E3S Web of Conferences **395**, 01003 (2023) https://doi.org/10.1051/e3sconf/202339501003
*ETSAIC2023*

# Substantiation of the helicoid fertilizer dispenser parameters

*Denis S.* Kalugin*, *Egor V.* Kulaev, *Lyubov I.* Vysochkina, and *Mikhail V.* Danilov

Stavropol State Agrarian University, Stavropol, Russia

**Abstract.** The article presents the results of research on a new design of a helicoid dispenser that allows to apply various types of mineral fertilizers in compliance with the requirements for uneven fertilizer application. The material for the study was ammonium nitrate and ammophoska. The dispenser consists of two cylinders with a helicoid surface located between them. The advantage of the design is that the helicoid shape of the dispenser eliminates the cramped state of fertilizer granules during their movement and provides the required application rate range. Studies have shown that with the maximum diameter of fertilizer granules $d_{Gmax} = 6$ mm, the number of entries of the helicoid surfaces will be equal to three, the inclination angle of the helical line of the coils $\alpha = 14$ degrees. Based on analytical studies, the parameters and operating modes of the helicoid dispenser are substantiated, which allow reducing the unevenness of mineral fertilizers up to 3.4% and increasing the device productivity.

## 1 Introduction

To intensify production and obtain a guaranteed high yield of agricultural crops, it is necessary to fertilize them with mineral fertilizers [1]. For mineral fertilization, fertilizer devices with different types of dispensers are used: drum, roll, spiral-screw, rotary table, belt, etc. Based on the requirements, the dispenser must provide a specified application rate (10 – 45 g/m$^2$) with an acceptable application unevenness of no more than 7,5 % [2, 3, 4].

At present, dosing devices with spiral-screw dispensers are widely used, providing high reliability of the material feeding process. Nevertheless, they do not fully ensure the application rate of solid mineral fertilizers and the required uniformity of dosing, which leads to a crop shortage of 20% [3, 4, 5]. According to studies [3, 5, 6], uneven fertilization leads to annual losses of more than 19% of the sugar beet crop, 16% of hay and haylage, up to 10% of grain and potato. The reason for the uneven dosing is that during the spiral-screw dispenser operation, a hidered effect on fertilizer granules may occur between the dispenser casing and its spiral-screw part, which will lead to jamming up of fertilizer granules and increased energy consumption [7, 8].

It follows herefrom, the relevance of such a dispenser development, which eliminates the hindered state of fertilizer granules during their movement, ensures the required application rate range and the fulfillment of agrotechnical requirements for the uneven fertilizer application.

* Corresponding author: dnk713@mail.ru

## 2 Materials and Methods

To eliminate the above disadvantages, we have developed a scheme and manufactured a design of a mineral fertilizer dispenser (Fig. 1) consisting of two cylinders with a helicoid surface located between them [9]. The inner cylinder of the dispenser is put on the drive shaft of the dosing unit. When the drive is turned on, mineral fertilizers coming from the dispenser hopper move along the helicoid surface and enter the dispensing area. The helicoid surface makes it possible to implement the principles of uniform translational and rotational movement of the material on the surface, which ensures accurate dosing of mineral fertilizers.

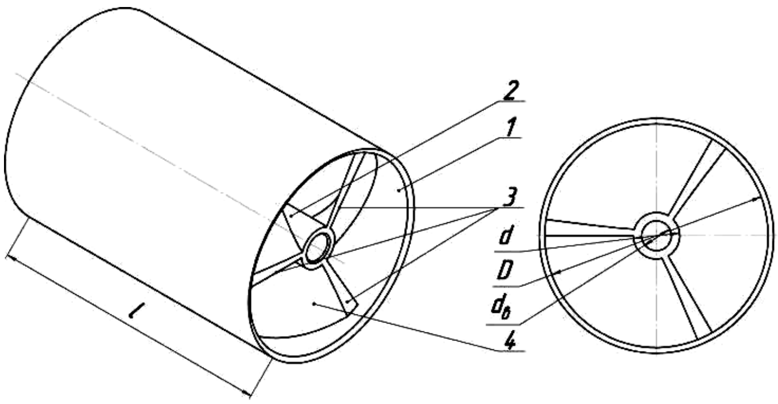


**Fig. 1.** Helicoid dispenser diagram: 1 – outer cylinder; 2 – inner cylinder; 3 – entry; 4 – screw surface; *D* – outer cylinder diameter; *d* – inner cylinder diameter; $d_s$ – shaft diameter; l – dispenser length.

To find the dispenser parameters and operating modes, theoretical studies were carried out, based on which we adopted the "granular material" model.

Consider the movement of fertilizer granules along the helical surface of the dispenser. Fertilizers enter the dispenser and act upon the outer cylinder surface by gravity Ft at point A (Fig. 2).

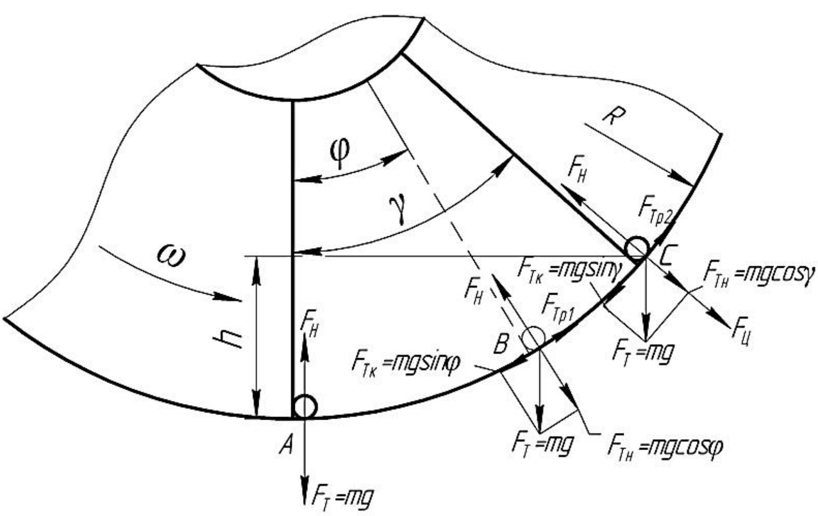


**Fig. 2.** Diagram of the action of forces arising during the dispenser operation.

The helix lead is equal to:

$$t = 2 \cdot \pi \cdot R \cdot \mathrm{tg}\alpha. \quad (1)$$

where $R$ is the inner radius of the outer cylinder, m;

α - the helix inclination angle.

When the dispenser rotates due to the action of the friction force $F_{fr1}$, mineral fertilizers rise to point $B$ and are pressed against the inner surface of the outer cylinder due to the centrifugal force $F_c$:

$$F_c = m \cdot \omega^2 \cdot R. \quad (2)$$

where $m$ is the mass of fertilizers, kg;

ω - angular velocity, $s^{-1}$.

The centrifugal force contributes to an increase in the friction force $Ffr2$:

$$F_{\mathrm{fr2}} = \mathrm{m}[g \cdot \cos\gamma + (2\pi \cdot n)^2 R] \cdot f. \quad (3)$$

where $n$ is the dispenser rotation speed, $s^{-1}$;

$g$ is the acceleration of gravity, m/s.

$\gamma$ is fertilizer elevation angle, deg.;

$f$ is the coefficient of fertilizer movement friction on the dispenser surface.

The fertilizer elevation angle γ is determined from the equation:

$$\gamma = \phi + arcsin\left(\frac{\omega^2 R}{g} \cdot tg\phi\right). \quad (4)$$

where φ is the friction angle.

The speed of fertilizer movement is found by the following dependence:

$$V_0 = \pi \cdot D \cdot n \cdot sin\,\alpha\,(1 - f), \quad (5)$$

To select the geometric dimensions, we analyzed the designs of spiral-screw dispensers. The drive shaft diameter $d_{sh}$ and the wall thickness of the inner cylinder δ are taken equal to the same dispensers: $d_{sh} = 20$ *mm*, $\delta = 2.5$ *mm*, $D = 80$ *mm*.

Let's use the dependence to find the critical rotation frequency of the dispenser $n_{cr}$ at which the movement of fertilizer granules along the axis of dispenser rotation stops:

$$m(2\pi \cdot n_{cr})^2 \cdot \frac{D}{2} = mg, \quad (6)$$

The dispenser critical rotation frequency, obtained experimentally $n_{cr}$ ($min^{-1}$) is equal to

$$n_{kp} = \frac{42{,}3}{\sqrt{D}}. \quad (7)$$

Hence $D = 42{,}3^2/(2{,}5 \cdot 60)^2 = 0{,}08$ m. The maximum operating speed of the helicoid dispenser is equal to $n_{max} = 0{,}7...0{,}8\ n_{cr}(s^{-1})$.

The number of helicoid entries $N_e$ is associated with the condition of the passage of mineral fertilizers through the cavities formed between the inner and outer cylinders of the dispenser and the coils:

$$\frac{D-d}{\mathrm{Ne}} \geq 3 \cdot d_{Gmax}, \quad (8)$$

where $d_{Gmax}$ is the maximum diameter of the granules.

With a maximum diameter of granules $d_{Gmax} = 6$ mm, the number of entries will be less than or equal to three $N_e \leq 3$.

For uniform fertilizer feeding, it is necessary to determine the dispenser filling factor:

$$\psi = \frac{A_\partial}{A}, \quad (9)$$

where $A_d$ is the volume of fertilizers in the dispenser, $m^3$;

$A$ is the dispenser capacity, $m^3$.

The capacity of the helicoid dispenser is equal to:

$$A = l \cdot (D - d) \cdot \left[\frac{\pi(D+d)}{4} - \frac{\Delta \cdot Ne}{\sin\alpha}\right], \quad (10)$$

where Δ is the coil thickness, m.

To exclude self-spilling of fertilizer granules from the dispenser and to perform a rational arrangement of the fertilizer device in accordance with the row spacing width for arable crops $b_m$ = 0.45...0.7 meters, the dispenser length should be greater than or equal to twice screw surface pitch $l \geq 2t$.

Considering the fertilizer speed $V_o$ and the dispenser filling area, we determine the dispenser productivity $Q$ (kg/s):

$$Q = \frac{\pi^2 \cdot (D^2 - d^2)}{4} \cdot \left(1 + \frac{tg\beta}{N_e}\right) \cdot D \cdot tg\alpha \cdot n \cdot \sin\alpha \cdot (1 - f) \cdot \rho, \quad (11)$$

where $\rho$ is the fertilizer bulk density, $kg/m^3$.

Thus, the performance of the helicoid dispenser depends on the frequency of the dispenser rotation $n$, the number of coil entries $N_e$, and the helix inclination angle $\alpha$, the remaining parameters ($D, d, \beta, \varphi, p$) are set structurally and technologically.

The studies were carried out with solid mineral fertilizers on a laboratory unit. Ammonium nitrate was selected as crystalline one, and ammophoska was selected as granular one.

## 3 Results and Discussion

In accordance with the research program, the physical and mechanical properties of mineral fertilizers were determined.

The diameters of the fertilizer granules ranged from $d_{Gmin}$ = 3.1 mm to $d_{Gmax}$ = 6 mm. The average value of the granule diameter was $d_{Gav}$ = 4.1 mm. These size values fully satisfy the agrotechnical requirements for the fertilizer application.

When performing a complete factorial experiment, regression equations of the dispenser performance and uniformity of fertilizer feeding in natural form were obtained:

$$Q = 0{,}0206 \cdot \alpha + 24{,}397 \cdot n - 10{,}398 \cdot Ne + 1{,}990 \cdot \alpha \cdot n + 0{,}7016 \cdot \alpha \cdot Ne - 6{,}118 \cdot n \cdot N_e + 14{,}315. \quad (12)$$

$$M = 0{,}025 \cdot \alpha \cdot n - 0{,}415 \cdot n - 3{,}768 \cdot Ne - 0{,}411 \cdot \alpha + 0{,}108 \cdot \alpha \cdot N_e + 0{,}160 \cdot n \cdot Ne - 0{,}0126 \cdot \alpha \cdot n \cdot Ne + 14{,}781 \quad (13)$$

Analysis of two-dimensional sections of the response surface showed that performance depends on the speed of dispenser rotation ($X_2$) and the helix inclination angle ($X_1$), the feed unevenness (%) is more affected by the number of coil entries ($X_3$) and the helix inclination angle ($X_1$) (Fig. 3 and 4).

 https://doi.org/10.1051/e3sconf/202339501003

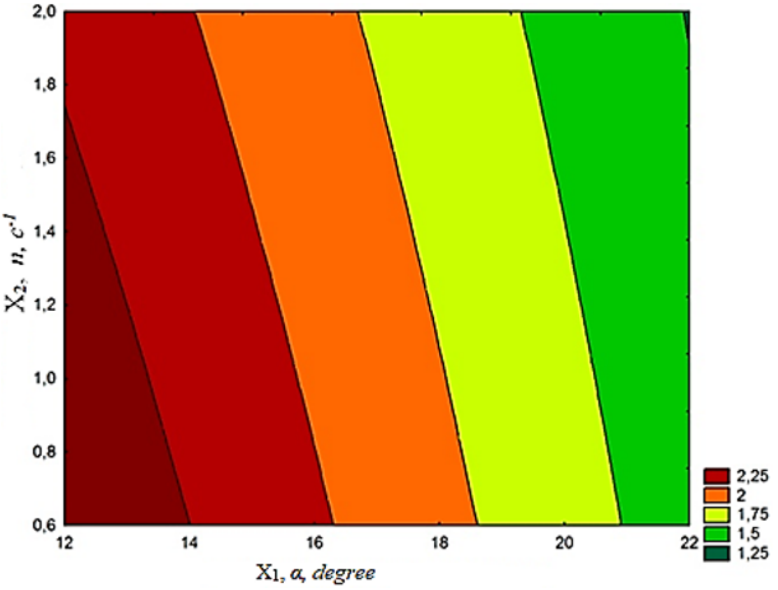


**Fig. 3.** Two-dimensional cross-section of the response surface of the uneven feeding of fertilizers M ($N_e = 3$).

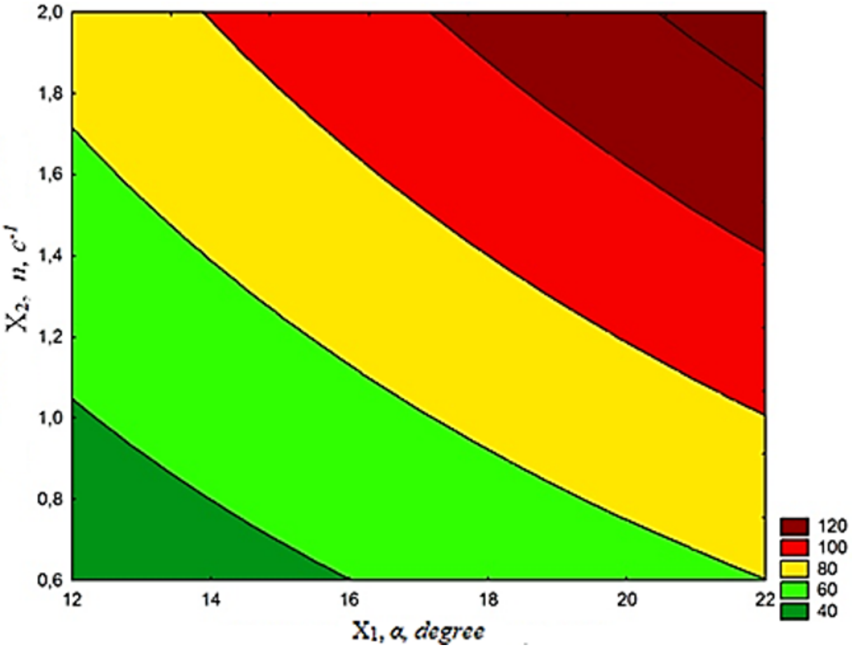


**Fig. 4.** Two-dimensional cross-section of the response surface of the dispenser performance Q ($N_e$ = 3).

From the analysis of the cross-sections of the response surfaces, it can be seen that the best quality of fertilizer dosing is provided at the inclination angle of coils' helix α = 14 degrees, the number of entries of the dispenser turns equal to 3 pcs.The rotation speed can be selected differently depending on the specified rate of mineral fertilizer application.

# 4 Conclusions

At the same time, the uneven feeding of fertilizers is reduced.

With an increase in the speed of dispenser rotation, the dispenser productivity and speed of fertilizers' movement increase, the dispenser filling factor does not change significantly and is 0.43...0.50, the feeding unevenness almost does not change.

The uneven application of mineral fertilizers using the developed helicoid dispenser is 3.4%, for serial one - 11.6%.

# References

1. The agronomy handbook. URL: http://www.bourgault. com/LinkClick. aspx?fileticket=nh1WmwT_ pH4%3d&tabid=416&language=en-US.
2. N.Ya. Kazantsev, Grain and Grain Products **3(4),** 42-43 (2004)
3. J. Thimon, Fertilirer Solution **18,** 6 (1974)
4. K. Wiemann, Ubersicht g 24 **10** 765–769 (1973)
5. E. Tola, T. Kataoka, M. Burce, H. Okamoto, S. Hata, Biosystems Engineering **101(4),** 411–416 (2008)
6. D. Eskhozhin, S. Nukeshev, Z. Zhaksylykova, K. Eskhozhin, A. Balabekova, Mechanics **24(3),** 343-351 (2018)
7. J. H. Yu, Y. J. Kim, K. H. Ryu, *Development of a controller for variable-rate application of granular fertilizer in paddy farming. In 2006 ASAE Annual Meeting* (p. 1). American Society of Agricultural and Biological Engineers (2006).
8. K. Wiemann, Ubersicht g 24 **10,** 765–769 (1973)
9. N.E. Rudenko, E.V. Kulaev, D.S. Kalugin, I.A. Nosov Tractors and agricultural machines **81(10),** 10-11 (2014)