I-EDU GROUP

Article

Theoretical analysis of wind influence in aerial seeding

Shohruh Muhiddinov [1]*

[1] Doctoral student, Samarkand Agroinnovations and Research University, Samarkand, Uzbekistan
* Correspondence: shohruhmuhiddinov432@gmail.com

Abstract: This study is devoted to a theoretical assessment of the influence of wind on the restoration of pastures by means of drones that deliver seed-bearing clay balls (mudballs). The effect of the wind flow on the aerial trajectory of a mudball released from a quadcopter is examined for three cases: wind blowing in the direction of flight, against it, and from the side. The results show how the wind alters the trajectory and how far the landing point of the ball departs from the intended spot as the wind speed grows.

Keyword: quadcopter; mudball; aerial sowing; wind action; trajectory.

Quoting: Sh. Muhiddinov. Theoretical analysis of wind influence in aerial seeding. **2026**, 4, 1, 9. https://doi.org/10.35938/AY-2026-4-00009

Received: 10.10.2026
Corrected: 18.10.2026
Accepted: 05.11.2026
Published: 25.11.2026

Copyright:

OPEN ACCESS

Check for updates

CC BY

1. Introduction

The use of unmanned aerial vehicles for sowing seeds in forest and pasture restoration, as well as in crop production, is receiving increasing attention. In areas with uneven terrain that are difficult for ground machinery to access, the capabilities of mechanized methods are limited, while aerial seeding provides a way to overcome these constraints [1–3]. Existing developments have mainly addressed uniform seed distribution through various types of metering and spreading devices. At the same time, technologies for aerially distributing seeds directly to improve pastures are available [4], and projects aimed at sowing seed-bearing mudballs using drones have also been implemented [5,6]. However, if the effect of wind is not taken into account during aerial seeding from a specified height, seeds may fail to land at the intended points and may instead become unevenly distributed across the area. Although wind is invisible, it can deflect a mudball moving through the air from its intended path; therefore, quantitatively assessing its effect is a central part of this problem.

The aim of this article is to seek a solution to the above problem through mathematical modeling that accounts for wind: the trajectory of a mudball is analyzed under three wind directions-along the direction of flight, opposite to it, and from the side-and the displacement of its landing point is evaluated.

2. Materials and Methods

A quadcopter-type drone equipped with a sowing device mounted underneath it was used as the aerial seeding system. The device releases seed-bearing mudballs uniformly at specified time intervals; its metering unit is a rotary-disc type, which is widely used due to its simplicity [7,8], and is not examined in detail in this article. To assess the effect of wind, analyses were carried out at different constant drone speeds and at a flight height of up to 5 m, while the mudball was treated as a body falling freely in the wind flow.

The spherical mudball has a diameter of d = 15 mm and an approximate mass of m = 5 g. These dimensions were selected to provide aerodynamic stability of the ball while maintaining the payload mass. It should be noted that airflow can have a considerable effect even on an object with such a small mass.

The motion of each mudball after it separates from the device is described by an inertial equation, in which the ball is acted upon by gravity and the wind force [9]:

$$m\frac{dv_n}{dt} = F_g \pm F_w, \quad (1)$$

where $-v_n$ is the relative velocity of the mudball, m/s; $-F_g$ is the weight (gravitational force) acting on the mudball; and $-F_w$ is the force exerted by the wind in the vertical direction on the mudball released into the air.

The $\pm$ sign in the equation indicates the direction of the wind force relative to the mudball's motion in the vertical direction: the vertical wind may be directed upward or downward.

The force with which wind acts on an object depends on its frontal area, the aerodynamic drag coefficient, and the wind speed, and is determined using the following expression [10]:

$$F_w = \frac{1}{2}\rho C_D A v_w^2, \tag{2}$$

where ρ is the air density, 1.22 kg/m^3; C_D is the aerodynamic drag coefficient (0.65 for the clay ball); A is the frontal area of the mudball with a diameter of 15 mm, m^2; and v_w is the wind speed, m/s.

As can be seen from the formula, the wind force is proportional to the square of its speed: if the wind speed doubles, the force exerted by the wind on the mudball increases approximately fourfold. In addition, this force increases as the frontal area of the ball increases.

The equation of motion of the mudball after it separates from the device can be determined using the following system of equations:

$$\begin{cases} x = v_x t \\ y = \frac{1}{2} g t^2 \end{cases} \tag{3}$$

By eliminating time from the system, we obtain the general function of the trajectory:

$$y = \frac{g}{2v_n^2} x^2 \tag{4}$$

The formula for determining the deviation of the mudball from its intended landing point in the horizontal plane under the influence of wind is:

$$\Delta x = \frac{1}{2} a_x t^2, \tag{5}$$

where Δx – is the deviation relative to the x-axis, and a_x – is the acceleration imparted to the mudball by the wind, which is determined as follows:

$$a_x = \frac{F_w}{m}, \tag{6}$$

Substituting formulas (2) and (5) into (6) and simplifying gives the general formula for determining the deviation – Δx.

$$\Delta x = \frac{\rho C_d A v_w^2 h}{2 m g}, \tag{7}$$

If the wind blows in the direction of the mudball released from the drone (in the same direction or in the opposite direction), the formula for determining its deviation is as follows:

$$\Delta x = \frac{\rho C_d A (v_{sh} \pm v_d)^2 h}{2 m g} \tag{8}$$

where is v_d the drone speed, which is equal to the horizontal velocity of the mudball along the x direction (x-axis) at the moment of release ($v_d = v_x$).

3. Analysis and Results

Figure 1 presents a 3D graph of the trajectories of seed-bearing clay balls released from a height of 5 m under the influence of crosswind. The drone flight speed was set at three values: 0, 5 and 10 m/s. The crosswind speed was examined at 5, 10 and 15 m/s. The colors in the graph represent the drone speed, while the line styles represent the wind speed.

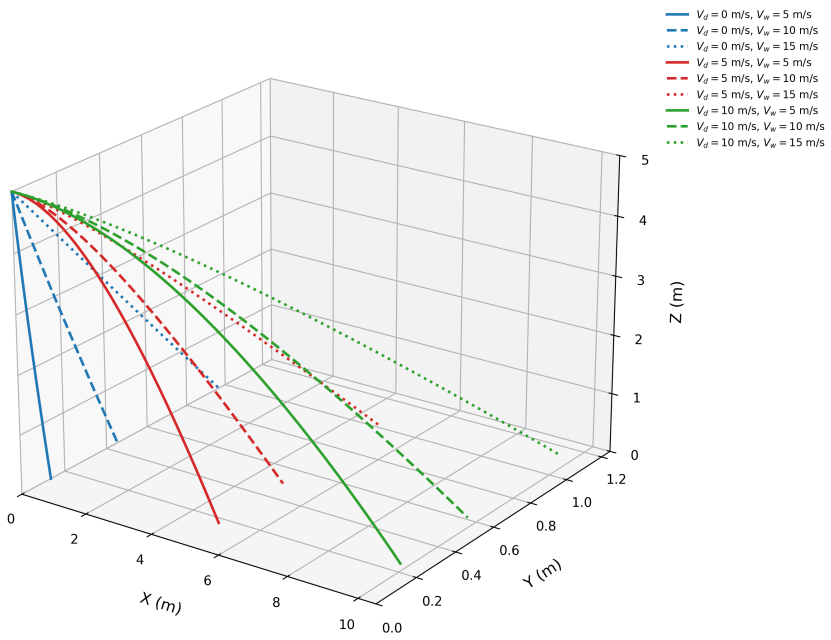


Figure 1. Trajectories of the mudball at different wind speeds when released from point (0;0;5). Parameters: d=15 mm, m=5 g, h_0=5 m.

The graph shows that crosswind has a significant effect on the trajectory of seed-bearing clay balls. As wind speed increases, the lateral displacement of the balls along the y-axis also increases. In particular, an increase in wind speed from 5 m/s to 15 m/s increases the lateral displacement distance of the balls.

Using the formulas above, the parameters of the mudball at different drone and crosswind speeds are presented below:

Table 1. Mudball Deflection at Different Wind and Drone Speeds

No.	v_d (m/s)	v_w (m/s)	Deviation Δx (m)	Distance from the initial point Δs (m)	Impact velocity v_n (m/s)
1	0	5	0.168	0.77	8.76
2	0	10	0.552	2.42	9.33
3	0	15	1.121	4.84	11.00
4	5	5	0.168	5.24	10.09
5	5	10	0.552	6.09	10.81
6	5	15	1.121	7.87	12.37
7	10	5	0.168	9.88	12.09
8	10	10	0.552	10.47	13.30
9	10	15	1.121	11.41	14.39

Table 1 shows that when the wind blows from the side (perpendicularly), the distance of deviation from the x-axis is not related to the drone speed; that is, the two horizontal components of the mudball velocity are determined separately. The overall deviation in the table Δs is the distance between the ground projection of the point (0; 0; 0), corresponding to the mudball's release from the hopper, and its landing point. The relative velocity column represents the impact velocities at the ground.

The graph below shows the trajectory of a mudball released from a stationary drone at three different wind speeds. In this case, h_0 = 5 m, the drone speed v_d = 0 and the graph was obtained using formula (8) for three wind speeds of 5; 10 and 15 m/s along the x-axis:

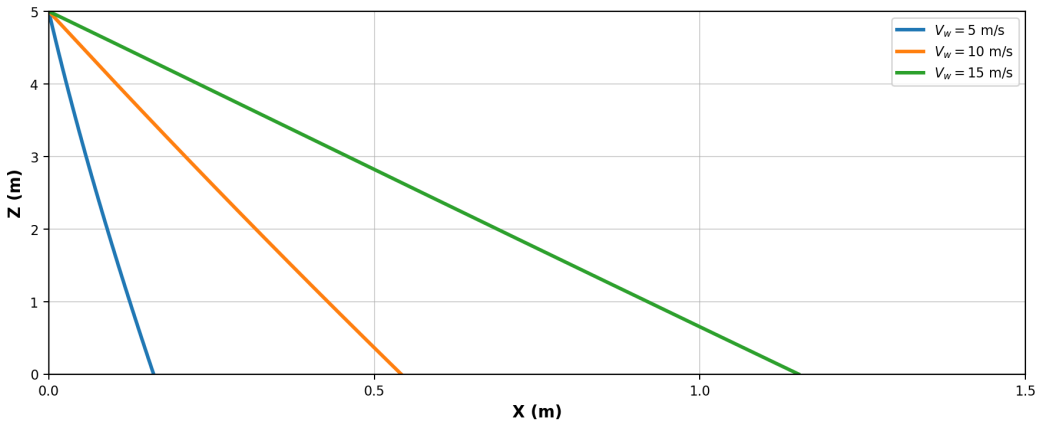


Figure 2. Trajectories of the mudball when released with zero initial velocity under different wind speeds.

4. Conclusion

Based on the theoretical analysis, the following conclusions can be drawn. The trajectory and landing position of a seed-bearing mudball released from a quadcopter are affected by wind direction and wind speed. When the wind acts from the side, the lateral deviation along the y-axis increases as wind speed rises from 5 m/s to 15 m/s. According to Table 1, the lateral deviation values are 0.168 m, 0.552 m and 1.121 m for wind speeds of 5 m/s, 10 m/s and 15 m/s, respectively; these values are the same for the considered drone speeds of 0; 5 and 10 m/s. The total distance from the initial ground point to the landing point increases with both drone speed and crosswind speed in the presented calculation results. For a stationary drone, the reported total deviations are 0.77 m, 2.42 m and 4.84 m at wind speeds of 5 m/s, 10 m/s and 15 m/s, respectively. The corresponding impact velocities are 8.76 m/s, 9.33 m/s and 11.00 m/s. When planning aerial sowing with seed-bearing mudballs, both wind speed and wind direction should be considered to estimate the landing point and reduce deviation from the intended sowing location.

References

[1] Ergashev I.T., Islomov Y.I., Tashtemirov B.R., Pardaev K.K. Combined tool for improving arid pastures. In E3S Web of Conferences, EDP Sciences, 390 (2023).
[2] Ergashev, I.T., Tashtemirov, B.R., Muxiddinov, Sh.X., & Avazov, S.A. (2026). Urug‘larni aralash usulda ekuvchi uchuvchisiz uchish qurilma [An unmanned aerial vehicle for mixed-method seed sowing]. O‘zbekiston qishloq va suv xo‘jaligi, (4), 48–49. (in Uzbek).
[3] Ergashev I.T., Islomov Y.I., Tashtemirov B.R. Restoring degraded arid pasture in Uzbekistan. European science review, (1-2), 187-189 (2017).
[4] Liu, W. et al. Disc spreader/discharge studies for UAV application. Computers and Electronics in Agriculture, 2023.
[5] Xunwei, W. et al. Distribution uniformity improvement methods of a large-load UAV spreader. Computers and Electronics in Agriculture, 2024.
[6] Ergashev, I., Pardayev, X., & Muxiddinov, Sh. (2025). Cho‘llarda o‘simliklar xilma-xilligini saqlashda “mudball” texnologiyasining ahamiyati [The importance of mudball technology in preserving plant diversity in deserts]. Agro ilm, Special Issue 6 [115], 452–454. (in Uzbek).
[7] Griffiths J.W. Viability of seed balls for large-scale restoration. New Zealand Journal of Botany, 2025.
[8] Great Basin Fire Science Exchange. They Pulled Off a Drone Seeding — And Trees Grew // Project brief, 2022.
[9] White F.M. Fluid Mechanics. McGraw-Hill // Purdue University notes: Lift and Drag reading 2021.
[10] John D.A. Fundamentals of Aerodynamics. New York-2017.

Disclaimer of liability/Publisher’s Note: The statements, opinions and data contained in all publications belong exclusively to individuals.The authors and participants, and the editors. The journal and the editors are not responsible for any damage caused to people or property resulting from any ideas, methods, instructions or products mentioned in the content.