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Research Article

Effect of different herbicide spray volumes on weed control efficiency of a battery-operated Unmanned aerial vehicle sprayer in transplanted rice (*Oryza sativa* L.)

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Abstract

The effect of spray volume on weed control in transplanted rice ecosystems using the Unmanned aerial vehicle (UAV) needs to be better understood for management in the advancements of UAV-based spraying technology. The present study aimed to find out the influence of varied spray volumes of 15 L/ha, 20 L/ha and 25 L/ha using the UAV and 500 L/ha using a Knapsack sprayer (KS) to compare the weed density, weed dry matter and weed control efficiency and yield in transplanted rice (*Oryza sativa* L.). Pre-emergence (PE) application of Pyrazosulfuron-ethyl at 25 g a.i./ha at three days after transplanting (DAT) and post-emergence (PoE) application of Bis-pyribac sodium at 25 g a.i./ha at 25 DAT were used as herbicide treatments. The results revealed that varied spray volumes significantly influenced the weed density, dry matter, and weed control efficiency of the UAV and KS. Application of herbicides using KS (500 L/ha) and UAV (25 L/ha) had better control on the weeds by reducing weed density and dry matter at 20, 40, and 60 DAT, with no significant difference. Higher grain yield and straw yield were recorded in KS (500 L/ha) and UAV (25 L/ha), with no significant difference. However, applying 25 L/ha had better weed control efficiency and higher yield, possibly due to optimum deposition. Considering the low volume application of UAV (25 L/ha) as compared with KS (500 L/ha), it is better to go for the optimal application of 25 L/ha, which is an energy-efficient and cost-effective, labour-saving approach compared to KS.

Keywords: Herbicide application, Knapsack sprayer, Spray volume, Unmanned aerial vehicle, Weed control efficiency

INTRODUCTION

More than 50% of the world's population depends on rice as a staple diet. Since rice is associated with people's livelihood in Asia, nearly 90% of the world's rice is produced and consumed (Chauhan *et al*., 2012 ; Shankar *et al*., 2021). Worldwide, rice 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 (FAOSTAT, 2022). India is the world's second-largest producer of rice and it is grown on 4.4 million hectares in India, with an average yield of 2.7 t/ha and a production of 118 million tonnes (Government of India, 2020).

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 (Barbaś *et al*., 2020; Hasan *et al*., 2021 and Mahé *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. Electric knapsack sprayers are the most important tool for applying herbicides in small field operations, in experiments pertaining to weed science research, and in pasture land where targeted application to patches of invasive species was indeed necessary for efficient control of weeds (Meyer *et al*., 2016). 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*., 2016). Additionally, manual spray guns and knapsack sprayers use a high volume of pesticide application, which results in low pesticide-use efficiency (Garcerá *et al*., 2011). There is a paucity of research comparing Knapsack sprayers (KS) with spraying Unmanned aerial vehicles (UAVs) for the application of pest control products.

UAVs can substantially manage a variety of pests and diseases by adjusting the application parameters. The loss of weedicides and reduced effectiveness of weed management techniques can result from higher spray volume. In addition, none of the previous research studies looked at how different UAV water spray volumes affect the ability to control weeds in rice fields. Accordingly, based on the results of the available studies, it is unknown how effectively the low-water-consumption spray used by the UAV will suppress weeds. As a result, the present study aimed to analyze the effects of different water spray volumes using UAVs and a traditional KS on weed control efficiency in transplanted rice (*Oryza sativa* L.) to find the ideal water application volume.

MATERIALS AND METHODS

The weed parameters were examined using three different spray volumes (15, 20, and 25 L/ha) in order to optimize the spray volume. A KS sprayer with a single spray volume (500 L/ha) was used as a reference. The efficacy of the aforementioned methods in controlling weeds was assessed using a weed control treatment.

The experiment was conducted in the ‘S’ Block of Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar (11.4734N, 77.1389E), India, in 2022 (Fig. 1). 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 herbicide application, 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. Treatments and the spraying of herbicides on two dates after transplanting from 8.30 AM to 10.00 AM are shown in Table 1. The temperature and wind speed were recorded using CFM/CMM Thermo-anemometer (Metravi Instruments Pvt. Ltd, Kolkata, India). The temperature varied between 28.4^0-30.5^0C and 28.3^0-29.4^0C during the first and second spraying, and the wind speed ranged from 0.9-1.8 km/hr to 0.8-1.2 km/hr during the first and second spraying. Relative humidity was found to be 80% and 84% during the first and second spraying.

Spraying equipments

The aviation platform was a battery-operated hexacopter UAV (Fig. 2) integrated with a Global Navigation Satellite System and Real-Time Kinematic (GNSS RTK) navigation technology. The UAV was powered by a Li-Po (16000mAh) battery with 180kV BLDC motors and had six rotors with 57.5 cm length propellers. UAV

Table 1. Treatments of different spray volumes using herbicides

Treatment	Spray Volume (L/ha)	14 March 2022 Pyrazosulfuron-ethyl (10%WP) g a.i. /ha	05 April 2022 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)

Fig. 1. *Spraying of herbicides by UAV in the experimental*

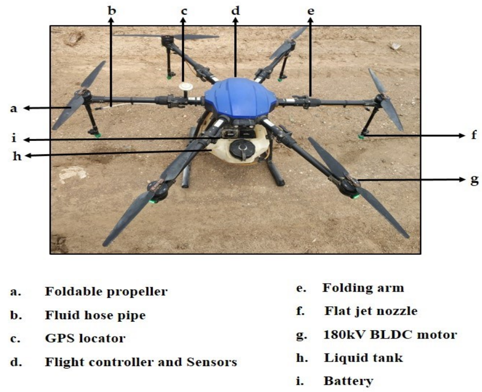

Fig. 2. *Battery-operated hexacopter UAV sprayer*

operating parameters are shown in Table 2. Herbicides used for the experiments were Pyrazosulfuron-ethyl 10%WP @ 25g a.i/ha (UPL Ltd., India), a pre-emergence, systemic herbicide applied on 14 March 2022, 3 days after transplanting and Bispyribac Sodium 10%SC @ 25g a.i/ha (PI Industries ltd., India), a post-emergent, systemic herbicide applied on 05 April 2022 at 25 days after transplanting.

Weed control efficiency

The major weed flora found in the field were grasses, sedges and broad-leaved weeds (*Echinochloa colona* L., *Cyperus difformis* L., *Cyperus iria* L., *Sphenochloa zeylanica* Gaertn., *Marsilea quadrifolia* L., *Monochoria vaginalis*). Weed density was calculated by placing a quadrant of area 0.25 m^2 at four random locations in each experimental plot and repeating the process three times. Weeds rooted within this zone in each treatment were counted at harvest. The harvested weeds were oven dried to a constant weight at 105^0c to calculate the weed dry matter. The weed control efficiency (WCE) was calculated following the formula of Olayinka and Etejere (2015), as shown in Equation (1).

WCE (%) = Weed density in control plot - Weed density in treatments / Weed density in control plot X 100 Eq. 1

Table 2. Operating parameters of UAV sprayer

Tank capacity (litre)	10
Nozzle mounting (on boom/below propeller)	Below Propeller
No. of nozzles	4
Type of nozzle	Extended Range Flat Fan (XR 110 15 VP)
Cone Angle	110^O
Discharge/Flow rate through nozzle (litre/minute)	1-2
Operating Pressure (Kg/ cm^2)	3.059
Flight mode	Autonomous
Flying speed (m/s)	0-12
Height above the canopy (m)	1.0
Swath (m)	4.0
Spray width (m)	4.0
Spray flow (lit/min)	1.5

Statistical analysis

The results of weed parameters, grain yield and straw yield were subjected to one-way analysis of variance (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). Data pertaining to weed parameters were square-root transformed and analyzed. Precise data are depicted as the mean and standard deviation (SD). All the graphical representations and other equations were generated using Origin 2019 software (OriginLab Co., Northampton, MA, USA).

RESULTS AND DISCUSSION

Weed density, weed drymatter, weed control efficiency and yield in the rice field

The effect of spray volumes compared to weed density is shown in Fig. 3. Among all treatments, KS (500 L/ha) recorded lower weed density than the other treatments during 20 DAT, but statistically, it showed non-significant results with UAV (25 L/ha) and UAV (20 L/ha) ($p > 0.05$). Among the different spray volumes of UAV, UAV (25 L/ha) recorded lower weed density compared with other spray volumes, but statistically, non-significant with UAV (20 L/ha) at 20 DAT ($p = 0.053$). Meanwhile, all the different spray volumes showed significant differences over the weedy check. During 40 and 60 DAT, spraying of herbicides with KS (500 L/ha) observed the lowest weed density than other treatments, but statistically, there was a non-significant difference with UAV spraying with 25 L/ha. Spraying of

UAVs with 25 L/ha was observed to have less weed density than other UAV spray volumes at 40 and 60 DAT, but statistically, it was non-significant with UAV (20 L/ha) ($p > 0.05$). The maximum number of weeds was recorded with UAV (15 L/ha) than other treatments.

Among different spray volumes, weed dry matter accumulation was found lower with the application of herbicides with KS (500 L/ha) compared to other spray volumes using UAVs and with no significant difference between KS (500 L/ha) and UAV (25 L/ha) at 20, 40 and 60 DAT ($p > 0.05$) (Fig. 4). Among different spray volumes of UAVs, the lowest weed dry-matter was recorded with UAV (25 L/ha) than other UAV spray volumes and found a significant difference with UAV (15 L/ha) at 20 and 40 DAT but statistically non-significant with UAV (20 L/ha). During 60 DAT, the density of weeds was significantly lower when sprayed with UAV (25 L/ha) compared to other treatments. Further, all the treatments recorded lower weed density and found significant differences over the weedy check at all the stages of observations.

The weed control efficiency of two sprayers applying Pyrazosulfuron-ethyl 10%WP @ 25g a.i/ha at 3 DAT (PE) and Bis-pyribac sodium 10%SC @ 25ml a.i/ha (PoE) at 25 DAT in rice field as shown in Fig. 5. The maximum weed control efficiency of 87, 91 and 80% was recorded over weedy check during 20, 40 and 60 DAT, respectively, when sprayed with KS (500 L/ha). After the application of Pyrazosulfuron ethyl 10%WP (PE) and Bis-pyribac sodium 10%SC (PoE), the best weed control efficiency of 85, 84 and 72% was found with UAV (25 L/ha) followed by UAV (20 L/ha) and UAV (15 L/ha) during 20, 40 and 60 DAT, respectively in comparison with the weedy check. Although the UAV and knapsack sprayer's spray distribution characteristics were significantly different, the differences in weed control efficiency were not remarkable.

The comparison of four treatments found that the UAV (25 L/ha) and KS (500 L/ha) sprayers reduced weed population and dry matter. The best weed control efficiency following the first and second spraying was achieved at 500 L/ha, which does not significantly differ from UAV (25 L/ha) at 20, 40, and 60 DAT. This indicated that UAV (25 L/ha) was associated with a more extended period of weed control efficiency during the crop growth period. Following the deposition results, the KS (500 L/ha) had the best coverage uniformity, which is beneficial for controlling weed flora in the rice field, considering that rice weeds are typically found in the ground layers of the rice canopy (Shilin *et al*., 2017 and Kumar *et al*., 2023). The wider area of coverage and the greater number of droplet deposits enhanced the potential of the active ingredient's interaction with the weed population. Even though the UAV (25 L/ha) applied a significantly lower water spray volume and had a lower percentage of coverage area, weed density, weed dry matter, and weed control efficiency of the UAV (25 L/ha) was generally equal to that of the KS (500 L/ha) sprayer. Because the droplet density is inversely related to the particle size of the droplets, the coverage rate is increased by spray volume. Greater coverage area, droplet density, and spray uniformity might be the reason for the slight increase in the weed

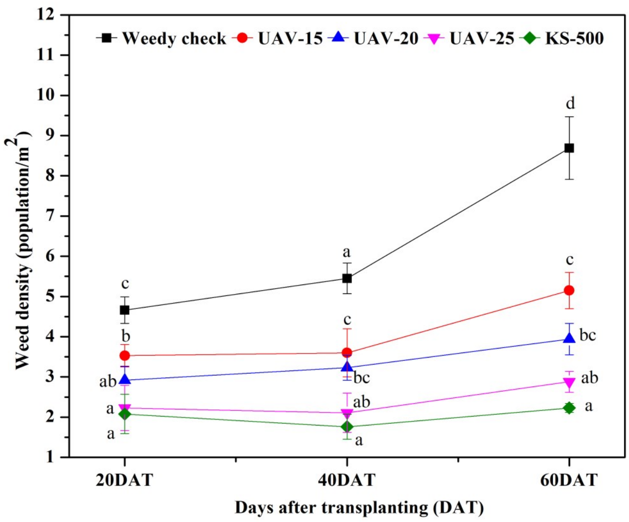

Fig. 3. *Effect of four different spray volumes on weed density/m^2 in the rice field during 20, 40 and 60 DAT. Data were subjected to square root transformation. One-way ANOVA followed by the Tukey-HSD test was conducted, and different letters above the points represented the significant differences among treatments ($p < 0.05$)*

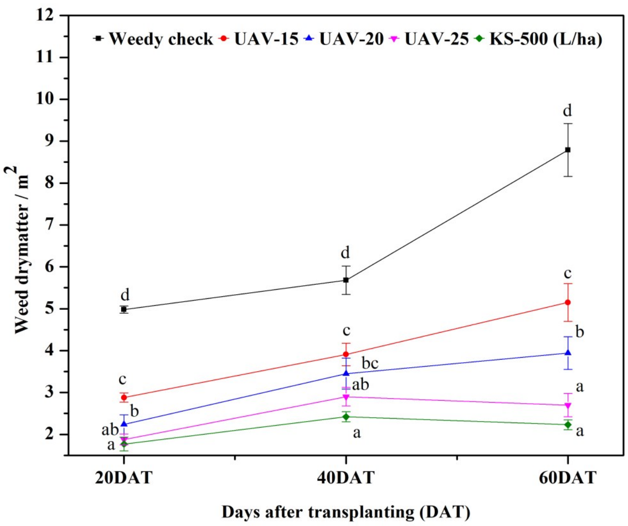

Fig. 4. *Effect of four different spray volumes on weed drymatter /m^2 in the rice field during 20, 40 and 60 DAT. Data were subjected to square root transformation. One-way ANOVA followed by the Tukey-HSD test was conducted, and different letters above the points represented the significant differences among treatments ($p < 0.05$)*

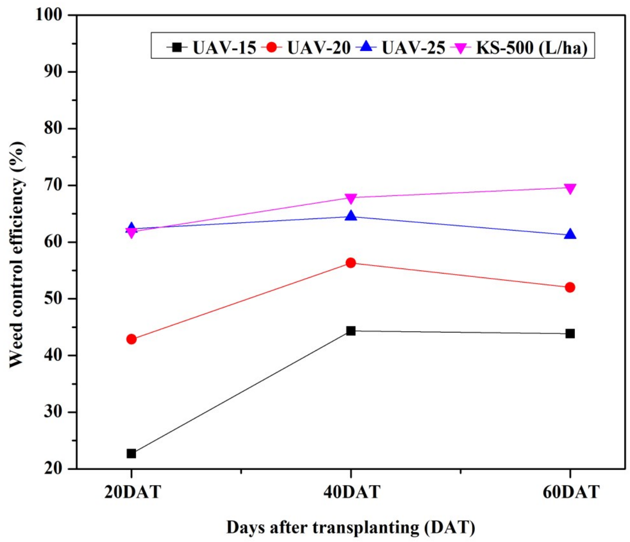

Fig. 5. *Effect of four different spray volumes on weed control efficiency (%) in the rice field during 20, 40 and 60 DAT*

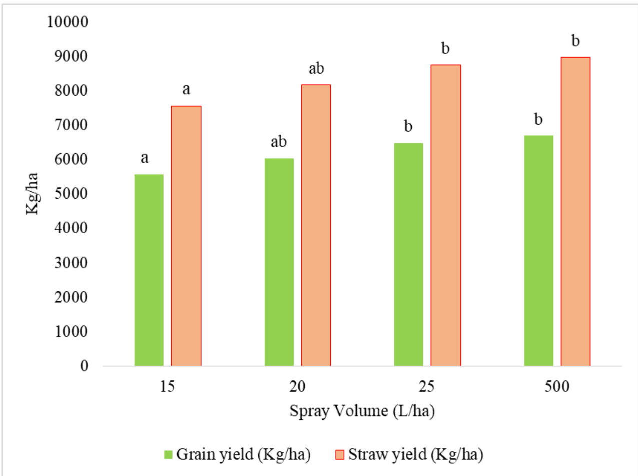

Fig. 6. *Effect of four different spray volumes on grain yield and straw yield (Kg/ha) in the rice field. One-way ANOVA followed by the Tukey-HSD test was conducted, and different letters above the bars represent the significant differences among treatments ($p < 0.05$)*

control efficiency in comparison to UAV (25 L/ha) (Ferguson *et al*., 2016; Wang *et al*., 2019; Mehta *et al*., 2023). In the study, the area of coverage obtained by UAV (25 L/ha) was significantly lower than the knapsack sprayer on account of the application volume. This is because the droplet size of the UAV nozzle is significantly lower than that produced by the knapsack sprayer. The droplet density per unit area is an important indicator in weed control. In herbicide spraying, using a large amount of solution is not necessary, as a certain number of droplet deposits achieves good weed control efficiency (Yuan *et al*., 2015 ; Roslim *et al*., 2021).

The grain yield and straw yield of two sprayers applying Pyrazosulfuron-ethyl 10%WP @ 25g a.i/ha at 3 DAT (PE) and Bis-pyribac sodium 10%SC @ 25ml a.i/ha (PoE) at 25 DAT in rice field as shown in Fig. 6. Among different treatments, higher grain yield (6694 and 6474 Kg/ha) and straw yield (8961 and 8755 Kg/ha) was recorded in KS (500 L/ha) and UAV (25 L/ha), respectively. Both KS (500 L/ha) and UAV (25 L/ha) were non-significant with each other ($p > 0.05$), which was significantly higher in grain and straw yield compared to UAV (15 L/ha) but not with UAV (20 L/ha). This might be due to lower weed density and weed dry matter as well as higher weed control efficiency with the application of 25 L/ha using UAV and KS (500 L/ha). In this perspective, UAV (25 L/ha) can be adopted for spraying over KS sprayer due to its low volume application and high work ability over knapsack sprayer (Song *et al*., 2020; Subramanian *et al*., 2021).

The studies demonstrated that weed control in rice was affected by different spray volumes for efficient weed control and its influence on yield. Using either high-volume spraying with a knapsack sprayer or low-volume spraying with a UAV at a rate of 25 L/ha will not affect the effectiveness of the spraying. However, UAVs are a potential alternative because of their high working efficiency and decreased runoff compared to knapsack sprayers. Further research should evaluate the effects of coverage rate, droplet size, deposition, number of spray deposits, droplet penetrability, and different doses or concentrations on effectively controlling weeds in rice fields using minimal herbicide.

Conclusion

The investigation of the effect of spray volumes on weed control efficiency and yield using UAV and KS sprayers in rice cropping systems showed promising results. Routine experiments conducted in the farmer's field over the years using a KS results have shown runoff and lower deposition, reducing the rice field's weed control efficiency as well as yield and here, we concluded that Low-volume spraying with the UAV was also more cost and energy-efficient than traditional KS since it reduced the spray volume by more than 20 times. An optimal weed control efficiency and higher grain and straw yield using the UAV was achieved at 25 L/ha with the pre-emergence application of Pyrazosulfuron ethyl 10%WP and the Post-emergence application of Bispyribac sodium 10%SC, which can be recommended to farmers as a substitute for conventional KS. Further, studies suggest improving spray uniformity, coverage rate and different nozzles.

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Conflict of interest

The authors declare that they have no conflict of interest.

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