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THEORETICAL ANALYSIS OF THE FLOW DIVIDER OF SOLID MINERAL FERTILIZERS

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Abstract. *The main mass of granular mineral fertilizers is applied by spreading them over the surface of the field, both during the main fertilization of the soil and when feeding agricultural crops. Existing machines of domestic production do not meet agronomic requirements in terms of indicators of uneven application of mineral fertilizers. At the current stage, there are no theoretical dependencies that would adequately describe: the process of feeding fertilizers through the lower link of the feeder-conveyor; the movement of fertilizers from the feeder to the fat diverter and their movement along the latter; the movement of fertilizers from the working body to the surface of the field under wind conditions. Known models of applying mineral fertilizers to the surface of the field do not agree with the real process and contradict the standard method of determining the unevenness of their application on the working width of the machines. The purpose of the work: to develop an analytical model that functionally describes the process of movement of mineral fertilizers in the guide cone of the divider of the distribution device depending on the parameters of the working body. The article provides a theoretical analysis of the movement of a particle of mineral fertilizers along the curved surface of the divider, taking into account the direction of the wind and the resistance of the air environment. According to the research results, an analytical and graphical model was developed that characterizes the change in the speed of movement of mineral fertilizers depending on the initial coordinates of their placement in the guide cone of the divider. It was established that with changes in coordinates within 0.1...0.4 m and the diameter of fertilizers from 4 to 6 mm, the resulting speed of movement of fertilizers is in the range of 1.0...2.9 m/s.*

Key words: *solid mineral fertilizers, divisor, resulting speed, coordinate, curved surface.*

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1. INTRODUCTION

Modern science is in constant search for the task of increasing the uniformity of the application of solid mineral fertilizers in the farming system and producing high-quality products. In world practice, almost 100% of machines are used with throw-type sowing devices [1–3].

The serious disadvantages of such machines include the fact that they have an uneven application legalized by agricultural requirements – 25% for throw-type machines for surface application [4–6].

However, when applying fertilizers with such unevenness at in unfavorable weather conditions, depending on the changing physical and mechanical properties, it can reach over 50% [7]. With high unevenness, the yield constantly fluctuates, which causes un simultaneous ripening of grain crops, unsatisfactory performance of harvesting machines, as well as the accumulation of nitrates in products in areas that received an increased dose of fertilizers.

For the period from 1995 to 2022, the volume of mineral fertilizers applied in some regions of Ukraine decreased to 60–70% [8, 9].

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Therefore, the problem of effective use of mineral fertilizers is of particular relevance. Scientific research has established that when adding an average dose of nutrients using conventional technologies, one kg of active substance gives an increase in yield of up to 4 kg of grain [11–13].

It has also been established that the yield of agricultural crops depends on the nature of the distribution of fertilizer doses across the field. With increasing unevenness of fertilizer application, the responsiveness of plants to fertilizers significantly deteriorates. Uneven application of fertilizers affects the properties of the crop and also leads to environmental pollution [15].

2. EXPERIMENTAL METHODS

The fundamental criteria of modern technologies for cultivating agricultural crops are the preservation and increase of soil fertility, resource conservation, economic and environmental safety of products and the environment [16]. Therefore, studying effective energy-saving technologies for soil cultivation using rational doses of solid mineral fertilizers is one of the urgent tasks of modern agriculture. Science and practice have established that more than 50% increase in yield crops can be obtained through the systematic application of fertilizers [17]. During the technological process of sowing fertilizers machines, the most important indicators of the quality of their work is the uniform distribution of fertilizers over the field area and, accordingly, over the plant nutrition area.

Based on the above, a schematic diagram has been proposed pneumatic rod machine for applying solid mineral fertilizers is shown in Fig 1.

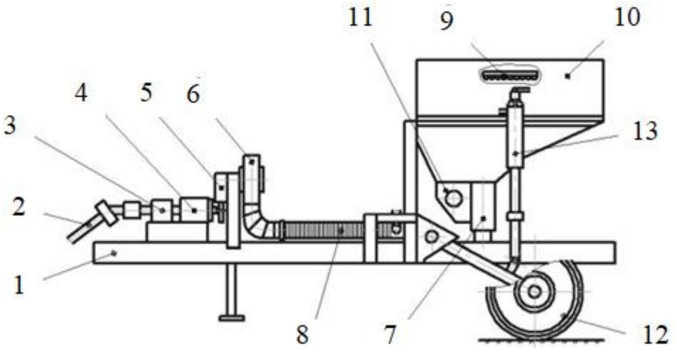

Figure 1. Schematic diagram of a pneumatic rod machine for dispersing solid mineral fertilizers:
1 – frame; 2 – cardan shaft; 3 – overrunning clutch; 4 – elastic coupling; 5 – belt drive; 6 – fan;
7 – air ejector; 8 – corrugated pipe; 9 – fertilizer distributor; 10 – bunker;
11 – sowing device; 12 – wheel; 13 – hydraulic cylinder; 14 – rod

3. RESULTS AND DISCUSSION

When operating boom pneumatic machines for surface application of solid mineral fertilizers, the latter are fed by the sowing apparatus into the distributor guide cone, which focuses them in the center of the divider (Fig. 2).

The parameters of the divider will largely depend on the initial speed of the fertilizer at the moment of contact with its surface. The initial velocity of the fertilizer particle ϑ_o will depend on the height of the guide cone. The shape and parameters of the upper part of the divider must be selected based on the condition of ensuring the maximum speed of the particle at the moment when it leaves its surface (Fig. 3).

To establish the relationship between quantities, consider the condition free fall of fertilizer particles in the air, taking into account air resistance and write it as

$$\vec{F}_r = m\vec{g} + \vec{F}_a + \vec{F}_d + \vec{F}_f + \vec{N}, \qquad (1)$$

where F_r – resultant force, N; m – mass of fertilizer, kg; g – acceleration of gravity, m/s^2;
F_a – air speed resistance force, N;
F_d – air density resistance force, N;
$F_f = fN$ – friction force, N,
where f – friction coefficient; N – reaction force, N.

According to [8], the resistance force F_a air flow speed is determined by the formula

$$F_a = mk_\vartheta \vartheta, \qquad (2)$$

where k_ϑ – wind age factor, 1/s^2.

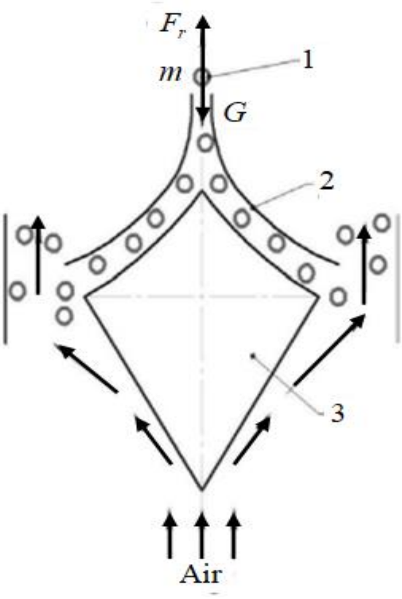

Figure 2. Schematic diagram of a fertilizer flow divider: 1 – fertilizer; 2 – curved surface; 3 – divider

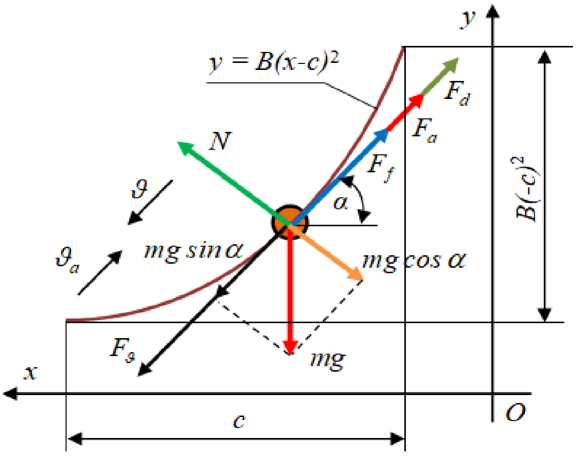

Figure 3. Scheme of movement of part of the fertilizer along a curved surface divisor

The air density resistance force F_d of the air environment, which prevents the free movement of the fertilizer particle, will also depend on the area S (m^2) of the cross-section of the particle and the plane of the air ρ (kg/m^3) of the air environment.

According to[8], the force F_d is determined by the formula

$$F_d = 0.5\xi S\vartheta^2\rho, \quad (3)$$

where ξ – air density drag coefficient;
S – particle cross-sectional area, m^2;
ρ – particle density, kg/m^3.

In addition, let us imagine the resultant force F_r according to Newton’s 2nd law that is

$$F_r = m\frac{d\vartheta}{dt}. \quad (4)$$

Substituting the expression $\vec{F}_r = m\vec{g} + \vec{F}_a + \vec{F}_d + \vec{F}_f + \vec{N}$ for the values of its components with (2), (3) and (4), we obtain the dependence.

$$m\frac{d\vec{\vartheta}}{dt} = m\left(\vec{g} + k_\vartheta\vec{\vartheta}\right) + 0.5\xi S\vec{\vartheta}^2\rho + \vec{N}\left(f+1\right); \quad (5)$$

$$\frac{d\vec{\vartheta}}{dt} = \vec{g} + k_\vartheta\vec{\vartheta} + \frac{1}{m}\left[0.5\xi S\vec{\vartheta}^2\rho + \vec{N}\left(f+1\right)\right]. \quad (6)$$

Then, taking the form of a fertilizer particle at the end of the ball (particle cross-sectional area $S = 0.25\pi d_p^2$, particle mass $m = V\rho = \left(4/3\right)\left(0.5\pi d_p\right)^3\rho$, V – where volume of the ball, m^3; d_p is the diameter of the particle, m), the projections of the acting forces on the *Ox* and *Oy* axes will be equal:

$$\frac{d\vartheta_x}{dt} = \frac{6}{\pi d_p^3\rho}N\left(1+f\right) - \frac{3}{4d_p}\xi\vartheta_x^2 - k_\vartheta\vartheta_x; \quad (7)$$

$$\frac{d\vartheta_y}{dt} = \frac{g}{sin\alpha} - k_\vartheta\vartheta_y + \frac{6\pi d_p^3}{\rho}N\left(1-f\right) + \frac{3}{4d_p}\xi\vartheta_x^2, \quad (8)$$

or:

$$\int_0^{\vartheta_x} d\vartheta_x = \int_o^{\sqrt{2x/g}}\left(\frac{6}{\pi d_p^3\rho}N\left(1+f\right) - \frac{3}{4d_p}\xi\vartheta_x^2 - k_\vartheta\vartheta_x\right)dt; \quad (9)$$

$$\int_0^{\vartheta_y} d\vartheta_y = \int_0^{\sqrt{2y/g}}\left(\frac{g}{sin\alpha} - k_\vartheta\vartheta_y + \frac{6}{\pi d_p^3\rho}N\left(1-f\right) + \frac{3}{4d_p}\xi\vartheta_x^2\right)dt. \quad (10)$$

The solution of integral equations (9) and (10) within the limits of integration has the following expression:

$$\vartheta_x = \frac{6}{\pi d_p^3 \rho} N\left(1+f\right)\sqrt{\frac{2x}{g}} + \frac{3}{4d_p}\frac{\xi c^2\sqrt{g}}{\left(e^{\sqrt{2x/g}}\right)^2\sqrt{2x}} - \frac{k_\vartheta c\sqrt{g}}{e^{\sqrt{2x/g}}\sqrt{2x}}; \tag{11}$$

$$\vartheta_y = \frac{g}{k_\vartheta}\left(\frac{1}{sin\,\alpha} - \frac{y\sqrt{g}}{e^{k_\vartheta\sqrt{2y/g}}\sqrt{2y}}\right) + \frac{6}{\pi d_p^3 \rho} N\left(1-f\right)\sqrt{\frac{2y}{g}} + \frac{3}{4d_p}\frac{\xi y^2\sqrt{g}}{\left(e^{\sqrt{2y/g}}\right)^2\sqrt{2y}}. \tag{12}$$

Then, the resulting speed ϑ of movement of the fertilizer particle according to (11) and (12) is equal to

$$\vartheta = \sqrt{\begin{aligned}&\left(\frac{6}{\pi d_p^3 \rho} N\left(1+f\right)\sqrt{\frac{2x}{g}} + \frac{3}{4d_p}\frac{\xi c^2\sqrt{g}}{\left(e^{\sqrt{2x/g}}\right)^2\sqrt{2x}} - \frac{k_\vartheta c\sqrt{g}}{e^{\sqrt{2x/g}}\sqrt{2x}}\right)^2 + \\ &+\left(\frac{g}{k_\vartheta}\left(\frac{1}{sin\,\alpha} - \frac{y\sqrt{g}}{e^{k_\vartheta\sqrt{2y/g}}\sqrt{2y}}\right) + \frac{6}{\pi d_p^3 \rho} N\left(1-f\right)\sqrt{\frac{2y}{g}} + \frac{3}{4d_p}\frac{\xi y^2\sqrt{g}}{\left(e^{\sqrt{2y/g}}\right)^2\sqrt{2y}}\right)^2\end{aligned}}. \tag{13}$$

Taking into account the fact that $N = mg\,cos\,\alpha = \frac{\pi d_p^3}{6}\rho g\,cos\,\alpha$, formula (13), which determines the resulting speed of movement ϑ of a particle of mineral fertilizers in the divider, will have an output

$$\vartheta = \sqrt{\begin{aligned}&\left(g\,cos\,\alpha\left(1+f\right)\sqrt{\frac{2x}{g}} + \frac{3}{4d_p}\frac{\xi c^2\sqrt{g}}{\left(e^{\sqrt{2x/g}}\right)^2\sqrt{2x}} - \frac{k_\vartheta c\sqrt{g}}{e^{k_\vartheta\sqrt{2x/g}}\sqrt{2x}}\right)^2 + \\ &+\left(\frac{g}{k_\vartheta}\left(\frac{1}{sin\,\alpha} - \frac{y\sqrt{g}}{e^{k_\vartheta\sqrt{2x/g}}\sqrt{2x}}\right) + g\,cos\,\alpha\left(1-f\right)\sqrt{\frac{2x}{g}} + \frac{3}{4d_p}\frac{\xi y^2\sqrt{g}}{\left(e^{\sqrt{2x/g}}\right)^2\sqrt{2y}}\right)^2\end{aligned}}. \tag{14}$$

According to equation (14), a graphical interpretation of the dependence of the change in the resulting speed of movement ϑ of a particle of mineral fertilizers on the coordinates x and y is constructed as a function: $\vartheta = f_\vartheta\left(x,y\right)$, Fig. 4a, b, c; $\vartheta = f_\vartheta\left(x\right)$, Fig. 4 d.

For changes in the coordinates x and y within 0.1...0.4 m and the diameter d_p of a particle of mineral fertilizers from 0.004 to 0.006 m, the resulting speed of movement of the particle ϑ changes in a wide range – from 1.0 to 2.9 m/s.

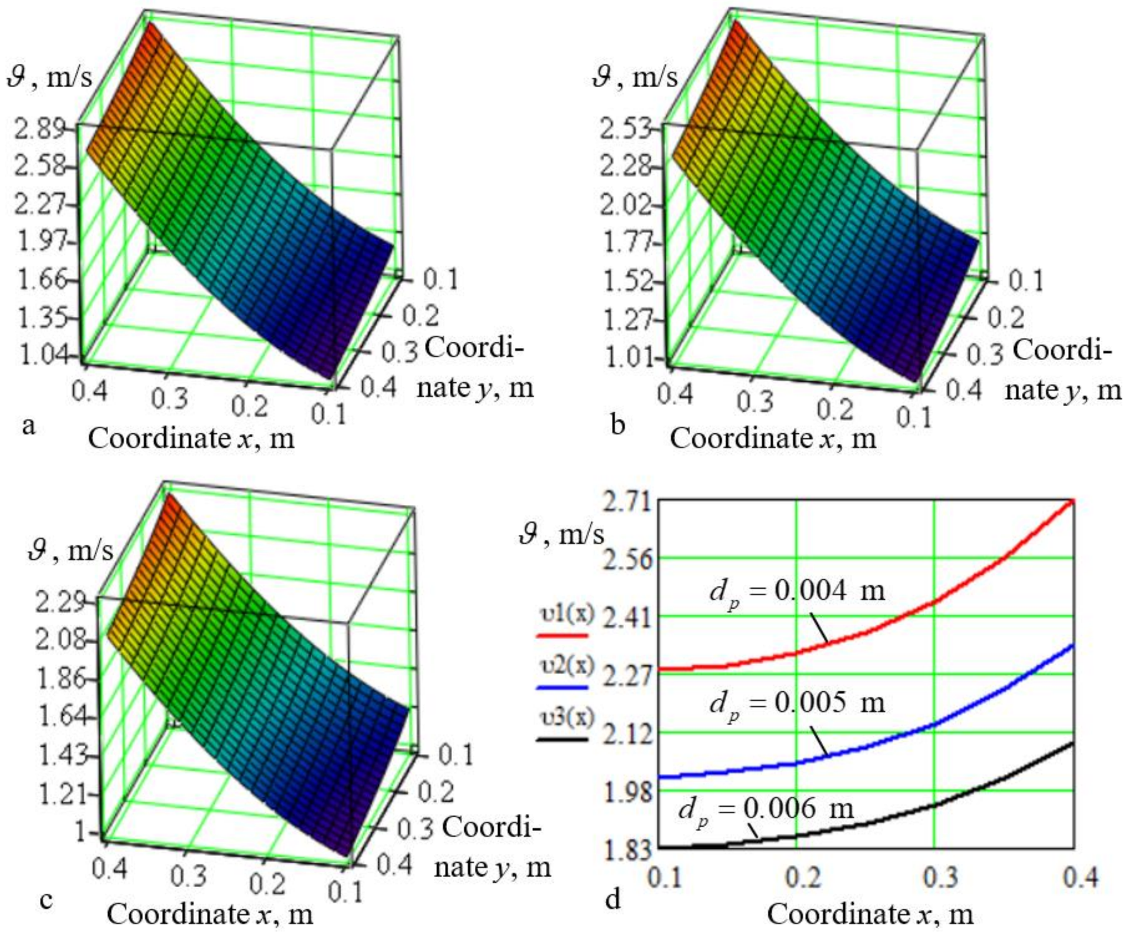

Figure 4. Dependence of the change in the resulting speed of movement ϑ of a particle of mineral fertilizers on the coordinates x and y as a function: a, b, c – $\vartheta = f_{\vartheta}(x, y)$, $d_p = 0.004; 0.005; 0.006$ m; d – $\vartheta = f_{\vartheta}(x)$, y = 0.04 m

With:

- for the diameter d_p of a particle of mineral fertilizers, which is equal to d_p = 0.004 m, the resulting speed ϑ of its movement varies from 1.2 to 2.9 m/s;
- for the diameter d_p of a particle of mineral fertilizers, which is equal to d_p = 0.005 m, the resulting speed ϑ of its movement varies from 1.0 to 2.5 m/s;
- for the diameter d_p of a particle of mineral fertilizers, which is equal to d_p = 0.006 m, the resulting speed ϑ of its movement varies from 1.0 to 2.3 m/s.

The dominant influence on the functional change in the value of the resulting speed ϑ of movement of a particle of mineral fertilizers in the machine divider is exerted by the vertical coordinate y – the speed of movement ϑ increases by 1.9 m/s. At the same time, the speed ϑ of the change in particle motion relative to the *Ox* axis is insignificant – on average, only 0.3...0.4 m/s.

4. CONCLUSIONS

1. The main provisions that characterize the movement of a particle of mineral fertilizers in the cone of the divider, taking into account the active accompanying air jet during the application of fertilizers to the surface of the field by a fat spreading device, are outlined.

2. According to the research results, an analytical and graphic model was developed that characterizes the change in the speed of movement of mineral fertilizers depending on the initial vertical and horizontal coordinates of their placement in the guide cone of the divider.

3. It was established that with changes in coordinates within 0.1...0.4 m and the diameter of fertilizers from 4 to 6 mm, the resulting speed of movement of fertilizers is in the range of 1.0...2.9 m/s.

4. The proposed theoretical model is a further step in the improvement of the methodology for the development of machines for the application of solid mineral fertilizers and allows optimizing the structural parameters of the working bodies of the machines at the design stage at the analytical level.

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ТЕОРЕТИЧНИЙ АНАЛІЗ ПОДІЛЬНИКА ПОТОКУ ТВЕРДИХ МІНЕРАЛЬНИХ ДОБРИВ

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Резюме. *Основну масу гранульованих мінеральних добрив вносять шляхом їх розсівання по поверхні поля як при основному удобренні грунту, так і при підживленні сільськогосподарських культур. Існуючі машини вітчизняного виробництва не задовольняють агрономічні вимоги за показниками нерівномірності внесення мінеральних добрив. На сучасному етапі відсутні теоретичні залежності, які б адекватно описували: процес подавання добрив нижньою ланкою живильника-конвеєра; рух добрив від живильника до тукоспрямовувача та їх рух уздовж останнього; умови захвату добрив робочими органами; рух добрив від робочого органу до поверхні поля в умовах дії на них вітру і супроводжуючого повітряного струменя. Відомі моделі внесення мінеральних добрив на поверхню поля не узгоджуються з реальним процесом і заперечують стандартній методиці визначення нерівномірності їх внесення на робочій ширині захвату машин. Мета роботи: розробити аналітичну модель, яка функціонально описує процес переміщення мінеральних добрив у направляючому конусі подільника розподільного пристрою залежно від параметрів робочого органу. Наведено теоретичний аналіз процесу руху частинки мінеральних добрив по криволінійній поверхні подільника з урахуванням напрямку дії вітру та опору повітряного середовища. За результатами досліджень розроблено аналітичну та графічну моделі, які характеризують зміну швидкості переміщення мінеральних добрив залежно від початкової вертикальної та горизонтальної координати їх розміщення в направляючому конусі подільника. Встановлено, що за зміни координат у межах 0,1...0,4 м та діаметра добрив від 4 до 6 мм результуюча швидкість руху добрив перебуває в діапазоні 1,0...2,9 м/с. Запропонована теоретична модель дозволяє на аналітичному рівні провести оптимізацію конструктивних параметрів робочих органів машин для внесення твердих мінеральних добрив.*

Ключові слова: *мінеральні тверді добрива, подільник, результуюча швидкість, координата, криволінійна поверхня.*

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