Indian Journal of Agricultural Sciences **93** (7): 720–725, July 2023/Article
https://doi.org/10.56093/ijas.v93i7.133995

Effect of different spray volumes on deposition characteristics of a fuel-operated UAV sprayer using herbicides in transplanted rice (*Oryza sativa*)

NARAYANASWAMY JEEVAN[1], SELLAPERUMAL PAZHANIVELAN[1]*, RAMALINGAM KUMARAPERUMAL[1], KALIAPERUMAL RAGUNATH[1], P MURALI ARTHANARI[2], N SRITHARAN[1], A KARTHIKKUMAR[1] and S MANIKANDAN[1]

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003, India

Received: 4 March 2023; Accepted: 20 June 2023

ABSTRACT

A field experiment was conducted at the Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar, during 2021–23 to study the effect of spray volume (SV) on deposition characteristics of a fuel-operated UAV sprayer (25 L/ha, 37.5 L/ha and 50 litre/ha) and knapsack sprayer (KS) (500 litre/ha) in the rice (*Oryza sativa* L.) field. Results showed that herbicides spraying using UAV (37.5 litre/ha) had a higher droplet deposition (0.077 and 0.075 µL/cm^2) than knapsack spraying of 500 litre/ha (0.06 and 0.049 µL/cm^2) in the ground layer of first (PE) and second (PoE) spraying, respectively. KS (500 litre/ha) had significantly higher droplet coverage rate, droplet size ($Dv_{0.5}$) over other UAV spray volumes. Subsequently, variation in spray uniformity was found between two sprayers. Among UAV spray volumes, application of 50 litre/ha had better deposition, coverage rate and number of spray deposits/cm^2 compared to UAV (37.5 litre/ha), with no significant difference between them. Further, application of 25 litre/ha using UAV recorded lower deposition characteristics over other treatments. So, considering low volume application of UAV (37.5 litre/ha), comparable with high volume KS (500 litre/ha), it is better to go for optimal application of UAV (37.5 litre/ha), which is having better working efficiency, profitability and labor-saving approach compared to knapsack sprayer.

Keywords: Droplet deposition, Herbicide, Knapsack sprayer, Spray volume, Unmanned aerial vehicle

Worldwide, rice (*Oryza sativa* L.) is cultivated on 164.1 million hectares in 120 countries, with a productivity of 4.6 t/ha and a production of 756.74 million tonnes. India bears annual losses from weeds of 4420 million USD (Gharde *et al.* 2018). Weeds are one of the biggest biological barriers to growing rice at its full potential. Highly efficient spraying equipment is necessary to optimize the efficacy of agrochemicals (Yang *et al.* 2018). Knapsack sprayers and spray guns are the most often used sprayers, however, they are ineffective since they demand a lot of labour and expose labour to more pesticides. Moreover, high-volume application using hand sprayers and knapsack sprayers leads to reduced efficiency of pesticides. There is a lack of research comparing backpack sprayers with UAVs related to the application of pests (Garcera *et al.* 2011). In East Asia, electric multi-rotor UAV sprayers with autonomous navigation control that can spray pesticides on a wide variety of crops are increasingly a widespread substitute for the traditional knapsack spraying approach (He 2018). UAVs deliver pesticides with reduced spray volume than conventional airborne or ground-based spraying and at a higher flight height than ground-based treatments using a manual knapsack sprayer (Fritz *et al.* 2006). UAVs have the capability to fill this need since they can fly at lower elevations and hover effectively, and precisely at various heights as well as flight velocity close to plant canopies. The primary elements that determine the droplet dispersion for different spray volumes are spray coverage, number of spray deposits and droplet deposition (Xiao *et al.* 2020). When it comes to the management and control of weeds, too much watering can reduce the effectiveness of pesticides and cause their loss. However, none of the aforementioned research studies looked at how different UAV spray volumes affect the droplet characteristics in rice fields. Based on the results of the existing studies, it is uncertain how well the low-water-consumption spray used by the UAV suppress weeds. The impact of three different water spray volumes employing a fuel-operated UAV and a manual knapsack sprayer on deposition characteristics in a rice field was compared in order to determine the optimum water spray volume.

[1]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu; [2]Sugarcane research station, TNAU, Tiruchirapalli, Tamil Nadu. *Corresponding author email: pazhanivelans@gmail.com

MATERIALS AND METHODS

A field experiment was conducted during summer season in Southern Block, Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar (11.4734^0 N, 77.1389^0 E), during 2021–23. Annually, the cultivated land was rice followed by rice rotation. The soil in the field was sandy clay loam with neutral reaction. The rice variety ASD 16 was used as test material. The plant spacing and population were 25 cm × 25 cm and 1,60,000 plants/ha, respectively during spraying. The plant height was recorded to be 14.34 ± 2.12 cm (PE) and 45.50 ± 4.62 cm (PoE) spraying. The herbicides were sprayed in the field during 8.30 AM to 10.00 AM (Table 1). The temperature, wind speed was recorded using Thermo-anemometer. The temperature was found to be between 28.4–30.5°C (pre-emergence, PE), 28.3–29.4°C (post-emergence, PoE) spraying. Wind speed varied 0.9-1.8 km/hr (PE) to 0.8–1.2 km/hr (PoE) spraying. Relative humidity was found to be 80% (PE) and 84% (PoE) spraying.

Instruments and spraying equipment: The fuel-operated quadcopter UAV served as the aircraft platform. With the use of the Global Positioning System and Real-Time Kinematic (GNSS RTK) guidance technology, the flying height and flying velocity of an aerial vehicle were precisely regulated to stay within the centimeter-level range. BLDC motors and a Li-Po (16000 mAh) battery powered the UAV. The maximum take-off weight for the UAV was 45 kg, and it has 4 rotors and propellers with a 16 L water tank. The flying time is 3 hours using 3 L of fuel (petrol). There were 4 flat-jet nozzles mounted in UAV. The movement of the UAV and KS was appropriate with a direction parallel to the plot lines. Different UAV water SVs were applied by adjusting the flow rate and flight speed. According to equation (a), the corresponding flight speeds for water SVs were determined (Biglia *et al.* 2022).

Table 1 Treatments of different spray volumes

Treatment	Spray volume (litre/ha)	Pyrazosulfuron Ethyl (10% WP) g a.i. /ha (PE)	Bispyribac-sodium (10% SC) ml a.i./ha (PoE)	Sprayer
1	25	25	25	Fuel-operated unmanned aerial vehicle (UAV)
2	37.5	25	25	
3	50	25	25	
4	500	25	25	Knapsack sprayer (KS)

$$V = \frac{K \times R}{\beta_v \times W} \quad [a]$$

where, β_v, spray volume (litre/ha); R, output nozzle flow rate (litre/min); K, constant (600); V, flight speed (km/h); W, spray width (m).

Estimation of droplet deposition distribution: The objective of UAV spraying evaluation was to assess the homogeneity and droplet deposition in the paddy field. Prior to application, a portable GPS transmitter was used to establish the coordinates of spraying zone. In the test area, a line leading to the spray belt included 8 equally uniformly spaced sample collecting locations. The centre of the spray deposition area was traversed by the UAVs (Fig 1). Filter paper (FP) and water-sensitive paper (WSP) were placed on the metal rod in the rice canopy prior to flight since rice leaves are thin. The upper layer and ground layer of the rice canopy were comparable to the heights of the WSP and FP. Each high-resolution image of WSPs were captured separately using a digital camera, 10 cm above the WSPs (Lou *et al.* 2018). WSPs were analyzed using a Micro and Macro Droplet Analyzer (Labline-dms 101, India) and further, deposit Scan software (USDA, Wooster,

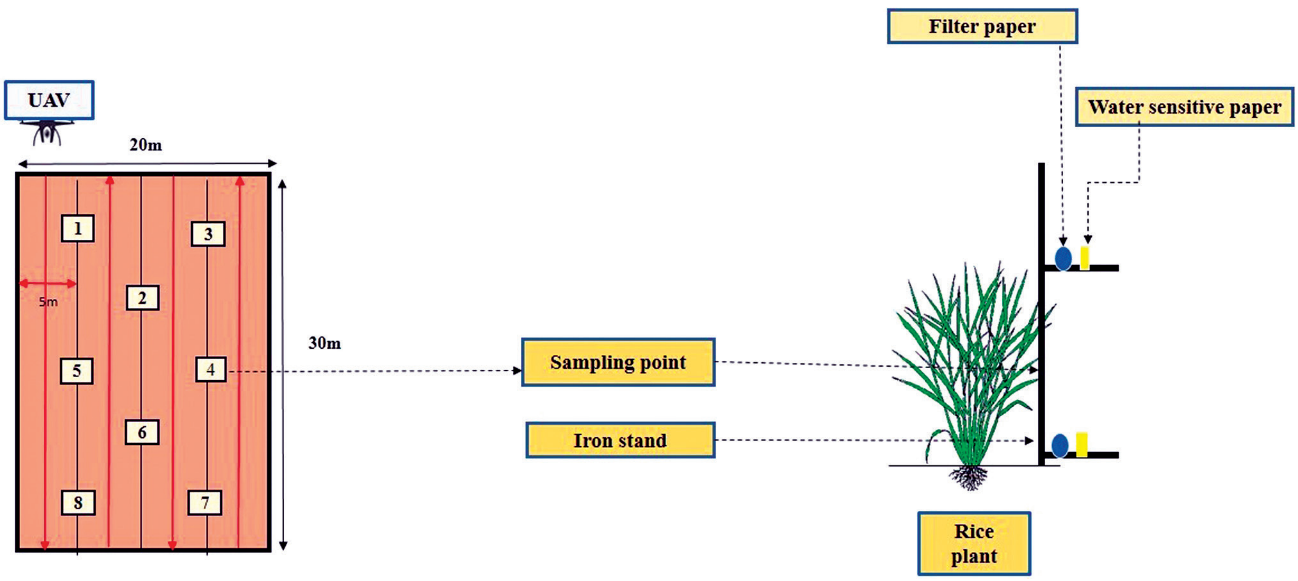

Fig 1 Placement and layout of sampling points in the field.

OH, USA) was used for image processing. Then, each image was cropped and transformed to an 8-bit format to remove the background, and then the threshold was modified individually. Each image was analyzed for the number of spray deposits and per cent coverage area. Coverage was determined based on percentage of the card deposited with droplet stain (Ferguson *et al.* 2016).

FPs were analyzed for evaluating the volume of deposition in the laboratory. A spraying solution was utilized in each test, including water and the allura red tracer. Each FP sample in ziplock bag was washed in double distilled water (20 ml) to dissolve the dye into the water solution and samples were shaken, and vibrated for 10 min (Qiu *et al.* 2007). The solution was filtered using a 0.20 µm membrane filter after vibration and elution by measuring absorbance value using ultraviolet-visible spectrophotometer at an absorption wavelength of 514 nm by pouring the solution into a cuvette. Based on the absorbance readings of the 6 solutions, the standard curve was plotted for different concentration of allura red. Droplet deposition was calculated as per the standard curve in order to generate the linear fitting curve for absorbance and standard solution concentration. The droplet deposition on the rice plants was calculated using equation (b).

$$\beta_{dep} = \frac{(\rho_{sml} - \rho_{blk}) \times F_{cal} \times V_{dil}}{\rho_{spray} \times A_{col}} \quad [b]$$

where β_{dep}, droplet deposition (µL/cm^2); ρ_{sml}, absorbance reading of the sample; ρ_{blk}, blank absorbance reading; $F_{cal,}$ relationship between the Allura red concentration and the absorbance reading in (µg/L/unit); V_{dil}, liquid volume used to dilute the tracer (litre); ρ_{spray}, tracer concentration during spray (g/L); A_{col}, area of the filter paper (cm^2).

Droplet deposition uniformity: The CV (%) of coverage rate was calculated by equations (c) and (d).

$$CV = \frac{SD}{\overline{X}} \times 100\% \quad [c]$$

$$SD = \sqrt{\sum_{i=1}^{n} (X_i - \overline{X})^2 / (n-1)} \quad [d]$$

where SD, sample standard deviation; X_i, droplets per unit area (for each sampling point); $\overline{X}$, mean droplets per unit area of sample; and n, total number of sampling points for each layer.

Statistical analysis: The statistical analysis for droplet deposition characteristics was performed using one-way ANOVA along with Tukey Honest Significant Difference (HSD) test (P<0.05) using SPSS v22.0. Data were represented accurately as mean and standard deviation (SD).

RESULTS AND DISCUSSION

Droplet coverage rate: The effect of different SVs on droplet coverage rate (%) in a paddy field is shown in Fig 2. The droplet coverage rate when spraying with KS (500 litre/ha) was significantly higher than that of UAV treatments. This is because KS (500 litre/ha) has 20, 13.33, and 10 times higher spraying volume than UAV; 25 litre/ha, UAV; 37.5 litre/ha, and UAV; 50 litre/ha; respectively. This demonstrates that the SV has a significant impact on pesticide droplet coverage and has a positive correlation with the droplet coverage rate (Meng *et al.* 2019). The droplet coverage rate of UAV; 50 litre/ha was significantly higher than UAV; 25 litre/ha in the ground layer of both PE and PoE spraying (P<0.05), but statistically, no significant difference was observed with UAV; 37.5 litre/ha. The difference in the coverage rate of all UAV treatments was found to be significant with the KS (500 litre/ha) in the upper layer of PoE spraying, with no significant difference between the coverage rate of all other UAV treatments. The upper layer received a greater coverage rate than the ground layer during PoE spraying, particularly for the UAV treatments. This might be due to canopy hindrance, resulting in lower penetrability of droplets into the ground layer from the upper layer. Our results revealed that a higher coverage rate of UAV was associated with increasing SV on both upper and ground layer of rice canopy (Rincon *et al.* 2017). Furthermore, higher number of spray deposits per unit area may have resulted in higher coverage rate and run-off of herbicide solution (Qin *et al.* 2018 and Xiao *et al.* 2019).

Droplet deposition density: The droplet density in the upper layer was found higher compared to ground layer and increased along with SV (Fig 2). During PE spraying, spray volume of 500 litre/ha using knapsack sprayer found to be having greater number of droplet deposits on the ground layer than that of other UAV spray volumes but found non-significant with UAV; 37.5 litre/ha, (P=0.377) and 50 litre/ha, (P=0.992). Among UAV treatments, the application of 50 litre/ha produced 47.10 and 20.45% more droplets in the ground layer than UAV; 25 litre/ha during PE and PoE spraying, respectively, with no significant difference at 37.5 litre/ha. During PoE spraying, KS (500 litre/ha) recorded lower droplets in the ground layer in comparison with the upper layer. This might be due to absence of downwash wind from knapsack sprayer equipment compared to UAV (Shan *et al.* 2022). The number of spray droplets has shown an increasing trend with the increase in application volume (Yuan and wang 2015, Li *et al.* 2021). Despite the possibility that the UAV's lower application volume may result in a poorer coverage rate and fewer droplet deposits, the concentration of pesticides sprayed per unit area was not obviously lower than that of conventional spraying methods since each droplet will have a greater concentration (Zhu *et al.* 2011).

Volume median diameter ($Dv_{0.5}$): Standardizing the $Dv_{0.5}$ for different SVs is essential to attain better droplet distribution of herbicides. The $DV_{0.5}$ varied with different SVs (Fig 2). $Dv_{0.5}$ of KS (500 litre/ha) was significantly larger than that of UAV treatments in all the layers of PE and PoE spraying. In case of PE spraying, $Dv_{0.5}$ was attained highest with UAV spraying at 50 litre/ha, which was non-significant with other UAV treatments (P>0.05). During PoE spraying, UAV (50 litre/ha) recorded significantly higher $Dv_{0.5}$ compared to UAV (25 litre/ha). In both PE and PoE sprayings, the $Dv_{0.5}$ of the KS (500 litre/ha) was found to be 1.80 to 2.30 times higher than that of other SVs of UAV. This might have occured due to knapsack sprayer's nozzle's poor atomization effect. The relationship between SV and $Dv_{0.5}$ resulted in difference in the spray coverage rate, which had a significant influence on herbicide efficacy (Butts *et al.* 2019). In our study, $Dv_{0.5}$ increased with increase in application volume for the sprayers (Derksen *et al.* 2008, Wang *et al.* 2019).

Deposition: The droplet deposition varied with different SV for different sprayers (Fig 2). The post-emergence application of herbicide using KS (500 litre/ha) recorded lower deposition in the ground layer compared to upper layer. During PE and PoE spraying, SV using 50 litre/ha recorded significantly higher droplet deposition than KS (500 litre/ha) ($P<0.05$) in the ground layer. Due to the increased downwash wind by the UAV's rotors towards the rice canopy and its effective atomization, UAVs have more penetrability into the ground layer than knapsack sprayers. Spraying with 50 litre/ha produced more droplet deposition than all other SVs, however, this difference was not found to be statistically significant. UAV treatments had seen an increase in deposition because of the reduced SV, higher herbicide concentration of droplets and less runoff of spray droplets to the ground surface (Xinyu *et al.* 2014, Lan *et al.* 2021).

Spray uniformity: A lower CV (%) value depicts that the droplets distribution (coverage rate) in the rice canopy was more uniform (Fig 3). The spray coverage uniformity was recorded to be higher for KS (500 litre/ha) compared to other UAV spray volumes. Spray uniformity varied between 18.50–26.42% among different application volumes of UAV. This might be due to variation in the environmental parameters such as wind velocity, relative humidity and temperature during aerial spraying. Several variables have influence on the uniformity of the droplet deposition by different UAVs (Shilin *et al.* 2017), accuracy of flight, flight parameters (Qin *et al.* 2016), spraying system and biased rotor's downwash wind of the UAV (Shengde *et al.*

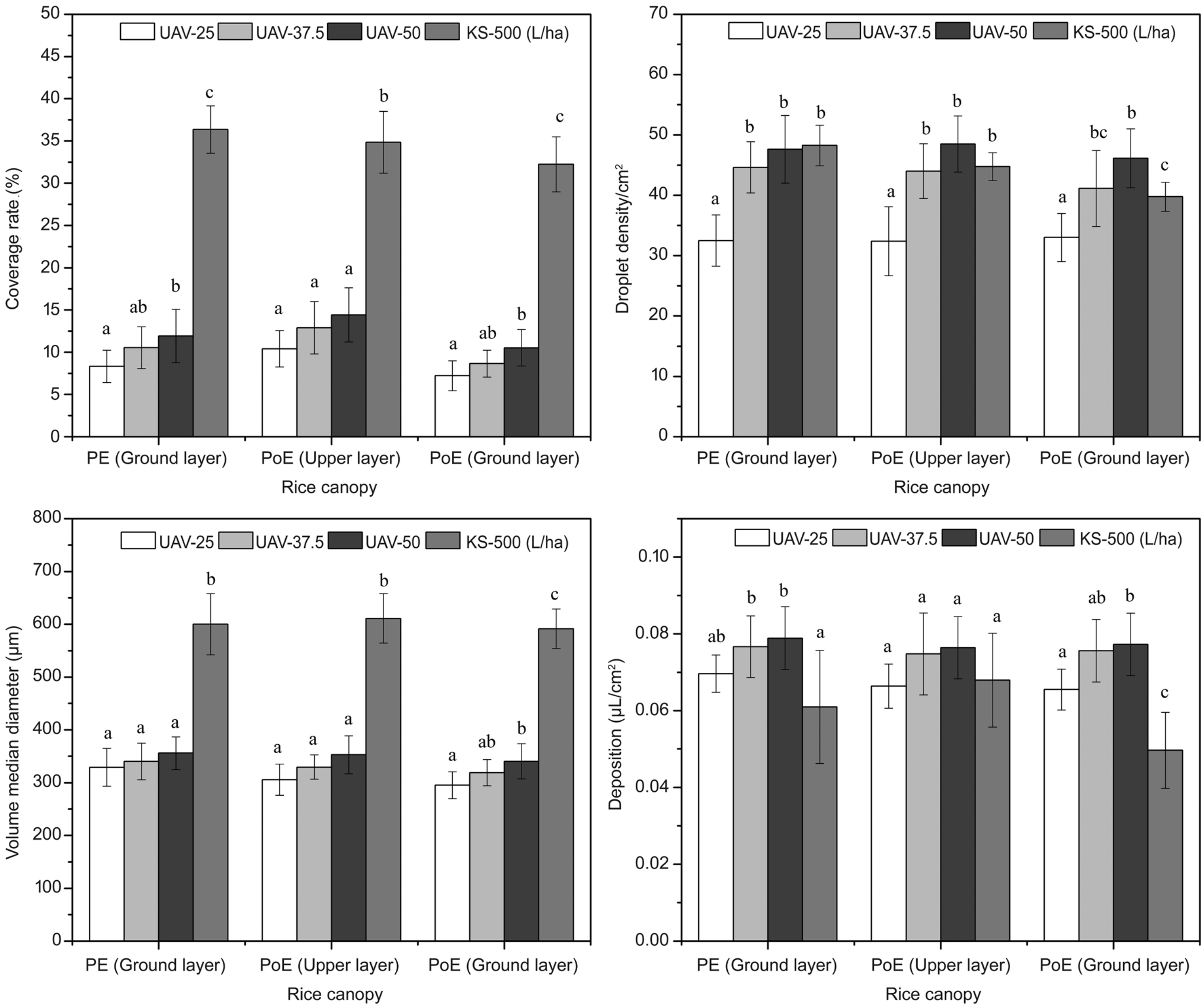

Fig 2 Coverage rate (%), droplet density, volume median diameter, deposition of 4 different spray volumes in different rice canopy layers.

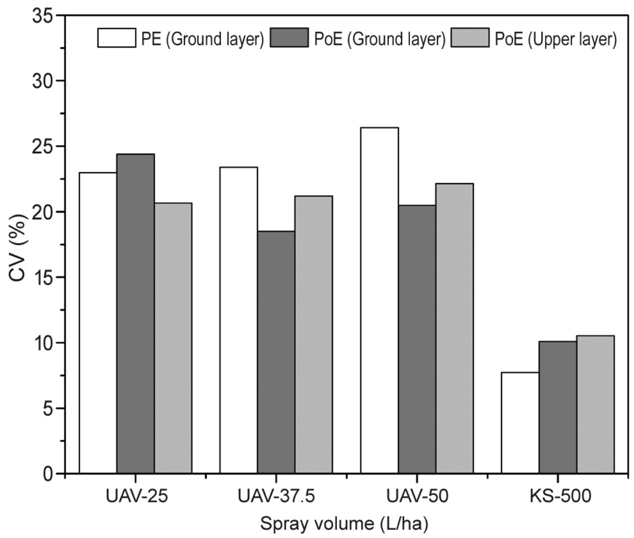

Fig 3 CV (%) of spray coverage of different spray volumes in rice canopy layers during PE and PoE spraying.

2017), and the meteorological condition prevailing during the flight. Also, the uniformity of the knapsack sprayer was greatly influenced by the operator's arm actions and travel speed along the spraying path.

Our studies demonstrated the type of sprayer and different SVs, and their effect on spray deposition characteristics. The coverage rate when spraying of 37.5 litre/ha using UAV was 62.96–73.16% lesser than spraying of 500 litre/ha using KS in the ground layer of PE and PoE spraying, respectively. The number of spray deposits from aerial spraying of 37.5 litre/ha was not significantly different from high-volume spraying using KS. The deposition using low volume application of 37.5 litre/ha was recorded higher in comparison to knapsack spraying of 500 litre/ha in all the layers of spraying. $Dv_{0.5}$ of knapsack spraying was significantly higher than others, when compared with UAV SVs. However, SV of 37.5 litre/ha had optimum number of spray deposits and $Dv_{0.5}$ for better weed control using the herbicides. In comparison with UAV; 50 litre/ha, spraying of 37.5 litre/ha using UAV shown non-significant results in terms of deposition characteristics. So, use of either high-volume spraying with a 50 litre/ha or low-volume spraying with a UAV at a rate of 37.5 litre/ha will not affect the effectiveness of the spraying. Low-volume spraying with the UAV is also more energy and cost-efficient than traditional knapsack sprayers since it reduced the SV by 13.33 times. For better herbicide performance, significant improvements in spray uniformity should be achieved while using UAVs. However, UAVs are an appropriate replacement due to their improved operational efficiency and less run-off as compared to knapsack sprayers. Further research should assess the impact of deposition attributes at various concentrations or doses using a lower quantity of herbicide.

ACKNOWLEDGEMENT

The authors are grateful to UGC for providing national fellowship.

REFERENCES

Biglia A, Grella M, Bloise N, Comba L, Mozzanini E, Sopegno A, Pittarello M, Dicembrini E, Alcatrao L E, Guglieri G and Balsari P. 2022. Uav-spray application in vineyards: flight modes and spray system adjustment effects on canopy deposit, coverage, and off-target losses. *Science of the total environment* **845**:157292.

Butts T R, Samples C A, Franca L X, Dodds D M, Reynolds D B, Adams J W, Zollinger R K, Howatt K A, Fritz B K and Clint H W. 2019. Spray droplet size and carrier volume effect on dicamba and glufosinate efficacy. *Pest management science* **74**(9): 2020–29.

Derksen R, Zhu H, Ozkan H, Hammond R, Dorrance A and Spongberg A. 2008. Determining the influence of spray quality, nozzle type, spray volume, and air-assisted application strategies on deposition of pesticides in soybean canopy. *Transactions of the ASABE* **51**(5): 1529–37.

Ferguson J C, Chechetto R G, Hewitt A J, Chauhan B S, Adkins S W, Kruger G R and O'Donnell C C. 2016. Assessing the deposition and canopy penetration of nozzles with different spray qualities in an oat (*Avena sativa* L.) canopy. *Crop Protection* **81**: 14–19.

Fritz B K, Kirk I W, Hoffmann W C, Martin D E, Hofman V L, Hollingsworth C, McMullen M and Halley S. 2006. Aerial application methods for increasing spray deposition on wheat heads. *Applied Engineering in Agriculture* **22**(3): 357–64.

Garcerá C, Moltó E and Chueca P. 2011. Effect of spray volume of two organophosphate pesticides on coverage and on mortality of California red scale (*Aonidiella aurantii*). *Crop Protection* **30**(6): 693–97.

Gharde Y, Singh P, Dubey R and Gupta P. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**: 12–18.

He X. 2018. Rapid development of unmanned aerial vehicles (UAV) for plant protection and application technology in China. *Outlooks on Pest Management* **29**(4): 162–67.

Lan Y, Qian S, Chen S, Zhao Y, Deng X, Wang G, Zang Y, Wang J and Qiu X. 2021. Influence of the downwash wind field of plant protection UAV on droplet deposition distribution characteristics at different flight heights. *Agronomy* **11**(12): 2399.

Li X, Giles D K, Niederholzer F J, Andaloro J T, Lang E B and Watson L J. 2021. Evaluation of an unmanned aerial vehicle as a new method of pesticide application for almond crop protection. *Pest Management Science* **77**(1): 527–37.

Lou Z, Xin F, Han X, Lan Y, Duan T and Fu W. 2018. Effect of unmanned aerial vehicle flight height on droplet distribution, drift and control of cotton aphids and spider mites. *Agronomy* **8**(9): 187.

Meng Y, Song J, Lan Y, Mei G, Liang Z and Han Y. 2019. Harvest aids efficacy applied by unmanned aerial vehicles on cotton crop. *Industrial Crops and Products* **140**: 111645.

Qin W C, Qiu B J, Xue X Y, Chen C, Xu Z F, Zhou and Q Q. 2016. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. *Crop Protection* **85**: 79–88.

Qin W, Xue X, Zhang S, Gu W and Wang B. 2018. Droplet deposition and efficiency of fungicides sprayed with small UAV against wheat powdery mildew. *International Journal of Agricultural and Biological Engineering* **11**(2): 27–32.

Qiu Z, Yuan H and Lou S. 2007. The research of water soluble dyes of allura red and ponceau-G as tracers for determing pesticide spray distribution. *Pesticides-Shenyang* **46**(5): 323.

Rincon V J, Sanchez-Hermosilla J, Paez F, Perez-Alonso J and Callejon A J. 2017. Assessment of the influence of working pressure and application rate on pesticide spray application with a hand-held spray gun on greenhouse pepper crops. *Crop Protection* **96**: 7–13.

Shan C, Wu J, Song C, Chen S, Wang J, Wang H, Wang G and Lan Y. 2022. Control efficacy and deposition characteristics of an unmanned aerial spray system low-volume application on corn fall armyworm *Spodoptera frugiperda*. *Frontiers in Plant Science* **13**.

Shengde C, Lan Y, Jiyu L, Zhiyan Z, Aimin, L and Yuedong M. 2017. Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying. *International Journal of Agricultural and Biological Engineering* **10**(3): 67–77.

Shilin W, Jianli S, Xiongkui H, Le S, Xiaonan W, Changling W, Zhichong W and Yun L. 2017. Performances evaluation of four typical unmanned aerial vehicles used for pesticide application in China. *International Journal of Agricultural and Biological Engineering* **10**(4): 22–31.

Wang G, Lan Y, Qi H, Chen P, Hewitt A and Han Y. 2019. Field evaluation of an unmanned aerial vehicle (UAV) sprayer: effect of spray volume on deposition and the control of pests and disease in wheat. *Pest management science* **75**(6): 1546–55.

Xiao Q, Xin F, Lou Z, Zhou T, Wang G, Han X, Lan Y and Fu W. 2019. Effect of aviation spray adjuvants on defoliant droplet deposition and cotton defoliation efficacy sprayed by unmanned aerial vehicles. *Agronomy* **9**(5): 217.

Xiao Q, Du R, Yang L, Han X, Zhao S, Zhang G, Fu W, Wang G and Lan Y. 2020. Comparison of droplet deposition control efficacy on *Phytophthora capsica* and aphids in the processing pepper field of the unmanned aerial vehicle and knapsack sprayer. *Agronomy* **10**(2): 215.

Xinyu X, Kang T, Weicai Q, Yubin L and Huihui Z. 2014. Drift and deposition of ultra-low altitude and low volume application in paddy field. *International Journal of Agricultural and Biological Engineering* **7**(4): 23–28.

Yang S, Yang X and Mo J. 2018. The application of unmanned aircraft systems to plant protection in China. *Precision agriculture* **19**: 278–92.

Yuan H and Wang G. 2015. Effects of droplet size and deposition density on field efficacy of pesticides. *Plant protection* **41**(6): 9–16.

Zhu H, Salyani M and Fox R D. 2011. A portable scanning system for evaluation of spray deposit distribution. *Computers and Electronics in Agriculture* **76**(1): 38–43.