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Influence of Spray Parameters of a UAV Sprayer on Droplet Size in Paddy Spraying

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Unmanned aerial vehicles (UAVs) have emerged as promising technologies for agricultural applications, including pesticide spraying in paddy fields. Droplet size is a critical factor influencing the effectiveness and efficiency of pesticide application. This study investigated the impact of

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various spray parameters of UAV sprayers on droplet size during paddy spraying. The experimental setup involved a UAV equipped with different nozzle types (flat fan nozzle, hollow cone nozzle and spinning disc nozzle), operating at varying forward speeds (2, 3, 4, 5 and 6 m s^{-l}) and spray heights (l, 1.5, 2, 2.5 and 3 m above the crop canopy). The results demonstrated that among the three operational parameters, the type of nozzle had a significant effect on the droplet size, whereas the forward speed and height of the spray were not significantly different. A larger droplet size was obtained for the flat fan nozzle, followed by the hollow cone and spinning disc nozzles. These findings provide valuable insights for optimizing UAV sprayer settings to achieve the desired droplet size distributions and improve pesticide application efficiency in paddy fields.

Keywords: UAV sprayer; paddy; type of nozzle; droplet size.

1. INTRODUCTION

Pesticide application is a crucial aspect of paddy cultivation and is aimed at controlling pests and diseases (Herbst et al., 2020). Traditional methods of pesticide application, such as manual spraying or tractor-mounted sprayers, can be labor intensive, time consuming, and inefficient. In recent years, unmanned aerial vehicles (UAVs) have emerged as promising alternatives for spraying pesticides in paddy fields (Yongjun et al., 2017; Zhang et al., 2021). UAVs offer several advantages, including increased efficiency, precision, and reduced environmental impact (Chen et al., 2022; Khoshnam, 2022).

Droplet size is a critical factor influencing the effectiveness and efficiency of pesticide application (Mat Su et al., 2018; Nordin et al., 2021). Smaller droplets can penetrate the dense canopy of paddy plants more effectively, reaching target pests and diseases (Chen et al., 2020; Hu et al., 2021). However, excessive droplet drift can lead to off-target pesticide deposition, environmental contamination, and reduced pesticide efficacy (Rao et al., 2024; Wang et al., 2024; Wongsuk et al., 2024). A larger droplet size leads to runoff and pesticide waste (Al Heidary et al., 2014; Desa et al., 2023). Therefore, understanding the factors influencing droplet size in UAV-based paddy spraying is essential for optimizing pesticide application practices (He et al., 2018; Jeevan et al., 2023). This study investigated the impact of various spray parameters of UAV sprayers, such as the type of nozzle, forward speed and spray height, on the droplet size during paddy spraying.

2. MATERIALS AND METHODS

2.1 UAV Sprayer

Unmanned aerial vehicles are classified into three major types: quadcopters, hexacopters and octocopters. The quadcopter of the four arms has less stability during flight. It is small in size and has less payload capacity (Yuan & Wang, 2015). Compared with all available technologies, octocopters are bulky and more expensive (Yallappa et al., 2023; Zhu et al., 2011). Hence, it is suggested to use a hexacopter equipped with a sprayer system, as it is more stable during the spraying process than a quadcopter and is more economical than an octocopter (Susitra *et al.*, 2020). The hexacopter (Fig. 1) can be selected and modified for pesticide application. The components of the UAV sprayer are shown in Table 1.

Fig. 1. Hexacopter UAV sprayer

Table 1. Components and images of selected UAV sprayer

Sl. No.	Components	Images
1	Fuselage	
2	Landing gear	
3	Arms	
4	Lithium polymer battery	
5	Propeller	
6	Brushless DC (BLDC) motor	
7	Electronic speed controller	
8	Power distribution board	
9	Remote controlled transmitter	

Sl. No.	Components	Images
10	Receiver	
11	Flight controller	
12	Global positioning system	
13	Pump motor	
14	Nozzles	
15	Chemical tank	

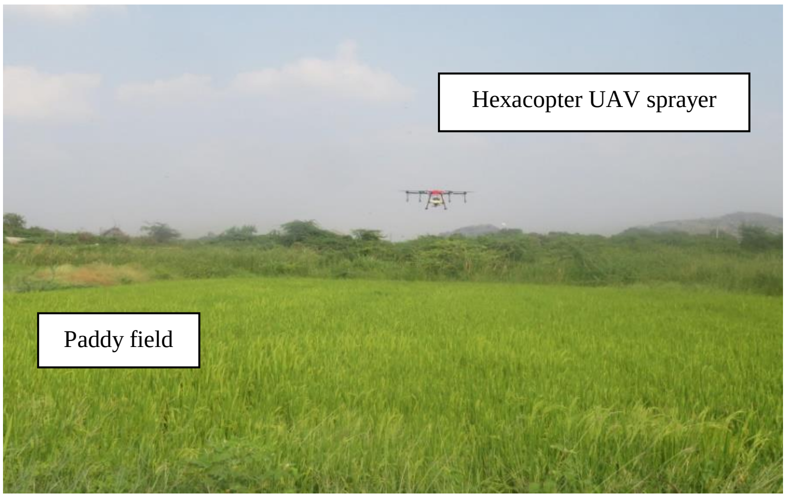


Fig. 2. Operating UAV sprayer over a paddy crop in the farmer's field to record droplet size

Table 2. Three types of nozzles selected for the study

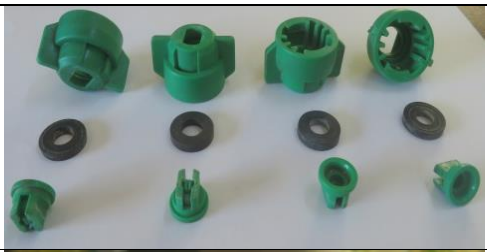
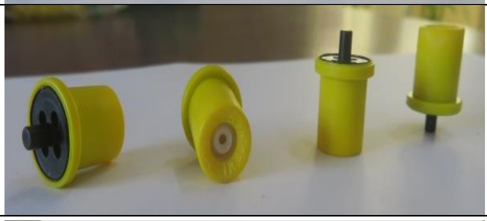
Sl. No.	Type of nozzle	Nozzle view
1	Flat fan nozzle	
2	Hollow cone nozzle	
3	Spinning disc nozzle	

Table 3. Taguchi L-25 orthogonal experimental design for recording droplet size produced by various nozzle types attached to a UAV sprayer

Experiment No.	Type of nozzle	Forward speed (m s^{-1})	Height of spray (m)
1	Flat fan nozzle	2	1
2	Flat fan nozzle	3	1.5
3	Flat fan nozzle	4	2
4	Flat fan nozzle	5	2.5
5	Flat fan nozzle	6	3
6	Flat fan nozzle	2	1.5
7	Flat fan nozzle	3	2
8	Flat fan nozzle	4	2.5
9	Flat fan nozzle	5	3
10	Flat fan nozzle	6	1
11	Hollow cone nozzle	2	2
12	Hollow cone nozzle	3	2.5
13	Hollow cone nozzle	4	3
14	Hollow cone nozzle	5	1
15	Hollow cone nozzle	6	1.5
16	Spinning disc nozzle	2	2.5
17	Spinning disc nozzle	3	3
18	Spinning disc nozzle	4	1
19	Spinning disc nozzle	5	1.5
20	Spinning disc nozzle	6	2
21	Spinning disc nozzle	2	3
22	Spinning disc nozzle	3	1
23	Spinning disc nozzle	4	1.5
24	Spinning disc nozzle	5	2
25	Spinning disc nozzle	6	2.5

2.2 Experimental Setup

The study was conducted at the farmer's field (Hosur village, Raichur District), and a 1000 m^2 area was marked in the paddy field to carry out the trials (Fig. 2). A hexacopter UAV sprayer was used for the experiments. The three different types of nozzles that were tested were flat fans, hollow cones, and spinning disc nozzles (Table 2) with 100% openings. The forward speed and height of the spray of the UAV sprayer were varied during the experimental trials according to the Taguchi L-25 orthogonal experimental design (Table 3).

2.3 Droplet Size Measurement

Nozzles produce droplets of various sizes ranging from very fine (<60 μ) to ultracoarse (>665 μ). It is essential to choose the right nozzle to reduce spray drift and obtain maximum coverage simultaneously. Droplet sizes are usually measured in microns (micrometers). One micron equals 0.001 mm. The micron is a useful unit of measurement because it is small enough that whole numbers can be used in drop size measurement. By cutting a droplet in half, we can produce eight times the number of droplets. Hence, with the same amount of chemical, we can increase the area of coverage by reducing the droplet size (Lan et al., 2021). A nozzle with a coarse or very coarse droplet is usually selected to minimize off-target spray drift, whereas a nozzle with a fine droplet is required to obtain maximum surface coverage of the target plant.

The size of the spray droplet is represented as the volume median diameter (VMD). The volume median diameter (VMD) is the midpoint droplet size, where half of the volume of spray contains droplets larger than the VMD in μm and the other half contains droplets smaller than the VMD. To reduce experimental error, water-sensitive papers (7.6 cm × 2.6 cm) were placed at the upper and lower leaf surfaces at the top, middle and bottom canopies of the paddy plants to record the droplet size received from the spraying nozzle (Lv et al., 2019).

A total of three paddy plants (three replications) were selected for each trial, and WSPs were carefully placed on the paddy leaves (Fig. 3). In particular, six WSPs were used per paddy hill and placed at upper and under surfaces of top, middle and bottom canopy of paddy plant. Pure water was used for spraying. The droplets result in blue deposits when deposited on the WSPs. The WSPs were carefully removed with clean tweezers and sealed in Ziploc bags after spraying. The collected WSPs were qualitatively analyzed to determine droplet size (Tang *et al.,* 2018; Martin et al., 2019).

2.4 Data Processing

The WSPs were scanned into a digital image with a high pixel resolution (600 dpi × 600 dpi). The droplet size on the WSPs was evaluated via Deposit Scan software (Tang *et al.,* 2018).

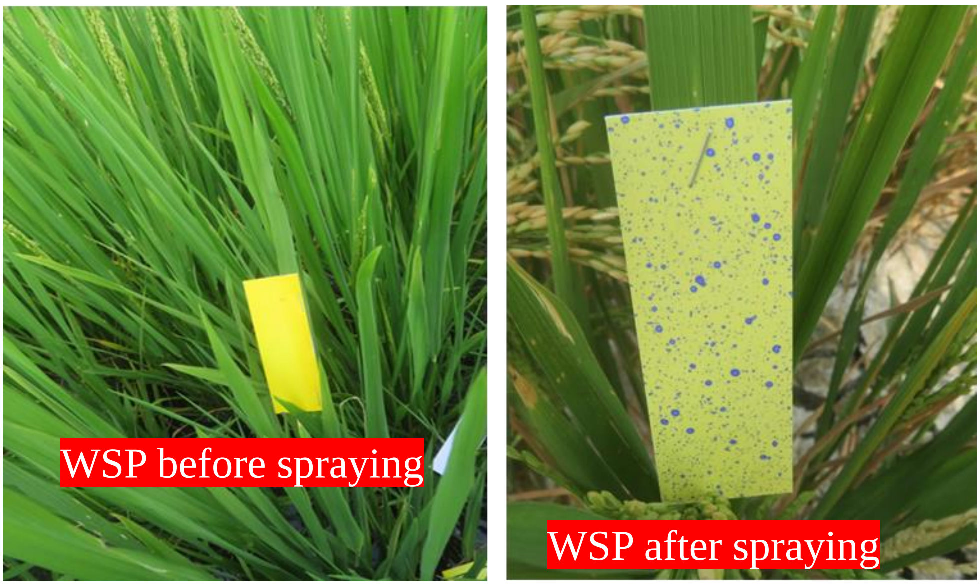


Fig. 3. Placement of water-sensitive paper to collect spray droplets for measuring droplet size

2.5 Statistical Analysis

A Taguchi L-25 orthogonal experimental design was used to evaluate the individual effects of nozzle type, forward speed and spray height on droplet size. Minitab 19 was used for analyzing the data (Yang and Tang, 1998). A Pareto chart was generated to indicate the most significant parameter among the selected independent variables on the basis of the standardized effect values at the 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Influences of the Type of Nozzle, Forward Speed and Height of Spray on the Droplet Size Collected from Paddy Leaves

The Pareto chart determines the magnitude and importance of the effects of the operational parameters on the performance parameters. On the Pareto chart, bars that cross the reference line (2.09) are statistically significant at the 0.05 level. The Pareto charts for the droplet sizes at the top, top, middle upper, middle lower, bottom upper and bottom under the surfaces of the paddy leaves are presented in Figs. 4, 5, 6, 7, 8 and 9, respectively.

3.2 Influence of Nozzle Type

The Pareto chart (Figs. 4 to 9) revealed that the nozzle type significantly influenced the droplet size. The spinning disc nozzle produced smaller droplets, followed by hollow cone nozzles and flat fan nozzles, because flat fan, hollow cone and spinning disc nozzles have varying orifice sizes and discharge rates, which affect mainly the droplet size produced from the nozzle (Houston, 2022). Similar results were obtained for droplet size at the upper and lower surfaces of the top, middle and bottom canopies of paddy leaves.

3.3 Effect of Forward Speed

The droplet size did not change significantly with forward speed. This was in agreement with the results of Martin *et al.* (2019). Similar results were observed for droplet size at the upper and lower surfaces of the top, middle and bottom canopies of paddy leaves.

3.4 Effect of Spray Height

The droplet size on the paddy leaves was not significantly related to the height of the spray above the crop canopy at the upper and lower surfaces of each canopy. However, the downwash air flow of the drone-mounted sprayer breaks up the droplets into smaller sizes. This may be because when the height of the spray increases, it leads to increased air turbulence, longer travel distances and greater exposure to air currents, but it does not significantly change the average droplet size (Houston, 2022).

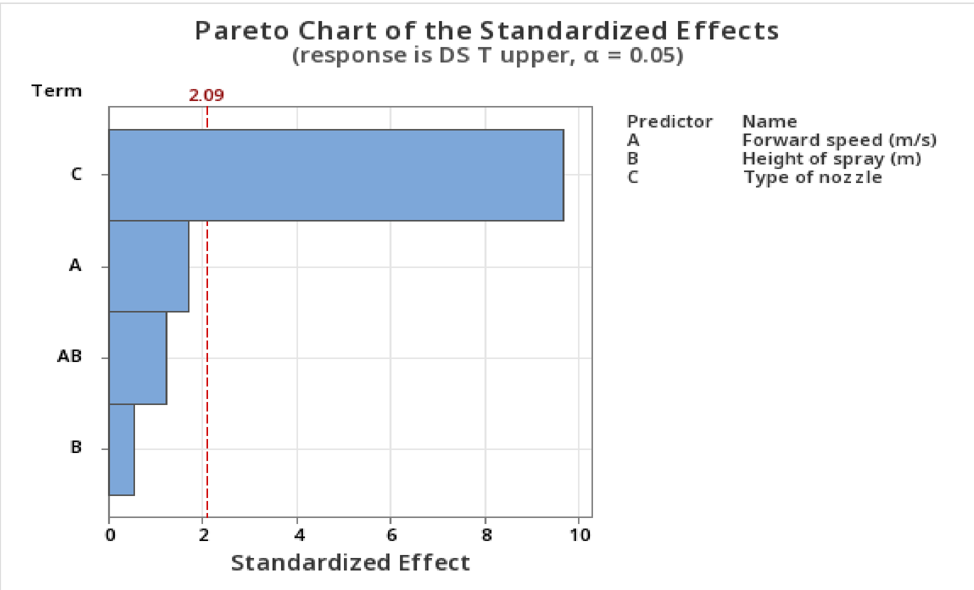


Fig. 4. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size at the top upper surface of paddy leaves

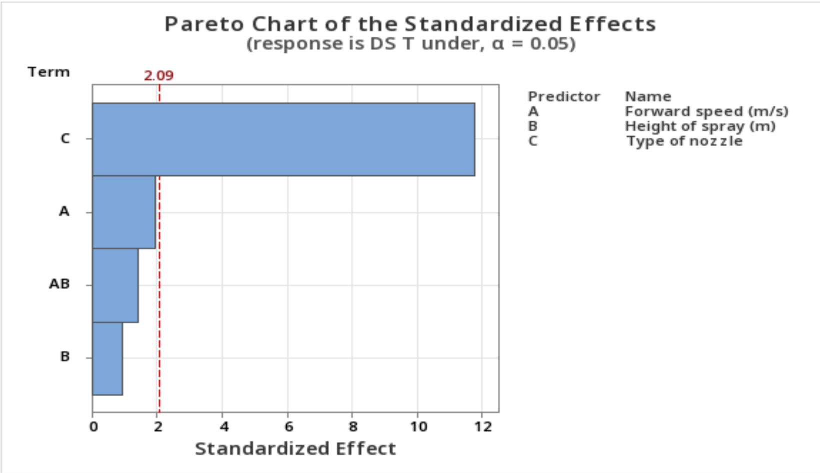


Fig. 5. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size at the top under the surface of the paddy leaves

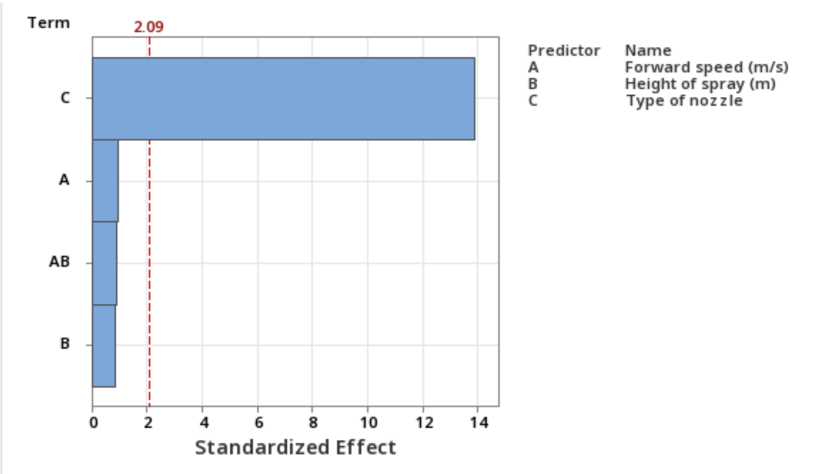


Fig. 6. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size at the middle upper surface of the paddy leaves

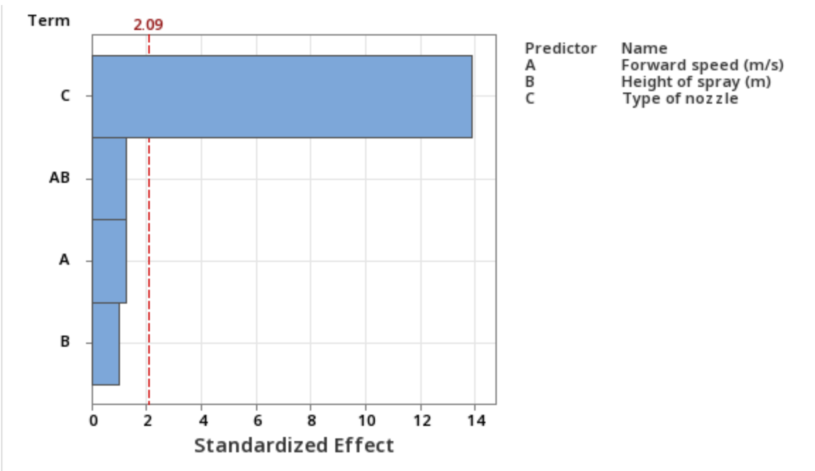


Fig. 7. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size in the middle of the surface of the paddy leaves

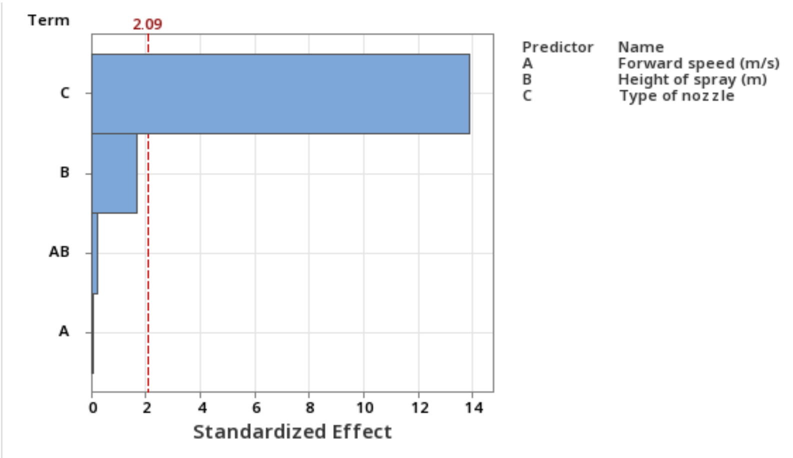


Fig. 8. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size at the bottom upper surface of the paddy leaves

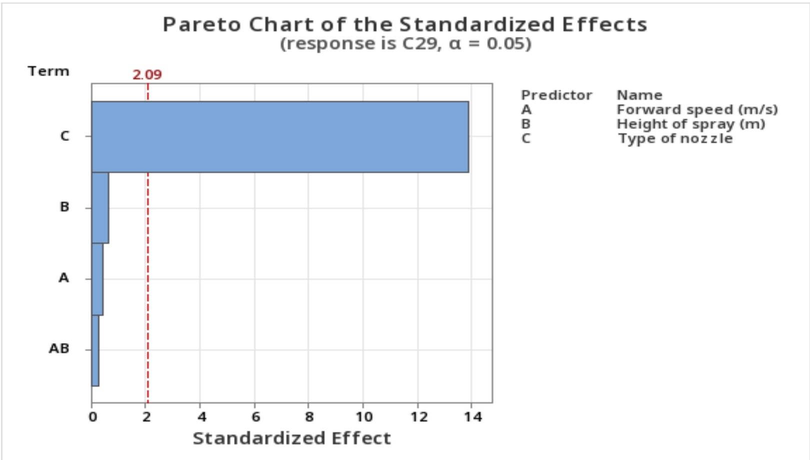


Fig. 9. Pareto chart of the standardized effects of the type of nozzle, forward speed and height of the spray on the droplet size at the bottom under surface of the paddy leaves

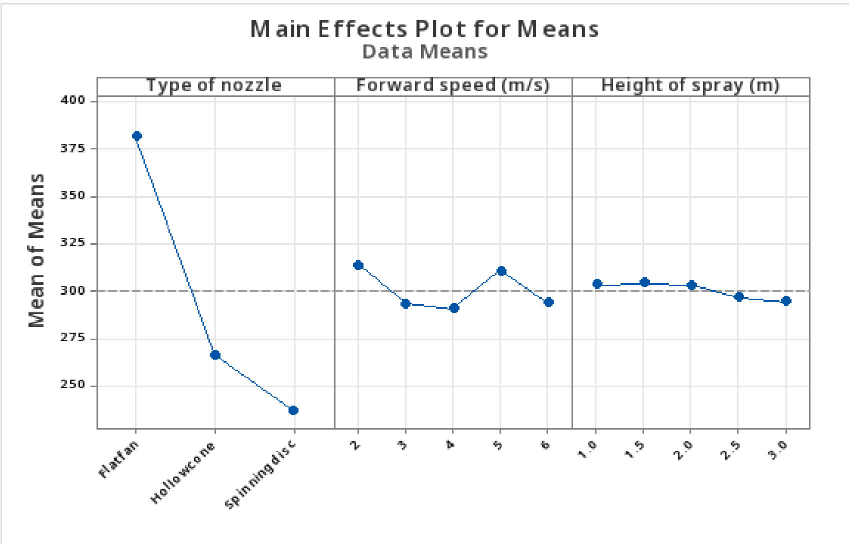


Fig. 10. Main effects plot for means of operational parameters on droplet size at the top upper surface of paddy leaves

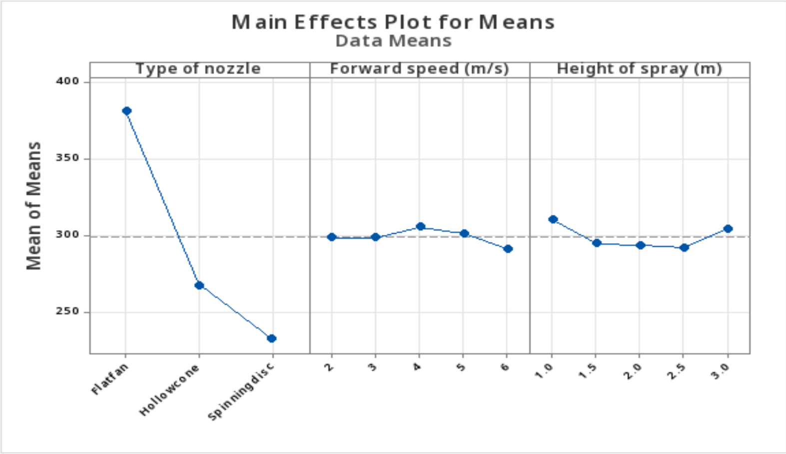


Fig. 11. Main effects plot for means of operational parameters on droplet size at the top under surface of paddy leaves

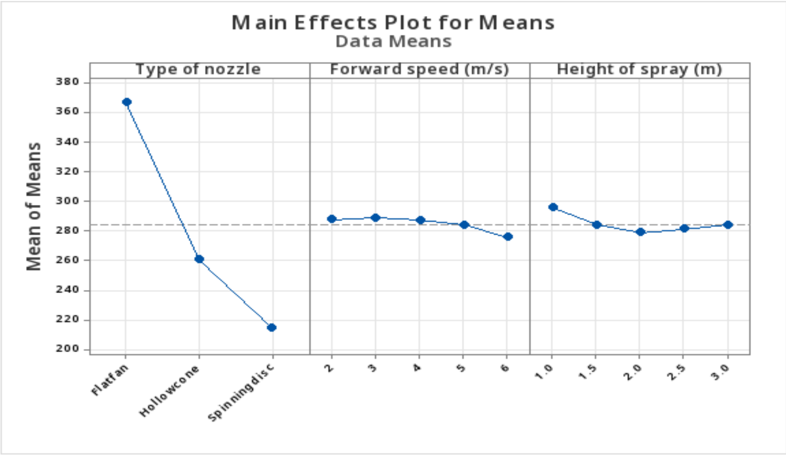


Fig. 12. Main effects plot for means of operational parameters on the droplet size at the middle upper surface of paddy leaves

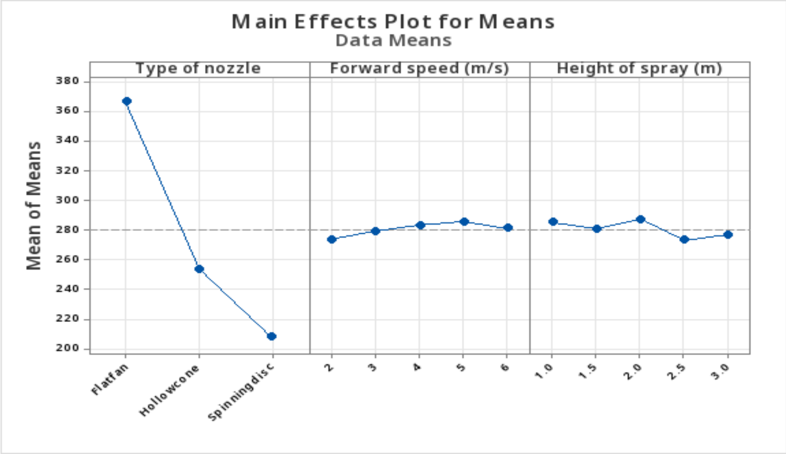


Fig. 13. Main effects plot for means of operational parameters on droplet size at the middle under surface of paddy leaves

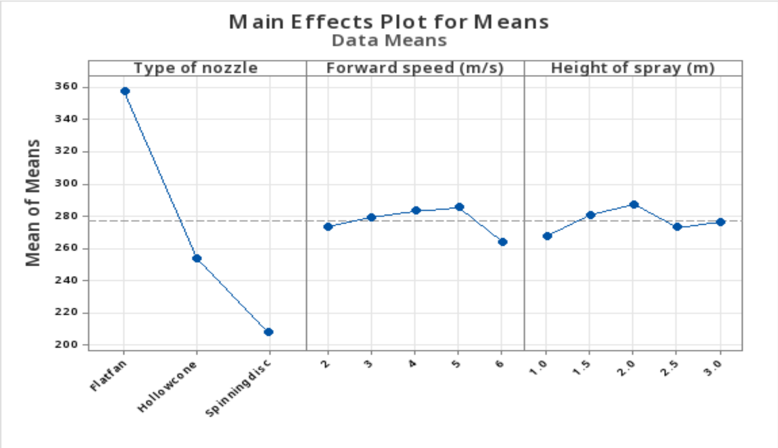


Fig. 14. Main effects plot for means of operational parameters on the droplet size at the bottom upper surface of paddy leaves

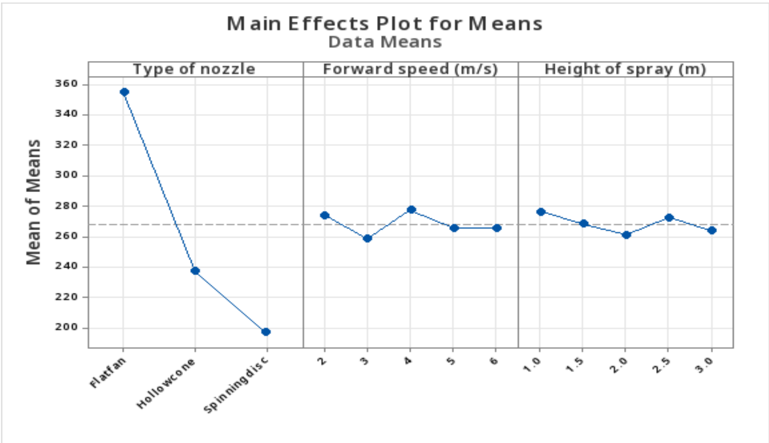


Fig. 15. Main effects plot for means of operational parameters on the droplet size at the bottom under surface of paddy leaves

3.5 Main Effects Plot for Means

The main effects plot for means (Figs. 10 to 15) describes the mean values of the performance parameter along with the individual response of the operational parameters. The highest mean value of droplet size on the top upper leaves of the paddy crop (Fig. 10) was observed with the combination of a flat fan nozzle, 2 m s^{-1} forward speed and 1.5 m height of spray, whereas the lowest mean value of droplet size on the top upper leaves of the paddy crop was observed with the combination of a spinning disc nozzle, 6 m s^{-1} forward speed and 3 m height of spray. The main effect plots for droplet size at the top, middle upper, middle lower, bottom upper and bottom under the surfaces of the paddy leaves are presented in Figs. 11, 12, 13, 14 and 15, respectively.

4. CONCLUSION

Experiments were conducted to determine the impact of the operational parameters (nozzle type, forward speed and spray height) of the UAV sprayer on the droplet size in paddy fields. This study concludes that the type of nozzle used on the UAV sprayer significantly influences the droplet size during paddy spraying, with flat fan nozzles producing the largest droplets, followed by hollow cone nozzles and spinning disc nozzles. In contrast, the forward speed and spray height had no significant effect on the droplet size. These findings suggest that selecting the appropriate nozzle type is crucial for optimizing pesticide application efficiency and minimizing drift in paddy fields.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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