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The Effect of Nozzle Type and Height on the Performance of the Ferto-15 Drone

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ABSTRACT

The efficiency of agricultural spraying drones heavily relies on hardware selection, such as nozzles, and operational parameters like flight height, which creates a trade-off between spray coverage and drift. This study aimed to analyze the effect of three nozzle types (flat fan, even fan, cone) and three flight heights (2 m, 2.5 m, and 3 m) on spray area, drift, efficiency, and uniformity (CU and DU) on the Ferto-15 drone. The research method employed a Completely Randomized Design (CRD) under static and dynamic test conditions, with spray volume data collected using catch cans. The results indicated that flight height was the most dominant factor; increasing height expanded the spray area but increased drift and decreased efficiency in dynamic tests. Nozzle type and its interaction with height had a pronounced effect under dynamic conditions, where the Flat-Fan nozzle consistently produced the most superior distribution uniformity (CU and DU). The main conclusion shows that the most optimal configuration was the use of the Flat-Fan nozzle at a 2-meter height, which provided the best balance between high deposition efficiency (95.89%), low drift (0.411 L), and superior uniformity (CU 89.89%). This finding demonstrates that achieving effective spraying performance depends on the synergistic combination of nozzle type and flight height.

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1. INTRODUCTION

Modern agricultural technology plays a crucial role in addressing the challenges of improving efficiency and productivity in global agriculture, particularly in the face of limited land, labor shortages, and climate change. One sector that is greatly influenced by technological advancements is crop protection, where the efficiency of pesticide use and the effectiveness of pest control serve as key indicators of production success. Innovation in agricultural mechanization, especially in liquid application systems such as pesticides and fertilizers, is highly needed to increase yields while reducing losses caused by plant pests and diseases (FAO, 2021).

In recent years, the use of agricultural drones or unmanned aerial vehicles (UAVs) has experienced rapid development, particularly in the application of liquid pesticides and fertilizers. Spraying drones offer various advantages compared to conventional methods, including time efficiency, reduced labor requirements, and improved precision in the spatial application of chemicals. In addition, drones can also reduce operators' direct exposure to hazardous chemicals and minimize environmental pollution through more controlled spray volume management. The adoption of this technology has become one of the leading approaches in precision agriculture systems, especially in countries facing high food demand pressures (Bolat & Özlüoymak, 2020).

One type of spraying drone widely used in Indonesia is the Ferto-15 Drone, developed with a tank capacity of around 15 liters and equipped with a multi-nozzle spraying system. This drone is designed to perform spraying at adjustable speeds and altitudes depending on field conditions. Several technical features such as automatic GPS, altitude sensors, and stable flight speed make the Ferto-15 Drone a preferred option for medium to large-scale pesticide applications. According to factory specifications, this drone has a horizontal spraying range of up to ±5 meters and can operate at altitudes of 1.5 to 3 meters above the crop canopy (PT Buaya Aerotech, 2022).

Quantitatively, the performance of a spraying drone is measured through dependent variables that determine the effectiveness and efficiency of application. These crucial variables include droplet deposition (droplet density per unit area), droplet distribution uniformity, effective swath width, and spray drift level (the percentage of liquid failing to reach the target). Inaccurate measurements or suboptimal settings of these variables will directly lead to wasted inputs, reduced efficacy of pest control, and increased risks of environmental contamination (Thạch & Vũ, 2022).

This study focuses on analyzing the effects of two critical independent variables in spraying operations: nozzle type and flight altitude. Nozzle type directly influences output variables such as droplet size and spectrum, which in turn affect the spray pattern. Meanwhile, flight altitude has a strong causal relationship with coverage width and spray drift potential. Inappropriate altitude will result in non-uniform distribution data and high levels of losses (Wang et al., 2022).

Although many studies have examined the operational parameters of spraying drones, there remains a lack of empirical data and statistical analyses specific to the Ferto-15 model under Indonesia's agroclimatic conditions. Existing recommendations are often general in nature and not based on quantitative evaluation specific to the Ferto-15 drone.. This gap highlights the urgent need for quantitative research to model the relationship between nozzle type and flight altitude with spraying performance variables.

Therefore, this study aims to quantitatively evaluate the effects of these two operational variables and their interaction in order to produce evidence-based recommendations for optimizing the performance of the Ferto-15 drone.

2. MATERIALS AND METHODS

2.1. Experimental Design and Environmental Conditions

This study employed a factorial Completely Randomized Design (CRD) to evaluate the operational performance of the Ferto-15 spray drone. The experiments were conducted in Sleman, Yogyakarta (October–December 2024), in an open field where microclimate conditions were strictly monitored using a digital anemometer. Air temperature was maintained between 25.3–28.7 °C, with relative humidity of 73–93% and low wind speeds (1–2 m/s) to minimize external bias on droplet movement.

2.2. Instrumentation and Operational Parameters

The primary research object was a Ferto-15 Unmanned Aerial Vehicle (UAV) with a 15-liter tank capacity. The evaluation focused on three nozzle types (flat fan, even fan, and cone nozzle) integrated with three flight heights (2 m, 2.5 m, and 3 m). Fresh water was used as a pesticide substitute to physically measure spray volume distribution.

Figure 1. Drone Ferto-15

Table 1. Specifications of the Ferto-15 Drone.

Specifications	Description
Productivity	+/- 6 ha/hour
Number of Rotors	6
Tank Capacity	15 L
Battery	16.000 mAh
Spray Width	3-4 Meters
Number of Nozzles	4
Cruising Speed	2-6 m/s

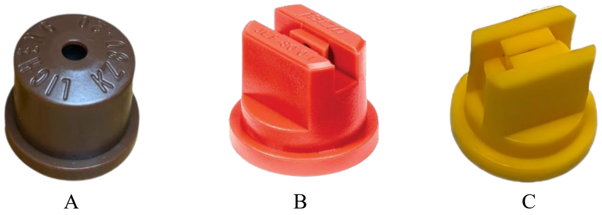


Figure 2. The nozzles used were: (A) Cone Nozzle, (B) Flat Fan Nozzle, (C) Even Fan Nozzle

2.3. Data Acquisition Procedures

Spray distribution was measured through two testing scenarios: static (hovering) and dynamic (linear spray simulation). A total of 25 catch cans were arranged in a 5x5 grid matrix within the target area to capture the liquid volume. During each flight pass, the captured volume was quantified to calculate the effective coverage area and the volume of liquid lost or failing to reach the target (drift).

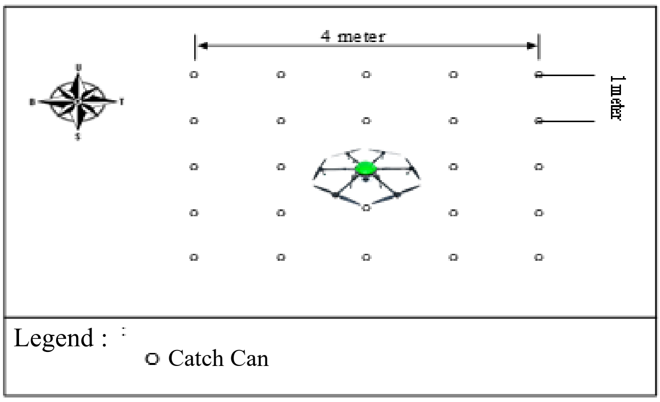


Figure 3. Sketch of the Ferto-15 Drone Static Test.

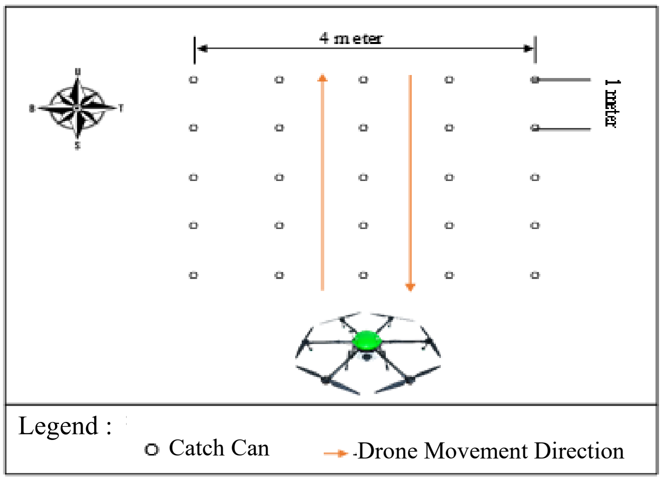


Figure 4. Sketch of the Ferto-15 Drone Dynamic Test.

2.4. Quantitative Analysis and Optimization

2.4.1. Spray Drift and Deposition Efficiency

Spray drift is a critical parameter as it represents both application inefficiency and a potential risk for environmental contamination (Teske et al., 2019). In this study, drift was quantified by calculating the difference between the total volume discharged by the nozzle and the volume successfully captured by the collectors. Deposition efficiency was subsequently determined as the percentage of liquid volume deposited within the target area, serving as a primary indicator of operational success (Pan et al., 2016). These parameters were calculated using the following mass balance equations:

$$\text{Drift} = V_{\text{initial}} - V_{\text{collected}} \qquad (1)$$

$$V_{\text{collected}} = A \times d \qquad (2)$$

Where Vinitial is the total volume emitted (L) and Vcollected is the volume captured in the catch cans (L).

2.4.2. Coefficient of Uniformity (CU) and Distribution Uniformity (DU)

CU and DU are standard metrics employed to measure the homogeneity of liquid distribution. While CU provides a general overview of deposition variation across the target area, DU specifically evaluates performance in areas with the lowest deposition (ASAE Standards, 2015). Maintaining high uniformity is crucial to prevent phytotoxicity caused by excessive dosing and to avoid pest control failure or resistance development in under-sprayed areas (Wu et al., 2022).

The Coefficient of Uniformity (CU) was determined using Christiansen's formula:

$$\mathrm{CU} = 100\% \times \left(1 - \frac{\Sigma|x_i - x|}{\Sigma x_i}\right) \qquad (3)$$

Where CU (Coefficient of Uniformity (%)), xi (Volume of each measured catch can), x (Average volume of the catch cans measured.

Distribution Uniformity (DU) was determined using the following formula:

$$\mathrm{DU} = \frac{\frac{1}{4} \times \text{average of the lowest volume values}}{\text{average of the collected volume values}} \times 100 \qquad (4)$$

Where DU = Distribution Uniformity (%).

2.4.3. Multi-Criteria Analysis (Simple Additive Weighting - SAW)

To identify the optimal operational configuration, a Multi-Criteria Decision Analysis (MCDA) approach was used to manage the trade-offs between conflicting objectives, such as minimizing drift while maximizing uniformity. The Simple Additive Weighting (SAW) method was selected for its conceptual simplicity and computational efficiency (Triantaphyllou, 2000).

Criteria Weights, the weights of the criteria were determined based on priority, where Distribution Uniformity and Coefficient of Uniformity were considered more important and thus assigned a weight of 0.30. Drift and Efficiency were then assigned a weight of 0.20.

Normalization of the Decision Matrix (R)

1. For benefit criteria:

$$r_{ij} = \frac{x_{ij}}{\max(x_{ij})} \qquad (5)$$

2. For cost criteria:

$$r_{ij} = \frac{\min(x_{ij})}{x_{ij}} \qquad (6)$$

3. Preference Value Vi: The final ranking was obtained by:

$$V_i = \sum_{j=1}^{n} (w_j \times r_{ij}) \qquad (7)$$

Where rij (normalized value of alternative i on criterion j), xij (actual value of alternative i on criterion j)

2.4.4. Quadratic Regression Analysis

A quadratic regression model was utilized to capture non-linear relationships and determine the mathematical "turning point" of the performance curves, which represents the optimal altitude (Gujarati, 2009). This analysis provides a dynamic insight into how variables respond to changes in flight height:

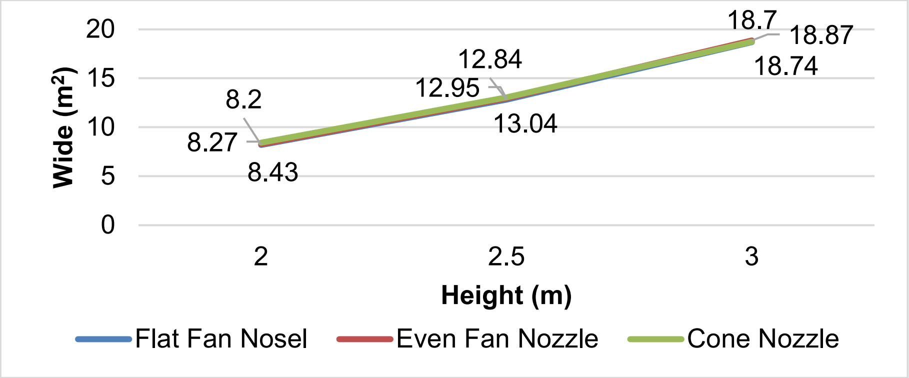
$$Y = ax^2 + bx + c + \epsilon \qquad (8)$$

Where Y represents the dependent variables (drift, efficiency, CU, or DU), X is the independent variable (altitude), and a, b, c are the regression coefficients estimated from the research data.

3. RESULTS AND DISCUSSION

3.1 Spray Coverage

The effective spray area is a fundamental parameter that determines the field capacity of a spraying drone. The analysis of this parameter aims to understand how nozzle configuration and altitude influence the drone's working range, which directly affects the speed of task completion in the field. The spray area was measured by assessing the wetted area during spraying.



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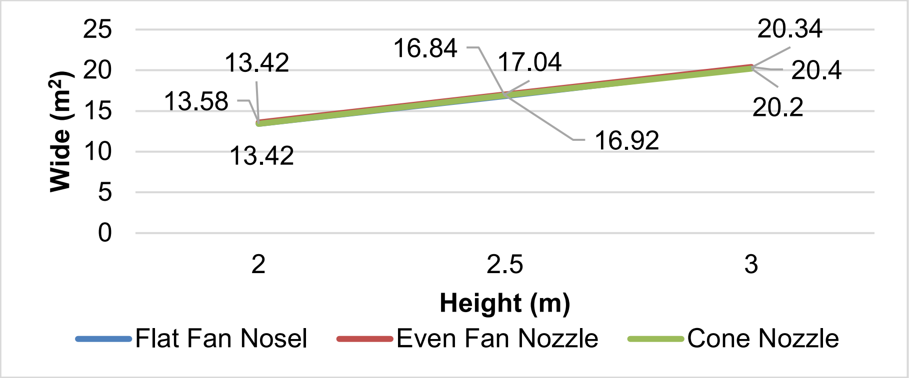


(b)

Figure 5. Spray Coverage Area (m²) in Static Test (a) and Dynamic Test (b) Based on Nozzle Type and Altitude

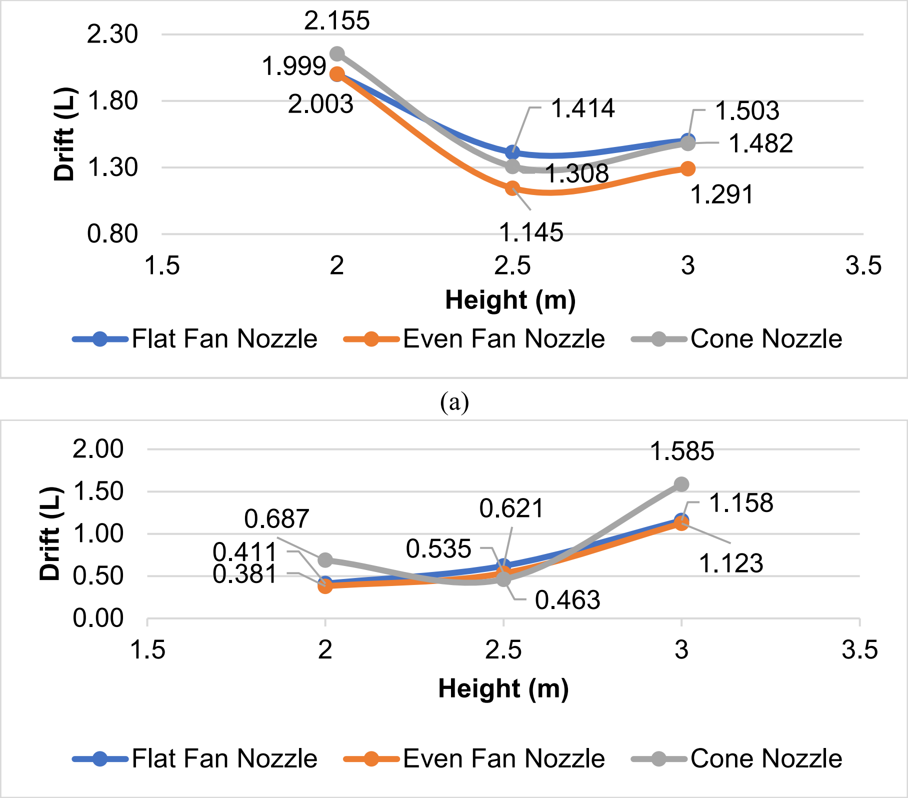
The static test results showed that flight altitude strongly influenced the spray coverage area. The higher the drone was operated, the wider the coverage area became, since the spray droplets had more time to spread laterally before reaching the target surface. However, the differences among nozzle types under static conditions were not very pronounced, as airflow was only influenced by the rotors without interaction from the drone's forward movement. These findings are consistent with Pan et al. (2016), who emphasized that increasing flight altitude tends to expand droplet spread, although it may affect the uniformity of spray distribution.

In the dynamic test, the spray coverage area increased more markedly compared to static conditions. This was due to the translational effect of the drone while moving forward, which pushed the spray pattern laterally, thereby expanding the coverage width. Moreover, the interaction between rotor downwash and the drone's forward motion created a broader spread than in the static test. Under these conditions, nozzle type began to play an important role, with the flat-fan nozzle producing a relatively more uniform spread compared to the cone nozzle. This phenomenon is supported by Qin et al. (2016), who explained that dynamic testing better reflects field conditions, as the combination of drone translation and rotor airflow significantly broadens the effective swath.

Overall, the results indicated that increasing flight altitude expanded the spray coverage area under both static and dynamic conditions, but the effect was more pronounced under dynamic conditions due to the combination of drone translation and rotor downwash airflow. In terms of nozzle comparison, the flat-fan nozzle produced a relatively stable and uniform coverage, the even-fan nozzle provided fairly good coverage though with less consistent distribution, while the cone nozzle tended to produce a narrower spread with finer droplets that were more easily influenced by wind. The consistency of these results with spray aerodynamics theory reinforces the argument (Pan et al., 2016; Qin et al., 2016) that the interaction among altitude, flight dynamics, and nozzle design is a determining factor of effective spray width.

3.2 Drift

Drift management is one of the fundamental pillars of responsible and efficient aerial spraying applications, as it not only determines economic losses but also ecological impacts. The analysis of this parameter aims to identify the most effective operational combinations for minimizing spray losses to non-target areas.



(a)

(b)

Figure 6. Spray Drift (L) in Static Test (a) and Dynamic Test (b) Based on Nozzle Type and Altitude

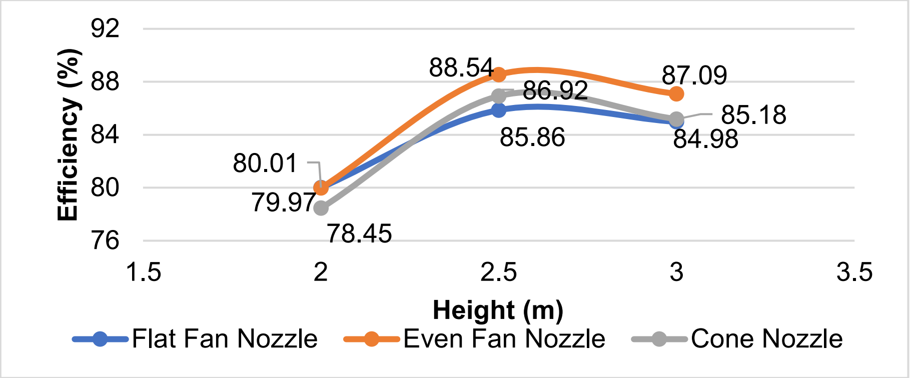
Under static conditions, the results showed that drift did not always decrease with lower altitude. In fact, at the lowest altitude, drift values were relatively high due to strong turbulence from rotor downwash rebounding off the ground surface and pushing droplets outside the target area. This phenomenon caused part of the spray to exit the capture zone even though the drone was stationary. This condition is consistent with the findings of Zhang et al. (2022), who stated that rotor airflow patterns in hovering mode tend to generate turbulent vortices around the drone, leading to unstable droplet distribution. This explains why drift can still be considerable at low altitudes even when the drone is not moving.

Under dynamic conditions, drift patterns were more consistent: the higher the drone was operated, the greater the volume of spray lost outside the target area. The forward motion of the drone actually helped suppress drift at low altitudes because translational airflow stabilized the spray pattern and pushed droplets downward. However, as altitude increased, droplet energy decreased before reaching the target, making them more easily carried away by wind. The analysis indicated that at low altitudes, the even-fan nozzle performed best in minimizing drift, whereas the cone nozzle consistently produced the highest drift values at all altitudes because the fine droplets it generated were highly susceptible to air currents. These findings are consistent with Wang et al. (2023), who emphasized that nozzles producing fine droplets carry a high risk of increasing drift, particularly when combined with higher flight altitudes.

Overall, the comparison between static and dynamic tests highlighted the important role of drone forward motion in stabilizing spray airflow. Drift in static tests tended to be higher at low altitudes due to rotor turbulence, whereas under dynamic conditions, drift increased sharply with rising altitude. Comparing nozzle types showed that the even-fan nozzle was most effective in reducing drift at low altitudes, the flat-fan nozzle provided relatively stable results across different altitudes, while the cone nozzle performed the worst due to producing fine droplets prone to drift. These findings reinforce the theory of Delpuech et al. (2022), which stated that lowering flight altitude is the most effective strategy for drift mitigation, and support Biglia et al. (2022), who asserted that nozzle selection is the primary factor in reducing spray loss. Thus, the best drift control strategy is to operate drones at low altitudes using flat fan or even-fan nozzles, depending on whether the priority is spray stability or distribution uniformity.

3.3 Spraying Efficiency

Spraying efficiency is a key benchmark of application success, representing how much input effectively reaches the target. Low efficiency indicates that the active ingredient dose received by the plants falls below the required threshold, which can lead to crop failure or wasted resources.



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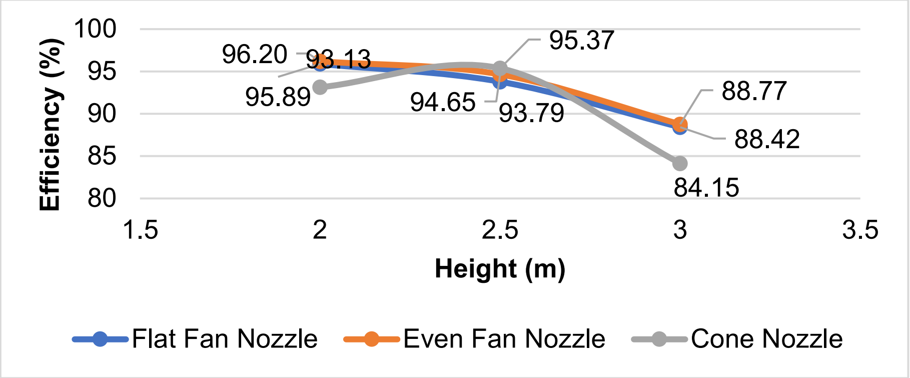


(b)

Figure 7. Spraying Efficiency in Static Test (a) and Dynamic Test (b) Based on Nozzle Type and Altitude

In static conditions, spraying efficiency did not show a simple decreasing trend with increasing height. Efficiency was lowest at 2 m and increased at 2.5 m, likely due to reduced near-ground turbulence and more complete capture within the collector grid, before declining slightly at 3 m. This non-linear pattern was consistent across all three nozzle types, although differences among nozzle types under static conditions were not very pronounced. This indicates that without the effect of translational motion, height influenced efficiency in a more complex manner than a simple distance effect. This pattern only partially aligns with Pan et al. (2016), who reported that increasing altitude tends to reduce droplet deposition on the target; in the present static tests, the relationship between height and efficiency was non-monotonic across the tested range.

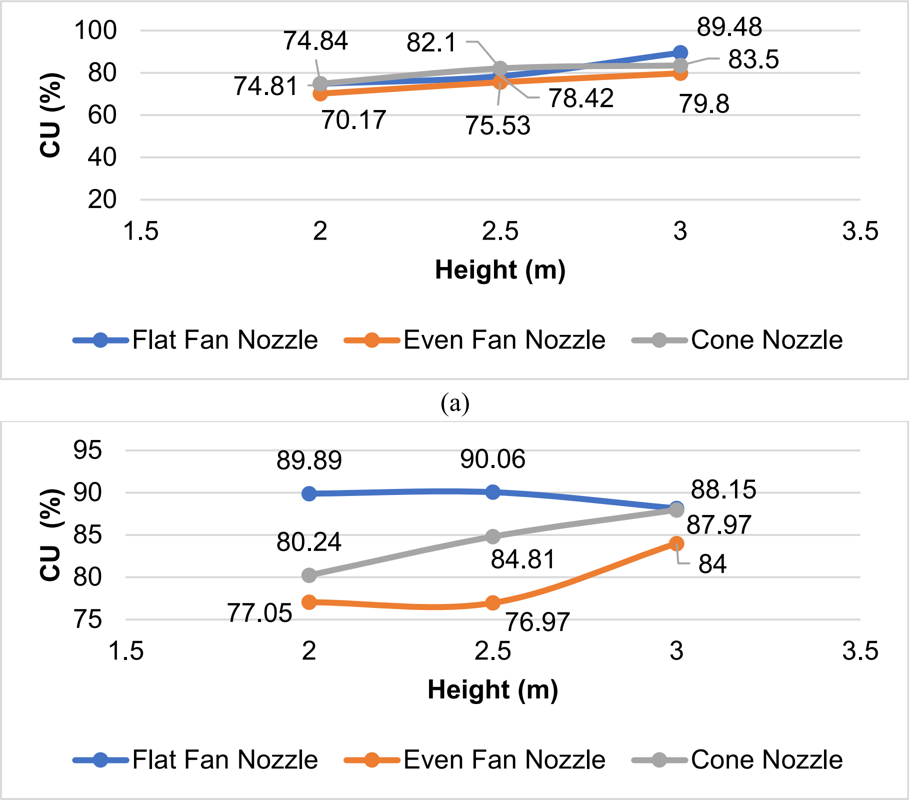
The dynamic test results show a strong inverse relationship between flight altitude and spraying efficiency. At an operational height of 2 m, the highest deposition efficiency was consistently achieved across all nozzle types, as droplets reached the target more quickly before being carried away by wind currents. However, differences among nozzles became more evident as altitude increased. The cone nozzle experienced the sharpest efficiency drop due to producing finer droplets that are easily carried by the wind. Conversely, the flat fan and even-fan nozzles were better able to maintain efficiency because they produce coarser droplets with higher momentum. These results align with Biglia et al. (2022), who stated that nozzles producing larger droplets perform better in maintaining efficiency under less favorable flight conditions.

Overall, the findings show that spraying efficiency decreases with increasing altitude, with differences becoming more pronounced under dynamic conditions. A comparison of nozzle types indicates that flat fan and even-fan nozzles are relatively more stable in maintaining efficiency across different altitudes, while the cone nozzle shows the steepest decline due to fine droplets being easily drifted by wind. These findings are consistent with spray aerodynamics theory, which states that droplet size spectrum directly influences deposition success (Pan et al., 2016; Biglia et al., 2022). Thus, this research confirms that variations in efficiency are not only influenced by flight altitude but are also closely linked to each nozzle’s characteristics in producing droplet size and distribution

3.4 Coefficient of Uniformity (CU)

The results of the static test showed that the value of the Coefficient of Uniformity (CU) tended to be lower compared to the dynamic condition. In this condition, the spray pattern was more concentrated in the center and thinned out toward the edges, resulting in greater variation in the collected volume across measurement points.

Differences between nozzle types were also not clearly pronounced in the static condition, since without translational movement of the drone, the spray pattern was only influenced by the nozzle flow shape and rotor downwash. This finding is consistent with Zhang et al. (2022), who explained that the rotor flow field in a static hovering position tends to be uneven, making it difficult to achieve spray distribution uniformity.



(a)

(b)

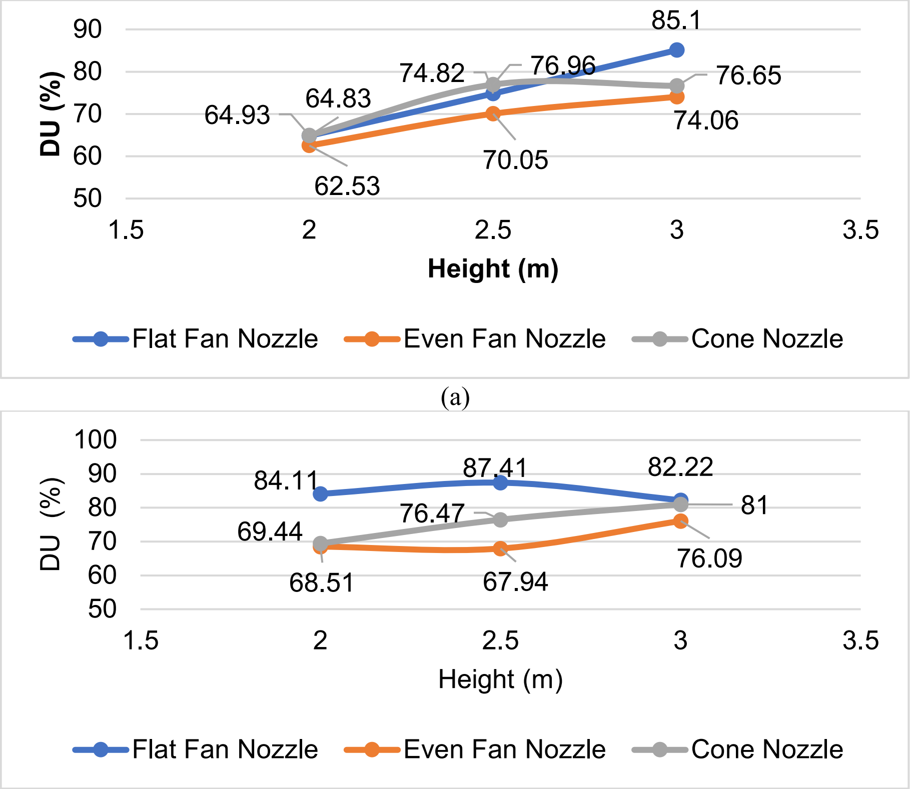
Figure 8. Coefficient of Uniformity (CU) in Static Test (a) and Dynamic Test (b) Based on Nozzle Type and Altitude

In the dynamic condition, CU values increased consistently for all nozzle types and flight heights. The forward motion of the drone played an important role in improving the homogeneity of the distribution through a translational effect that widened the spray pattern and overlapped areas that were previously under-deposited. Among the three nozzle types tested, the flat-fan nozzle showed the highest CU values at all heights, followed by the even-fan nozzle, while the cone nozzle produced the lowest CU values. This is because the flat-fan nozzle generates a fan-shaped spray pattern with tapered edges, which, when the drone is moving, allows spray patterns to overlap more effectively. This result is in line with Wu et al. (2022), who reported that flat-fan nozzles were able to produce better distribution uniformity compared to other nozzle types.

Overall, the comparison between static and dynamic conditions confirms that the forward movement of the drone contributes positively to improving CU values by reducing deposition variation among points. In terms of nozzle comparison, the flat-fan consistently demonstrated the highest uniformity performance, the even fan was at a medium level, while the cone nozzle tended to be lower due to the fine droplets it produced being more easily affected by turbulence. These findings reinforce the theory of spray distribution uniformity, which states that nozzle design and droplet size are key factors in achieving homogeneity (Wu et al., 2022; Chen et al., 2022). Thus, this study shows that CU values are simultaneously influenced by flight conditions and nozzle design, both of which must be considered when evaluating the performance of spraying drones.

3.5 Distribution Uniformity (DU)

Unlike CU, which evaluates overall uniformity, Distribution Uniformity (DU) offers a more in-depth analysis by focusing on the areas receiving the least spray volume. DU analysis is highly important because under-dosed areas may serve as the starting point of control failure and simultaneously increase the risk of resistance development



(b)

Figure 9. Distribution Uniformity (DU) in Static Test (a) and Dynamic Test (b) Based on Nozzle Type and Altitude

In the static test, the Distribution Uniformity (DU) values tended to be lower due to large variations in deposition between measurement points. The spray pattern was more concentrated in the center of the catchment area and decreased drastically at the edges, so the portion receiving the lowest volume was relatively much smaller compared to the average. Differences among nozzle types were not clearly pronounced, since the absence of translational movement made the spray pattern entirely dependent on the nozzle spray shape and rotor turbulence. This is consistent with Zhang et al. (2022), who explained that under static conditions, instability in downwash airflow can produce uneven deposition patterns and result in low DU.

The dynamic test results showed a clear increase in DU values for all nozzle types. The forward movement of the drone caused the spray patterns to overlap, so points with low deposition still received additional spray from subsequent passes. Among the nozzle types, the flat-fan nozzle showed the highest performance with the most stable DU values at all heights, followed by the even-fan nozzle, which produced moderate uniformity, while the cone nozzle produced the lowest DU values. This pattern occurred because the droplets generated by the flat-fan nozzle were more evenly distributed and able to cover areas with minimum deposition. This phenomenon supports Li et al. (2022), who stated that the best distribution uniformity is achieved when the spray pattern is able to compensate for weaknesses in areas with the lowest deposition.

Overall, the results showed that DU values were much higher under dynamic conditions compared to static ones, indicating that the translational movement of the drone greatly helps improve uniformity in areas with the lowest deposition. In terms of nozzle comparison, the flat-fan nozzle consistently provided the highest DU values, the even-fan nozzle occupied the middle position, while the cone nozzle tended to produce low DU values because its fine droplets were easily carried by the wind and unable to reach areas with minimum deposition. These findings are consistent with Wu et al. (2022), who emphasized the importance of nozzle design in ensuring uniform distribution, and also support Li et al. (2022), who noted that achieving optimal distribution uniformity results from a balance between spray pattern and flight conditions. Thus, DU is influenced by the interaction between drone aerodynamics and nozzle characteristics.

3.6 Determination of Optimal Configuration

A comprehensive evaluation using the Simple Additive Weighting (SAW) method under dynamic conditions allows the ranking of performance for all treatment combinations based on their simultaneous contribution to all performance parameters.

Table 2. Performance Ranking of Each Nozzle and Altitude Combination under Dynamic Conditions

Nozzle Type	Height (m)	Drift (L)	Efficiency (%)	CU (%)	DU (%)	Preference Score (V)	Rank
Flat Fan	2	0.411	95.89	89.89	84.11	0.973	1
Flat Fan	2.5	0.621	93.79	90.06	87.41	0.918	2
Cone	2.5	0.463	95.37	84.81	76.47	0.908	3
Even Fan	2	0.381	96.20	77.05	68.51	0.892	4
Even Fan	2.5	0.535	94.65	76.97	67.94	0.829	5
Flat Fan	3	1.158	88.42	88.15	82.22	0.825	6
Cone	2	0.687	93.13	80.24	69.44	0.810	7
Cone	3	1.585	84.15	87.97	81.00	0.794	8
Even Fan	3	1.123	88.77	84.00	76.09	0.793	9

The analysis results indicate that the most optimal configuration is the use of a Flat-Fan nozzle at a flight altitude of 2 meters, based on its highest overall SAW preference score (0.973). This score reflects the best weighted compromise across all tested parameters rather than superiority on every individual parameter: drift was in fact slightly lower for the Even-Fan nozzle at 2 m (0.381 L versus 0.411 L), and both CU and DU for the Flat-Fan nozzle were marginally higher at 2.5 m (CU 90.06%, DU 87.41%) than at 2 m (CU 89.89%, DU 84.11%). Flat-Fan at 2 m nonetheless provided the most balanced combination of high efficiency, low drift, and strong uniformity simultaneously. This success results from the synergistic interaction between the stable spray pattern characteristics of the Flat-Fan nozzle and the strong, directed aerodynamic effects of downwash at low altitude. Empirically, this underscores the importance of a holistic optimization approach, as described by Li et al. (2022), who stated that application success does not rely on a single factor but rather on the proper combination of nozzle type and altitude to ensure an ideal spray distribution.

3.7 Flight altitude evaluation

To identify the optimal flight height for each nozzle type under dynamic conditions, a quadratic regression analysis was conducted for each performance parameter. This approach allows the determination of the turning point representing the optimal operating condition. The resulting optimal values and corresponding flight heights for drift, efficiency, CU, and DU are summarized in Table 3.

Table 3. Optimal Performance and Optimal Altitude for Each Nozzle Type under Dynamic Conditions

Nozzle Type	Variabel Dependen	Optimum Value	Optimum Height
Flat Fan	*Drift* (L)	0.410	1.93
	Efficiency (%)	95.92	1.93
	CU (%)	90.24	2.29
	DU(%)	87.46	2.44
Even Fan	*Drift* (L)	0.380	2.07
	Efficiency (%)	96.24	2.07
	CU (%)	76.12	2.26
	DU(%)	67.12	2.28
Cone	*Drift* (L)	0.388	1.67
	Efficiency (%)	96.12	2.33
	CU (%)	90.11	3.87
	DU(%)	83.15	3.66

Note: It should be noted that some predicted optimum heights, particularly for the Cone nozzle CU and DU, exceeded the tested height range of 2–3 m. Therefore, these values should be interpreted as model-based estimates rather than directly validated operational settings.

The modeling results consistently indicate that, to minimize drift and maximize efficiency, lower operational altitudes are superior. On the other hand, analysis of uniformity parameters (CU and DU) reveals an opposite trend, where higher altitudes are required to allow the spray pattern to spread and overlap adequately. This conflict between the need for low-altitude flight to reduce drift and high-altitude flight to improve uniformity represents a core challenge in calibrating spraying drones. This highlights the risk of optimizing a single parameter and emphasizes the importance of a holistic approach. As emphasized in the optimization study by Souza et al. (2022), changes in altitude directly affect droplet density and penetration, ultimately impacting both uniformity and efficacy. Therefore, the findings of this study underline that achieving superior application performance is rarely accomplished by maximizing a single variable, but rather through finding a balanced compromise acceptable across multiple conflicting objectives.

CONCLUSION

Based on the study "The Effect of Nozzle Type and Height on the Performance of the Ferto-15 Drone", the following conclusions can be drawn:

1. Flight altitude is the most dominant factor affecting all spraying parameters, including spray coverage, drift, efficiency, Coefficient of Uniformity (CU), and Distribution Uniformity (DU). At lower altitudes, droplet deposition and efficiency are generally higher, whereas at higher altitudes, spray coverage increases and drift increases. Uniformity responses (CU and DU) varied depending on nozzle type rather than following a single consistent trend with height; however, the flat-fan nozzle maintained the most stable uniformity across the tested heights.
2. Nozzle type has a notable influence, particularly under dynamic conditions. The Flat-Fan nozzle consistently shows the best performance in terms of spray coverage, efficiency, and uniformity (CU and DU). The Even-Fan nozzle ranks in the middle, offering an advantage in minimizing drift at low altitudes, while the Cone nozzle tends to produce the lowest efficiency and uniformity, despite generating fine droplets capable of penetrating the crop canopy.
3. Comparison among the three nozzle types highlights distinct characteristics. The Flat-Fan nozzle excels in uniformity and efficiency across various altitudes. The Even-Fan nozzle is fairly effective in reducing drift, though its distribution is less consistent. The Cone nozzle is more susceptible to spray loss (drift) and efficiency reduction, especially at higher altitudes.
4. For dynamic operation performance, the configuration providing the best balance between high efficiency, low drift, and superior uniformity is the Flat-Fan nozzle at a flight altitude of 2 meters. This configuration is recommended as a reference standard for spraying operations using the Ferto-15 drone to achieve the most effective and efficient results.

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