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Agricultural drone spraying efficiency enhancement via patternater-based effective swath width determination

Shubham Dhakad, RC Salunkhe, KL Dabhi and Pankaj Gupta

Abstract
The study focuses on the development of a patternater and the determination of effective swath width for an agricultural drone sprayer. The experiment involved assessing the uniformity coefficient (UC), coefficient of variation (CV) and off-target losses for various combinations of spraying height and discharge rate. A patternater with 40 V-shaped channels was fabricated to collect spray liquid for analysis. The calibration of the drone was conducted to measure the spray pattern at different treatment combinations. Overlapping of the spray pattern was employed to find the effective swath width by optimized UC and CV. The results revealed that the effective swath width was influenced by spraying height. Discharge rate had no significant effect on effective swath width. The findings provide valuable insights for optimizing agricultural drone sprayer operations to achieve uniform application of spray liquid during field spraying. The effective or actual swath width was found as 2.1, 2.3 and 2.5 m for spraying height 2.0, 2.5 and 3.0 m respectively for the drone sprayer under study.

Keywords: Agricultural drone sprayer, drone sprayer, patternater, swath width

1. Introduction

The efficiency of agricultural operations is crucial for increasing production and productivity while minimizing losses. However, India's farm mechanization level has been relatively low, around 40-45%, compared to other countries like the USA (95%), Brazil (75%) and China (57%). Farm mechanization has the potential to save costs, enhance productivity and reduce dependency on labor. One of the major challenges faced by Indian agriculture is the shortage of agricultural labor due to rural-urban migration. This shortage results in increased labor costs, making crop production more expensive. To address this issue, there is a pressing need to increase the level of farm mechanization (Tiwari *et al.*, 2019) [6].

Traditional hand-operated spraying methods can lead to excessive chemical applications, causing environmental pollution and increased production costs. Additionally, it becomes challenging to achieve uniform spray coverage in dense crop fields. The improper use of chemical control techniques can lead to inefficient pest control.

Drone technology has emerged as a transformative innovation in agriculture, offering the potential to revolutionize traditional farming practices. Drones equipped with sensors, cameras and actuators can perform various tasks in agricultural operations, including surveying, crop scouting, spraying, seed broadcasting and livestock surveillance.

The use of drones in agricultural spraying offers several advantages over conventional methods. Drones can cover larger areas in a shorter time, especially in difficult terrains. They also minimize the risks to human operators and reduce water and soil pollution.

The adoption of drone technology in agriculture, particularly in maize farming, offers significant potential to enhance productivity, optimize resource management and reduce environmental impacts. Effective spraying can only be achieved by knowing about the effective swath width of the sprayer where one can get maximum spray uniformity. The big size patternater would be required for calibration the drone sprayer. Hence the study was undertaken to develop the patternater which would be useful for calibration of the drone sprayer to find the effective swath width.

Luck *et al.* (2006) [4] introduced an automated spray pattern measurement system using digital sensors, precisely quantifying nozzle performance. This system demonstrated minimal deviation, averaging 0.1 mm (0.4%) on a 3.05 m wide patternator surface, showing comparable results to manual methods with a 0.15% difference. The system's repeatability was excellent, ensuring reliable assessments of nozzle configurations. Shesah and Kleisinger (2009) [5] investigated crosswind effects on spray patterns in a lab using a 150-tube patternater, showing wind speed's influence on dose uniformity and noting the impact of nozzle types. Gupta *et al*. (2011) [3] focused on measuring spray drift potential, using a lab-based setup to identify risks linked to nozzle pressure, air and forward speed. Drift potential ranged from 4.21% to 46.81%, emphasizing the need for optimized pesticide application.

2. Materials and Methods

2.1 Selection of Agriculture drone sprayer

The hexacopter type agriculture drone sprayer was selected for the study. It consists of a chemical tank, motor, pump, discharge controller valve, pipe, nozzle holder and nozzles. The tank had a capacity of approximately 12 liters and a brushless diaphragm pump type motor was used to transfer the chemical from the tank to the nozzles through pipes. A discharge controller valve was provided to control the discharge rate of chemicals. The anti-drift flat fan nozzles were mounted on nozzle holders placed just below the propeller motors to achieve stability against wind speed.

2.2 Development of Patternater

To conduct the laboratory study on drone sprayer a bigger size patternater (about 4 m length) was required. The required size patternater was developed under the study.

The patternater frame was fabricated by using MS angle of size 20 mm x 20 mm x 3mm.

The V channel section was made from 0.9 mm GI sheet. One channel was made with 100 mm width, 100 mm depth (BIS standard IS 3652:1995) [1] and apex angle 53°. The slope to the channel section was provided as 9° for quick flow of spray liquid.

The plastic funnels were placed at the end of each 'V' channel. The plastic pipes were used to connect the funnel and plastic bottle. The plastic bottles were placed in a tray and these were used to collect the sprayed liquid from each channel.

The tray used to place the bottles was made from GI sheet with dimension 4000 mm x 100 mm x 100 mm. The overall dimensions of the developed patternater are shown in Fig. 1 and given in Table 1.

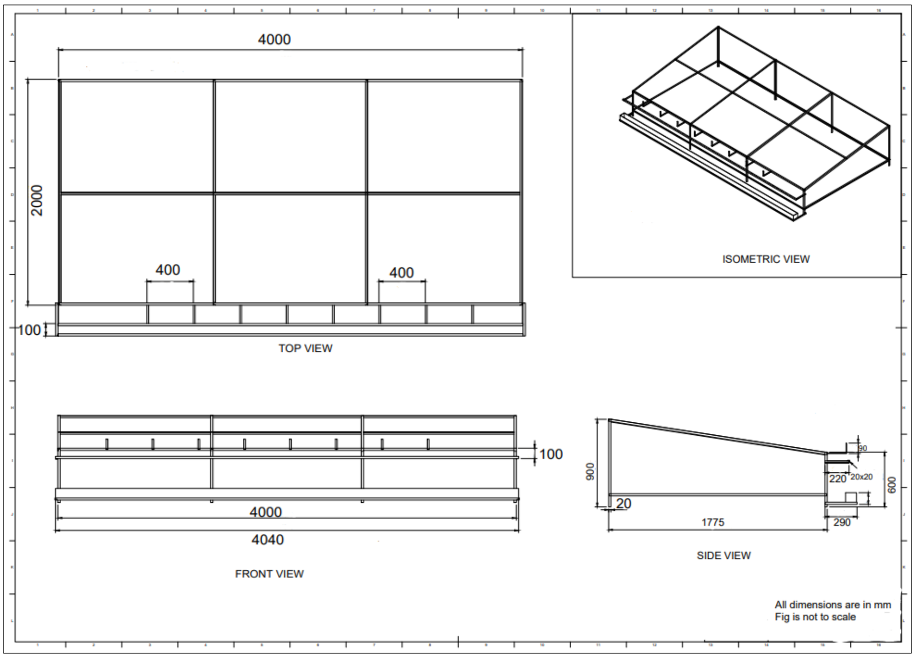

Fig 1: Orthographic view of patternater frame

Table 1: The overall dimensions of patternater

S. No.	Parameters	Value
1.	Overall length, mm	4000
2.	Overall width, mm	2000
3.	Height on eleveted side, mm	900
4.	Height in lower side, mm	600
5.	Slope	9°
6.	Number of channels, number of funnel, number of bottles	40
7.	Width of each channel, mm	100
8.	Depth of each channel, mm	100

Table 2: ANOVA table for uniformity coefficient

Source of Variation	DF	SS	MS	F-Value	Significance	C.D.	F- critical
Factor H	2	43.32	21.66	1,480.03	0	0.121	3.56
Factor D	2	0.07	0.03	2.57	0.10393	N/A	3.56
Interaction H X D	4	0.16	0.04	2.79	0.05771	N/A	2.93
Error	18	0.26	0.01				
Total	26	43.82					

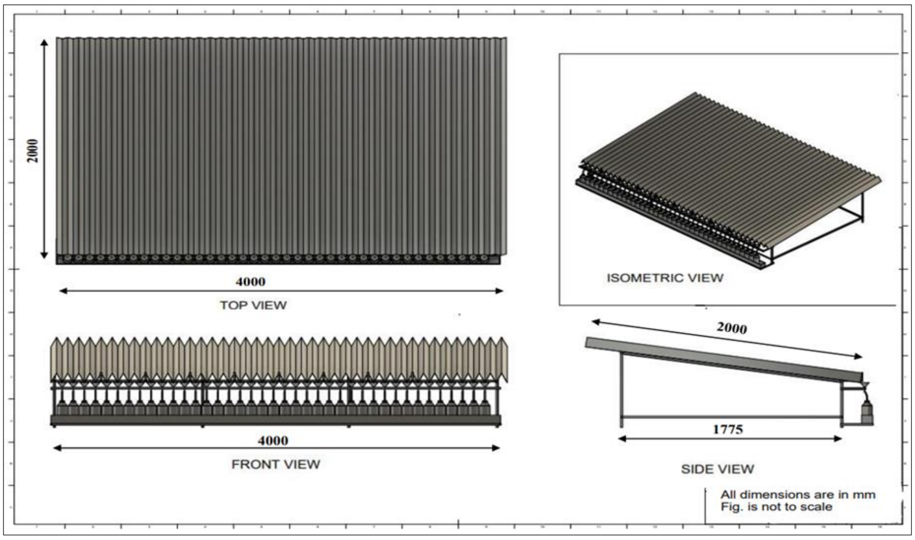

Fig 2: Orthographic solid view of developed patternater

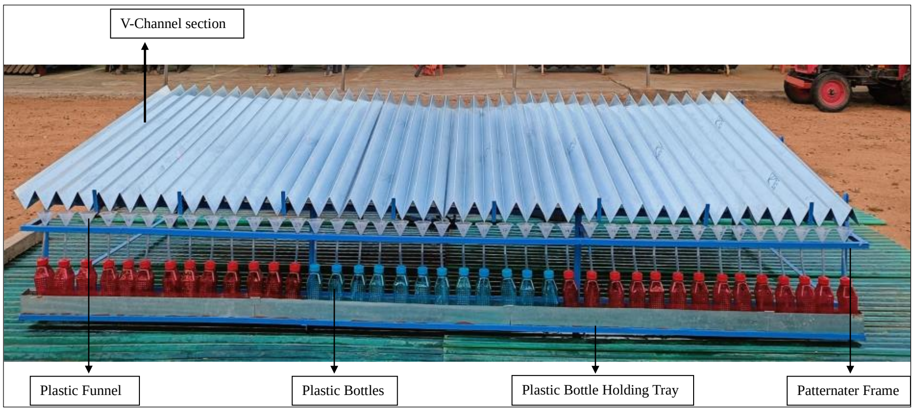

Fig 3: Developed patternater

2.3 Calibration of Drone Sprayer

The site-specific calibration of the drone was essential to properly working of its navigation system as per location where it was going to fly. The drone was equipped with a GPS module that allows it to know the location relative to the network of orbiting satellites. To perform functions like position hold, autonomous flight, return to home and waypoint navigation, the signals from the connecting satellites were used. For setting the signals, the calibration of the drone was conducted with the following steps.

1. The batteries were connected to the drone.
2. Turn 'ON' the drone and established the connection between the drone and the radio transmitter (remote).
3. The calibration option was selected in radio transmitter display.
4. The drone was steered by lifting up manually on the horizontal axis and turned it at 360^0 rotations for approximately two times until the red indicator on the drone turns into blue.
5. The drone was steered by lifting up manually on the vertical axis and turned it at 360^0 rotations for approximately two times until the blue indicator on the drone turns into green.
6. After completion of calibration, the message like 'Calibration is done' was showed in the radio transmitter display.

2.4 Experimental details

The experiment was conducted on the open ground. The developed patternater was set on the center of the ground. The trials were conducted for combinations of three levels of the spray height from the top surface of the patternater as 2.0, 2.5 and 3.0 m and three levels of the discharge rate as 100, 80 and 60% with three repetitions.

The following procedure was followed for conducting each trial.

1. The sprayer tank was filled with known quantity of water.
2. The parameters of the drone flying were set as per the treatment combinations.
3. The drone was flown over the patternater keeping it steady at the center position of the patternater. (As shown in Fig. 4 and Fig. 5)
4. After stabilizing the drone at required height spraying was started with discharge rate as per treatment combinations till the tank became empty.
5. The sprayed water was collected in the plastic bottle from each channel.
6. After completion of the spraying, the water collected in the plastic bottles were measured with the help of measuring cylinder (As shown in Fig. 6) and the readings were recorded for each of 40 bottles.

Fig 4: Stabilization of the drone over Patternater

Fig 5: Spraying of liquid by drone on the patternater

Fig 6: Measurement of water volume selected in the plastic bottle

2.5 Parameters studied

From the collected data, the parameters like coefficient of variation (CV), uniformity coefficient (UC) and off-target losses were calculated by using following standard formulas.

a) Coefficient of variation (CV)

The spray distribution was determined in terms of coefficient of variance (CV) by using the standard equation given below

$$\text{Coefficient of veriation (CV) \%} = \frac{\text{SD}}{\bar{x}} \times 100$$

Where, SD is the standard deviation and $\bar{x}$ is mean of the data.

b) Uniformity coefficient (UC)

The spray uniformity was determined by Christiansen's uniformity coefficient (UC) method of calculating the uniformity of the spraying systems (Gomaa *et al*., 2017) [2].

$$\text{Uniformity coefficient (UC) \%} = 100 \times \left(1 - \frac{\Sigma|x - \bar{x}|}{n \times \bar{x}}\right)$$

Where, n = number of data, $\bar{x}$ = mean of the data, X = individual data

iii) Off-target losses

It is the spray liquid flown outside of the patternater. The off-target losses were then calculated by subtracting the total volume collected in the bottles from total volume of water filled in the tank. It was calculated as.

$$\text{Off target losses \%} = \frac{\text{Total filled water in spray tank(ml)} - \text{Total water collected in all bottles (ml)}}{\text{Total filled water in spray tank(ml)}} \text{X } 100$$

2.6 Determination of effective swath width
The overall swath width, spanning between the outer edges of the patternater, was measured for each combination. To determine the effective swath width, a method of overlapping was employed. The left side of the spray pattern was progressively overlapped onto the right side by summing the extreme measurements. At each step of overlapping, CV and UC were recalculated. Interestingly, a point was identified where further overlapping led to a decrease in UC and an increase in CV. This marked the specific point beyond which continuing the overlapping didn't yield desirable results. The width of the spray pattern at this point of optimal overlapping was noted as the effective swath width.

3. Results and Discussion
The data obtained during the experiment was analyzed statistically analysis and ANOVA tables are given in Table 1, 2 and 3 for UC, CV and off target loss respectively.

Table 3: ANOVA table for coefficient of variation

Source of Variation	DF	SS	MS	F-Value	Significance	C.D.	F- critical
Factor H	2	61.61	30.80	1,642.33	0	0.137	3.56
Factor D	2	0.08	0.04	2.24	0.13532	N/A	3.56
Interaction H X D	4	0.22	0.05	2.99	0.04663	0.237	2.93
Error	18	0.33	0.01				
Total	26	62.25					

Table 4: ANOVA table for off target losses

Source of Variation	DF	SS	MS	F-Calculated	Significance	C.D.	F- critical
Factor H	2	4.55	2.27	588.42	0	0.062	3.56
Factor D	2	50.62	25.31	6,544.94	0	0.062	3.56
Interaction H X D	4	0.98	0.24	63.50	0	0.108	2.93
Error	18	0.07	0.01				
Total	26	56.23					

From ANOVA table, it was found that the spraying height had significant effect on UC, CV and off target losses and discharge rate had no significant effect on UC and CV except off target losses%.
It meant that effective swath width was only changed according the height of spray.

3.1 Spray Pattern Obtained
The spray pattern at different treatment combinations of height of spray and discharge rate were obtained as shown in Fig. 7 to Fig. 15. These figures showed that more volume of water was sprayed at the center and it decreased towards the end of swath width.

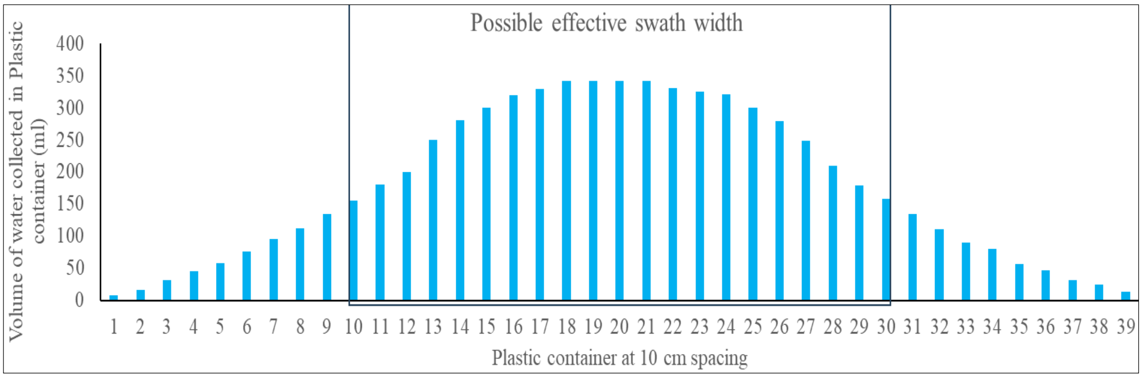

Fig 7: Spray pattern obtained for spraying height 2 m and 100% discharge rate

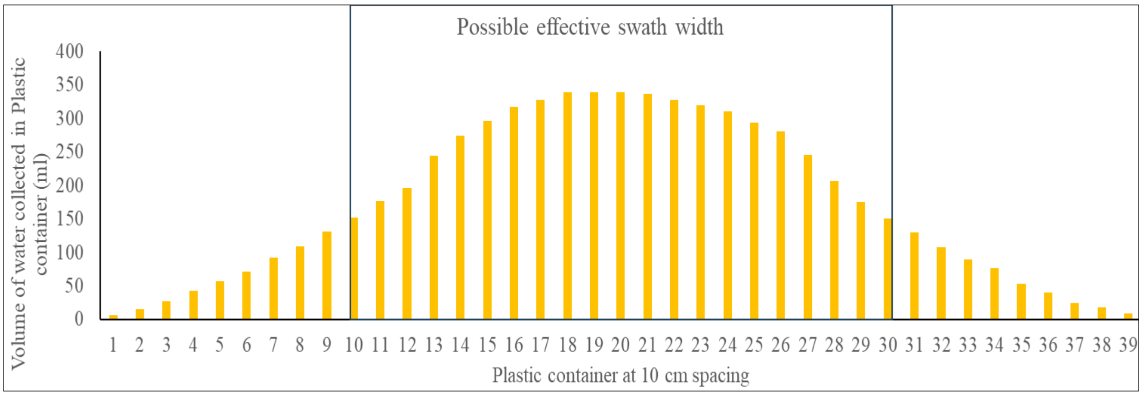

Fig 8: Spray pattern obtained for spraying height 2 m and 80% discharge rate

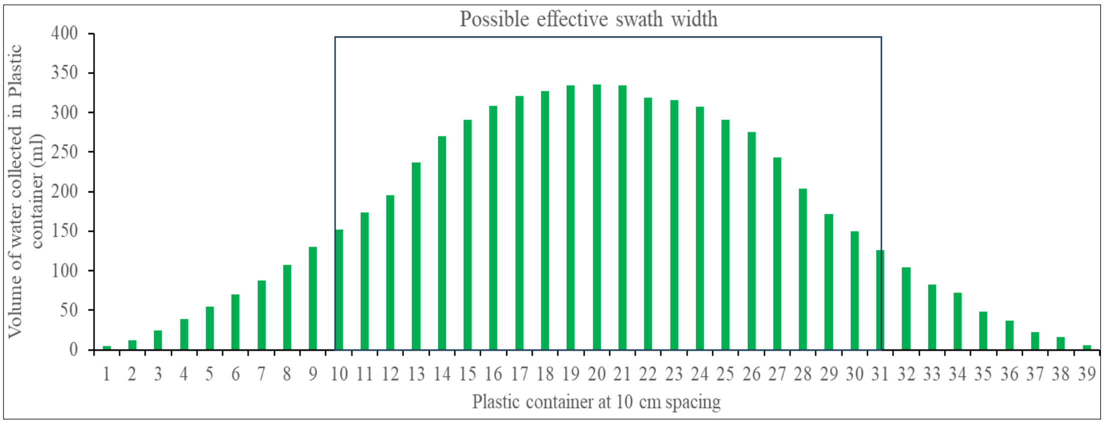

Fig 9: Spray pattern obtained for spraying height 2 m and 60% discharge rate

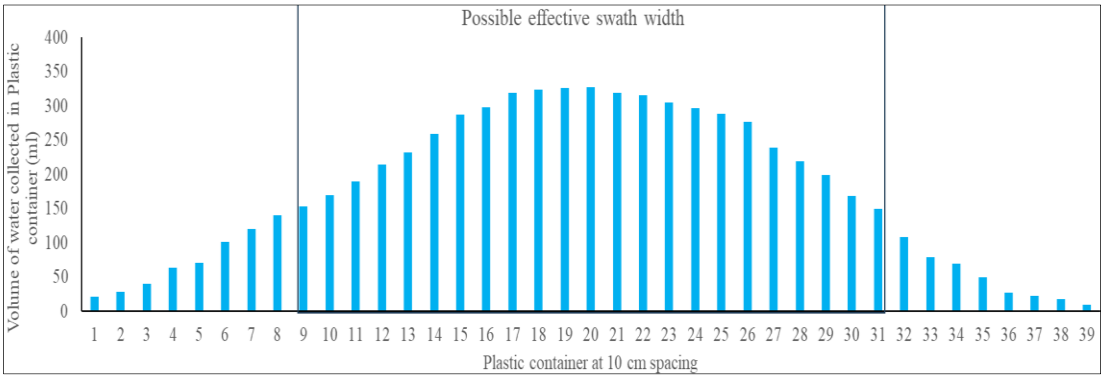

Fig 10: Spray pattern obtained for spraying height 2.5 m and 100% discharge rate

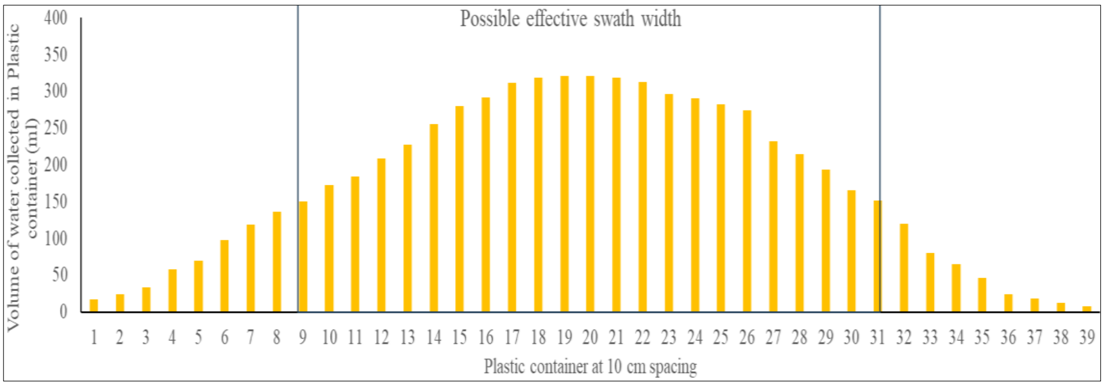

Fig 11: Spray pattern obtained for spraying height 2.5 m and 80% discharge rate

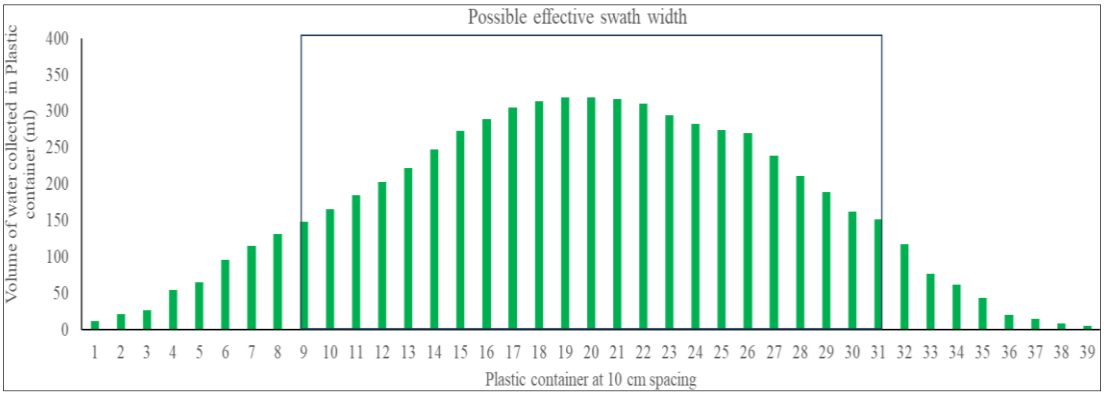

Fig 12: Spray pattern obtained for spraying height 2.5 m and 60% discharge rate

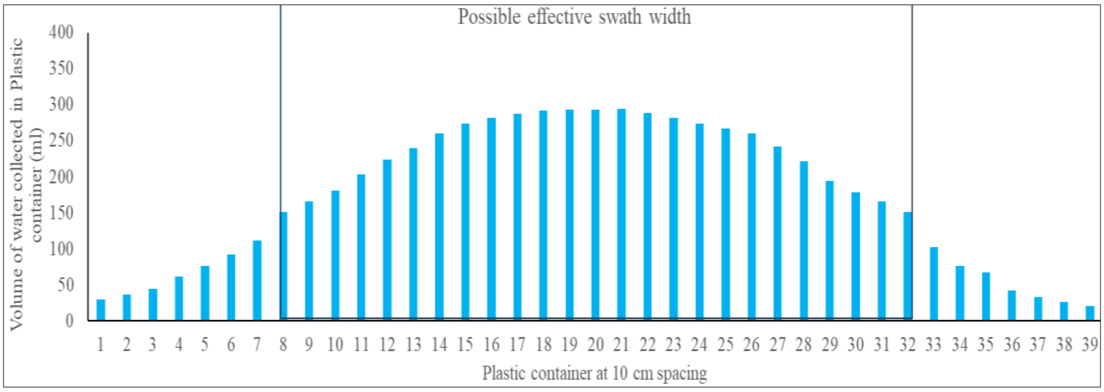

Fig 13: Spray pattern obtained for spraying height 3 m and 100% disc hare rate

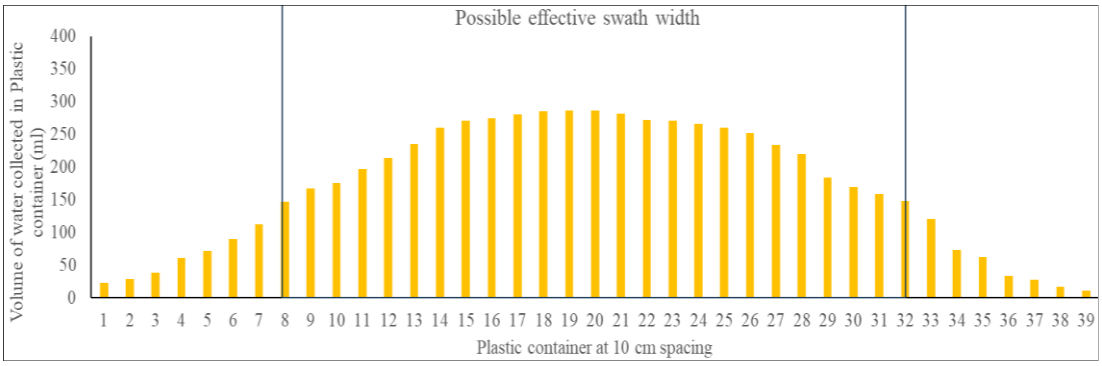

Fig 14: Spray pattern obtained for spraying height 3 m and 80% discharge rate

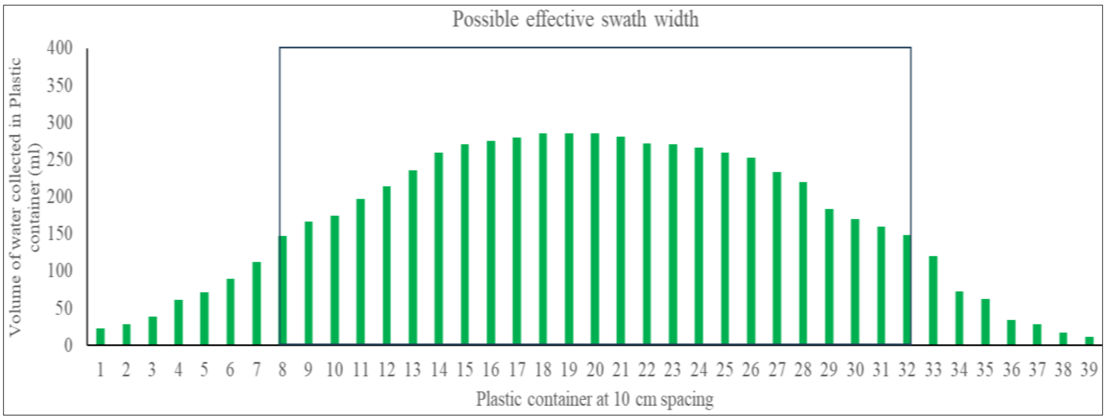

Fig 15: Spray pattern obtained for spraying height 3 m and 60% discharge rate

3.2 Determination of Effective Swath Width

The effective swath width for each combination was determined from the overall swath width on the basis of coefficient of variation and uniformity coefficient.

Table 4 shows CV and UC of overall swath width and off target losses obtained for different combinations of spraying height (H) and discharge rate (D).

Table 5: UC, CV and off target losses for different combinations of H & D during laboratory evaluation

For overall swath width							
Treatments	Volume of Water filled in drone chemical Tank (ml)	Total volume of water collected in all bottles (ml)	Average volume of water collected in each bottle(ml)	SD	CV (%)	UC (%)	Off target losses%
H1D1	8000.00	6901.67	176.97	118.88	67.18	40.40	13.73
H1D2	8000.00	6753.67	173.17	119.09	68.77	38.99	15.58
H1D3	8000.00	6597.33	169.16	117.77	69.62	38.23	17.53
H2D1	8000.00	6848.33	175.60	110.65	63.02	44.56	14.40
H2D2	8000.00	6704.00	171.90	109.72	63.83	44.23	16.20
H2D3	8000.00	6568.00	168.41	109.60	65.08	43.18	17.90
H3D1	8000.00	6787.33	174.03	97.63	56.10	50.66	15.16
H3D2	8000.00	6657.00	170.69	97.19	56.94	50.03	16.79
H3D3	8000.00	6567.33	168.39	96.61	57.37	50.08	17.91

Above table showed that UC found was less than 50% and CV was found more than 57% in overall swath width and hence there was need of overlapping of spray pattern to improve the UC and reduce the CV. The above table also showed that off target losses were increased with increase in the spray height due to more wind velocity and also it was Increased with increase in the discharge rate.

By doing various combinations of overlapping and calculating UC and CV each time, maximum possible overlapping was found were maximum UC and minimum CV was found. This procedure was carried out for spray pattern obtained in each treatment combination. The spray patterns drawn after overlapping are shown in Fig. 16 to 24 for each combination.

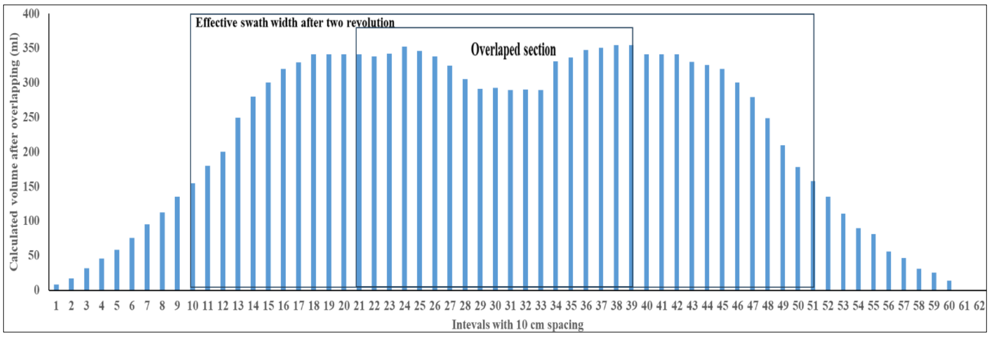

Fig 16: Spray pattern after overlapping at spraying height 2 m and 100% discharge rate

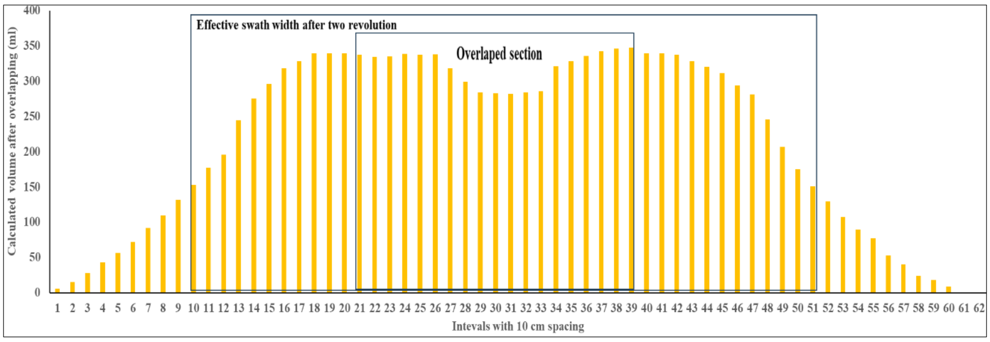

Fig 17: Spray pattern after overlapping at spraying height 2 m and 80% discharge rate

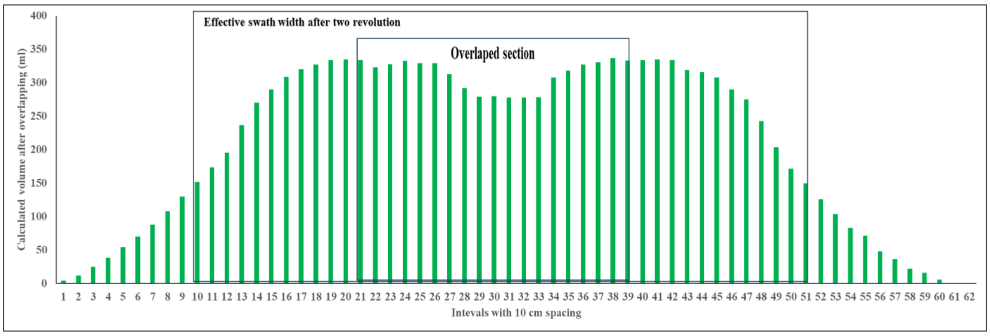

Fig 18: Spray pattern after overlapping at spraying height 2 m and 60% discharge rate

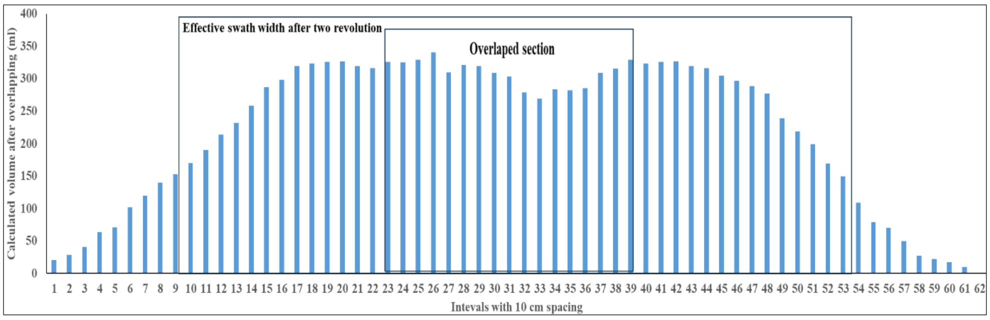

Fig 19: Spray pattern after overlapping at spraying height 2.5 m and 100% discharge rate

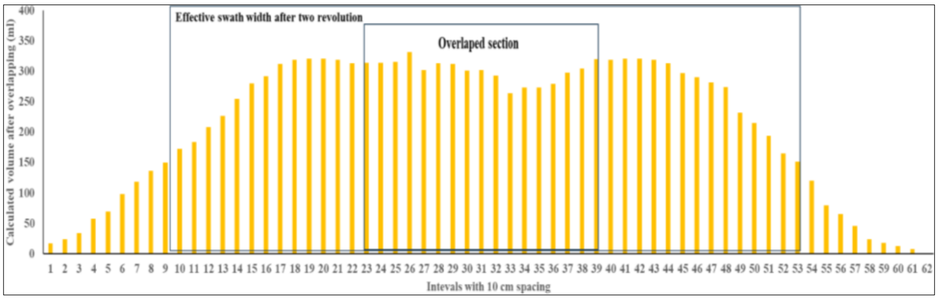

Fig 20: Spray pattern after overlapping at spraying height 2.5 m and 80% discharge rate

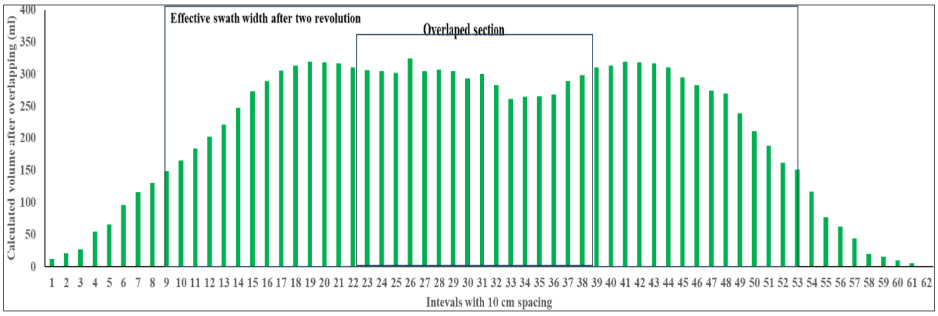

Fig 21: Spray pattern after overlapping at spraying height 2.5 m and 60% discharge rate

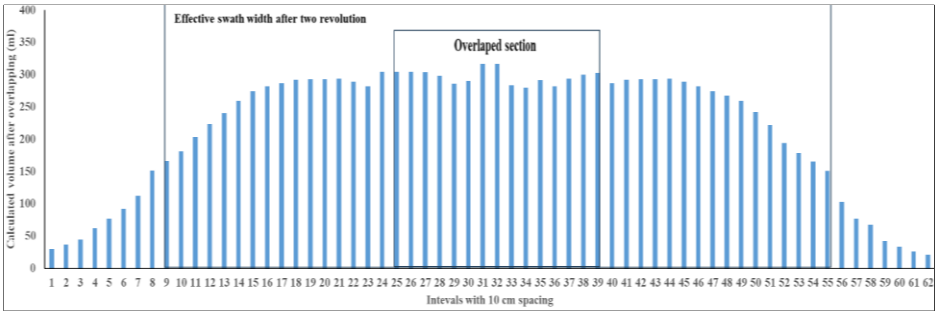

Fig 22: Spray pattern after overlapping at spraying height 3 m and 100% discharge rate

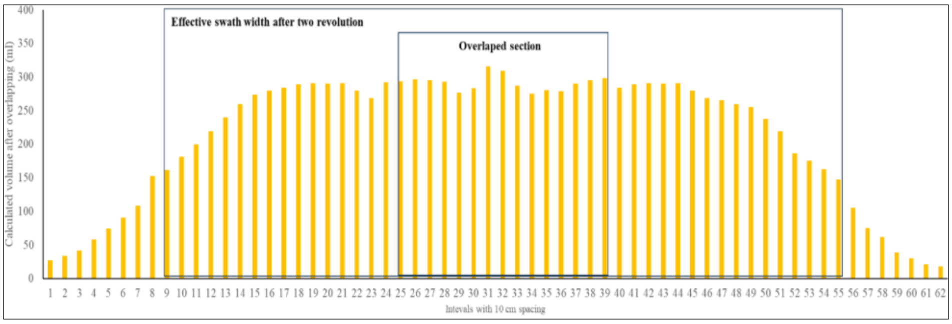

Fig 23: Spray pattern after overlapping at spraying height 3 m and 80% discharge rate

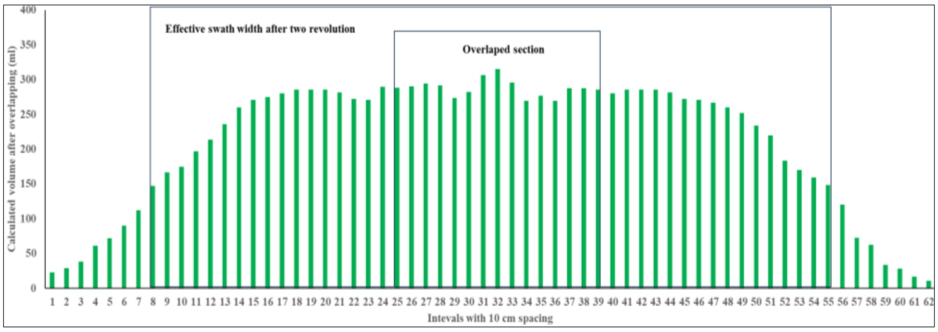

Fig 24: Spray pattern after overlapping at spraying height 3 m and 60% discharge rate

Actual swath width was calculated for each combination where minimum CV and maximum UC were found. Table 5 shows the effective swath width found with respective CV and UC.

Table 6: Effective swath width at which maximum UC and minimum CV obtained in each combination after overlapping of spray pattern

Treatments	Effective swath width (m)	Average volume of water calculated in each bottle (ml)	SD	CV (%)	UC (%)
H1D1	2.1	272.94	66.75	24.45	78.95
H1D2	2.1	269.24	66.97	24.87	78.59
H1D3	2.1	264.46	65.13	24.63	78.77
H2D1	2.3	255.51	61.33	24.00	78.89
H2D2	2.3	251.06	60.11	23.94	78.85
H2D3	2.3	247.55	59.69	24.11	78.94
H3D1	2.5	238.52	50.46	21.15	81.57
H3D2	2.5	234.92	49.73	21.17	81.53
H3D3	2.5	231.87	49.16	21.20	81.43

Table 5 shows that the effective swath width was found as 2.1, 2.3 and 2.5 m at spraying height 2.0, 2.3 and 2.5 m respectively. At this effective swath width UC was found more than 78.59% and CV was found less than 24.87%. Thus, UC was improved by overlapping the spray pattern and the range of UC and CV found was satisfactory and within the acceptable limit. Also, it was clear that effective swath width only changes accordingly to spraying height and not by the discharge rate.

4. Conclusions

1. From the study, it was revealed that for evaluation of the drone sprayers (hexacopter), a patternater of size 4 x 2 m (minimum) was required to study uniformity in depositing sprayed liquid across the spray width.
2. In case of drone sprayer in which nozzles were attached under propeller motor, it was found that the deposition of the sprayed liquid was more at the center of the spray width and it decreased towards edges of the spray width hence UC was found less than 50% in overall spray (swath) width.
3. The UC of spray pattern might be increased by overlapping of two consecutive spray patterns and actual swath width was found to utilize it during field experiments.
4. The effective or actual swath width was found as 2.1, 2.3 and 2.5 m for spraying height 2.0, 2.5 and 3.0 m respectively.
5. It was also found that the profile of the spray pattern (UC or CV) was not affected by the discharge rate.
6. These findings can be valuable for optimizing agricultural drone sprayer operation parameters and ensuring efficient and effective spraying in the field through drone sprayer.

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