

Research Article

Theoretical Substantiation of Mineral Fertilizer Movement in the Fertilizer Tube

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Abstract

The development and implementation of energy and resource-saving types of machinery and equipment for agricultural activities in crop fields dedicated to vegetable cultivation is gaining a leading position worldwide. "Considering that vegetable crops are cultivated on over 58.2 million hectares globally it is a crucial task to introduce high-performance, modern technical means for fertilizing vegetable crops and inter-row cultivation. In this regard, special attention is being paid to using compact, low-energy-consuming technical means that allow for increasing the efficiency of fertilizer use in vegetable cultivation and applying them to the specified depth and width. World-wide, research and development efforts are underway to develop new scientific and technical solutions for resource-saving technical means that apply fertilizers locally and work in open conditions for inter-row cultivation, with the aim of reducing the amount of applied fertilizers and increasing their effectiveness in preserving the natural properties of vegetables. In this direction, particular attention is paid to developing a drill coulter design that ensures the operation of working bodies in open conditions to reduce energy consumption during local fertilizer application and inter-row cultivation in a single pass for onions, as well as scientifically substantiating the technological processes and parameters they performed. This article presents the results of theoretical studies conducted on the movement of mineral fertilizers from the metering device through the fertilizer conduit. The main factors affecting the movement of mineral fertilizers in the fertilizer conduit are analyzed. Based on the research, graphs illustrating the change in the fertilizer exit rate from the conduit over time are constructed. Based on the results obtained, scientifically based recommendations for uniform fertilizer application are provided. The length of the fertilizer tube and the angles of the guide installation can be selected depending on the speed of the fertilizer machine, the falling distance of the fertilizer, and the application rate.

Keywords

Mineral Fertilizer, Conduit, Movement, Coulter, Factor, Expression, Equation, Plane, Construction, Speed, Time

1. Introduction

Achieving high and stable yields in agriculture requires the effective use of modern technologies and resources [2]. In this regard, mineral fertilizers play an important role in the nutrition of cultivated crops. Timely and even application of min-

eral fertilizers to the soil depends on specialized technical equipment - fertilizer applicators. The efficiency of fertilizer applicators and the even distribution of fertilizer depend largely on the design of the fertilizer conduit, which is its main

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working component, and the characteristics of fertilizer particle movement within it. The movement of fertilizer particles in the fertilizer conduit is a complex physical process influenced by the type of fertilizer, its physical properties (moisture content, particle size distribution, specific gravity), the geometric shape of the fertilizer conduit, operating speed, and many other factors. Uneven fertilizer flow from the fertilizer conduit or its blockage negatively affects their uniform distribution, leading to a decrease in yield. Therefore, theoretically studying the movement of mineral fertilizers in the fertilizer conduit, identifying the factors affecting this process, and substantiating optimal design parameters are crucial. [1].

2. Experimental Procedures

The uniform distribution of fertilizers at a set rate largely depends on the regulating device and the design of the fertilizer tube [3]. Therefore, studying the movement of fertilizers in the fertilizer tube is important. This is because the speed of falling fertilizers should correspond to the speed of the machine for uniform application, and the fertilizers should reach the soil at the set rate for uniform distribution within the norm [4].

In the theoretical study of fertilizer movement in the fertilizer tube, it is first necessary to clarify the factors influencing the process. When studying the movement of mineral fertilizer particles, we consider them as a point K [5]. Consequently, we consider the movement of point K in separate sections of the fertilizer tube AC .

First, let's consider the movement of point K in the segment AB (Figure 1). Starting from point A , taken as the origin, we consider that as point K moves downward under the action of gravity G , it is subjected to air resistance (Figure 2). The initial conditions of motion are taken as follows: $t=0$, $y_0=0$, and according to the data given in [6], we take $\dot{y}=1$ m/s.

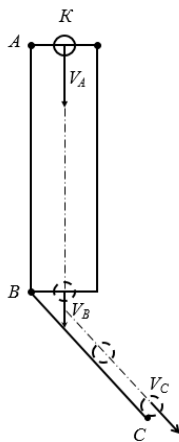


Figure 1. Diagram of the movement of a mineral fertilizer particle in a fertilizer tube.

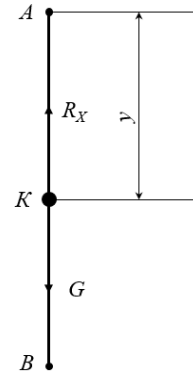


Figure 2. Diagram of the movement of point K in segment AB .

Using Figure 2, we construct the equation of motion of point K in segment AB [7].

$$m\ddot{y} = G - R_y \quad (1)$$

where m - mass of the mineral fertilizer particle, kg; $\ddot{y}$ - acceleration of mineral fertilizer particles along the Oy axis, m/s^2 ; G - force of gravity, N ; R_y - projection of the air resistance force on the y axis, N .

The force of gravity and the air resistance force are expressed as follows [8]

$$G = mg \quad (2)$$

$$R_y = \frac{1}{2} \mu \varsigma S V_A^2, \quad (3)$$

where g - acceleration due to gravity, m/s^2 ; μ - drag coefficient, accounting for the shape of the fertilizer, ς - density of air, kg/m^3 ; S - surface area of the fertilizer, m^2 ; V_A - velocity of the fertilizer, m/s .

Considering expressions (2) and (3), we make changes to (1).

$$m\ddot{y} = mg - \frac{1}{2} \mu \varsigma S V_A^2, \quad (4)$$

or

$$m\ddot{y} = mg - \frac{1}{2} \mu \varsigma S \dot{y}^2 \quad (5)$$

Now let's investigate the motion according to equation (5). To simplify the problem, divide both sides of the equation by the mass of the substance m [9]. In this case,

$$\ddot{y} = g - \frac{1}{2} \frac{\mu \varsigma S \dot{y}^2}{m} \quad (6)$$

For the convenience of performing operations using equality (6), we introduce notations [10], i.e. $\frac{\mu \mathcal{S}}{2m} = A^2$, and $\dot{y} = V_A(t)$. Considering this, equality (6) takes the following form:

$$V_A' = g - A^2 V_A^2 \quad (7)$$

We determine dt from equality (7):

$$dt \frac{dV_A}{g - A^2 V_A^2} \quad (8)$$

Then

$$\int \frac{dV_A}{g - (AV_A)^2} = t + \ln C_3 \quad (9)$$

If we consider the equivalent $\int \frac{dx}{a^2 - x^2} = \frac{1}{2a} \ln \frac{a+x}{a-x}$ [11], then expression (9) takes the following form:

$$\frac{1}{2A\sqrt{g}} \ln \frac{\sqrt{g} + AV_{AB}}{\sqrt{g} - AV_{AB}} = t + \ln C_1, \quad (10)$$

$$\ln \frac{\sqrt{g} + AV_{AB}}{\sqrt{g} - AV_{AB}} = 2At\sqrt{g} + \ln C_1 \quad (11)$$

$$\frac{\sqrt{g} + AV_{AB}}{\sqrt{g} - AV_{AB}} = C_1 e^{2At\sqrt{g}}, \quad (12)$$

$$\sqrt{g} + AV_{AB} = C_1 \sqrt{g} e^{2At\sqrt{g}} - C_1 AV_{AB} e^{2At\sqrt{g}}, \quad (13)$$

$$AV_{AB} = (1 + C_1 e^{2At\sqrt{g}}) = C_1 \sqrt{g} e^{2At\sqrt{g}} - \sqrt{g}, \quad (14)$$

$$V_{AB} = \frac{\sqrt{g}}{A} \cdot \frac{C_1 e^{2At\sqrt{g}} - 1}{C_1 e^{2At\sqrt{g}} + 1}, \quad (15)$$

or

$$V_{AB} = \frac{\sqrt{g}}{A} \cdot \frac{e^{2At\sqrt{g}} - C_1}{e^{2At\sqrt{g}} + C_1}. \quad (16)$$

$$\dot{y}(0) = 1, \quad (17)$$

Using the initial conditions (17), we determine the value of the constant coefficient C_1 in equation (16)

$$C_1 = \frac{\sqrt{g} - A \cdot V_A}{\sqrt{g} + A \cdot V_A} \quad (18)$$

Substituting the obtained value of C_1 into expression (16), we get the following:

$$V_{AB} = \frac{\sqrt{g}}{A} \cdot \frac{\sqrt{g}(e^{2At\sqrt{g}} - 1) + A \cdot V_A(e^{2At\sqrt{g}} + 1)}{\sqrt{g}(e^{2At\sqrt{g}} + 1) + A \cdot V_A(e^{2At\sqrt{g}} - 1)} \quad (19)$$

In the next stage of the study, we consider the movement of fertilizers in segment BC [12]. We assume that the fertilizers move along an inclined plane located at an angle α to the horizontal plane (Figure 3).

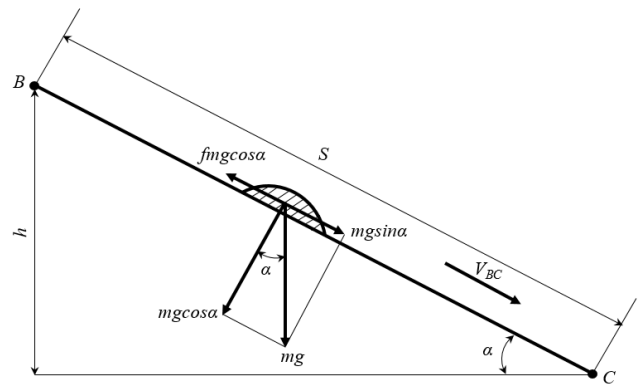


Figure 3. Diagram of fertilizer movement in part BC.

Using the scheme presented in Figure 3, we formulate the differential equation describing the movement of a particle in segment BC [13].

$$m \frac{dV_{BC}}{dt} = mg \sin \alpha - fmg \cos \alpha \quad (20)$$

where f - coefficient of compression. The equality (20) is also satisfied for $m=0$.

Dividing both sides of the differential equation (20) by m , we get the following:

$$\frac{dV_{BC}}{dt} = g \sin \alpha - fg \cos \alpha \quad (21)$$

Considering the initial conditions $V=V_{AB}$, $S=0$, $t=0$, and $f=tg\varphi$, and integrating the differential equation (21) once, we get the following:

$$V_{AC} = V_{AB} + \frac{\sin(\alpha - \varphi)}{\cos \varphi} gt \quad (22)$$

where φ - angle of inclination, degrees.

Considering expression (19), we rewrite expression (22) as

follows and determine the exit velocity of particles from the fertilizer tube [14, 15]. From $S = V t$

$$V_{AC} = \frac{\sqrt{g}}{A} \cdot \frac{\sqrt{g}(e^{\frac{2At\sqrt{g}}{A}} - 1) + A \cdot V_{BC}(e^{\frac{2At\sqrt{g}}{A}} + 1)}{\sqrt{g}(e^{\frac{2At\sqrt{g}}{A}} + 1) + A \cdot V_{BC}(e^{\frac{2At\sqrt{g}}{A}} - 1)} + \frac{\sin(\alpha - \varphi)}{\cos \varphi} g t \quad (23)$$

In order to determine the speed of mineral fertilizer movement in the fertilizer tube depending on time, we perform a numerical solution of expression (23) using the "Microsoft Excel" program. The numerical solution of expression (23) is performed with the following parameter values: $g=9.8$ m/s²; $e=2.7$; $r=0.0018$ m; $\mu=0.47$; $\zeta=1.293$ kg/m³; $\pi=3.14$; $m=0.00004$ kg; $VA=1$ m/s; $\alpha=(60^\circ, 70^\circ, 80^\circ)$; $\varphi=30^\circ$; $t \in [0; 2.5]$ s.

Based on the numerical solution of (23), graphs of the change in the speed of mineral fertilizer movement in the fertilizer tube depending on time were obtained (Figure 4). From the graph, it is clear that with the passage of time, the speed of mineral fertilizer movement increases according to a curved line. Additionally, from the curved line of the graph, it is evident that as the angle of inclination of the guide increases, the falling speed of mineral fertilizers significantly increases. For example, with an initial fertilizer speed of 1 m/s and a guide inclination angle of 60° , the falling speed of mineral fertilizers increases from 1 m/s to 28.96 m/s in 2.5 seconds; at an inclination angle of 70° , the falling speed increases from 1 m/s to 33 m/s in 2.5 seconds; and at an inclination angle of 80° , the falling speed of mineral fertilizers reaches 36.49 m/s in 2.5 seconds.

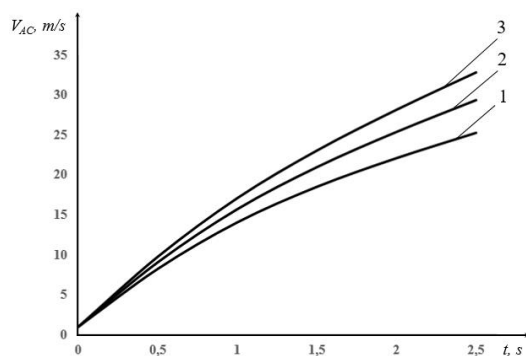


Figure 4. Graph of the change in the speed of mineral fertilizer movement in the fertilizer tube depending on time.

3. Conclusions

In conclusion, based on the results of the conducted studies, it becomes possible to select the geometric dimensions of the fertilizer tube in accordance with the operating modes of the fertilizer machine. Using the graph presented Figure 4, the length of the fertilizer tube and the angles of the guide installation can be selected depending on the speed of the fertilizer machine, the falling distance of the fertilizer, and the

application rate.

Abbreviations

Φ	Angle of Inclination, Degrees
M	Mass of the Mineral Fertilizer Particle, kg
$\ddot{Y}$	Acceleration of Mineral Fertilizer Particles Along the Oy Axis, m/s ²
G	Force of Gravity, N
Ry	Projection of the Air Resistance Force on the y Axis

Author Contributions

Turdaliyev Voxidjon Maxsudovich: Conceptualization, Data curation, Funding acquisition, Methodology, Resources, Supervision, Validation, Visualization

Eksanova Santalatxon Sharobidinovna: Conceptualization, Formal Analysis, Investigation, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



advancement of machine design has made him a key figure in his field, with a lasting impact on both academia and industry.



Turdaliyev Voxidjon Maxsudovich is a highly respected Doctor of Technical Sciences and a professor, renowned for his extensive contributions to the field of machine details. He has authored numerous articles and books, which are considered fundamental references in the industry. His expertise and profound knowledge have earned him recognition both locally and internationally. Currently, he serves as a department professor at the prestigious Tashkent Institute of Textile and Light Industry, where he imparts his valuable knowledge to the next generation of engineers. Throughout his distinguished career, Professor Djuraev has mentored numerous students, many of whom have gone on to achieve great success in their professional fields. His dedication to research, education, and the advancement of machine design has made him a key figure in his field, with a lasting impact on both academia and industry.

Eksanova Santalatxon Sharobidinovna is a PhD candidate and a junior lecturer at the Department of Mechanics. He is currently working on his doctoral research and contributing to the field through teaching and academic involvement. He graduated Namangan Engineering-Construction Institute in 2020, and his Master of Mechanical engineering from the same institution in 2022. He has participated in multiple international research collaboration projects in recent years.

Research Field

Turdaliyev Voxidjon Maxsudovich: Theory of Machines and Mechanisms, Mechanical Engineering, Elastic Elements in Gear Transmissions, Dynamics and Kinematics of Technological Machines, Vibration Analysis in Gear Systems, Reliability and Efficiency of Machine Components.

Eksanova Santalatxon Sharobidinovna: Soil science, Modern methods of soil cultivation, Agricultural machinery, Reliability and repair of machines, Fundamentals of designing agricultural machinery and equipment, Operation and technical service of the machine-tractor fleet.