lateral discharge through overflow - D1 (B), two helicoids - D2 (C), and helical by longitudinal discharge through overflow - D3 (D)

Results and Discussion

There was a significant interaction between the factors. Thus, modeling was performed for each metering, using the

Eqs. 2, 3, and 4, in which it is possible to find the dosage values ($g\ s^{-1}$) when using the metering with a helicoid and lateral discharge through overflow (D1), the metering with two helicoids and two outlets for gravity discharge (D2), and the metering with a helicoid and longitudinal discharge through overflow (D3), respectively.

The statistical models of multiple regression of Eqs. 2, 3, and 4 demonstrate that helical meterings with one and two helicoids differently influence the distribution of fertilizers according to the longitudinal inclinations (LI), angular speed (S and helical pitch (P) used. In contrast, the variation in transverse inclination (TI) was not significant, and it is therefore not present in Eqs. 2, 3, and 4.

As for TI, the results of Eq. 2 disagree with that reported by Bonotto et al., (2012), while using metering with lateral discharge through overflow (D1), observed an increase in dosage, since this is the flow side. However, the results observed with TI in Equation 2 corroborate with Franck et al. (2015). They found that meterings with lateral discharge through overflow (D1) did not influence the fertilizer distribution due to the variation of transverse inclination. In the same study, in meterings with longitudinal discharge through overflow and meterings with a helicoid without overflow, the authors verified an influence on fertilizer distribution according to the transverse inclination variation from -11 to 11°.

Eqs. 2, 3, and 4 showed positive values for the longitudinal inclination estimator. It can be said that positive (upslope) and negative (downslope) longitudinal inclinations cause increases and decreases, respectively, in the fertilizer dosage, a fact that corroborates with Ferreira et al. (2010) and Garcia et al. (2017).

A similar effect was observed by Franck et al. (2015) in metering with longitudinal discharge through overflow and metering without overflow, which presented positive values for the longitudinal inclination estimator; and in metering with lateral discharge through overflow, with a negative estimator, the opposite effect was observed.

Positive values presented in Eqs. 2, 3 and 4 concerning the angular speed and helical pitch estimators prove that the higher the angular speed of the dosing drive shaft and the helical pitch, the higher the dosing rate, corroborating with Camacho-Tamayo et al. (2009) and Galvão et al. (2018). This

fact justifies the choice of higher rotations and greater helical pitches during the adjustment of a seed cum fertilizer drill to increase the fertilizer dose.

Although Eqs. 2, 3, and 4 describe the specific behavior of the variables, they do not make it possible to analyze the three-dimensional vector behavior. Thus, it was necessary to dismember the variables to analyze the dosing behavior, according to the variables longitudinal and transverse inclination inserted at each level of the factors, metering, angular speed, and helical pitch.

The dosing behavior, according to the longitudinal and transverse inclination of the metering with lateral discharge through overflow (D1), can be seen in Figure 2. Each figure (Figures 2A, 2B, 2C, and 2D) presenting a perspective that characterizes the flat surface in three-dimensional space with its respective projection on the XY-plane. An arrow on the three-dimensional surface represents the gradient vector. The gradient indicates the greatest variation in the dosage rate, expressed in $g\ s^{-1°-1}$ (grams per second for each degree of inclination), that is, if the gradient vector is null, there was no variation in the dosage.

In Figure 2A, which characterizes the metering D1 with an angular speed of 16 rpm and helical pitch of 1" (D1S1P1), the gradient vector was $0.07\ g\ s^{-1°-1}$, 41% lower than that found in the higher speed (46 rpm) (Figure 2B). The plane equation (Eq. 5) shows that there was an increase of $0.07\ g\ s^{-1}$ for each degree of longitudinal inclination and a decrease of $0.02\ g\ s^{-1}$ for each degree of transverse inclination.

Figure 2B represents the dosage of the metering D1 with an angular speed of 46 rpm and helical pitch of 1" (D1S2P1). The plane equation (Eq. 6) shows that there was an increase of $0.13\ g\ s^{-1}$ for each degree of longitudinal inclination and a decrease of $0.04\ g\ s^{-1}$ for each degree of transverse inclination. Also, in the largest variation of dosage, the gradient was $0.17\ g\ s^{-1°-1}$, according to the arrow in Figure 2B.

Figures 2C and D represent the same characteristics of the metering D1 presented in Figures 2A and B, except for the helical pitch, in this case, is 2", working at 16 and 46 rpm, respectively. Equations 7 and 8 indicate that there was an increase of 0.14 and $0.24\ g\ s^{-1}$ for each degree of longitudinal inclination, and a decrease of 0.03 and $0.05\ g\ s^{-1}$ for each degree of transversal inclination.

Table 1. Predictive models of fertilizer dosage (D) of the meterings in the combinations with longitudinal inclination (LI), transverse inclination (TI), angular speed (S), and helical pitch (P)

Equation	Denomination	Equations*	R^2
(2)	D1	D = -31.77 + 0.15LI + 0.59S + 21.42P	0.87
(3)	D2	D = -13.17 + 0.03LI + 0.48S + 10>14P	0.89
(4)	D3	D = -24.33 + 0.21LI + 0.57S + 17.18P	0.87
(5)	D1S1P1	D = 4.51 + 0.07LI - 0.02TI	0.90
(6)	D1S2P1	D = 15.14 + 0.13LI - 0.04TI	0.86
(7)	D1S1P2	D = 11.49 + 0.14LI + 0.03TI	0.91
(8)	D1S2P2	D=43.70+0.24LI-0.05TI	0.86
(9)	D2S1P1	D = 6.56 + 0.004LI² + 0.001TI² + 0.002LITI + 0.042LI + 0.001TI	0.89
(10)	D2S2P1	D = 10.64 + 0.007LI² + 0.002TI² + 0.003LITI + 0.040LI + 0.011TI	0.61
(11)	D2S1P2	D = 15.63 + 0.003LI² + 0.001TI² + 0.001LITI + 0.032LI - 0.003TI	0.38
(12)	D2S2P1	D = 31.85 + 0.003LI² - 0.003TI² + 0.001LITI + 0.004LI - 0.039TI	0.18
(13)	D3S1P1	D = 6.54 + 0.12LI - 0.02TI	0.89
(14)	D3S2P1	D = 14.57 + 0.15LI + 0.02TI	0.87
(15)	D3S1P2	D = 14.48 + 0.24LI + 0.01TI	0.86
(16)	D3S2P1	D = 40.80 + 0.31LI - 0.06TI	0.93

* - All coefficients are significant (p ≤ 0.05) by the F-test
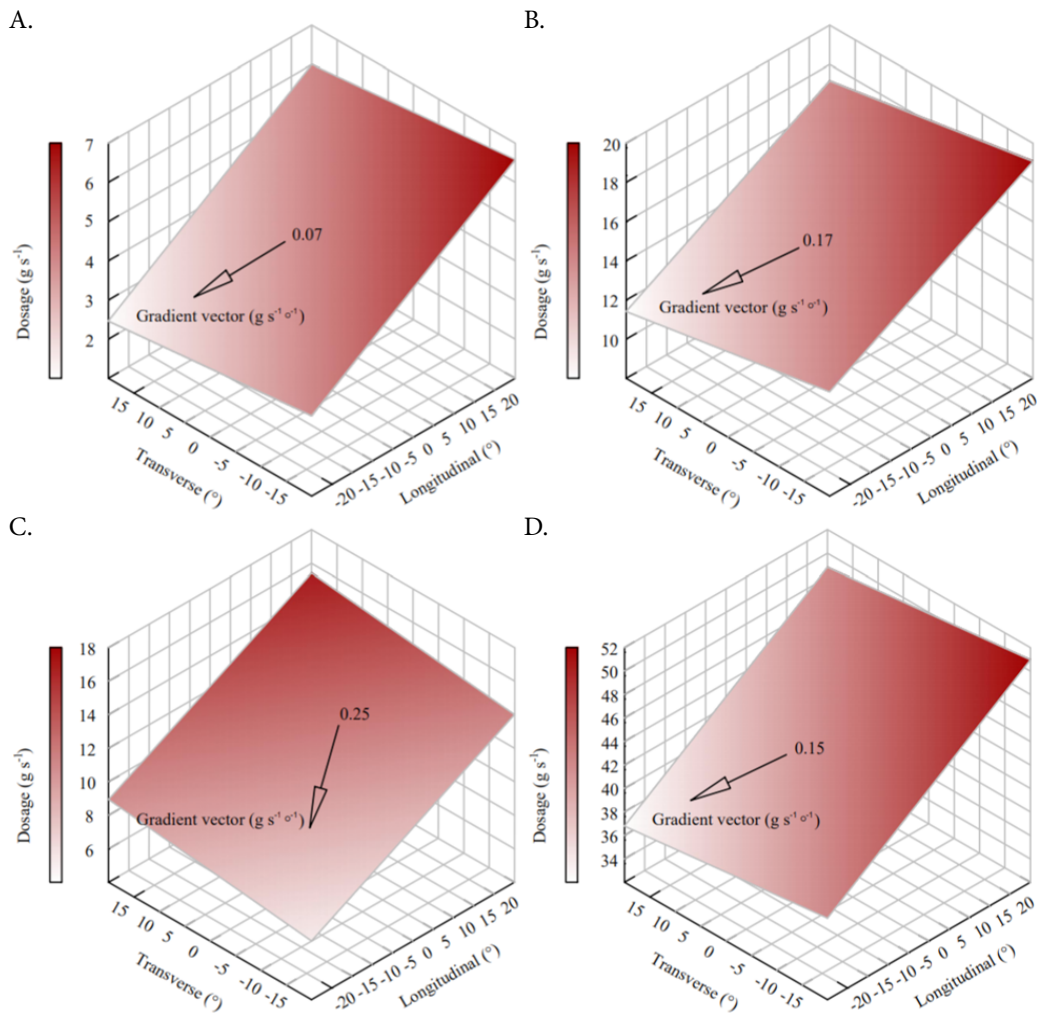
A.

B.

C.

D.

Figure 2. Fertilizer dosage in the helical metering by lateral discharge through overflow (D1) according to the longitudinal and transverse inclinations: D1S1P1 - the angular speed of 16 rpm and helical pitch of 1" (A), D1S2P1 - the angular speed of 46 rpm and helical pitch of 1" (B), D1S1P2 - the angular speed of 16 rpm and helical pitch of 2" (C), and D1S2P2 - the angular speed of 46 rpm and helical pitch of 2" (D)

When using helical meterings, the angular speed of activation and/or the helical pitch must be increased to increase the fertilizer dose. According to Camacho-Tamayo et al. (2009) and Bonotto et al. (2013), there are angular speed ranges in which the helicoid helps the fertilizer flow more efficiently, providing better distribution, according to the constructive characteristics of the metering. From Figures 2B and C, it is possible to affirm that, when using the metering D1, to increase the dose, it is preferable to increase the angular speed of the drive shaft (Figure 2B) instead to increasing the helical pitch (Figure 2C) since the gradient vector was smaller.

The dosage values referring to the use of the metering with two helicoids (D2) are shown in Figures 3A and B, which vary according to the paraboloid surface, whose concavity is facing downwards, indicating that the dosage values increase from the center to the extremities. The variation rate in the extremities is higher than the variation rate in the central region, which evidences a higher dose gradient with a greater inclination in absolute value, whether longitudinal or transversal.

Figures 3A and B represent the Eqs. 9 and 10, respectively, noting that the longitudinal and transverse inclination showed significance for the quadratic effect (LI² and TI²), as well as

for the interaction (LI x TI), however, their moduli have low values, with little effect on dosage.

Eqs. 11 and 12 presented values of determination coefficient (R^2) considered low due to the high oscillation between the values, preventing their use. When using metering with two helicoids, the angular speed of 16 rpm, and helical pitch of 2" (D2S1P2), the dosage was 15.63 g s⁻¹, ranging 4 g s⁻¹ more or less, regardless of the longitudinal and transversal inclination used. When using metering with two helicoids, the angular speed of 46 rpm, and helical pitch of 2" (D2S2P2), the dosage was 31.85 g s⁻¹, varying 5 g s⁻¹.

In Figures 3A and B, the mean gradient vector showed values very close to zero, that is, although the functions represent cylindrical surfaces, and have more than one gradient, the amplitude between the extremities of each function is small, evidencing low dosage variation, regardless of the inclination used. The highest mean dosage gradient was 0,12 g s⁻¹°⁻¹, evidencing an increase of 1.2 g s⁻¹ (Figure 3B) when used in the inclination of 10°, resulting in an increase of around 10% concerning the dosage at level 0°.

Higher values were found by Garcia et al. (2017), which quantified in the same inclination of 10°, variation around 22% in the dosage. The difference is attributed to the fact
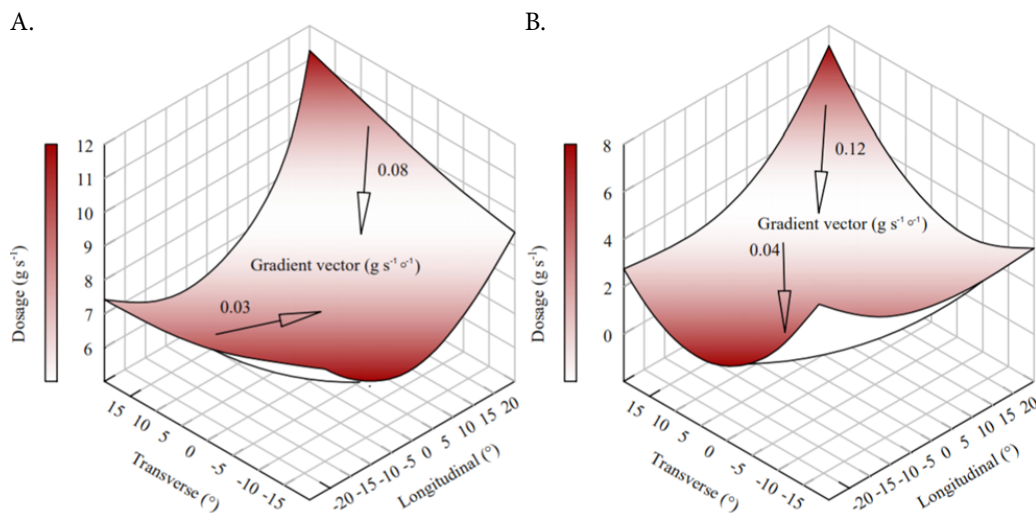
Figure 3. Fertilizer dosage in the metering with two helicoids (D2) according to the longitudinal and transverse inclinations: D2S1P1 - the angular speed of 16 rpm and helical pitch of 1" (A) and D2S2P1 - the angular speed of 46 rpm and helical pitch of 1" (B)

that Garcia et al. (2017) have evaluated helical metering without overflow but containing only one helicoid. According to Spagnolo et al. (2018), metering with two helicoids, when subjected to the longitudinal inclination of the land shows less variation in dosage when compared to meterings that have only one helicoid even if they have an overflow mechanism.

The lowest dosage values are observed when the metering D2 is level, with an increase in dosage as the longitudinal upslope and downslope increase (Figure 3). It was also found that the increase of the angular speed and helical pitch increases the fertilizer dose. However, it does not significantly change the gradient, and it can be inferred that the metering with two helicoids allows us to obtain uniform dosing, regardless of the longitudinal and transversal inclination, the angular speed of drive shaft, and helical pitch used.

Transverse inclination had a small effect on the dosage, when using metering with a helicoid and longitudinal discharge through overflow (D3), as shown by the values related to the axis of the ordinates in Eqs. 13, 14, 15, and 16. The variation of longitudinal inclination (abscissa axis) provided increases in dosage of 0.12 g s^{-1} (Eq. 13), 0.15 g s^{-1} (Eq. 14), 0.24 g s^{-1} (Eq. 15), and 0.31 g s^{-1} (Eq. 16) for each degree of longitudinal inclination. Relating these values to those found when the D1 and D2 meterings were used, it is evident that the action of gravity influences the high dosage variability, especially when using meterings with only one helicoid.

The variation rate of the dosage, the gradient of the metering D3, presented values higher than the meterings D1 and D2 when the angular speed of the helicoid was 16 rpm, and the helical pitch was 1". There is a 71% increase in the dosage gradient value when comparing values of 0.24 g s^{-1} $^{\circ-1}$ from D1S1P1 (Figure 2A), with values of 0.07 g s^{-1} $^{\circ-1}$ from D3S1P1 (Figure 4A), and 66% when compared to D2S1P1, which had a higher gradient of 0.08 g s^{-1} $^{\circ-1}$ (Figure 3A).

A 19% increase in the gradient value was found when comparing D1S1P2 (Figure 2C) and D3S1P2 (Figure 4C). The only moment when the gradient of meterings D1 and D3 equalized, with a value of 0.15 g s^{-1} $^{\circ-1}$ (Figures 2D and D), occurred when the angular speed of 46 rpm and the helical

pitch of 2" was used. With an angular speed of 46 rpm and helical pitch of 1", the metering D1 provided a gradient of 0.17 g s^{-1} $^{\circ-1}$ (Figure 2B), 29% lower than the gradient presented by the D2 and D3 meterings (0.12 g s^{-1} $^{\circ-1}$, Figures 3B and B).

When using the meterings D1 and D3, to adjust the increase in the dosage of fertilizers, it can be inferred that it is preferable to use a shorter pitch helicoid combined with the increase in the rotation of the drive shaft (D1S2P1 and D3S2P1), concerning the increase in helical pitch combined with a lower rotation of axis (D1S1P2 and D3S1P2), as the variation rate of the dosage (gradient) is lower, according to the longitudinal and transverse inclination of the land.

Although the present study has not evaluated the uniformity of the application on the row, it is important to emphasize that the fuller the helicoid is, the higher its efficiency concerning the effects of the "pulse", the variation of the application that occurs during the time required to perform a complete lap of distribution axis (Garcia et al., 2012).

According to Verardi et al. (2019), the smaller the helical pitch, the higher the uniformity of fertilizer application on the row. When using meterings with two helicoids, the same authors found variations around 36% in the deposition of fertilizers in the application row.

In general, the metering with two helicoids (Figure 3) showed lower gradient values compared to the meterings equipped with one helicoid, regardless of the factors studied. Ferreira et al. (2010) and Garcia et al. (2017) report that meterings with longitudinal or lateral discharge through overflow mechanisms provide greater uniformity to the dose applied compared to meterings that act only by gravity. However, the meterings with two helicoids (Figure 3) even acting without overflow, only by gravity, as it has two helicoids that rotate in opposite directions, provides a reduction in the effect of gravity, causing less variation in the applied dose per hectare when working on sloping terrain.

With the aid of the Equations (Table 1), as well as Figures 2, 3, and 4, it is possible to estimate the fertilizer flow rate for each studied condition. For example, analyzing Eq. 15 and Figure 4C, it is observed that the metering with longitudinal discharge
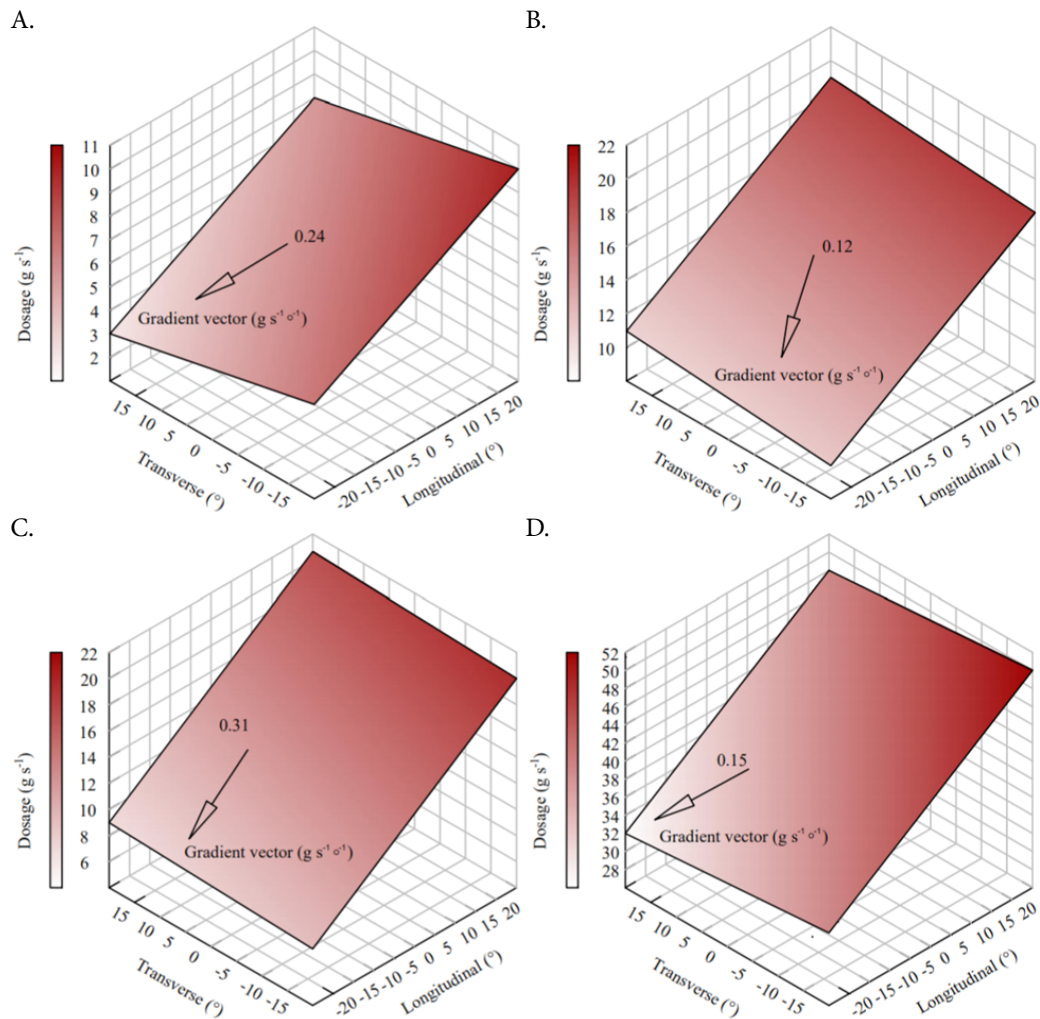
A.

B.

C.

D.

Figure 4. Fertilizer dosing in the helical metering by longitudinal discharge through overflow (D3) according to the longitudinal and transverse inclinations: D3S1P1 - the angular speed of 16 rpm and helical pitch of 1"(A), D3S2P1 - the angular speed of 46 rpm and helical pitch of 1" (B), D3S1P2 - the angular speed of 16 rpm and helical pitch of 2"(C), and D3S2P2 - the angular speed of 46 rpm and helical pitch of 2" (D)

through overflow, equipped with a 2" helicoid, working at 16 rpm is applying 14.48 g s^{-1} when leveled at 0°, both longitudinal and transversal. With the constant spacing between rows of 0.45 m and the application speed of 5 km h^{-1}, it is possible to estimate the dose of approximately 104 kg ha^{-1}.

When using metering with longitudinal discharge through overflow, under the same conditions (D3S1P1 - Figure 4C), taking as reference the dosage value obtained in the 0° inclination (104 kg ha^{-1}), variations of -36.7, -27.5, -18.3, -9.2, 9.2, 18.3, 27.5, and 36.7% were found, on longitudinal inclinations of -20°, -15°, -10°, -5°, 5°, 10°, 15°, and 20°, respectively.

While using metering with lateral discharge through overflow, under the same conditions (D1S1P1 - Figure 2A), when leveled it was possible to estimate the dose of approximately 72 kg ha^{-1}, with variations of -31.0, -23.3, -15.5, -7.8, 7.8, 15.5, 23.3, and 31% on longitudinal inclinations of -20°, -15°, -10°, -5°, 5°, 10°, 15°, and 20°, respectively.

When leveled, the metering D2 (D2S1P1 - Figure 3A) presented a dose of approximately 105 kg ha^{-1}. When subjected to the same longitudinal inclinations of -20°, -15°, -10°, -5°, 5°, 10°, 15°, and 20°, it showed a variation of 11.6, 4.1, -0.3, -1.7, 4.7, 12.5, 23.3, and 37.2%, respectively. This is due to the

constructive characteristic of the metering, since it has an arrangement of helicoids parallel to each other, rotating in the opposite direction, with mass flow exit on opposite sides (Spagnolo et al., 2018).

The values prove that the angles of longitudinal inclination between -20° and 10° have less influence on the fertilizer flow when using metering with two helicoids. Inclination greater than 10° promotes variations in the dosage of more than 20% in all meterings.

Taking as a reference the dosage value obtained in the 0° inclination, Garcia et al. (2017) quantified variations of -9.0, -3.6, 5.9, and 9.7% using metering with longitudinal discharge through overflow, and values of -4.4, -1.0, 3.7, 6, and 5% using metering with lateral discharge through the overflow, on inclinations of -10°, -5°, 5°, and 10°, respectively.

Although the 10% variation is considered acceptable, variations in the fertilizer dose in the field exceed 40% (Weirich Neto et al., 2015; Rosa et al., 2019). The lack of fertilizer can reduce the yield (Weirich Neto et al., 2013), while overdose increases the risks of environmental degradation (Serrano et al., 2014).

Among the influencers of this variation is the irregularity of the terrain, the vibration of the seed drill (fertilizer deposit,

metering, conductor pipe, furrower), and slippage of the seeder driving wheel (Rosa et al., 2019).

According to Reynaldo & Gamero (2015), the best working condition is in the level situation, which reduces the variation in dosage during the sowing process. If this is not possible, it is recommended to use meterings that have less influence of gravity, so as not to compromise yield with underdoses and minimize the risks of environmental degradation with overdoses.

Conclusions

1. The adjusted models were efficient in predicting the dosage of helical meterings.

2. When using helical meterings with lateral and longitudinal discharge through overflow, the dosage increases with the variation of the longitudinal inclination, with higher variations in the metering with lateral discharge through the overflow.

3. The metering with two helicoids has less variation in the fertilizer discharge through overflow, regardless of the inclination, angular speed, and helical pitch used.

Literature Cited

ABNT - Associação Brasileira de Normas Técnicas. NBR NM 248: Agregados – Determinação da composição granulométrica. Rio de Janeiro: ABNT, 2003. 6p.

Bonotto, G. J. Desempenho de dosadores de fertilizantes de semeadoras-adubadoras em linhas. Santa Maria: UFSM, 2012. 97p. Dissertação Mestrado

Bonotto, G. J.; Alonço, A. S.; Bedin, P. R.; Altmann, A. S.; Lauri, J. M. Distribuição longitudinal de fertilizantes por dosadores de semeadoras adubadoras em linhas. Engenharia na Agricultura, v.21, p.368-378, 2013. https://doi.org/10.13083/reveng.v21i4.405

Camacho-Tamayo, J. H.; Barbosa, A. M.; Pérez, N. M.; Leiva, F. R.; Rodríguez, G. A. Operational characteristics of four metering systems for agricultural fertilizers and amendments. Engenharia Agrícola, v.29, p.605-613, 2009. http://dx.doi.org/10.1590/S0100-69162009000400010

Ferreira, M. F. P.; Dias, V. de O.; Oliveira, A.; Alonço, A. S.; Baumhardt, U. B. Uniformidade de vazão de fertilizantes por dosadores helicoidais em função do nivelamento longitudinal. Engenharia na Agricultura, v.18, p.297-304, 2010. https://doi.org/10.13083/reveng.v18i4.234

Francetto, T. R.; Dagios, R. F.; Leindecker, J. A.; Alonço, A. S.; Ferreira, M. F. Características dimensionais e ponderais das semeadoras-adubadoras de precisão no Brasil. Tecno-lógica, v.19, p.18-24, 2015. http://dx.doi.org/10.17058/tecnolog.v19i1.4500

Franck, C. J.; Alonço, A. S.; Machado, O. D. C.; Francetto, T. R.; Carpes, D. P.; Bellé, M. P. C. Modelos estatísticos para seleção de dosadores helicoidais com diferentes dispositivos de descarga de fertilizante. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.512–518, 2015. http://dx.doi.org/10.1590/1807-1929/agriambi.v19n5p512-518

Galvão, C. B.; Albiero, D.; Garcia, A. P.; Monteiro, L. de A. Fertilizer metering mechanism with helical conic cylindrical thread for family agriculture. Engenharia Agrícola, v.38, p.934-940, 2018. http://dx.doi.org/10.1590/1809-4430-eng.agric.v38n6p934-940/2018

Garcia, A. P.; Cappelli, N. L.; Umezu, C. K. Auger-type granular fertylizer distributor: Mathematical model and dynamic simulation. Engenharia Agrícola, v.32, p.151-163, 2012. http://dx.doi.org/10.1590/S0100-69162012000100016

Garcia, L. C.; Diniz, R. N.; Rocha, C. H.; Souza, N. M.; Weirich Neto, P. H. Desempenho de mecanismos de medição de adubos de plantadores como uma função de inclinação longitudinal. Engenharia Agrícola, v.37, p.1155-1162, 2017. http://dx.doi.org/10.1590/1809-4430-eng.agric.v37n6p1155-1162/2017

ISO - International Organization for Standardization. ISO 5690/2. Equipment for distributing fertilizers – Test methods - Part 2: Fertilizer distributors in lines. Switzerland, 1984.

Reynaldo, É. F.; Gamero, C. A. Avaliação de mecanismos dosadores de fertilizantes helicoidais em ângulos de nivelamento longitudinal e transversal. Energia na Agricultura, v. 30, p.125-136, 2015. https://doi.org/10.17224/EnergAgric.2015v30n2p125-136

Rosa, D. P. da; Pagnussat, L.; Alves, A.; Pesini, F.; Spagnolo, R. T. Methodology to evaluate the fertilizer distribution by helical doser from seed planter. Journal of Experimental Agriculture International. v.31, p.1-7, 2019. https://doi.org/10.9734/jeai/2019/v31i530087

Serrano, J.; Peça, J.; Silva, J. M.; Shahidian, S. Fertilizers application: Technology, energy efficiency and environment. Revista de Ciências Agrárias. v.37, p.270-279, 2014.

Spagnolo, R. T.; Pinho, M. S.; Oldoni, A. Rosa, D. P. da. Mais é melhor. Cultivar Máquinas, v. 181, p.13-14, 2018.

Verardi, J.; Rosa, D. P. da; Zancan, A.; Conte, P. H.; Longaretti, M.; Spagnolo, R. T. Distribuição longitudinal de fertilizante granulado em diferentes inclinações e posição da rosca de um dosador de rosca helicoidal dupla. Tecnologia em marcha, v.32, p.128-134, 2019. https://doi.org/10.18845/tm.v32i7.4272

Weirich Neto, P. H.; Fornari, A. J.; Justino, A.; Garcia, L. C. Qualidade na semeadura do milho. Engenharia Agrícola, v.35, p.171-179, 2015. http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v35n1p171-179/2015

Weirich Neto, P. H.; Justino, A.; Frare, I.; Gomes, J. N.; Garcia, L. C. Positioning of fertilizer in corn sowing. Engenharia Agrícola, v.33, p.1172-1179, 2013. http://dx.doi.org/10.1590/S0100-69162013000600010