Comparison of droplet distribution of herbicides using an unmanned aerial vehicle and a knapsack sprayer in transplanted rice (*Oryza sativa L.*)

[1]**Narayanaswamy Jeevan**
Ph.D scholar
Department of Agronomy
Tamil Nadu Agricultural University, Coimbatore-641003
Email: jeevanvnsp125@gmail.com

[2]**Sellaperumal Pazhanivelan**
Director
Water technology centre
Tamil Nadu Agricultural University, Coimbatore-641003
Email: pazhanivelans@gmail.com

[3]**Ramalingam Kumaraperumal**
Associate Professor,
Department of Remote sensing and GIS
Tamil Nadu Agricultural University, Coimbatore-641003
Email: kumaraperumal.r@gmail.com

[4]**P Murali Arthanari**
[4]Professor, Sugarcane research station,
Water technology centre,
Tamil Nadu Agricultural University, Tiruchirapalli-635115
Email: agronmurali@gmail.com

[4]**N Sritharan**
[4] Associate Professor, Department of Rice,
Tamil Nadu Agricultural University, Coimbatore-
Email: sritharan.n@tnau.ac.in

***Abstract*—** In rice crop, herbicide applications are often made using conventional manual spraying equipment. In India, recent advancements in aerial spraying technology, which includes unmanned aerial vehicles, have great potential to replace conventional knapsack sprayers. In our study, an unmanned aerial vehicle (UAV) (15 L/ha, 20 L/ha and 25 L/ha) and knapsack sprayer (KS)(500L/ha) with pre-emergence (PE) application of pyrazosulfuron ethyl (10%WP) at 25 g a.i./ha at 3 days after transplanting (DAT) and post-emergence (PoE) application of bis-pyribac Sodium (10%SC) at 25 g a.i./ha at 25 DAT were used to compare the droplet deposition characteristics for different spray volumes in rice field. The results revealed that the KS (500 L/ha) had a higher droplet coverage rate, droplet size ($Dv_{0.5}$), number of spray deposits/cm^2 and spray uniformity in comparison with UAV spray volumes. Among UAV spray volumes, the application of 25 L/ha had better coverage rate, spray uniformity and the number of spray deposits/cm^2. UAV (25 L/ha) recorded optimum droplet characteristics for herbicide application. Considering the low volume application of UAV (25 L/ha) as compared with high volume KS (500 L/ha), it is better to go for the optimal application of UAV (25 L/ha), which is energy efficient and cost-effective, labour-saving approach compared to conventional knapsack sprayer.

Keywords: Unmanned aerial vehicle, Knapsack sprayer, Spray volume, Herbicide application
DOI: 10.48047/ecb/2023.12.si4.973

I. INTRODUCTION

Rice is the most popular staple food for more than 50% of the world's population. Since rice is associated with people's livelihood in Asia, nearly 90% of the world's rice is produced and consumed (Shankar *et al*., 2021). In the world, rice is expected to witness a demand increase of 800 metric tonnes by the end of 2025 (Rana *et al*., 2020). India suffers annual losses of 4420 million USD due to weed infestation (Gharde *et al*., 2018). Weeds are undesirable plants that compete with crops for resources such as water, nutrients, sunlight, space, and carbon dioxide, with their main sources being the soil seed bank (Mahe *et al*., 2021). It is essential to use high-efficiency spraying equipment (Yang *et al*., 2018) to maximize the effectiveness of agrochemicals on the weed population. The most popular sprayers are manual knapsack sprayers and spray guns; however, they are inefficient due to their high labor requirements and higher pesticide exposure levels at work (Shengde *et al*., 2017). Additionally, manual spray guns and knapsack sprayers use a high volume of pesticide application, which results in low pesticide-use efficiency (Garcera *et al*., 2011). There is a paucity of research comparing knapsack sprayers with spraying UAVs for the application of pest control products. Because of the agrarian UAV's ability to fly at low altitudes, low volume spraying, low cost, good spraying effect, it is currently developing quickly and finding widespread use in rice production (Lan *et al*., 2017). UAVs spray pesticides with a lower spray volume than traditional aerial or ground-based spraying and at a greater flight height than ground-based applications using a knapsack sprayer (Fritz *et al*., 2006). The key factors defining the droplet distribution for various spray volumes are droplet coverage and density (Xiao *et al*., 2020).

As a result, to determine the optimal water application volume, there is a need to compare the effects of three different water application volumes using fuel operated UAV and a conventional knapsack sprayer on droplet distribution characteristics in rice field.

II. MATERIALS AND METHODS

Field plots

The experiment was carried out in the Southern Block of Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar (11^0 4734^1 N latitude, 77^0 1389^1 E longitude), India, in 2022. The cultivated land was annual rice-rice rotation. The soil in the field was sandy clay loam with a neutral reaction. The test material was the rice variety "ASD 16". During the application of herbicide, plant spacing and planting density were 25 × 25 cm and 1,60,000 plants/ha, respectively. The plant height was 14.34 ± 2.12 cm and 45.50 ± 4.62 cm during the first and second spraying (Table 1).

Instruments and spraying equipments

The aircraft platform was a hexacopter UAV provided with a Global Navigation Satellite System as well as Real-Time Kinematic technology. The UAV was powered by a Li-Po (16000 mAh) battery and 180 kV BLDC motors and It had six rotors along with propellers (57.5 cm length). The payload volume was 10 L along with 28 kg maximum take-off capacity. The flying time is 10 minutes with a full tank. Four flat-jet type nozzles were present. The flight height of the UAV ranged from 0–30 m, the flight velocity from 0–12 m/s, and the effective spraying width of 4 m. According to equation (1), the corresponding flight speeds for water spray volumes (15, 20, and 25 L/ha) were determined (American society of Agricultural engineers, 1995).

$$V = \frac{K \times R}{\beta_v \times W} \qquad (1)$$

where, βv is the water spray volume, L/ha; R is the output rate, L/min; K is a constant, 600; V is the flight speed, km/h; and W is the swath width, m.

Droplet distribution evaluation

The purpose of the UAV spraying was to evaluate the uniformity and droplet characteristics in the rice field. Eight sample collection points were arranged uniformly on the line to the spray belt in the test area (Figure 1). WSPs were placed at a height equivalent to the rice canopy's top and ground layers. After the field experiment, the WSPs were collected and kept in ziplock bags. A high-resolution digital single-lens reflex camera was used to take individual photos of each card on a light table 10 cm above the surface (Lou *et al*., 2018). WSPs were analyzed using a Macro Droplet Analyzer and Micro Droplet Analyzer instruments, and then images were processed with Deposit Scan software. Each card was cropped and converted to an 8-bit format to eliminate the background region, and then the threshold was modified individually (Figure 2). Each image was analyzed for the number of droplets, density, and percent coverage area and $DV_{0.5}$. Coverage was determined as the coverage percentage of the card from the droplets deposited (Ferguson *et al*., 2016).

Spray uniformity

To illustrate the spray uniformity of droplets between sampling points in the test, the uniformity was measured by the CV of coverage rate was calculated by equations (2) and (3).

$$CV = \frac{SD}{\bar{X}} \times 100\% \qquad (2)$$

$$\bar{X} = \sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2/(n-1)} \qquad (3)$$

SD refers to the standard deviation of the sample; X_i represents the droplets per unit area of each sampling point, X is the mean droplets per unit area of every sampling unit, and n is the total number of sampling points per layer.

Statistical analysis

The results of droplet density, coverage area and volume median diameter were subjected to one-way ANOVA analysis, followed by the Tukey Honest Significant Difference (HSD) test at a significance level of 95% confidence interval using SPSS v22.0 (SPSS Inc., IBM division). Precise data are depicted as the mean and standard deviation (SD). Different letters shown above the bars represented the significant differences among treatments ($p < 0.05$).

IV.RESULTS AND DISCUSSION

Droplet coverage rate

The effect of different spray volume on droplet coverage rate in rice field shown in Figure 3. When spraying with KS (500 L/ha), the droplet coverage rate was significantly higher than that of UAV spraying treatments due to its 20, 25 and 33.3times higher spray volumes than UAV (15 L/ha), UAV (20 L/ha), and UAV (25 L/ha), respectively. This illustrates that the spray volume considerably influences the pesticide droplet coverage, and the droplet coverage rate is positively correlated with the volume of spray (Meng *et al*., 2019). The droplet coverage rate of UAV (25 L/ha) was significantly higher than UAV (15 L/ha) in the ground layer of the first spraying ($p < 0.05$), but statistically, with no significant difference observed in other treatments. The difference in the coverage rate of UAV (25 L/ha) was found significant with UAV (15 L/ha) ($p < 0.0001$) and UAV (20 L/ha) ($p < 0.05$) in the upper layer of second spraying, with no significant difference between the coverage rate of UAV (15 L/ha) and UAV (20 L/ha). The upper layer received a greater coverage rate than the ground layer, particularly for the UAV treatments. In the ground layer of the second spraying, there was a significant difference between UAV (25 L/ha) and UAV (15 L/ha), with no significant difference between other treatments. Droplet density and coverage were lower on the ground layer of the plant canopy than on the upper layer in both sprayers; the reduced droplets on the ground layer resulted in lower chemical penetration and deposition. The results revealed that droplet density and coverage rate are associated with spray volume. The spray volume of 25 L/ha decreased the number of droplets and coverage rate on both the upper and ground layer of the rice canopy, while higher spray volume led to higher droplet density per unit area and resulted in the runoff of herbicide solution (Qin *et al*., 2018, Xiao *et al*., 2019).

Volume median diameter

Optimizing the droplet size for different spray volumes is essential to obtain better spray distribution and satisfactory application efficiency of herbicides. The Dv0.5 varied with different sprayer spray volumes (Figure 4). Dv0.5 of the knapsack sprayer was significantly larger than that of UAV treatments in all the layers of the first and second spraying of herbicides. In the case of first spraying, Dv0.5 was achieved highest with UAV spraying at 25 L/ha, which was significantly higher than 15 L/ha ($p = 0.004$) but showed a non-significant difference with 20 L/ha ($p = 0.202$). The difference in the Dv0.5 was found non-significant in the ground layer of the second herbicide spraying with all the UAV treatments ($p > 0.05$). During the second spraying, there was a significant difference between the UAV application of 25 L/ha and 15 L/ha ($p = 0.003$) and a non-significant difference with other treatments. In our experiment, Dv0.5 increased with an increase in spray volume for both the knapsack sprayer and UAV sprayer (Wang *et al*., 2019). In both the first and second sprayings, the droplet size of the KS (500 L/ha) was found to be significantly larger than that of the UAV, with an average droplet size of 1.80 to 2.30 times that of the UAV. This is due to the weak atomization action of the nozzle of the knapsack sprayer. Some studies have demonstrated that finer droplets will more easily penetrate into the lower parts of the canopy (Knoche, 1994), while others have depicted that coarser droplets will have greater penetrability (Derksen *et al*., 2008). Although the herbicidal effect of finer droplets was more significant at lower-volume sprayings, the droplet size had no impact on the efficiency of herbicides at larger application volumes (Butts *et al*., 2018).

Droplet deposition density

During the first and second spraying, with 500L/ha using a knapsack sprayer was found to have a greater number of droplet deposits on the ground layer than that of the other spray volumes using UAV but found non-significant with UAV (25 L/ha) ($p = 0.126$) (Figure 5). Among the UAV treatments, the application of 25 L/ha achieved a significant difference with other spray volumes in the upper layer during the first and second spraying. The difference in the droplet deposits have found to be significantly higher with the knapsack sprayer (500 L/ha) compared with UAV (15 L/ha) and UAV (20 L/ha), but statistically, it was found non-significant with UAV (25 L/ha) in the ground layer of first spraying. Among the UAV spray volumes, spraying of 25 L/ha was found to have a higher number of deposits/cm2 than with 15 L/ha and 20 L/ha. According to other studies (Yuan and Wang, 2015), the application volume had a substantial influence on the droplet, and with the increase in application volume, the number of spray deposits showed an increasing trend. It isn't easy to assess the spraying quality by a single index. In order to attain satisfactory control efficacy, the number of droplet deposits only needs to attain the threshold level (Ebert *et al*., 1999).

Spray uniformity

For different UAV spray volumes, the Coefficient of variation (CV) for the droplet coverage distribution in the upper layer of the rice canopy was better than that of the ground layer during the second spraying (Figure 6). A smaller CV value denotes that the rice canopy's droplets distribution (coverage rate) is more uniform. The coverage uniformity was found to be higher for KS (500 L/ha) than other UAV spray volumes during first and second spraying in both upper and ground layers. During the second spraying, UAV (25 L/ha) was observed with higher spray uniformity compared to other UAV spray volumes but lesser than KS (500 L/ha). The lesser the spray volume, higher the CV was observed among UAV treatments. The UAV's spray uniformity was influenced by numerous variables, such as the different types of UAV, the accuracy of flight, the various flight parameters, the spraying system, the biased downwash rotor wind fields (Shengde *et al*., 2017) and the meteorological condition prevailing during the flight. Furthermore, the knapsack sprayer's droplet distribution uniformity outperformed UAV spraying in terms of quality. However, UAVs are a potential alternative because of their high working efficiency and decreased run-off compared to knapsack sprayers.

IV.CONCLUSION

The investigation of the effect of spray volumes on droplet distribution and weed control efficiency using UAV and knapsack sprayers in rice cropping systems has shown promising results. The coverage rate, droplet density and droplet size varied with spray volume and the different sprayers. The coverage rate when spraying 25 L/ha using UAV was 27.57% and 24.66% lesser coverage rate than spraying 500 L/ha using a knapsack sprayer in the ground layer of the first and second spraying, respectively. The number of spray deposits from UAV (25 L/ha) was not significantly different from high-volume spraying using a knapsack sprayer. The spray coverage uniformity of UAV spray volumes varied from 25.60-34.95% and 17.38-27.38% in the ground layer of the first and second spraying in comparison with the knapsack sprayer. Compared with UAV spray volumes, the droplet size of knapsack spraying was significantly larger than others. Low-volume spraying with the UAV is also more cost-and energy-efficient than traditional knapsack sprayers since it reduces the spray volume by more than 20 times. Further research should evaluate the effects of coverage rate, droplet size, number of spray deposits and different doses or concentrations on the effective control of weeds in rice fields using a minimal amount of herbicide.

Acknowledgement

The authors thank the department of remote sensing and GIS, Tamil Nadu Agricultural University, Coimbatore, for providing technical assistance in conducting this research work.

Conflict of interests

The authors declare that there is no competing interest.

REFERENCES

American society of Agricultural engineers. (1995). Calibration and distribution pattern testing of agricultural aerial application equipment. State of Michigan. *American Society of Agricultural Engineers*, 229–232.

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. & Clint Hoffmann, W. (2018). Spray droplet size and carrier volume effect on dicamba and glufosinate efficacy. *Pest management science*, 74, 2020-2029.

Derksen, R., Zhu, H., Ozkan, H., Hammond, R., Dorrance, A. & 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, 1529-1537.

Ebert, T.A., Taylor, R.A.J., Downer, R.A. & Hall, F.R. (1999). Deposit structure and efficacy of pesticide application. 1: Interactions between deposit size, toxicant concentration and deposit number. *Pesticide Science*, 55, 783-792.

Ferguson, J.C., Chechetto, R.G., Hewitt, A.J., Chauhan, B.S., Adkins, S.W., Kruger, G.R. & 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. & Halley, S. (2006). Aerial application methods for increasing spray deposition on wheat heads. *Applied Engineering in Agriculture*, 22, 357-364.

Garcerá, C., Moltó, E. & Chueca, P. (2011). Effect of spray volume of two organophosphate pesticides on coverage and on mortality of california red scale aonidiella aurantii (maskell). *Crop Protection*, 30, 693-697.

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

Knoche, M. (1994). Effect of droplet size and carrier volume on performance of foliage-applied herbicides. *Crop protection*, 13, 163-178.

Lan, Y., Shengde, C. & Fritz, B.K. (2017). Current status and future trends of precision agricultural aviation technologies. *International Journal of Agricultural and Biological Engineering*, 10, 1-17.

Li, X., Giles, D.K., Niederholzer, F.J., Andaloro, J.T., Lang, E.B. & 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, 527-537.

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

Mahé, I., Cordeau, S., Bohan, D.A., Derrouch, D., Dessaint, F., Millot, D. & Chauvel, B. (2021). Soil seedbank: Old methods for new challenges in agroecology. Annals of Applied Biology, 178, 23-38.

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

Qin, W., Xue, X., Zhang, S., Gu, W. & 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, 27-32.

Rana, N., Rahim, M.S., Kaur, G., Bansal, R., Kumawat, S., Roy, J., Deshmukh, R., Sonah, H. & Sharma, T.R. (2020). Applications and challenges for efficient exploration of omics interventions for the enhancement of nutritional quality in rice (*oryza sativa* l.). *Critical reviews in food science and nutrition*, 60, 3304-3320.

Shankar, T., Malik, G.C., Banerjee, M., Dutta, S., Maitra, S., Praharaj, S., Sairam, M., Kumar, D.S., Dessoky, E.S. & Hassan, M.M. (2021). Productivity and nutrient balance of an intensive rice–rice cropping system are influenced by different nutrient management in the red and lateritic belt of west bengal, India. *Plants*, 10, 1622.

Shengde, C., Lan, Y., Jiyu, L., Zhiyan, Z., Aimin, L. & 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, 67-77.

Wang, G., Lan, Y., Qi, H., Chen, P., Hewitt, A. & 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, 1546-1555.

Xiao, J., Chen, L., Pan, F., Deng, Y., Ding, C., Liao, M., Su, X. & Cao, H. (2020). Application method affects pesticide efficiency and effectiveness in wheat fields. *Pest Management Science*, 76, 1256-1264.

Xiao, Q., Du, R., Yang, L., Han, X., Zhao, S., Zhang, G., Fu, W., Wang, G. & Lan, Y. (2019). Effect of aviation spray adjuvants on defoliant droplet deposition and cotton defoliation efficacy sprayed by unmanned aerial vehicles. *Agronomy*, 9, 217.

Yang, S., Yang, X. & Mo, J. (2018). The application of unmanned aircraft systems to plant protection in china. *Precision agriculture*, 19, 278-292.

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

Zhu, H., Dorner, J., Rowland, D., Derksen, R. & Ozkan, H. (2004). Spray penetration into peanut canopies with hydraulic nozzle tips. *Biosystems Engineering*, 87, 275-283.

Table 1: Treatments of different spray volumes using herbicides

Treatment	Spray Volume (L/ha)	Pyrazosulfuron-ethyl (10% WP) g a.i. /ha	Bispyribac-sodium (10%SC) ml a.i. /ha	Sprayer
1.	15	25	25	Battery Operated unmanned aerial vehicle (UAV)
2.	20	25	25	
3.	25	25	25	
4.	500	25	25	Knapsack sprayer(KS)

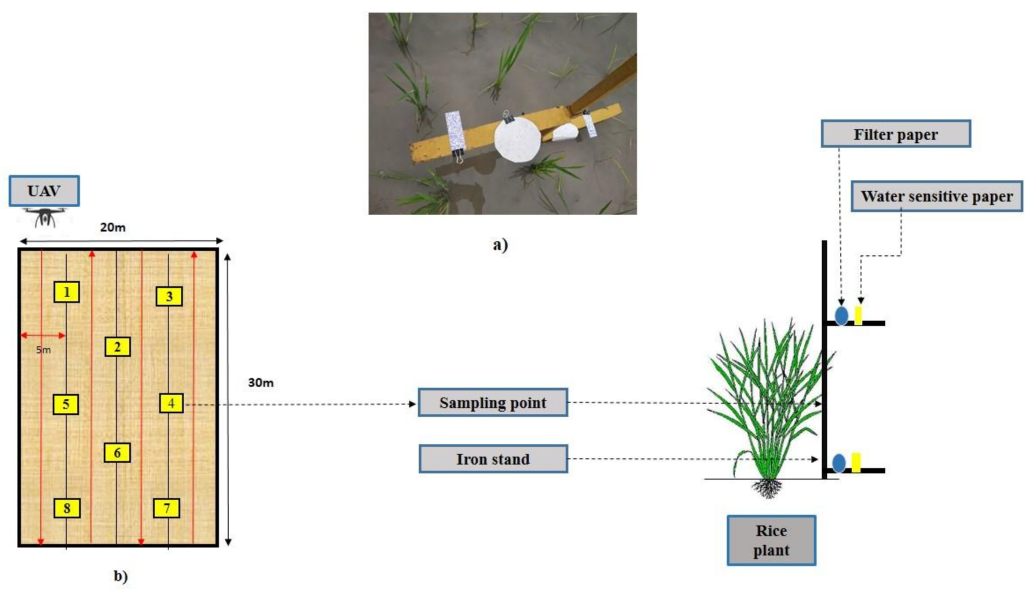
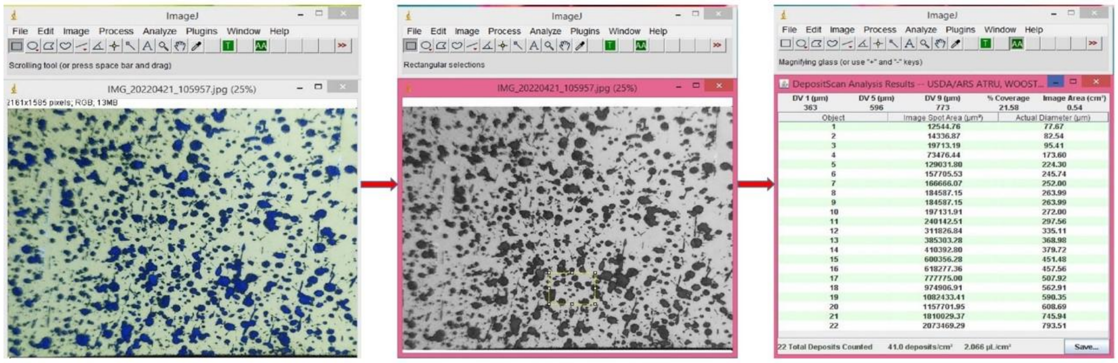


Figure 1. Placement and layout of sampling points in the field



A) **B)** **C)**

Figure 2. Procedure for the analysis of droplet characteristics under Depositscan software: (i) Importing WSP image to ImageJ software, (ii) Imported image color conversion to black and white for the marked area of the sample under 8 bit, and (iii) Further, green AA tool used for analysis.

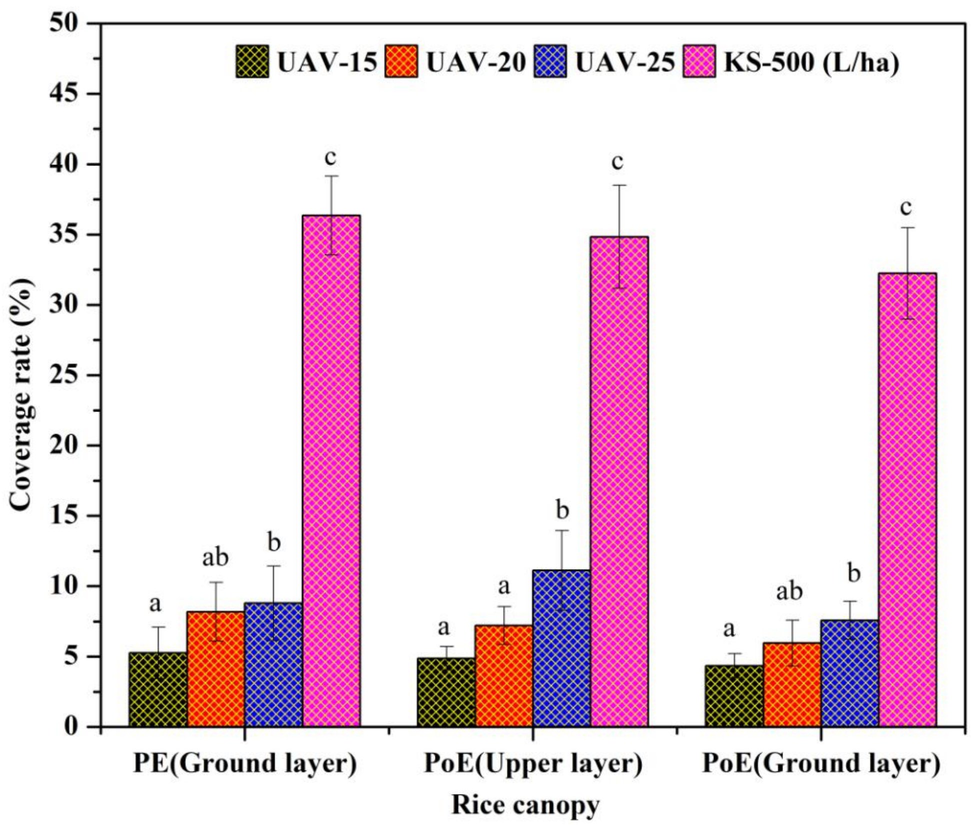


Figure 3. Coverage rate (%) of three different spray volumes of UAV (15 L, 20 L and 25 L/ha) and one knapsack sprayer (500 L/ha) in different rice canopy layers.

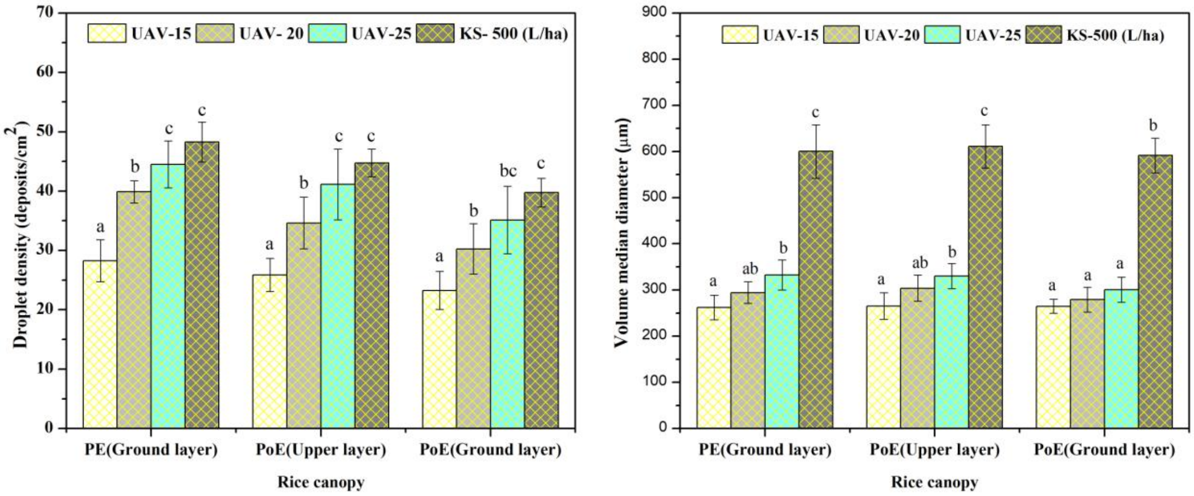


Figure 4. Droplet density and Volume median diameter (µm) of three different spray volumes of UAV (15 L, 20 L and 25 L/ha) and one knapsack sprayer (500 L/ha) in different rice canopy layers.

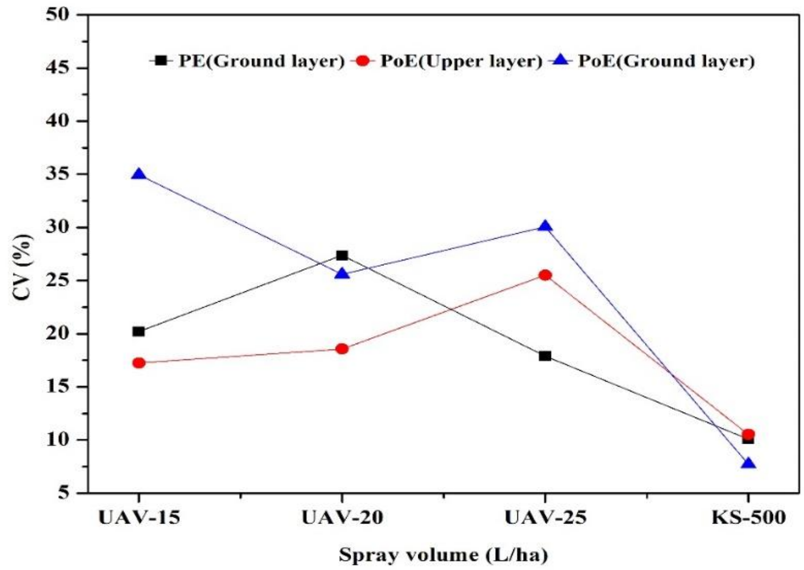


Figure 5. CV (%) of droplet coverage of different spray volumes in rice canopy layers during first and second spraying.