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RESEARCH ARTICLE

# Comparative study on droplet parameters and weed control efficiency under UAV and Knapsack manual sprayer for herbicide application in summer cotton

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## Abstract

A field experiment was conducted during the summer season of 2024 at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry to evaluate the impact of different spray volume using Unmanned Aerial Vehicles (UAV) sprayer and Knapsack Manual Sprayer (KMS) on droplet deposition, density, distribution, drift and weed control efficiency. The experiment involved the application of pre-emergence herbicide namely pendimethalin 1 kg/ha under UAV spray at 25, 37.5, 50 L/ha compared with KMS 500 L/ha and unweeded control in a randomized block design with three replications. The findings indicated that the KMS system at 500 L/ha demonstrated the highest droplet count, whereas the UAV system provided better droplet distribution at a spray volume of 37.5 L/ha. The theoretical field capacity, effective field capacity and Field Efficiency (FE) are higher in UAV spray (7.2, 3.3 and 80.7) respectively, than KMS (0.3, 0.1 and 33.3) respectively. Spray drift got reduced whenever spray volume decreased and vice versa. Whereas, UAV spray volume of 50 L/ha recorded drift at a distance of 5 m, unlike the other spray volumes tested. The UAV system at 37.5 L/ha achieved better weed control effectiveness which was statistically comparable to the KMS system at 500 L/ha. These findings highlight the effectiveness of the UAV spraying system at 37.5 L/ha spray volume in achieving efficient weed control with better droplet distribution. Thus, the UAV spraying system holds considerable potential as a practical and efficient alternative to manual knapsack spraying for herbicide application in summer cotton.

**Keywords:** cotton; pendimethalin; spray volume; unmanned aerial vehicle; weed control efficiency

## Introduction

Cotton (*Gossypium* sp.), most known as "white gold" or "king of fibre", is one of the most important commercial fibre crops that is cultivated in various agroclimatic conditions. It is a major cash crop which dominates the industrial economy and global agriculture. Around 33.3 million hectares of cotton are grown globally, with production and productivity of 25.5 million metric tons and 767 kg/ha, respectively (1). India is fourth among the world's top exporters of cotton, with 0.51 million metric tons traded annually. According to recent estimates, India's cotton area, production and productivity in 2022-2023 were 130.61 lakh ha, 336.6 lakh of 170 kg bales and 443 kg/ha, respectively (2). The whole area used for cotton cultivation in 2020-21 was stated to be 333 ha, of which 325 ha were in the Karaikal district and 8 ha were in Puducherry (3).

Cotton is widely spaced and grown slowly in its early phases of growth and development. Consequently, weeds compete with cotton for light, moisture and nutrients; the maximum competition occurs in the early stages of crop growth and lasts for up to 8 weeks after emergence (4). Cotton yield can be drastically decreased by weeds, with losses ranging from 50 to 85 % (5). Crop-weed competition is often influenced by the length of time weeds are present with the crop and the weed emergence time. Crop-weed competition reaches its crucial phase when both the crop and the weeds are at the same vegetate stage of growth. However, field operations are delayed during peak season of weed growth due to the lack of experienced workers for hand weeding. Among the dire repercussions of these delays is a notable decline in cotton yield. Additionally, farmers are forced to pay higher wages in order to guarantee the timely completion of field activities, which puts additional financial strain on them. Therefore, the use of herbicides is the most practical and cost-effective way to manage weeds in cotton.

Traditionally, knapsack sprayers that run on batteries or are manually driven are used to apply herbicides (6). However, these sprayers frequently result in non-uniform application, higher application costs, human drudgery and challenges navigating through muddy soil while carrying the load (7). In addition, the individuals who spray the herbicides run into a greater danger of being exposed to hazardous chemicals while using these sprayers. Furthermore, a significant amount of spray fluid is needed for hand-operated sprayers. An alternate technique for applying herbicides is required to solve the issues of labour shortages and water limitations. Applying herbicides with drones is incredibly effective, as it saves farmers time, energy and water by eliminating the need to carry bulky containers and walk into the fields (7).

Unmanned Aerial Vehicles (UAV's) are multipurpose tools used in a variety of agricultural applications, including pesticide spraying, bird control, soil analysis, seeding, groundwater quality monitoring and farming systems (8, 9). The use of UAV technology for agricultural purposes has grown in popularity worldwide (10). In agricultural systems where ground treatments are challenging, including wetter field condition and plantation crops, UAV crop protection applications might be beneficial (11). Therefore, in the sector of agriculture, using UAVs to spray plant protection chemicals are becoming more common.

The weed management in cotton is convenient with UAV-based herbicide applications. But at the same time, it is unclear whether UAV-based herbicide application influences weed control efficiency while saving carrier volume in the cotton system. The creation of standardized procedures for cotton herbicide spraying requires filling in these information gaps. In order to achieve optimum weed control efficacy, the particular goals of this study were to (i) compare the effectiveness of herbicide application using UAVs (hexacopters) with the KMS system and (ii) determine the effective spray volume for herbicide administration using UAVs.

## Materials and Methods

### Experimental site

A field experiment was conducted at the Eastern Farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry Union Territory, (10° 55' N latitude and 79° 49' E longitude, 4 m above mean sea level), India during February to July 2024 (summer). The details of soil parameters of the experimental sites are presented in Table 1.

### Agronomic practices

The experimental plot was ploughed twice with a 9 tyne tractor -drawn cultivator; then, a rotavator was used to loosen soil clods and to form a fine tilth. Cotton (Hybrid 'RCH 659 BG II' with duration of 160 days) seeds were sown on a petri dish for testing germination seed viability in order to ensure that seeds remained viable. An evaluation was conducted after 3 days. The results showed an average germination rate of 93.3 %, indicating that seeds were capable of sprouting and growing into healthy plants. It was sown on the fourth week of February and harvested during the fourth week of July. Seeding was done manually at the rate of 2.4 kg/ha, spaced at 90 cm x 60 cm and covered with soil. The size of the experimental plots adopted for the study was 10.8 m x 8.1 m. Immediately after sowing, the field was surface irrigated with farm pond water supply ensuring there was enough moisture before pre-emergence herbicide application. The recommended fertilizer dose of 120:60:60 kg/ha of N, $P_2O_5$ and $K_2O$ was applied in the form of urea, single super phosphate and muriate of potash. The entire quantity of phosphorus (60 kg/ha), 50 % of nitrogen and potash were applied basally. The remaining half dose were applied in two equal splits at 45 Days After Sowing (DAS) and 65 DAS.

**Table 1.** Soil parameters at the experimental sites

| Particulars | Value |
|---|---|
| Coarse sand (%) | 31.42 |
| Fine sand (%) | 30.71 |
| Silt (%) | 16.95 |
| Clay (%) | 20.65 |
| Textural class | Sandy clay loam |
| pH | 6.72 |
| EC ($dSm^{-1}$) | 0.11 |
| Organic carbon (%) | 0.40 |

### Equipment

Equipment in the study was hexacopter UAV outfitted with a variety of spraying components. The UAV sprayer included a 10 L pesticide tank, four nozzles spaced 0.70 m apart, two Lipo batteries, a flight controller, receiver, GPS unit and 180 kV Brushless Direct Current (BLDC) motors. It also had a 0.57 m foldable propeller. A pressure of 3.4 kg/$cm^2$ was applied to the spray liquid using a BLDC motor pump. The UAV sprayer's flow rate was modified to reach the required application flow rate and the flight planner was used to regulate the flying height and speed. Pre-flight calibration of the UAV spraying system was carried out before the flight. Conversely, the study's knapsack manual sprayer had a 13 L spray solution tank, a pump, a filter, a flow control valve, a delivery hose and a spray gun with nozzle. The specifications of UAV and KMS used in the spray studies are mentioned in Table 2.

**Table 2.** Specification of UAV and KMS used in the spray studies

| Specification | UAV | KMS |
|---|---|---|
| Model | Hexacopter | SRP/23 |
| Tank capacity (L) | 10 | 13 |
| Type of nozzle | Flat fan nozzle | Flat fan nozzle |
| Number of nozzles | 4 | 1 |

### Herbicide application

Pendimethalin (Stomp, 30 % EC) was applied at 1 kg/ha. The herbicide was applied as pre-emergence treatment on 3rd day after sowing using both KMS and UAV (Fig. 1). The treatments comprised spraying with UAV at the rate of 25, 37.5 and 50 L/ha, along with KMS at a rate of 500 L/ha. It also included intercultivation twice, intercultivation twice + manual weeding and unweeded control. The experimental units were arranged using the randomized block design, with three replications for each treatment. The UAV and KMS operational parameters are shown in Table 3. Numerous meteorological data, including temperature, relative humidity, rainfall and wind velocity, were recorded from the meteorological observatory during the herbicide application (Table 4).

### Sampling of spray deposition

Water-Sensitive Paper (WSP), size of 2.6 cm x 7.6 cm was fastened to a metal plate (0.05 m x 0.30 m) using paper clips and buried up to 0.5 m below the surface. The samplers were pointed toward the upwind side of the metal plate to keep them level and safe. A sampler was positioned inside the experimental plots. The first sampler was placed 4.05 m from the boundary row in the middle of the plot (Fig. 2a). For each spraying treatment plot, two samplers were placed 2 and 5 m away from the treatment plots known as drift 1 and drift 2, respectively, to examine the drift (Fig. 2b). After the herbicide was applied, the WSPs were allowed to air dry. Following drying, they were cautiously put in zip-tie bags. Afterward,

(A) (B)

**Fig. 1.** Spraying. (A) KMS herbicide spray operation, (B) UAV herbicide spray operation.

**Table 3.** Operational parameters of UAV and KMS

| Treatments spray fluid volume (L/ha) | Swath covered (m) | Speed (m/s) | Total spray fluid (l /ha) | Pass | Spray height (m) |
|---|---|---|---|---|---|
| KMS-500 | 2.7 | – | 500 | Three | 0.4 |
| UAV-25 | 2.7 | 7.4 | 25 | Three | 1 |
| UAV-37.5 | 2.7 | 4.4 | 37.5 | Three | 1 |
| UAV-50 | 2.7 | 2.7 | 50 | Three | 1 |

**Table 4.** Meteorological data observed during the flight operation

| Parameters | Values |
|---|---|
| Temperature (°C) | 28.1 |
| Relative humidity (%) | 77.0 |
| Rainfall (mm) | 0.0 |
| Wind speed (km hr$^{-1}$) | 4.0 |

DropLeaf software (2.8.1 version) was used to measure droplet count, droplet diameter, droplet density and coverage area on the WSPs (12).

- Coverage area: given in percentage of the covered area;
- Volumetric median diameter: given by the 50$^{th}$ percentile $D_{V0.5}$ of the diameter distribution;
- Relative span: given by $RS = \frac{Dv0.9 - Dv0.1}{Dv0.5}$ where $D_{V0.1}$ is the 10$^{th}$ percentile and $D_{V0.9}$ is the 90$^{th}$ percentile of the diameter distribution.

## Performance parameters of UAV and KMS

The performance of UAVs and KMS was calculated by using (13, 14):

$$TFC = \frac{S \times W}{10}$$

Where, TFC = Theoretical field capacity, ha h$^{-1}$, S = Speed of operation, km h$^{-1}$ and

W= Spray swath width, m (13)

$$EFC = \frac{A}{T \times 10000}$$

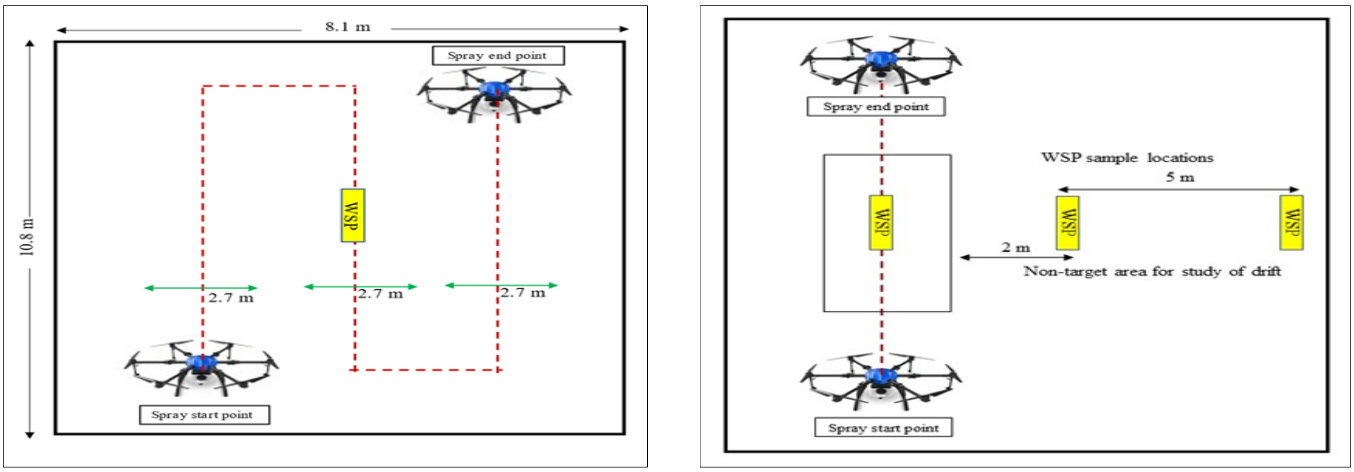
Where, EFC = Effective Field Capacity, ha h$^{-1}$, A = Area covered by the sprayer, m$^2$ and

T = Average Time taken, h

$$\text{Field efficiency (FE)} = \frac{EFC}{TFC} \times 100$$

## Weed biometric observations

At 60 DAS, the weed density (number of weeds/m$^2$) and dry weight (g/m$^2$) of experimental plot were recorded. In each plot, two quadrants (0.5 × 0.5 m) were used to measure the weed density. The weeds were pulled at ground level and left to dry in the shade in order to calculate their dry weight. They were then oven-dried until they reached a consistent weight at 78 ± 2° C. Weed control efficiency was computed and represented in percentage using the methods provided by (15). Prior to




(A) (B)

**Fig. 2.** Schematic diagram for (A) location of WSP sample, (B) location of WSP drift sample.

analysis, the weed density and dry weight data were normalized by square root transformation. $(\sqrt{x+0.5})$

WCE (%)=

$$\frac{\text{Weed dry weight in control plot - weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \times 100$$

## Results and Discussion

### Spray droplet spectra on WSPs

#### Number of spray droplets on WSP

UAV spray of 25 L/ha resulted in a lower droplet count (132 droplets), compared to an increase of 29.0 %, 41.8 % and 53.3 % droplets observed at spray volumes of 37.5, 50and 500 L/ha, respectively (Fig. 3). The number of spray droplets has shown an increasing trend with the increase in application volume (16, 17).

#### Area coverage

When assessing droplet deposition and sprayer efficacy, the percentage of spray area coverage is a crucial metric. The WSP's area coverage percentage was impacted by the varying spray volumes. The highest area coverage on WSP's was recorded with the KMS treatment at 500 L/ha, which was significantly higher from UAV treatments (Fig. 4). This is because the spraying volume of KMS (500 L/ha) is 20, 13.3 and 10 times greater than that of UAVs 25, 37.5 and 50 L/ha, respectively. This indicates that the spray volume positively correlates with the droplet coverage rate and significantly affects pesticide droplet coverage (18). In addition, a greater number of spray deposits per unit area would have led to a higher herbicide solution coverage rate and runoff (19, 20). UAV spraying at 50 L/ha produced a considerably greater droplet coverage rate followed by UAV spray at 37.5 L/ha. UAV spray of 25 L/ha with a speed of 7.4 m/s recorded a lower coverage area. This is because coverage rate decreased as the application speed increased.

#### Volume median diameter (Dv0.5)

It is crucial to standardize the Dv0.5 for varying spray volumes in order to improve herbicide droplet dispersal. When compared to UAV treatments, the KMS (500 L/ha) droplets' VMD was noticeably greater despite their low-pressure operation (Table 5). With UAV spraying, the maximum Dv0.5 was achieved at 50 L/ha, which was not significantly different from other UAV treatments. In this investigation, the VMD of the droplets increased as the volume of applications increased (21, 22).

#### Droplet distribution

The distribution of spray droplets is another crucial factor in assessing the effectiveness of sprays. A uniform distribution of droplets is indicated by a reduced Relative Span (RS). The results of the UAV treatments showed superior spray distribution throughout the experimental plots, as evidenced by reduced RS values as compared to the KMS treatment. The UAV spray of 37.5 L/ha with a speed of 4.4 m/s resulted in lower

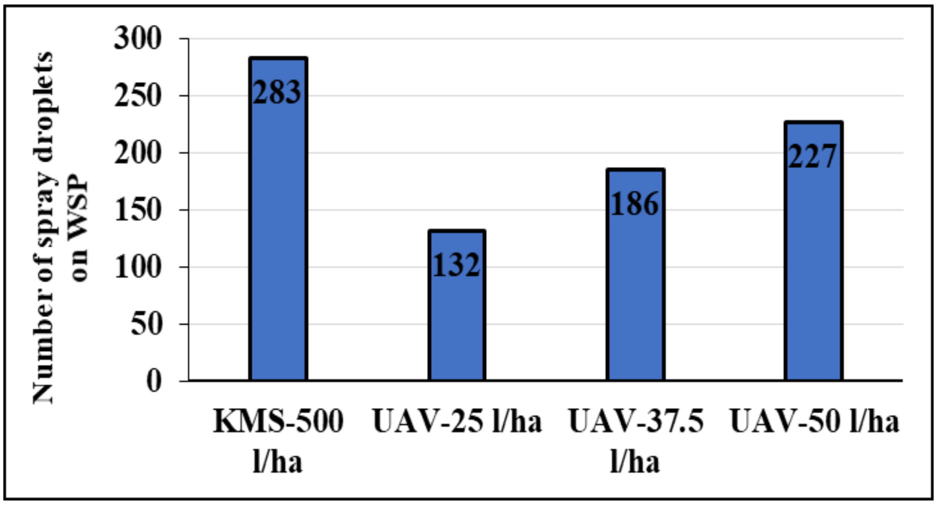



**Fig. 3.** Number of spray droplets on WSP.

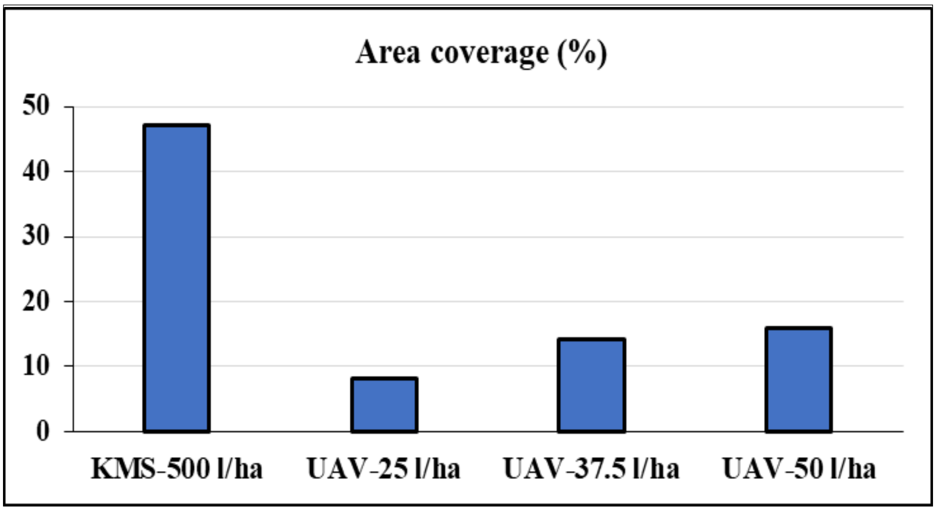



**Fig. 4.** Area coverage (%) of varied spray fluid.

**Table 5.** Effect of operational parameters on the volume median diameter (µm) and relative span

| Treatments spray fluid volume (L /ha) | Dv (µm) | | | RS |
|---|---|---|---|---|
| | 0.1 | 0.5 (VMD) | 0.9 | |
| KMS-500 | 772.4 | 2047.1 | 5981.4 | 2.50 |
| UAV-25 | 475.3 | 836.3 | 2304.2 | 2.18 |
| UAV-37.5 | 725.4 | 850.2 | 1451.2 | 0.85 |
| UAV-50 | 597.3 | 865.6 | 1943.2 | 1.50 |

RS (0.85), which led to better scattering and uniform size distribution of herbicides (Table 5). However, other spray volumes of 50, 25 and 500 L/ha resulted in 43 %, 61 % and 66 % higher RS, which clearly indicates the ununiform and less scattering of herbicides compared to 37.5 L/ha. Uniform distribution of pendimethalin resulted in even distribution in the soil resulting in better imbibition by weed seeds which in turn resulted in better weed control. Conversely, the operator's erratic arm and walking motion, as well as instances of missing and overlapping operations, might be the cause of the poor uniformity seen in the KMS treatment (22).

**Droplet density (drops cm$^{-2}$)**

During the spraying, KMS of 500 L/ha was found to have a higher droplet density than other UAV spray volumes (Fig. 5). Although the UAV's reduced application volume would lead to fewer droplet deposits, each droplet density will have a higher concentration, hence the concentration of pesticides sprayed per unit area was not noticeably lower than that of KMS techniques (23).

**Performance of UAV and KMS**

In comparison to other spray volumes, the maximum TFC and EFC were obtained with a UAV spray of 25 L/ha (Table 6). The FE was higher in UAV spray of 50 L/ha followed by UAV spray of 37.5 L/ha. As the speed of operation in 50 L/ha is lower than compared to other UAV spray volume it resulted in highest FE. On the other hand, KMS of 500 L/ha had the lowest TFC, EFC and FE because of its higher time consumption and lower work efficiency (24).

**Drift analysis**

Few droplets moved away from the intended target area due to the smaller droplet size produced at all spray volumes. In UAV spray of 25 L/ha at a speed of 7.4 m/s exhibited fewer droplets (58 droplets) compared to other UAV spray volumes (Fig. 6). The number of drops exhibited a gradual reduction as the spray volume decreased (25), at a drift distance of 2 m. A similar effect was observed when the drift distance increased to 5 m. The KMS showed less drift at 2 m compared to UAV spray and no drift was recorded at 5 m.

**Weed control efficiency**

The major weed flora discovered in the experimental field comprised volunteer rice, *Echinochloa colona, Dactyloctenium aegyptium, Leptochloa chinensis, Cyperus iria*, *Cleome viscosa*, *Corchorus tridens*, *Phyllanthus niruri* and *Trianthema portulacastrum.* The application of herbicide using both UAV and KMS sprayers resulted in significantly lower total weed density and weed dry weight compared to the unweeded control. When comparing UAV and KMS, the minimum weed density (38.7 weeds /m$^2$) and dry weight (11.0 g/m$^2$) was recorded in UAV spray of 37.5 L/ha, which was followed by KMS of 500 L/ha in case of weed density (46.7 weeds /m$^2$) and weed dry weight (12.1 g/m$^2$) (Table 7). In contrast, maximum weed density (559.0 weeds/m$^2$) and dry weight (369.7 g/m$^2$) was registered in unweeded control treatment. Application of pendimethalin 1 kg/ha under UAV spray at 37.5 L/ha with a speed of 4.4 m/s achieved the highest weed control efficiency by inhibiting micro tubulin formation, blocking cell division (26,

**Table 6**. Performance of UAV and KMS

| Treatments spray fluid volume (L/ha) | TFC (ha/h) | EFC (ha/h) | FE (%) |
|---|---|---|---|
| KMS-500 | 0.3 | 0.1 | 33.3 |
| UAV-25 | 7.2 | 3.3 | 45.8 |
| UAV-37.5 | 4.3 | 2.6 | 60.5 |
| UAV-50 | 2.6 | 2.1 | 80.7 |

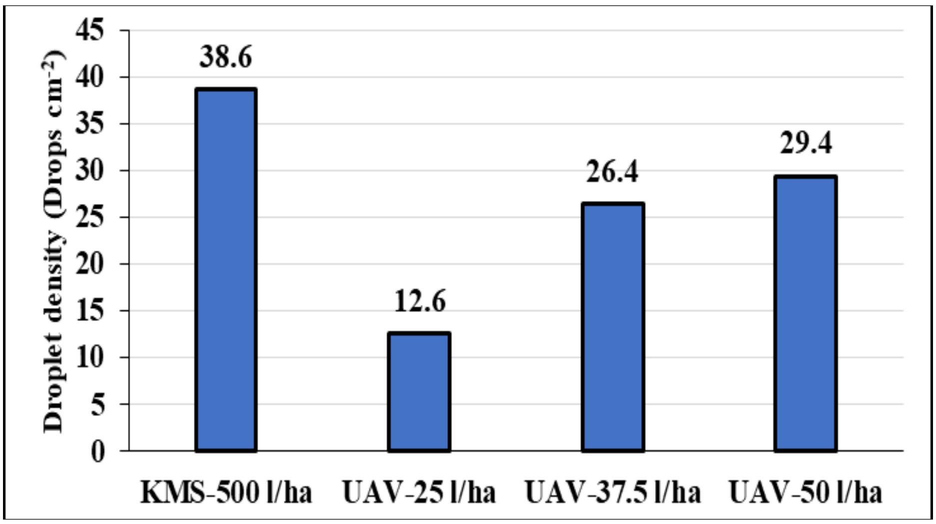



**Fig. 5**. Droplet density (Drops cm-2) of the varied spray fluid.

**Table 7.** Effect of weed management on weed density, weed dry weight and weed control efficiency at 60 DAS

| Treatments | Total weed density (No. /m$^2$) | Total weed dry weight (g/m$^2$) | Weed control efficiency(%) |
|---|---|---|---|
| KMS of 500 l ha$^{-1}$ | 6.87 (46.7) | 3.54 (12.1) | 96.7 |
| UAV spray of 25 l ha$^{-1}$ | 8.32 (68.7) | 4.71 (21.6) | 94.1 |
| UAV spray of 37.5 l ha$^{-1}$ | 6.26 (38.7) | 3.40 (11.0) | 97.0 |
| UAV spray of 50 l ha$^{-1}$ | 7.25 (52.0) | 4.27 (17.7) | 95.2 |
| Intercultivation twice | 7.74 (59.3) | 4.38 (18.7) | 94.9 |
| Intercultivation twice + manual weeding | 6.57 (42.7) | 3.32 (10.5) | 97.2 |
| Unweeded control | 23.65 (559.0) | 19.24 (369.7) | - |
| S. Ed. | 0.23 | 0.18 | - |
| C.D. (P=0.05) | 0.5 | 0.4 | - |

*Data in parentheses are original values Data were subjected to square root transformation $(\sqrt{x+0.5})$

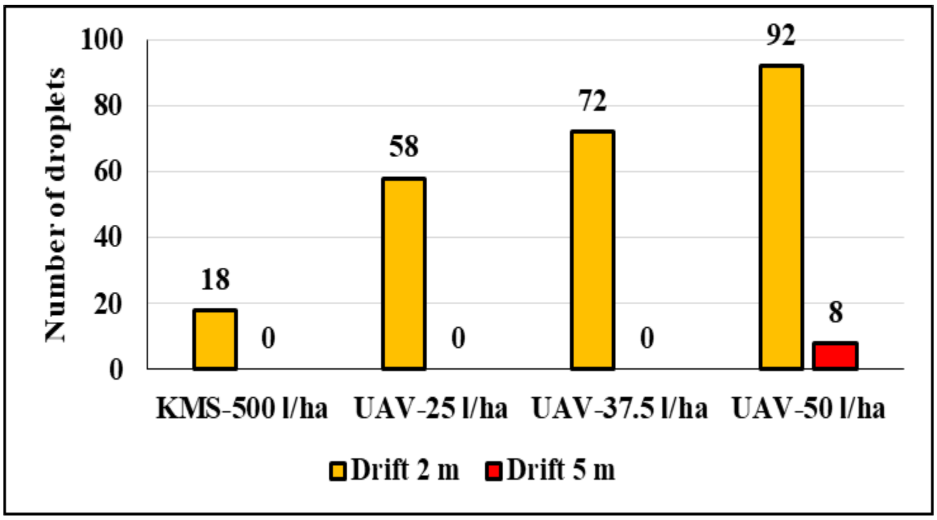



**Fig. 6.** Drift of 2 and 5 m away from the plot in varied spray fluid.

27) which resulted in lowest weed density and biomass. This was attributed to the increased turbulence, which created finer droplets with lower surface tension, resulting in better scattering and more uniform distribution.

## Conclusion

Thus, the KMS system at 500 L/ha demonstrated the highest droplet count, whereas the UAV system provided better droplet distribution at a spray volume of 37.5 L/ha. These findings highlight the effectiveness of the UAV spraying system at 37.5 L/ha spray volume in achieving efficient weed control with better droplet distribution. Thus, the UAV spraying system holds considerable potential as a practical and efficient alternative to manual knapsack spraying for herbicide application in summer cotton.

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## Authors' contributions

RV conducted the field trials and research work. PS conceptualized the study, contributed to the research work and provided final editing and suggestions for the manuscript. PR and KC contributed to the research work and assisted with editing and revisions. All authors have read and approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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