№ 2 (133) / 2026
ISSN: 2520-6168
Vol. 133, № 2 / 2026

Техніка, енергетика, транспорт АПК

Technology, energy, agriculture transport AIC

UDC 631.3 (075.8)
DOI: 10.37128/2520-6168-2026-2-15

ANALYTICAL STUDIES OF THE INFLUENCE OF VARIOUS FACTORS ON THE FLIGHT RANGE OF MATERIAL PARTICLES DURING TAKE-OFF FROM THE DISC OF A MINERAL FERTILIZER SPREADER

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The article presents a thorough analysis of the current state of development in the field of machines and mechanisms for surface application of mineral fertilizers - a technological process that remains one of the key ones in modern agriculture, but at the same time extremely sensitive to external conditions.

Particular attention is paid to the physics of the movement of fertilizer particles in the air environment. It was investigated how the coefficient of aerodynamic resistance (pressure coefficient Cx), air viscosity, size, shape, density of granules and their initial speed determine the flight trajectory. It was shown that even a small increase in wind speed significantly changes the picture: a headwind reduces the range of the discharge, a side wind causes a strong asymmetry of the distribution, and a tail wind can create excessive material overturning beyond the working area. As a result, the distribution variation coefficient increases sharply, which leads to an overexpenditure of fertilizers in some areas of the field and their deficiency in others, reducing the overall efficiency of fertilization and increasing the risk of uneven plant development.

A separate section is devoted to a quantitative description of the impact of wind. In particular, data is provided that at a wind speed of 4–6 m/s, the distance of particles can be reduced by 15–40% depending on the direction, and at 8 m/s and more, high-quality application with classic disc spreaders becomes practically impossible without special compensation measures.

That is why a significant part of the work is devoted to modern technical solutions that allow minimizing or almost completely neutralizing the negative impact of the weather. Among them is the WindControl system from Amazone , which works in conjunction with Argus sensors. Twin or independently: a high-frequency ultrasonic wind sensor records the speed and direction in real time, after which the on-board computer automatically adjusts the blade angle, disc rotation speed or deflector position, maintaining the specified width and uniform distribution even in moderately strong winds (up to 8–10 m/s).

Alternative approaches are also being considered: pneumatic boom spreaders with adjustable nozzles, multi-disc systems with lower initial ejection velocity (which reduces sensitivity to lateral wear), GPS/RTK systems with electronic rate setting maps and automatic section shut-off, and hybrid designs combining the centrifugal principle with controlled pneumatic conveying.

Key words: *mineral fertilizers, fertilizer spreader, particle flight range, particle trajectory, wind influence, air resistance, fertilizer distribution, spreading efficiency.*

Fig. 13. Table. 1. Ref. 8.

1. Problem formulation

Modern methods spreading fertilizer on fields salt economic appointment based on the use of automated equipment from using methods centrifugal forces. The most common is the disk spreader. The main job requirements which is secured uniformity sowing used area land with guaranteed maximum closing surfaces processed territories. Provision delivered requirements guaranteed smoothness spreading disc work the kvacha, its frequency rotation, weather conditions during the period works (wind , rain), Selection and

Article received 12.04.2026. Article accepted 01.05.2026. Article published 28.05.2026.

relationship all parameters provides stable indicators robot capabilities spreader . So mutual agreement weekend parameters (initial velocity, angular acceleration, radius material particles) is the main problem.

2. Analysis of recent research and publications

In [1], an analysis of the performance of centrifugal spreaders mineral fertilizers by range flight without taking into account secondary altitudes factors – wind, fraction material , friction on the surface spreader etc. Works [2-3] reveal recommended quantities widths processed surface depending from given uniformity coating surfaces without taking into account the velocity vector movement at each moment of analysis trajectories. Works [4-5] describe mathematical movement particles in gutters without specification further laws movement particles at the time of exit from zones limitation spreader.

3. The purpose of the article

The above information on the conducted research indicates the need to study the dependence of the productivity of centrifugal fertilizer spreaders on a certain flight range.

The purpose of the work is: optimization parameters workers organs during construction spreaders centrifugal type mineral fertilizers.

To achieve the goal, you need to decide next tasks:

- to investigate trajectory movement particles for the initial speed and taking into account forces wind;
- to determine dependence range flight particles from initial speed and taking into account forces wind;
- analyze effect of climb angle on range flight particles.

Conducting such a study gives possibility to evaluate quantitative the influence of the velocity vector of the particle's escape from the disk, the velocity vector wind and drag coefficient on trajectory and range flight particles.

4. Results and discussion

The productivity of centrifugal fertilizer spreaders is determined by the flight range when leaving the disk.

The uniformity of coverage of the treated surface in the direction of movement of the unit and along the width of the capture depends on the size of the particles, the direction of the velocity vector at each moment of trajectory analysis, the force of environmental resistance, wind speed, and other factors.

The article considers the influence of the drag coefficient (pressure) of the environment (the direction of the particle velocity vector , the magnitude of the wind speed) on the flight range of particles.

The work program is to determine the kinematics of a particle under various combinations of factors that affect the flight range of particles (Table 1).

Table 1.

Work program

No. s/n	Indicators	Numerical value			
1	Initial speed particles , m/s	8.0	18.0	25.0	30.0
2	The angle of inclination of the initial vector speed to the horizon, degrees	30.0	45.0	60.0	-
3	Radius material particles . m	$1\cdot10^{-3}$	-	$2\cdot10^{-3}$	$2.5\cdot10^{-3}$
4	Speed wind speed , m/s	5.0	8.0	30.0	-
5	Direction vector speed , hail	0°	180°	-	-

The research method is analytical. The main assumption is the dependence of the resistance/pressure of the medium on the first-order velocity [1, 2, 3].

The research results are presented in the form of a graph of the dependence of flight range on functions.

The height of the disk above the surface being processed is h = 0.6 m.

Fig. 1 shows the trajectory of a material particle after it leaves the disk.

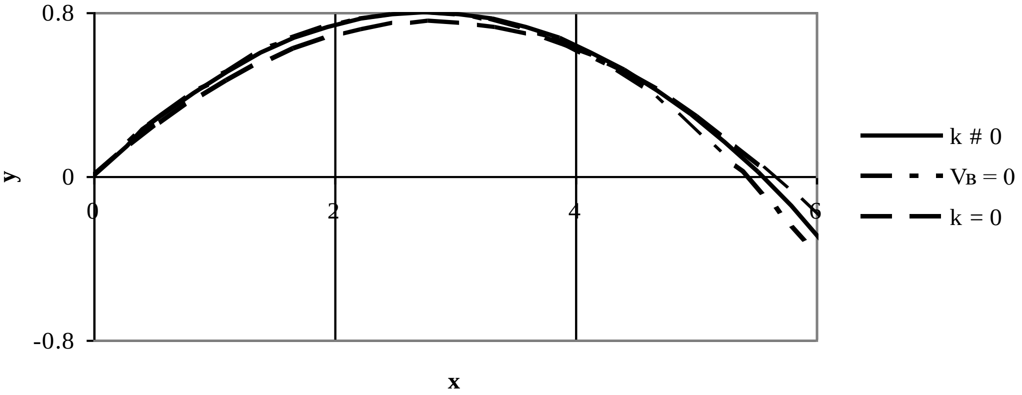

Fig. 1. Trajectory of particle motion

The graph is constructed for the following conditions: wind speed Vb = 5 m/s, β= 0º; the particle descends from the disk at an angle α0 = 30º to the horizon with an initial velocity V0 = 18 m/s. The solid line shows the trajectory of motion for k ≠ 0 (taking into account the resistance/pressure of the environment), the dotted line for k = 0 (absence of resistance/pressure of the environment), the dash-dotted line (Vb = 0) — assuming the absence of wind (but taking into account air resistance). As follows from the above patterns, the coefficient of resistance of the particle does not significantly affect the flight trajectory, which can be explained by a slight increase in air viscosity. When changing the direction of the wind to the opposite (other factors do not change), the results obtained are presented in Fig. 2.

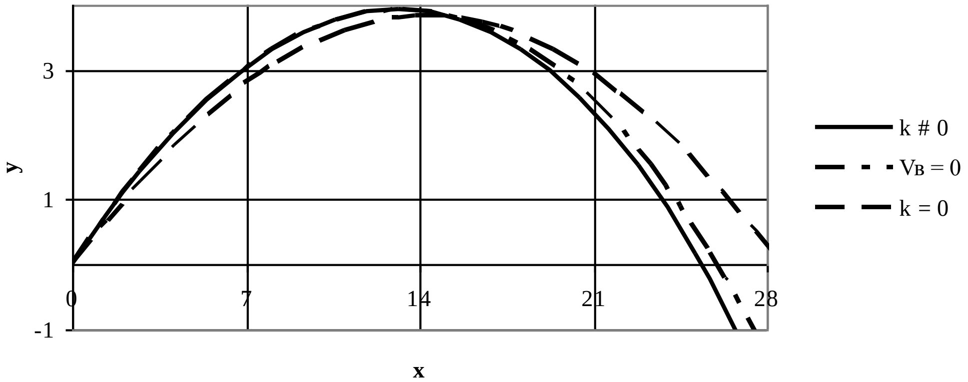

Fig. 2. Trajectory movement particles for the initial speed V_0 = 18 m/s and speeds wind V_b = 5 m/s at its direction β= 180º

The graph clearly shows a decrease in the Y coordinate from 8 to 4 and the X coordinate from 35 to 30 m.

Increasing the angle of departure of the particle from the disk to 60º at the parameters of wind speed and particle increases the trajectory height to 12 and the range to 27 m. (Fig. 3).

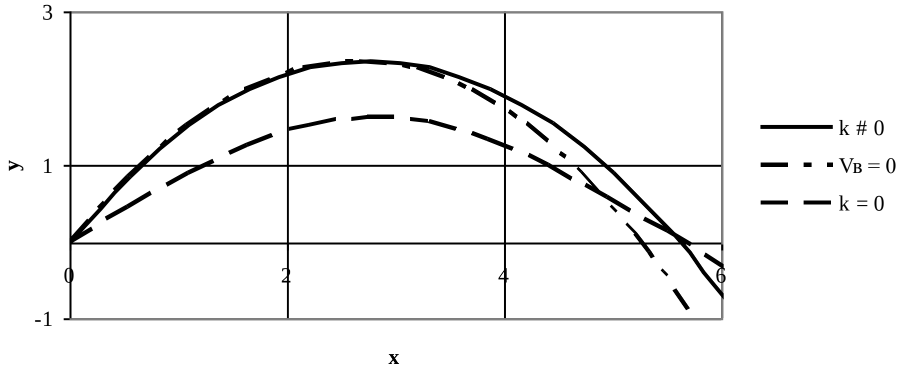

Fig. 3. Particle flight trajectory at angle α = 60º. Increasing particle descent velocity V0 from the disk up to 30 m/s, with a wind of 5 m/s and its direction β= 180º

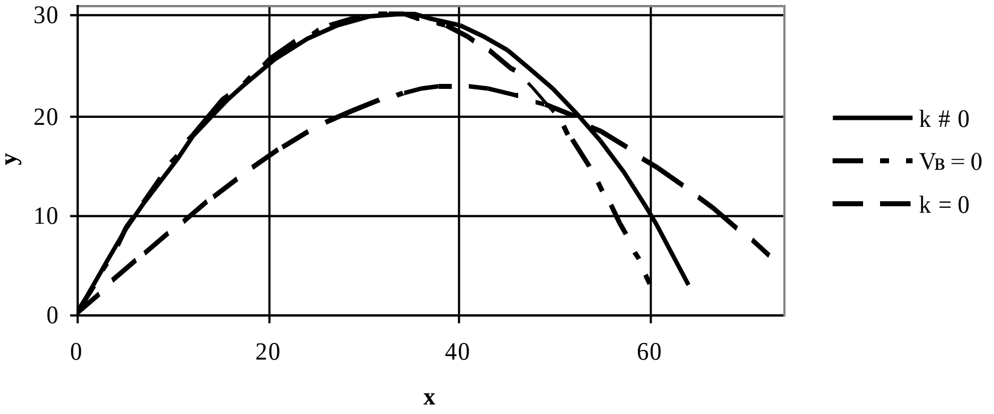

Fig. 4. Particle flight trajectory at V0 = 30m/s

It leads to an increase in the height of the parabola to 20 m, the X coordinate to 90 m (Fig. 4). However, at high particle speeds, the influence of the coefficient k is noticeable.

In fact, the case when the wind speed is quite high is unacceptable (Fig. 5).

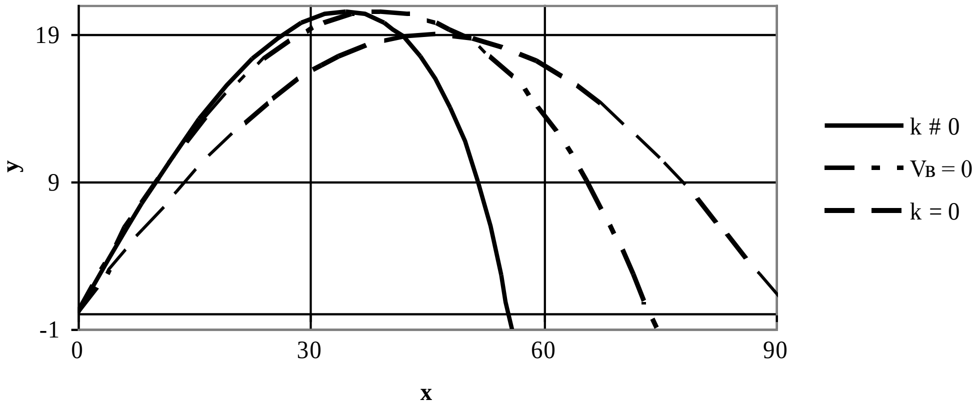

Fig. 5. Trajectory movement particles at V_b = 30m/s, V_0 = 30m/s, β= 180^o and α = 45^o

When the headwind speed increases to 30 m/s, the trajectory is flattened horizontally in height. Under these conditions, a clearly pronounced influence of the drag coefficient on the X coefficient is noted.

The flight range of mineral fertilizer particles determines the productivity of the unit. The flight range of granules depends on the following main parameters:

- initial flight speed (departure from the disk);
- the angle of inclination of the velocity vector when the particle leaves the disk;
- velocity vector and direction of its vector ;
- particle radius;
- mediocrity of particles;
- the resistance coefficient of the medium.

Fig. 6-9 shows the dependence of the flight range of material particles on the speed of their departure from the spreader disk.

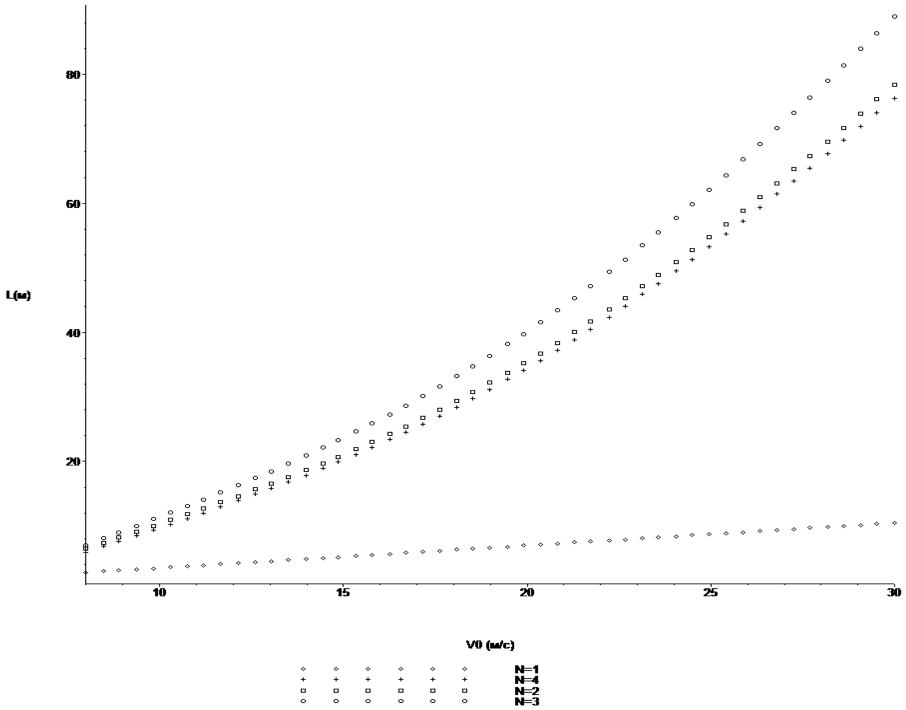

Fig. 6. Dependence of the flight range of a particle L on the initial velocity in the absence of wind ($V_b = 0$): N = 1 – α = 0º; N = 2 – α = 30º; N = 3 – α = 45º; N = 4 – α = 60º

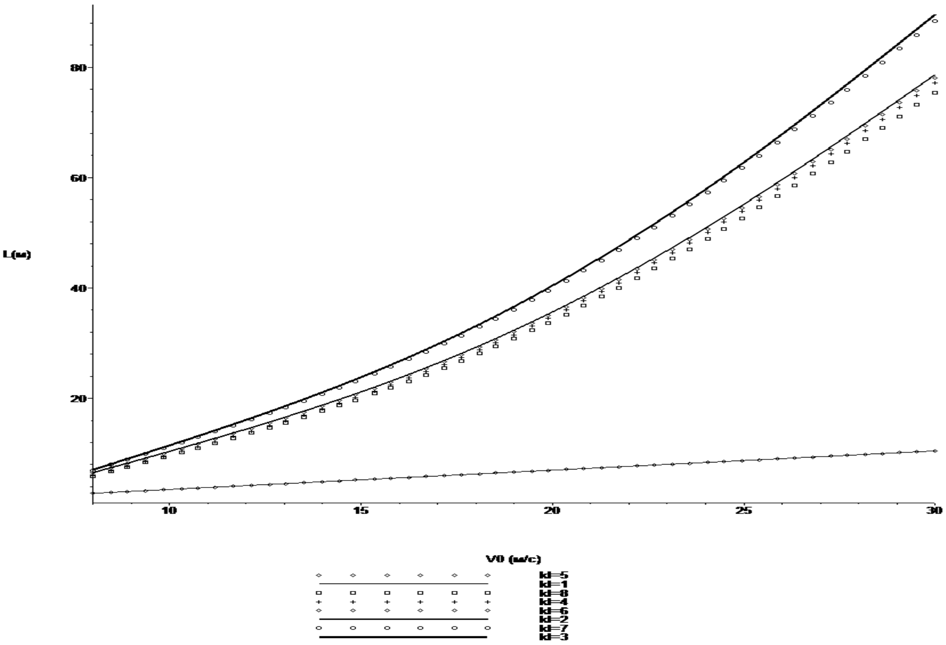

Fig. 7. Dependence of the flight range of a particle L on its initial velocity at $V_b = 5$ m/s: ki = 1 – α = 0º, β= 0º; ki = 2 – α = 0º, β= 180º; ki = 3 – α = 30º, β= 0º; ki = 4 – α = 30º, β= 180º; ki = 5 – α = 45º, β= 0º; ki = 6 – α = 45º, β= 180º; ki = 7 – α = 60º, β= 0º; ki = 8 – α = 60º, β= 180º

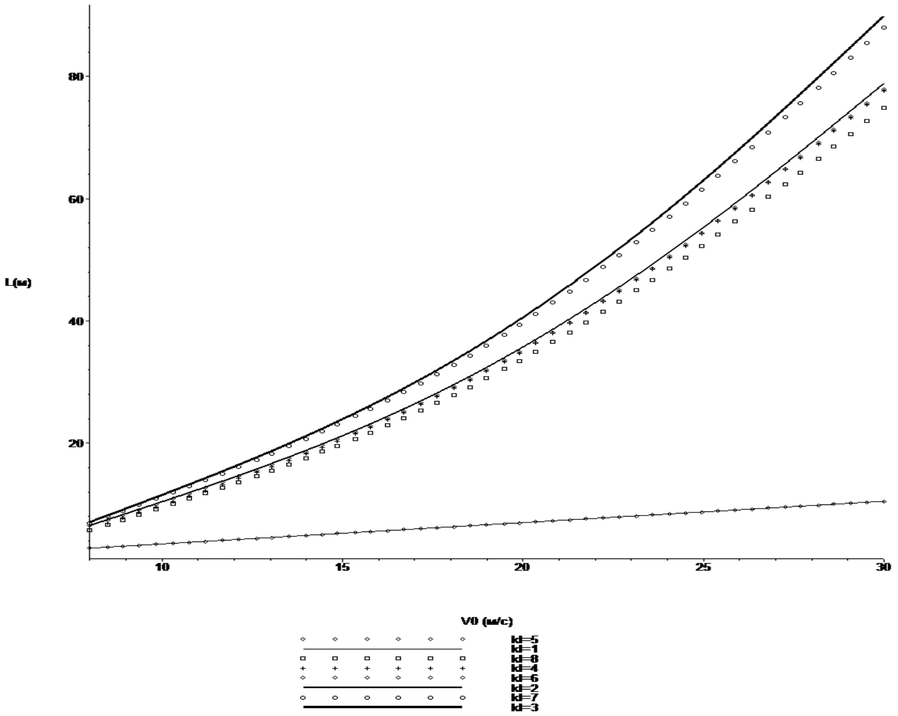

Fig. 8. Dependence of the flight range of a particle L on its initial velocity at $V_b = 8$ m/s: ki = 1 – $\alpha = 0^o$, $\beta = 0^o$; ki = 2 – $\alpha = 0^o$, $\beta = 180^o$; ki = 3 – $\alpha = 30^o$, $\beta = 0^o$; ki = 4 – $\alpha = 30^o$, $\beta = 180^o$; ki = 5 – $\alpha = 45^o$, $\beta = 0^o$; ki = 6 – $\alpha = 45^o$, $\beta = 180^o$; ki = 7 – $\alpha = 60^o$, $\beta = 0^o$; ki = 8 – $\alpha = 60^o$, $\beta = 180^o$

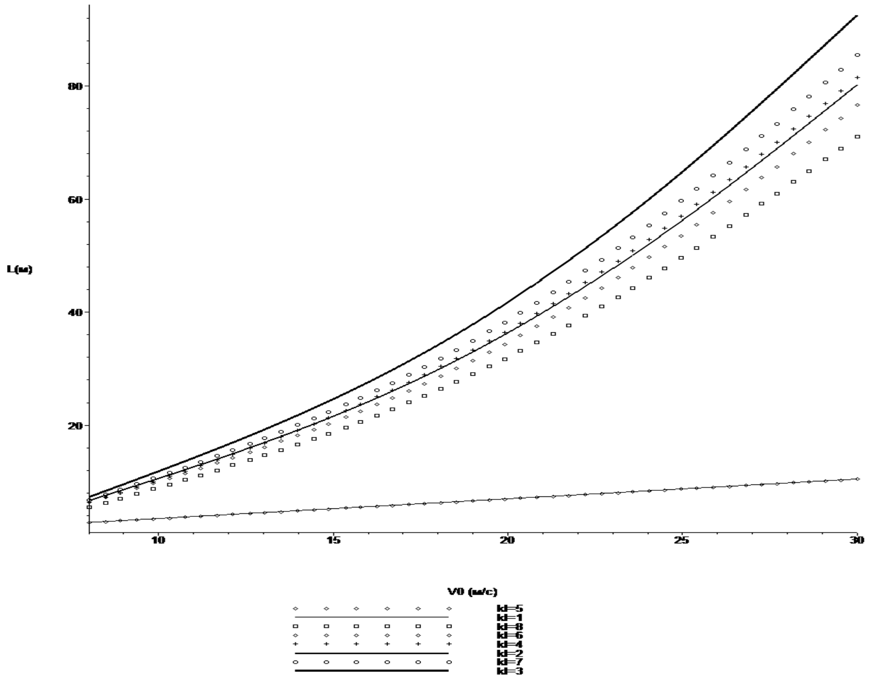

Fig. 9. Dependence of the flight range of a particle L on its initial velocity at $V_b = 30$ m/s: ki = 1 – $\alpha = 0^o$, $\beta = 0^o$; ki = 2 – $\alpha = 0^o$, $\beta = 180^o$; ki = 3 – $\alpha = 30^o$, $\beta = 0^o$; ki = 4 – $\alpha = 30^o$, $\beta = 180^o$; ki = 5 – $\alpha = 45^o$, $\beta = 0^o$; ki = 6 – $\alpha = 45^o$, $\beta = 180^o$; ki = 7 – $\alpha = 60^o$, $\beta = 0^o$; ki = 8 – $\alpha = 60^o$, $\beta = 180$

As can be seen from the graphs above, an increase in the speed of particle departure from the disk leads to an increase in their flight range. At the same time, a pattern of an increase in the flight range with an increase in the angle of particle departure from the disk is visible. At an angle $\alpha = 0^o$, the flight range in the studied speed range of 10…30 m/s is 5…8 m, at $\alpha = 60^o$ reaches its maximum.

The effect of wind directed in the direction of particle flight ($\beta = 0^o$) and against ($\beta = 180^o$), in the form of small sizes, is not clearly visible.

Fig. 10, 11 shows the influence of the initial angle of declination α_0 and the diameter of the particles on the range of their flight.

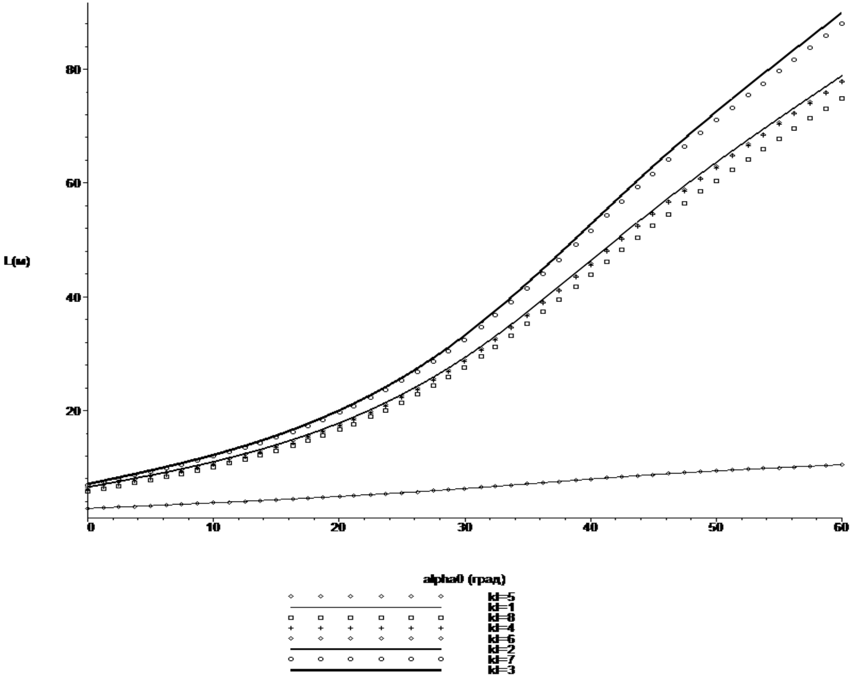

Fig. 10. Influence of the angle of convergence on the particle flight range L at $V_b = 8$ ***m/s :***
ki = 1 - $V_0 = 8$ ***m/s,*** $\beta = 0^o$***; ki = 5 –*** $V_0 = 8$ ***m/s,*** $\beta = 180^o$***; ki = 2 –*** $V_0 = 18$ ***m/s,*** $\beta = 0^o$***; ki = 6 –*** $V_0 = 18$ ***m/s,*** $\beta = 180^o$***; ki = 3 –*** $V_0 = 25$ ***m/s,*** $\beta = 0^o$***; ki = 7 –*** $V_0 = 25$ ***m/s,*** $\beta = 180^o$***; ki = 4 –*** $V_0 = 30$ ***m/s,*** $\beta = 0^o$***; ki = 8 –*** $V_0 = 30$ ***m/s,*** $\beta = 180^o$

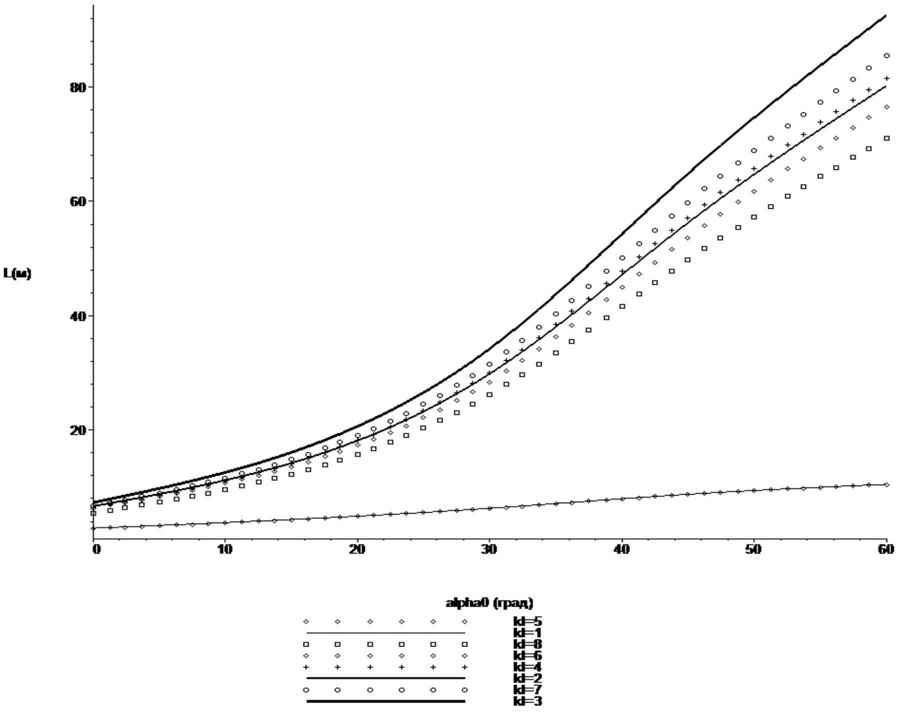

Fig. 11. Influence of the angle of departure α_0 ***on the flight range of particles L at*** $V_b = 30$ ***m/s :***
ki = 1 – $V_0 = 8$ ***m/s,*** $\beta = 0^o$***; ki = 5 –*** $V_0 = 8$ ***m/s,*** $\beta = 180^o$***; ki = 2 –*** $V_0 = 18$ ***m/s,*** $\beta = 0^o$***; ki = 6 –*** $V_0 = 18$ ***m/s,*** $\beta = 180^o$***; ki = 3 –*** $V_0 = 25$ ***m/s,*** $\beta = 0^o$***; ki = 7 –*** $V_0 = 25$ ***m/s,*** $\beta = 180^o$***; ki = 4 –*** $V_0 = 30$ ***m/s,*** $\beta = 0^o$***; ki = 8 –*** $V_0 = 30$ ***m/s,*** $\beta = 180^o$

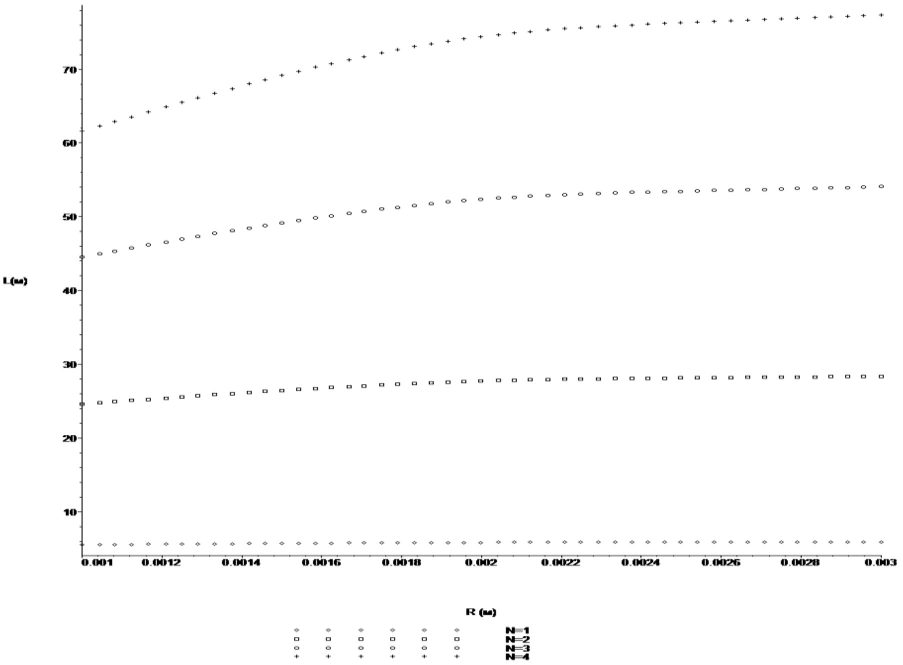

Fig. 12. Dependence of the flight range of a particle L on its radius R in the absence of wind ($V_b = 0$) and $\alpha_0 = 60^o$: $N = 1 – V_0 = 8$ m/s; $N = 2 – V_0 = 18$ m/s; $N = 3 – V_0 = 25$ m/s; $N = 4 – V_0 = 30$ m/s.

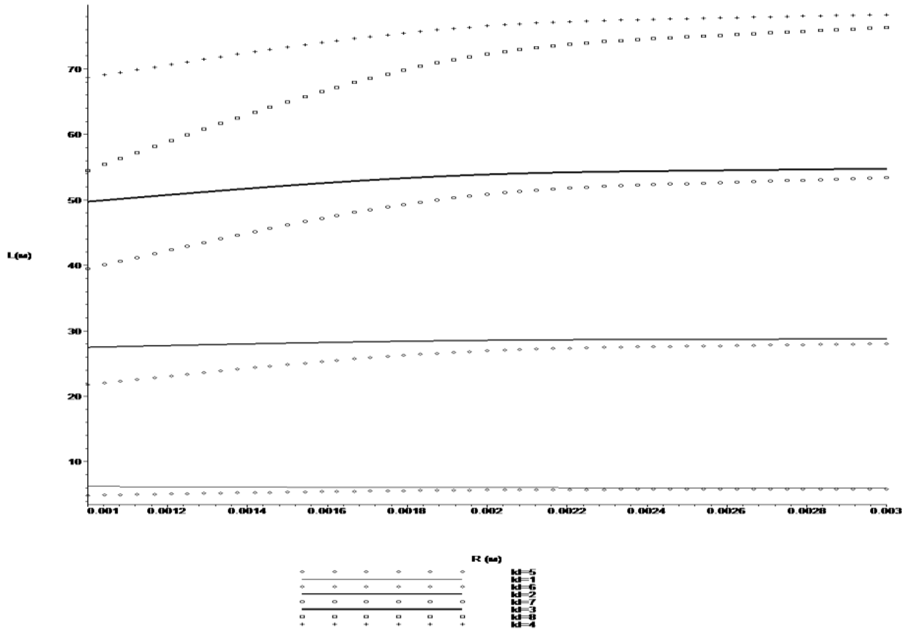

Fig. 13. Dependence of the flight range of a particle L on its radius R at $V_b = 8$ m/s and $\alpha_0 = 6\ 0^o$: ki = 1 – $V_0 = 8$ m/s, $\beta = 0^o$; ki = 5 – $V_0 = 8$ m/s, $\beta = 180^o$; ki = 2 – $V_0 = 18$ m/s, $\beta = 0^o$; ki = 6 – $V_0 = 18$ m/s, $\beta = 180^o$; ki = 3 – $V_0 = 25$ m/s, $\beta = 0^o$; ki = 7 – $V_0 = 25$ m/s, $\beta = 180^o$; ki = 4 – $V_0 = 30$ m/s, $\beta = 0^o$; ki = 8 – $V_0 = 30$ m/s, $\beta = 180^o$

From Fig. 10 and 11, the following conclusions can be drawn:

– increasing the angle of the particle's departure velocity vector from the disk increases the flight range in the entire studied velocity range;

– the wind direction does not significantly change the particle's flight range.

Fig. 12 and 13 show the influence of particle size (0.001...0.003 m) on their flight range at initial velocities of 8; 18; 25 m/s and the angle of the velocity vector of descent of 60°. From the above dependences (obtained under the assumption of the dependence of the medium resistance on the velocity of the first degree [1] it follows that in the range of real sizes of mineral fertilizer granules studied, their diameter slightly changes the flight range. To a greater extent, the flight range is determined by the initial velocity of the particles from the disk.

5. Conclusion

The analytical study established the key patterns of the influence of aerodynamic factors and structural -kinematic parameters on the trajectory and flight range of material particles (mineral fertilizer granules) during their descent from the centrifugal disc of the spreader. The results obtained confirm that the main determining parameters of the flight range are the initial velocity of the particle descent (V_0), the angle of the initial velocity vector to the horizon (α_0), as well as the velocity vector and wind direction (Vb , b).

In particular, it is shown that increasing the departure angle α_0 from 0° to 60° significantly increases the flight range in the entire studied range of initial velocities (8–30 m/s), providing maximum values of L for $\alpha_0 \approx 45–60°$. At the same time, in real granule sizes (radius R = 1–2.5 mm), the effect of particle diameter on the flight range turns out to be insignificant - the influence of V_0 and α_0 remains dominant.

Regarding the influence of the environment: at moderate wind speeds (up to 5–8 m/s), the drag coefficient (head) k and air viscosity have a limited effect on the trajectory and range, especially in the same direction. However, with a headwind or crosswind speed of 8 m/s and above, a noticeable reduction in range (up to 20–40% depending on the angle and V_0), asymmetry of the distribution and deformation of the trajectory are observed. Extreme values of Vb = 30 m/s lead to an almost horizontal "crushing" of the trajectory and a sharp drop in the efficiency of classical centrifugal scattering.

Thus, the analytical calculations and the construction of graphical dependencies allow us to conclude that it is necessary to optimize the parameters of the working elements of centrifugal spreaders taking into account real weather conditions . In particular, the rational choice of blade angles (45–60°), ensuring high but controlled V_0 values (about 20–30 m/s) and the implementation of adaptive control systems (for example, automatic change of disk rotations, the position of the fertilizer drop point or blade angles depending on wind sensor data in real time) makes it possible to significantly expand the working window of fertilizer application, maintain the distribution variation coefficient at ≤ 10–15% even under moderately adverse weather conditions and increase the overall efficiency of the units.

The obtained quantitative relationships can serve as a scientific basis for further improvement of disc spreader designs, development of adaptive control algorithms based on modern sensor systems and GPS correction, as well as refinement of agrotechnological regulations for surface application of mineral fertilizers in regions with unstable wind activity. This, in turn, will contribute to reducing fertilizer losses, increasing crop yields, and reducing the negative impact on the environment due to more accurate and economical fertilization.

References

1. Kobets, A. S., et al. (2010). Research on the movement of mineral fertilizer particles taking into account environmental resistance. *Bulletin of Petro Vasylenko Kharkiv National Technical University of Agriculture. Mechanization of Agricultural Production, 93*(2), 122–127. [in Ukrainian].
2. Pastukhova, V. I. (2001). *Handbook on the use of machinery in agriculture*. Vesna. [in Ukrainian].
3. Kovtun, Yu. V., & Netetsky, L. H. (2007). Statistical aspects of quality indicators in mechanized fertilizer application. *Scientific Works of Poltava State Agrarian Academy. Mechanization and Electrification of Agriculture, 6*(25), 65–68. [in Ukrainian].
4. Kravchuk, V. I., Hrytsyshyn, M. I., & Koval, S. M. (2004). *Modern trends in the development of agricultural machinery structures*. Agrarian Science. ISBN 966-540-089-4. [in Ukrainian].
5. Serilko, L. S., Lyashuk, O. L., Chasov, D. P., Serilko, D. L., & Ihnatiuk, R. M. (2025). Body movement along the surface of an inertial conveyor chute under combined friction. *Journal of Engineering Sciences, 12*(1), D1–D8. https://doi.org/10.21272/jes.2025.12(1).d1 [in English].
6. Vasilevskyi, O. M., Sevastianov, V. M., Ovchynnykov, K. V., Didych, V. M., & Burlaka, S. A. (2023). Accuracy of potentiometric methods for measuring ion activity in solutions. In *Lecture Notes in Networks and Systems* (Vol. 447, pp. 181–190). Springer. https://doi.org/10.1007/978-981-19-1607-6_16 [in English].
7. Yaropud, V., Aliiev, E., Mazur, I., & Burlaka, S. (2023). Simulating the process of operation of a vortex layer electromagnetic apparatus with ferromagnetic working elements. *Przegląd Elektrotechniczny, 99*(9), 64–71. https://doi.org/10.15199/48.2023.09.11 [in English].

8. Tokarchuk, O., Mytko, M., Burlaka, S., Zozulyak, I., & Stadnik, M. (2025). Comparison of technological operations in processing alfalfa hay in terms of their impact on forage quality and quantity. *Technology Audit and Production Reserves, 2*(3(82)), 43–51. https://doi.org/10.15587/2706-5448.2025.326047 [in English].

АНАЛІТИЧНІ ДОСЛІДЖЕННЯ ВПЛИВУ РІЗНИХ ФАКТОРІВ НА ДАЛЬНІСТЬ ПОЛЬОТУ МАТЕРІАЛЬНИХ ЧАСТОК ПРИ ЗЛЬОТІ ІЗ ДИСКУ РОЗКИДАЧА МІНЕРАЛЬНИХ ДОБРИВ

У статті представлено ґрунтовний аналіз сучасного стану розробок у сфері машин і механізмів для поверхневого внесення мінеральних добрив - технологічного процесу, який залишається одним із ключових у сучасному землеробстві, але водночас надзвичайно чутливим до зовнішніх умов.

Особливу увагу приділено фізиці руху частинок добрив у повітряному середовищі. Досліджено, як коефіцієнт аеродинамічного опору (коефіцієнт напору Cx), в'язкість повітря, розмір, форма, щільність гранул та їх початкова швидкість визначають траєкторію польоту. Показано, що навіть невелике зростання швидкості вітру суттєво змінює картину: зустрічний вітер скорочує дальність викиду, боковий - викликає сильну асиметрію розподілу, а попутний може створювати надмірне перекидання матеріалу за межі робочої зони. У результаті коефіцієнт варіації розподілу різко зростає, що призводить до перевитрат добрив у одних зонах поля та їх дефіциту в інших, знижуючи загальну ефективність підживлення та підвищуючи ризик нерівномірного розвитку рослин.

Окремий розділ присвячено кількісному опису впливу вітру. Зокрема, наведено дані, що при швидкості вітру 4–6 м/с дальність польоту частинок може зменшуватися на 15–40 % залежно від напрямку, а при 8 м/с і більше якісне внесення класичними дисковими розкидачами стає практично неможливим без спеціальних заходів компенсації.

Саме тому значна частина роботи присвячена сучасним технічним рішенням, які дозволяють мінімізувати або майже повністю нейтралізувати негативний вплив погоди. Серед них - система WindControl від компанії Amazone, що працює в парі з датчиками Argus Twin або самостійно: високочастотний ультразвуковий сенсор вітру в реальному часі фіксує швидкість і напрямок, після чого бортовий комп'ютер автоматично коригує кут нахилу лопатей, частоту обертання дисків або положення дефлекторів, підтримуючи задану ширину і рівномірність розподілу навіть за помірно сильного вітру (до 8–10 м/с).

Також розглядаються альтернативні підходи: пневматичні штангові розкидачі з регульованими форсунками, багатодискові системи з нижчою початковою швидкістю викиду (що зменшує чутливість до бокового зносу), GPS/RTK-системи з електронними картами завдання норми внесення та автоматичним секційним відключенням, а також гібридні конструкції, що поєднують відцентровий принцип з контрольованим пневматичним транспортуванням.

Ключові слова: *мінеральні добрива, розкидач добрив, дальність польоту частинок, траєкторія руху частинок, вплив вітру, опір повітря, розподіл добрив, ефективність внесення.*

Рис. 13. Табл. 1. Літ. 8.

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