Effect of Spraying Dispersion Using UAV Spraying System with Different Height at Paddy Field

Hazry Desa, Muhammad Azizi Azizan, Nik Noriman Zulkepli, Nurfadzillah Ishak, Teh Xi Hang, Siti Syuhaidah Yahya, Aisyah Arina Mohammad Shahrazel, Fakhrul Mukmin Mansor
Centre of Excellence for Unmanned Aerial Systems (COE-UAS), Universiti Malaysia Perlis (UniMAP), Malaysia

Siti Zaleha Abdul Aziz
Department of Robotic & Automation, Mara Japan Industrial Institute (MJII), Malaysia

Abadal-Salam T. Hussain
Department of Medical Instrumentation Engineering Techniques, Al-Kitab University, Altun Kupri, Kirkuk, Iraq

E-mail: hazry@unimap.edu.my, aziziazizan@unimap.edu.my, niknoriman@unimap.edu.my, nurfadzillah@unimap.edu.my, tehxh97@gmail.com, syuhaidah323@gmail.com, aisyahaa2300@gmail.com, keranamumalaya@gmail.com, szaleha.aziz@mara.gov.my, asth2@uoalkitab.edu.iq
www.unimap.edu.my

Abstract

This study investigated the UAV spraying system height in relation to spraying uniformity and dispersion. The operating heights of the UAV spraying system at heights of 1 m, 1.5 m, and 2 m from the hollow cone nozzles were investigated within a wind speed of 2.8 m/s. The tests were to determine the spray uniformity and dispersion on the water sensitive paper that was placed on the paddy plant. The results of water droplet samples were evaluated using ImageJ software. The results show the droplet distribution at 1.5 m height has high values for average droplet density, which is 162.7 deposits/cm² at the top area and 161.8 deposits/cm² at the bottom area. The percentage of coverage was also high, at 55.21% at the top area and 51.4% at the bottom area.

Keywords: UAV, Spraying System, Heights, Droplet Density, Average Coverage

1. Introduction

Throughout the Eleventh Malaysian Plan (2016–2020) and the National Agro-Food Policy (2011–2020), Malaysia continues its proactive and progressive measures to promote paddy and rice sector development. Agro-chemicals are being used on crops to control pests and weeds through conventional spraying systems with little consideration of substantial variation in plant populations and canopies [1]. It is estimated that about 3 million metric tons of pesticides are used annually worldwide to control the disease [2]. These chemicals not only control weeds but also help to control insect pest attacks that cause a reduction in crop yield and affect the crop quality as well [3]. However, the World Health Organization reported that around one million illness cases resulted from the manual spraying of pesticides in the fields [4].

Alternatively, UAV spraying systems are being used for crop monitoring and management for spraying pesticides. However, the proper spray height and nozzle opening need to be investigated. Investigations are needed as there are many problems in the area, such as non-uniform spray or late spraying [5], poor penetrability and poor distribution to the crop. A study conducted by [6] revealed that UAV spraying systems could increase efficiency by more than 60% with a 20–30% decrease in pesticide dose. Furthermore, the self-adjustment routing mechanism of UAVs can significantly reduce pesticide waste and fertilizer application [7]. [8] suggested that UAV spraying systems should be carefully tested to ensure application accuracy. It was also suggested to fly at a low altitude of 1 to 5 m. That will help in avoiding spray drift.

However, there is no study available on different flight configurations for altitude and spray nozzle openings that might be helpful for farmers to optimize the UAV spraying system. Such investigations will reduce the risks of overuse of pesticides due to their outside drift as well as overlap of areas under spray [1].

In the current study, an effort has been made to evaluate spraying dispersion through the UAV spraying system at different heights and to estimate the droplet dispersion, especially on paddy fields, to overcome these difficulties.

The findings will be helpful in recommending efficient spraying for paddy fields through UAV spraying systems as well as an alternative way to come up with standard guidelines for the incorporation of drones in agricultural operations.

2. Materials and methods

2.1. *Testing method and data collection*

This study was conducted at the open field near to the Centre of Excellence for Unmanned Aerial Systems (COEUAS), Universiti Malaysia Perlis (UniMAP), Malaysia (Latitude: 6.43744 N, Longitude: 100.18868 E). The total area of the field was 140 m x 70 m.

The UAV spraying system sprayer was tested at three different altitudes of 1 m, 1.5 m, and 2 m in height: wind speed of 2.8 m/sec with an average temperature of 33 °C and humidity of 84%. A hollow cone nozzle with 100% openings was used in this test. Water-sensitive papers (7.6 cm x 2.6 cm) were placed at the top and bottom areas of the paddy plant. The top area is the upmost part of the plant, whereas the bottom area is within 20 cm of the ground. The goal is to evaluate the water droplet sample obtained from the spraying nozzle, as shown in Figure 1.

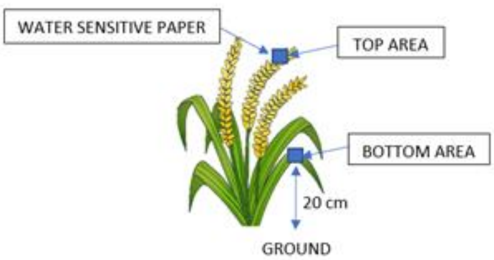

Fig. 1. Water sensitive paper placement

Attention was given to where the water-sensitive papers were placed at a 30 cm distance between the left and right areas of the main point paddy plant to get drone spray impressions (dots/marks) as shown in Fig. 2 and Fig. 3 below. A similar testing method to that in Fig. 2 was suggested by [9].

The UAV spraying system was flown at a speed of 12 m/s from point A to B and was controlled by IFLY application software with 10 repetitions for the hollow cone nozzle. Then, the samples were collected, and the paper was checked to be dried before the next procedure. The same methods were applied to the different heights of nozzle. This testing involved a total of 300 samples, with 100 samples for each type of nozzle.

The spray droplet impressions on water-sensitive paper were observed by using ImageJ software (DepositScan). The number of spray dots per cm² was counted. If the number of fine spray dots were equal to or greater than 100, then the spray was considered uniform. The number of spray dots per cm² should be equal to or greater than 100, depending on the level of height, wind speed and spray nozzle opening. This is the recommended value for uniformed spraying. On the other hand, if the number of spray counts is less than 100, the height level, wind speed, and spray opening nozzle are not the recommended values for uniformed spraying. As such, this would lead to non-uniformed spray and a waste of resources [9].

The spray dispersion was evaluated by analyzing three parameters: (i) average droplet density on water sensitive paper by counting the number of droplets per unit area (Deposits/cm²), (ii) average coverage, which represents the percentage of water sensitive surface covered by the droplet (%), and (iii) total deposit counted, which represents the total of droplet deposition distribution in the target area.

Fig. 2. Layout of WSP sampling

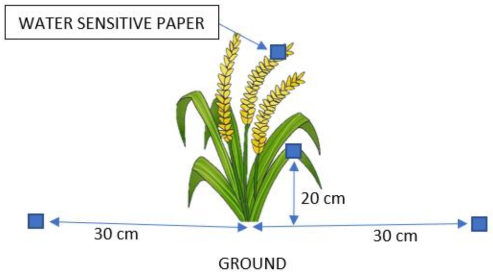

Fig. 3. WSP distances from the main plant

2.2. *Unmanned Aerial Vehicle (UAV) Spraying System Specifications*

In this study, the tested UAV spraying system is the HSSB10L-606 Sprayer Drone, as shown in Fig. 4, which has six arms, six motors, and a hollow cone type of spray nozzle. The complete specifications of this system are provided in Fig. 5 below. The spraying tank capacity was 10 liters with a UAV take-off payload capacity of 28 kg. This system had smooth take-offs and landings in its autonomous mode with a flying speed of 0–12 m/s. This UAV spraying system software interface used the IFLY application for instructions of flight height, spray span for overlapping or precise spray, flight speed, and turn time.

Fig. 4. HSSB10L-606 sprayer drone

UAV part	Description
Number of arms	6
Tank capacity	10 Litres
Maximum take-off capacity	28 kg
Flying time	10-15 minutes
Flying height	0-30m
Flying speed	0-12 m/s
Spray speed	0-8 m/s
Spray width	>4-6m
Spray flow	1-1.15 L/min
UAV size	2.0m*1.3m*0.45m

Fig. 5. UAV spraying system specification

3. Results and discussions

Spray uniformity and dispersion were tested with hollow cone nozzles at different heights. The spraying dots imprinted on the WSP were scanned using a scanner and uploaded to DepositScan software to determine the average number of droplets in the sample data. Tests were performed at 1 m, 1.5 m, and 2 m altitudes with a 100% nozzle opening and a wind speed of 2.8 m/sec. As shown in Fig. 6 below, the spray dots imprinted on the WSP have different working heights. The results of deposition analysis for this observation are provided in Fig. 7 and Fig. 8 below.

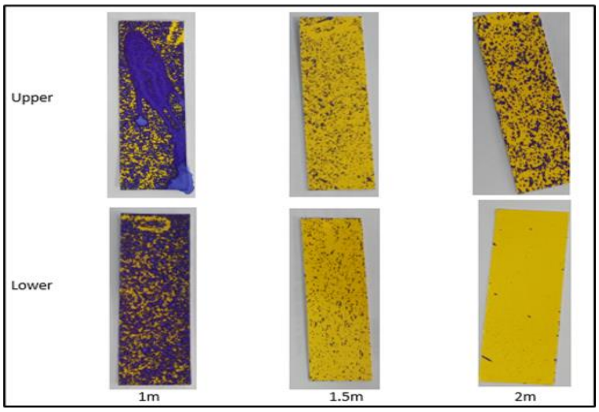

Fig. 6. Spraying pattern with three different working heights

Nozzles	Height (meter)	Sampling Site	Average Droplet Density (Deposits/ cm²)	Average Coverage (%)	Total Deposit Counted	Average coverage differences (%)
Hollow Cone Nozzle	1	Top Area	79.2	29.71	369	15.5
		Bottom Area	63.7	24.53	320	
	1.5	Top Area	162.7	55.21	1003	0.9
		Bottom Area	161.8	51.4	885	
	2	Top Area	45.7	12.58	214	6.9
		Bottom Area	38.8	3.46	171	

Fig. 7. Dispersion of a UAV spraying system at 100% nozzle opening and 2.8m/sec wind speed

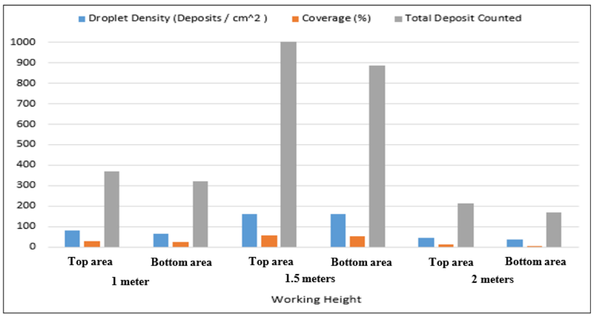

Fig. 8. Droplet deposition distribution

Fig. 8 shows the bar graph of spraying distribution for droplet density against working height from the nozzle. Based on Fig. 7, the hollow cone nozzle at 1.5 m height had the highest average droplet density on WSP, which was 162.7 deposit/cm² at the top and 161.8 deposit/cm² at the bottom area, with an average coverage of 55.2% at the top and 51.4% at the bottom area. Then, the total deposit count, which represents the total of droplet deposition distribution in the target area, was the highest, at 1003 at the top area and 885 at the bottom area. The percentage difference between the average coverage was the lowest value amongst working heights, at 0.9%, which found that the droplet successfully penetrated from the top area to the bottom area. In 1914, [10] proposed the general use of hollow-cone nozzles to apply pesticides or fungicides to field crops when foliage penetration and complete coverage of the leaf surface are required. The spray drift potential is higher from hollow-cone nozzles than from other nozzles due to the small droplets produced. Generally, this type of nozzle should not be used to apply herbicides. It is also stated by [11] that the spray can be effectively done with 100% nozzle openings at wind speeds less than 6 m/sec with a flying height of 1.5 m.

Then, the tested hollow cone nozzle at 2 m demonstrated a non-uniform pattern or less on spray distribution of droplet density, which is 79.0 deposit/cm² at the top area and 63.7 deposit/cm² at the bottom area, and the total deposit is counted by the lowest number between 214 at the top area and 171 for the bottom area. Because of the faulty height, the percentage difference between the average coverage was 6.9%, indicating that the droplet could not be distributed evenly or penetrated to the ground area. As stated by [11], a working height of 2 m is efficient at working nozzle opening at 75% with a wind speed of less than 5 m/sec. To avoid spray losses, the working height should be less than 2 m if the wind speed is greater than 5 m/sec.

The result also showed the highest differences for average coverage between the top area and the bottom area, at 15.5%, which found that the top area reached more droplets density compared to the bottom area. The effect of spraying dispersion at a working height of 1 m is poor. The WSP was drenched by too much drip. This is fine for water application but not suitable for pesticide application. Overdosing of the pesticide's chemical may also damage the paddy and waste the resource. This process is also similarly stated by [12] in their research paper that the droplet distribution in a 1.1 m canopy area is poor for pesticide spraying purposes, but it can be improved by increasing the spray volume in the future.

4. Conclusion

In this study, three flight heights of spraying nozzles were carried out by using a hollow cone nozzle with a 100% flow rate opening under wind conditions in a paddy field. The average droplet density, average coverage, and total deposit distribution of droplets in the target area between the top area and the bottom area were compared and analyzed in this research. The conclusions are shown as follows:

1. The average droplet density of droplet distribution in the target area was influenced by the height of the nozzle, windspeed, and flow rate. There were significant differences in the droplet distribution rate in the target area between the three-flight heights. The average droplet density at 1.5 m flight height had the highest and excellent result because the deposit density was more than 100 deposits/cm². This finding is in line with the study by [9]. The percentage of average droplet difference between the top area and the bottom area was also the lowest at 0.9%, which concluded that the droplet was successfully penetrated from the top area to the bottom area.
2. The average coverage results of the droplets were influenced by the total droplet distribution, which also depends on the flight height. The droplet dispersion at 1.5 m flight height had the highest percentage of average coverage at 55.21% for the top area and 51.5% for the bottom area.
3. The highest total deposit counted for the droplets in the target area of dispersion at a height of 1.5 m had the highest number of 1003 for the top area and 885 for the bottom area, which indicated a suitable working height of the nozzle for better droplet distribution.

The experiment demonstrated that the flight height of the nozzle is one of the most important factors that affect the droplet distribution and drift for pesticide spraying of UAVs. Experimental results revealed that, at 1.5 m flight height, with 100% nozzle opening at 2.8 m/sec wind speed, results in uniformed spraying results. Awareness and consideration for the use of a hollow cone nozzle with an appropriate flying height is critical for better spraying dispersion and droplet distribution while avoiding pesticide drift harm to the environment and humans. Consequently, the type of nozzle from the different flying heights, nozzle angle, and orientation should be studied for better precision in agricultural aerial spraying.

Acknowledgment

The authors would like to thank the Universiti Malaysia Perlis (UniMAP) for providing the facilities and financial support under Pre-Commercialisation Grant, Grant No: 9001-00639.

References

1. Faical, B.S., H. Freitas, P.H. Gomes, L.Y. Mano, G. Pessin, A.C. deCarvalho, B. Krishnamachari and J. Ueyama., "An adaptive approach for UAV-based pesticide spraying in dynamic environments", pp. 210-223, 2017.
2. Pimentel, D., "Pesticides and pest control. In: R. Peshin and A.K. Dhawan (eds.), Integrated Pest Management: Innovation-development process", 2005.
3. Tudi, M., Daniel Ruan, H. Wang. L., Lyu. J., Sadler. R., Connell. D., Chu. C., Phung. D.T., "Agriculture Development, Pesticide Application and Its Impact on the Environment", Int. J. Environ. Res. Public Health, pp. 2-23, 2021.
4. Mogili, R.U.M., B.B.V.L. Deepak, "Review on application of drone system in precision agriculture", International Conference on Robotics and Smart Manufacturing (RoSMa2018), Procedia Comput. Sci., pp. 502-509, 2018.

5. Hussain, S., Cheema, M. J. M., Arshad, M., Ahmad, A., Latif, M. A., Ashraf, S., & Ahmad, S, "Spray uniformity testing of unmanned aerial spraying system for precise agro-chemical applications", Pakistan Journal of Agricultural Sciences, Vol 56, No 4, pp. 897–903, 2019.
6. Qin, W., X. Xue, S. Zhang, W. Gu and B. Wang., "Droplet deposition and efficiency of fungicides sprayed with small UAV against wheat powdery mildew", Int. J. Agric. Biol. Eng. pp. 27-32, 2018.
7. Faical, B.S., F.G. Costa, G. Pessin, J. Ueyuma, H. Freitas, A. Colombo, P.H. Fini, L. Villas, F.S. Osorio, P.A. Vargar, T. Braun, "The use of unmanned aerial vehicles and wireless sensor networks for spraying pesticides", J. Syst. Architect, pp. 393-404, 2014.
8. Gao, Y., "Study on distribution of pesticide droplets in gramineous crop canopy and control effect sprayed by unmanned aerial vehicle, Northeast Agric. Univ. Harbin, China", 2013.
9. Yanliang, Z., L. Qi, Z. Wei. "Design and test of a six-rotor unmanned aerial vehicle (UAV) electrostatic spraying system for crop protection", Int. J. Agric. Biol. Eng, pp. 68-76, 2017.
10. Johnson, M. P., Swetnam, L. D., & Engineering, A. (n.d.), "Sprayer nozzles: selection and calibration", Agricultural Engineering.
11. Hussain, S., Cheema, M. J. M., Arshad, M., Ahmad, A., Latif, M. A., Ashraf, S., & Ahmad, S, "Spray uniformity testing of unmanned aerial spraying system for precise agro-chemical applications", Pakistan Journal of Agricultural Sciences, Vol 56, No 4, pp. 897–903, 2019.
12. Chen, P., Lan, Y., douzals, J.-P., Ouyang, F., Wang, J., & Xu, W., "Droplet distribution of Unmanned Aerial Vehicle under several spray volumes and canopy heights in the cotton canopy", International Journal of Precision Agricultural Aviation, pp. 74–79, 2018.

Authors Introduction

Prof. Dr. Hazry Desa

He received his Bachelor of Mechanical Engineering from Tokushima University, Japan. He pursued his Ph.D. at the Artificial Life and Robotics Laboratory, Oita University, Japan in 2003. He is also the Director at Center of Excellence for Unmanned Aerial Systems (COEUAS), Universiti Malaysia Perlis, Malaysia.

Dr. Muhammad Azizi Azizan

He received his PhD degree in Civil Engineering from Universiti Malaysia Perlis and is currently working as a Senior Lecturer at the same institution. He is also co-founder and director of Haas Solutions Sdn Bhd, a technology startup company of Universiti Malaysia Perlis.

Dr. Nik Noriman Zulkepli,

He received his PhD in polymer engineering from Universiti Sains Malaysia in 2011. He is currently working as a Senior Lecturer in the Polymer Engineering Division, School of Materials Engineering, Universiti Malaysia Perlis. He is also Head of Cluster (Materials) at the Centre of Excellence for Unmanned Aerial Systems.

Dr. Nurfadzillah Binti Ishak

She received her PhD in Building Engineering from the Universiti Malaysia Perlis. She is currently a Senior Lecturer in the same institution. She is Head of Built Environment Intelligent (BELL) at Centre of Ecellence for Unmanned Aerial System (COEUAS), Universiti Malaysia Perlis.

Mr. Teh Xi Hang

He received his Bachelor's Degree in Mechatronics Engineering in 2022 from the Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis (UniMAP) in Malaysia.

Ms. Siti Syuhaidah Yahya

She received her Bachelor of Engineering (Honours) in Electronics Engineering from the Universiti Malaysia Perlis (UniMAP), Malaysia.

Ms. Aisyah Arina Mohammad Shahrazel

She received her Bachelor of Engineering (Honours) in Manufacturing Engineering from the Universiti Malaysia Perlis (UniMAP), Malaysia.

Mr. Fakhrul Mukmin Mansor

He received his Bachelor of Electronic Engineering Technology in Electronic Network Design with Honours from the Universiti Malaysia Perlis (UniMAP), Malaysia.

Mrs. Siti Zaleha Abdul Aziz

She received her Master's degree in Green & Energy Efficient Building in 2014, a joint award between UniKL, Malaysia and the University of Applied Sciences Rosenheim, Germany. She is currently a Vocational Training Officer at Mara Japan Industrial Institute (MJII), Beranang.

Mr. Abadal-Salam T. Hussain

He is currently a Ph.D. faculty assistant professor and head of the department for Medical Instrumentation and Technique Engineering at Alkitab University. Previously, he was a staff member in the Faculty of Electrical Engineering Technology at Universiti Malaysia Perlis (UniMAP), Malaysia.