

Evaluation of remote-controlled spraying rover in high-density apple orchards

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Abstract: The study evaluates the performance, effectiveness and efficiency of the remote-controlled spraying rover in comparison to traditional sprayers for high-density apple orchards in Kashmir region of India. The analysis process involved spray pattern, Swath width, discharge rate, average droplet size, leaf coverage area, uniformity coefficient and field efficiency. It revealed that forward speed, boom height, and pump pressure significantly affect droplet characteristics in spraying. Higher pressure produced smaller droplets, while lower boom height and slower speed resulted in larger droplets. Optimal mean droplet sizes were found at 0.96 μm (top) and 29.47 μm (bottom). Droplet distribution and leaf coverage were influenced similarly, with the middle section having the highest droplet count and coverage. Uniformity coefficients varied from 0.5 to 0.94, showing optimal conditions at specific parameter combinations. Discharge rate responded to pressure changes, swath width and work rate increased with higher pressure and boom height. Field efficiency ranged from 82.12% to 82.73%. Optimized parameters of forward speed of 0.61 km h^{-1} , boom height of 135 cm, and pump pressure of 1.45 kg cm^{-2} , enhanced overall efficiency for agricultural spraying.

Keywords: remote controlled, rover, spraying, droplet size, boom height, forward speed, operating pressure

Citation: Shah, A.B., J. Dixit, H. A. Peerzada, and F. A. Bhat. 2025. Evaluation of remote-controlled spraying rover in high-density apple orchards. *Agricultural Engineering International: CIGR Journal*, 27(2):81-93

1 Introduction

The pests have inflicted substantial harm to agricultural output, with 70 causing frequent damage (Ratings Department of India, 2017). About 35%-45% of crop losses in India are attributable to insects, weeds, and diseases. Timely application of crop protection products (CPPs), such as insecticides, herbicides, fungicides, and nematicides, during critical growth stages is crucial for optimizing crop yields. CPP application with

manual mode or robots enhance CPP application efficiency with minimal effort (Shah et al., 2024). Currently, Indian farmers predominantly rely on manually operated or motorized sprayers such as hand, foot, knapsack, tractor-mounted, self-propelled and blower sprayers. While these sprayers are widely accepted, these have limitations. For instance, knapsack sprayers require farmers to shoulder them during fieldwork, making those physically taxing (Bhuse and Vyavahare, 2014; Dixit and Khan, 2009; Dixit et al., 2009). Pedal-operated

Received date: 20224-04-29 **Accepted date:** 2025-01-13

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pressure sprayers demand substantial human effort to operate. Power sprayers have fuel costs, noise, and imprecise application rates. Jammu and Kashmir contribute significantly to India's apple production, with approximately 77% of the country's apples originating from this region. The adoption of high-density plantation (HDP) has become essential due to population growth and resource constraints (Shah et al., 2024). For high-density apple orchards in Kashmir, knapsack and power sprayers are predominantly used. As the world faces an energy crisis, there is a growing need to explore alternative energy sources. Moreover, power sprayers often cause discomfort among farmers due to vibrations and excessive noise, making continuous work challenging. Precision in controlling the flow rate of CPPs during spraying is also a concern. Furthermore, the use of toxic CPPs in the field has serious health implications for farmers, leading to respiratory and skin ailments and, tragically, even fatalities (Nabi et al., 2018).

To address these issues various researchers have explored advancements in agricultural sprayer technology. Shalini (2016) designed a real-time robot guided by ultrasonic sensors for automated pesticide spraying based on crop detection. Xue et al. (2016) developed an unmanned aerial vehicle-based automatic aerial spraying system with advanced route planning capabilities. Pranoy et al. (2017) designed a pesticide sprayer on a 3-wheel kart with versatile pipe rotation and battery operation. While Bodke et al. (2017) created a manually operated spraying and fertilizer machine with a unique mechanism for translating rotary motion into reciprocating motion, addressing the needs of multiple crop lines. These innovations collectively contribute to the evolution of agricultural sprayer technology, enhancing efficiency and precision in pesticide application. Yallappa et al. (2016), Zhang et al. (2015), Jassowal (2016), Wandkar et al. (2017), Hussain et al. (2019), Gul et al. (2024) have evaluated the

performance of agricultural sprayers over the years considering discharge rate, swath width, droplet size, and uniformity. Knowledge gaps made a necessity for development of remote-controlled spraying in high-density orchards and vegetable fields in Jammu and Kashmir, where traditional spraying techniques led to higher labor requirements, increased costs, health hazards, and water wastage. Thus the main aim of the study was to develop a remotely operated robotic spraying rover to reduce drudgery in operators, increase operator's safety and address the shortage of labour in the peak spraying time of the season in the said region.

2 Material and methods

2.1 Rover

The study was carried out in the apple growing season of 2023 to develop an automated sprayer suitable for densely planted horticultural orchards and vegetable fields in the Kashmir region of India. The prototype was tested in the high-density apple field (Latitude 34.147190, Longitude 74.878498 and 1585 meters above sea level) in SKUAST-K. The distinct parts of the prototype (Figure 1) were constructed and brought together within the COAE&T Workshop and Electronics Instrumentation Lab at SKUAST-K, Shalimar. Specifications of the developed rover are given in Table 1. A fully constructed prototype operating in the field is shown in Figure 2.

2.2 Control and output parameters

This section focused on evaluation of distinct levels of forward speed 0.75 km h⁻¹ (S1) and 0.61 km hr⁻¹ (S2), boom height of 150 cm (H1, top position) and 135 cm (H2, bottom position), and operating pump pressure of 1.45 kg cm⁻² (P1), 1.35 kg cm⁻² (P2), and 1.20 kg cm⁻² (P3) with the response parameters of leaf coverage area, measured in micrometers squared (μm^2), indicates the extent to which the spray is effectively distributed across the targeted vegetation, the uniformity coefficient, expressed as a percentage

(%), gauges the consistency of distribution across the treated area, and the discharge rate in liters per minute, the working capacity in hectares per hour ($ha\ h^{-1}$), the field efficiency as a percentage

(%), and the swath width in centimeters (cm). Based on the permutation of input variables a test matrix was formed (Table 2) to plan the experiments.

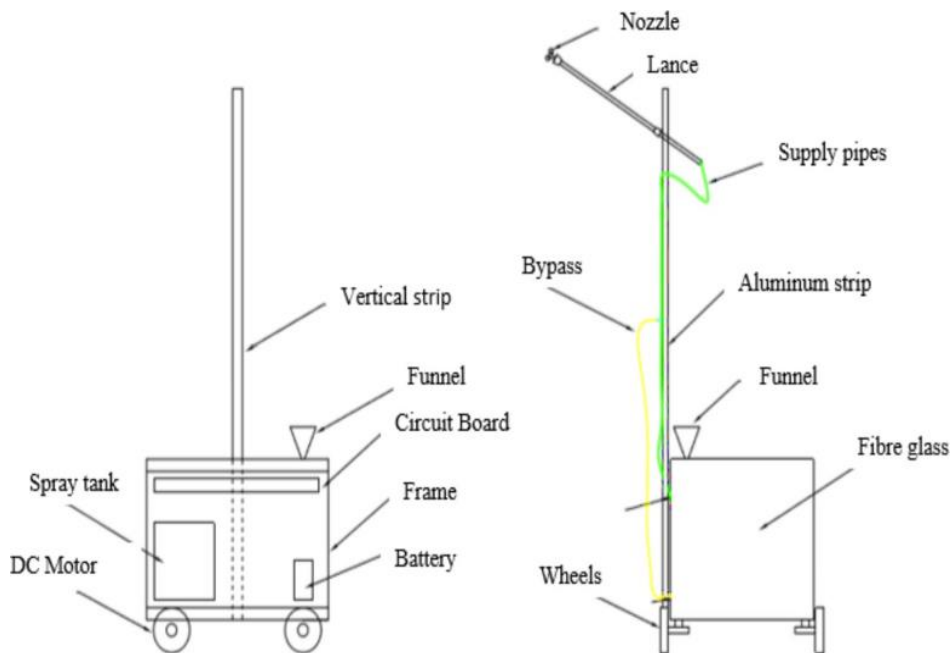


Figure 1 Schematic diagram of automated spraying rover of high-density apple orchards

Table 1 Specifications of Rover under consideration

Component	Specification
Dimensions (mm)	700 × 550 × 500
Frame material	Aluminum
Spray system	Boom sprayer
Height of boom (mm)	1650
Nozzle type	Flat fan type (2 in 1)
Pump	12-volt DC pump

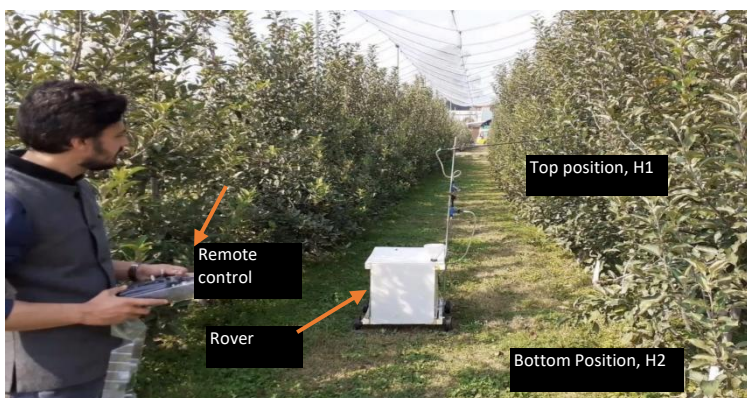


Figure 2 Remote controlled spraying rover in high-density apple orchard

2.3 Experimental setup

To investigate the influence of diverse control parameters on the output parameters, a series of laboratory-based setups utilizing specialized instruments and field-based evaluations were done. The factorial RBD (randomized block design) was followed in the study. Statistical analysis of experimental data with its Analysis of variance

(ANOVA) was done. The critical difference at 5% level of significance was calculated for testing the significance of difference between different parameters. The analysis of experimental data was done with the help of “SPCS Stat”.

2.3.1 Spray pattern analysis

A dedicated spray patternator, in the Farm Machinery Testing Centre (Latitude 34.147044,

Longitude 74.884969 and 1585 meters above sea level), located at SKUAST-K Srinagar, India, was employed to meticulously examine nozzle characteristics. The patternator was structured with 40 parallel-aligned channels, each equipped with a graduated glass tube positioned directly beneath it to facilitate the collection of sprayed substances. The internal dimensions of each channel measured $200 \times 2.5 \times 10$ cm. For the study, the prototype sprayer's boom was positioned perpendicularly to the patternator channels. The sprayer was then engaged to dispense spray over the patternator channels for a duration of one minute, varying the levels of pump pressure (1.45, 1.35, 1.20 kg cm⁻²) and boom height (150, 135 cm) in various combinations. This examination encompassed a total of six distinct combinations, each replicated thrice to ensure reliable results. The quantity of chemical spray emitted from different patternator channels was meticulously collected within glass tubes. Subsequent measurements and recordings were conducted to quantify and document the volume of sprayed chemical within each glass tube.

The nozzle's spray pattern was elucidated through the visualization of these recorded values, enabling a comprehensive analysis of its distribution characteristics.

2.3.2 Swath width

The spray patternator was utilized once again to facilitate this measurement. Specifically, the distance between the outermost channels on the spray patternator, which had been subjected to sprayed water, was meticulously measured in centimetres. This distance was subsequently interpreted as the indicative swath width of the nozzle's spray coverage.

2.3.3 Discharge rate analysis

The developed sprayer was engaged to dispense spray over the patternator for an interval of approximately one minute. Subsequently, the aggregate volume of liquid accumulated in various glass tubes within the patternator was meticulously quantified using a measuring cylinder. To ensure robust findings, each step of this procedure was repeated three times.

Table 2 Test matrix for evaluation of performance of the rover

Treatment	Symbol	Combination
T1	S1P1H1	0.75 km h ⁻¹ + 1.45 kg cm ⁻² + 150 cm
T2	S1P1H2	0.75 km h ⁻¹ + 1.45 kg cm ⁻² + 135 cm
T3	S1P2H1	0.75 km.h ⁻¹ + 1.35 kg cm ⁻² + 150 cm
T4	S1P2H2	0.75 km.h ⁻¹ + 1.35 kg cm ⁻² + 135 cm
T5	S1P3H1	0.75 km h ⁻¹ + 1.20 kg cm ⁻² + 150 cm
T6	S1P3H2	0.75 km h ⁻¹ + 1.20 kg cm ⁻² + 135 cm
T7	S2P1H1	0.61 km h ⁻¹ + 1.45 kg cm ⁻² + 150 cm
T8	S2P1H2	0.61 km h ⁻¹ + 1.45 kg cm ⁻² + 135 cm
T9	S2P2H1	0.61 km h ⁻¹ + 1.35 kg cm ⁻² + 150 cm
T10	S2P2H2	0.61 km h ⁻¹ + 1.35 kg cm ⁻² + 135 cm
T11	S2P3H1	0.61 km h ⁻¹ + 1.20 kg cm ⁻² + 150 cm
T12	S2P3H2	0.61 km h ⁻¹ + 1.20 kg cm ⁻² + 135 cm

2.3.4 Average droplet size

The investigation concerning the average droplet size was conducted within a field setting. Initially, the operational assessment of the developed sprayer prototype took place in a high-density apple orchard (30 × 3) m² at SKUAST-K, Shalimar. Glossy chart paper strips, each measuring 7 cm × 4 cm, were affixed to the upper, middle, and lower segments of apple trees, which averaged between 8 to 10 feet in height. For the purpose of

spraying and evaluating response parameters, a mixture of Methylene blue MS dye and water was employed at 5 ml l⁻¹.

The operational procedure entailed applying the sprayer to different combinations of input variables, followed by the spraying of dyed water onto the tree sections corresponding to the affixed paper strips. Subsequent to the drying of the sprayed water, the paper strips were carefully gathered for further analysis (Figure 3). The examination of

droplet size entailed categorizing the diameter of droplet spots on the paper strips into distinct size ranges (Table 3). This evaluation was conducted at the top, middle, and bottom positions of the plant. For accurate measurements, a CCD microscope was employed, coupled with De-winter material plus software. This allowed for the determination of the mean droplet size within each range. Moreover, the total count of droplets falling within each size range per square centimeter of paper strip area was

meticulously tallied and recorded at the three plant positions, utilizing De-winter material plus software. This quantified value, referred to as droplet density, indicated the concentration of droplets per unit area.

The computation of the volume attributed to a specific range of droplet size followed the equation (Chandrasekar et al., 2023):

$$\text{Volume contributed by particular range (V)} = \pi/6 \times (\text{mean droplet diameter})^3 \times (\text{number of droplets in that range}) \quad (1)$$

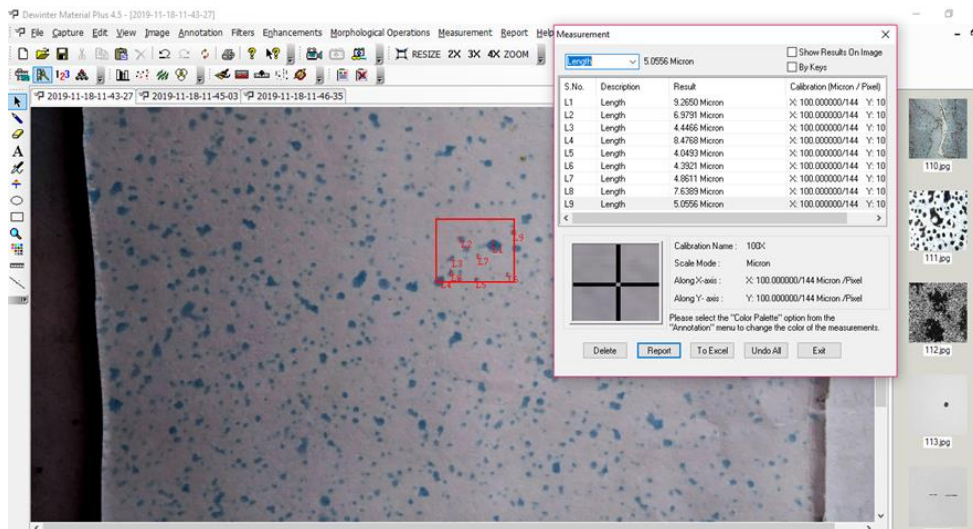


Figure 3 Droplet size analysis of sprayed chemical on paper strips with De-winter material plus software

Table 3 Different range of sizes of spray droplets

S.No	Range of sizes (μm)
r1	0 – 3
r2	4 – 7
r3	8 – 11
r4	12 – 15
r5	16 – 19
r6	20 – 23
r7	24 – 27
r8	27 – 30
r9	> 31

2.3.5 Leaf coverage area

The area encompassed by each individual spray droplet was computed through the utilization of De-winter material plus software. A parallel approach was employed to calculate the cumulative areas contributed by all the distinct ranges of droplet sizes. The summation of these areas, representing all size ranges within a one-square-centimetre portion of paper strip, yielded the comprehensive measurement of leaf coverage area per square centimetre.

2.3.6 Uniformity coefficient

This coefficient is determined through the

utilization of volume median diameter (VMD) and number median diameter (NMD) to characterize the size of droplets. VMD was established by identifying the droplet size at which the cumulative percentage of volume contributed 50% of the total spray volume. NMD was determined by pinpointing the droplet size at which the cumulative percentage of droplet number reached 50% of the total number of droplets. Percentages of volume contributed by each individual droplet size range were computed, along with cumulative of spray volume originating from the collective droplet ranges. By graphing the cumulative

percentages of volume against droplet diameter, the VMD of sprayed droplets was ascertained. Likewise, through a graphical representation of cumulative percentages of droplet number versus actual droplet diameter, the NMD of sprayed droplets was determined (Patel et al., 2016):

Uniformity coefficient calculation (UC):

$$UC = NMD/NMD \quad (2)$$

2.3.7 Field efficiency

Field efficiency was calculated as:

$$\text{Theoretical Field Capacity (ha h}^{-1}\text{)} = (W \times S \times 36) / 100 \quad (3)$$

Where, W represents the working width of the machine in meters and S represents the actual speed of the developed sprayer in meters per second

$$\text{Effective Field Capacity (ha h}^{-1}\text{)} = (A \times 36) / (T \times 100) \quad (4)$$

Where:

A denotes the area covered by the sprayer in square meters and T signifies the time taken for the operation in seconds

$$\text{Field efficiency} = \text{Actual field capacity} / \text{Theoretical field capacity} \times 100 \quad (5)$$

3 Results and discussion

Effect of forward speed, boom height and pump operating pressure on:

3.1 Spray pattern analysis

The quantity of chemical spray emitted from

Table 4 Effect of operating pressure of pump and boom height on Swath width (cm) of spray of the nozzle

	H1	H2	Mean
P1	141.66	136.66	139.16
P2	130	120	125
P3	88.33	78.33	83.33
Mean	120	111.16	

3.3 Discharge rate

The quantification of the nozzle's discharge rate was meticulously conducted using the spray patternator at the Farm Machinery Testing Centre of COAE&T. Within this controlled environment, the newly developed sprayer was systematically evaluated across an array of combinations encompassing various pump operating pressures (1.45, 1.35, and 1.20 kg cm²)

different patternator channels was meticulously collected within glass tubes. Subsequent measurements and recordings were conducted to quantify and document the volume of sprayed chemical within each glass tube. The nozzle's spray pattern was elucidated through the visualization of these recorded values, enabling a comprehensive analysis of its distribution characteristics.

3.2 Swath width

The findings definitively demonstrated a correlation between higher operational pressure, increased boom height, and the attainment of a broader swath width. Specifically, under the highest operating pressure of 1.45 kg cm⁻², the swath width was maximum as 139.16 cm. Conversely, the lowest operational pressure of 1.20 kg cm⁻² corresponded to a narrower swath width of 83.33 cm. Similarly, when the boom height was elevated to 150 cm, the nozzle's spray achieved its most expansive swath width of 120 cm. Conversely, a lower boom height of 135 cm led to a reduced swath width of 111.16 cm (Table 4). It is important to note that while greater swath widths can indeed be achieved through heightened pressure and elevated boom heights, these adjustments are not without consequences. Specifically, such increases in swath width could inadvertently lead to heightened drift losses, potentially impacting the efficiency and accuracy of the spraying process.

and boom heights (150 and 135 cm). This meticulous assessment allowed for a comprehensive understanding of the sprayer's performance characteristics. This enabled the visualization and study of the nozzle's spray pattern. Through this analytical process, noteworthy outcomes emerged. The findings indicated that the highest mean discharge, measuring 975.33 ml min⁻¹, was attained under pressure P1 (1.45 kg cm⁻²),

while the lowest mean discharge of 798.33 ml min⁻¹ was observed under pressure P3 (1.20 kg cm⁻²) (Table 5). Similarly, the plotting of volumes corresponding to the spray collected in various channels of the patternator provided insights into the spray pattern generated by the sprayer nozzle. Across all treatment configurations, a consistent trend was unveiled through the graphical representation. This trend showcased that the nozzle of the developed sprayer exhibited reduced volume deposition at the center of the patternator (Channel 20). In contrast, the volume of spray consistently increased when moving towards either the left or right of the patternator's center, aligning with the placement of the sprayer's boom. This observation is further elucidated in Figure 4.

3.4 Average droplet size

The velocity at which the sprayer moves forward, the operational pressure of the pump, and

the height of the spray boom each exert influence on this parameter. As the boom height decreases and the pump's operational pressure is lowered, there is a concurrent increase in the average droplet size. The current sprayer demonstrated optimal performance when operated at a pump pressure of 1.45 kg cm⁻² and a boom height of 150 cm, producing finer droplets. Moreover, the investigation showed that as the forward speed of the sprayer decreased from 0.75 km h⁻¹ to 0.61 km h⁻¹, the average droplet size consistently increased under the conditions of a forward speed of 0.75 km h⁻¹, a boom height of 150 cm, and a pump pressure of 1.45 kg cm⁻². Conversely, the largest mean droplet size, measuring 29.47 μm, was recorded at a forward speed of 0.61 km h⁻¹, a boom height of 135 cm, and a pump operating pressure of 1.20 kg cm⁻² (Table 6).

Table 5 Effect of operating pump pressure and boom height on discharge rate of nozzle (ml min⁻¹)

	H1	H2	Mean
P1	976.33	974.33	975.33
P2	947.33	948.33	947.83
P3	797.66	799.0	798.33
Mean	907.11	799.0	

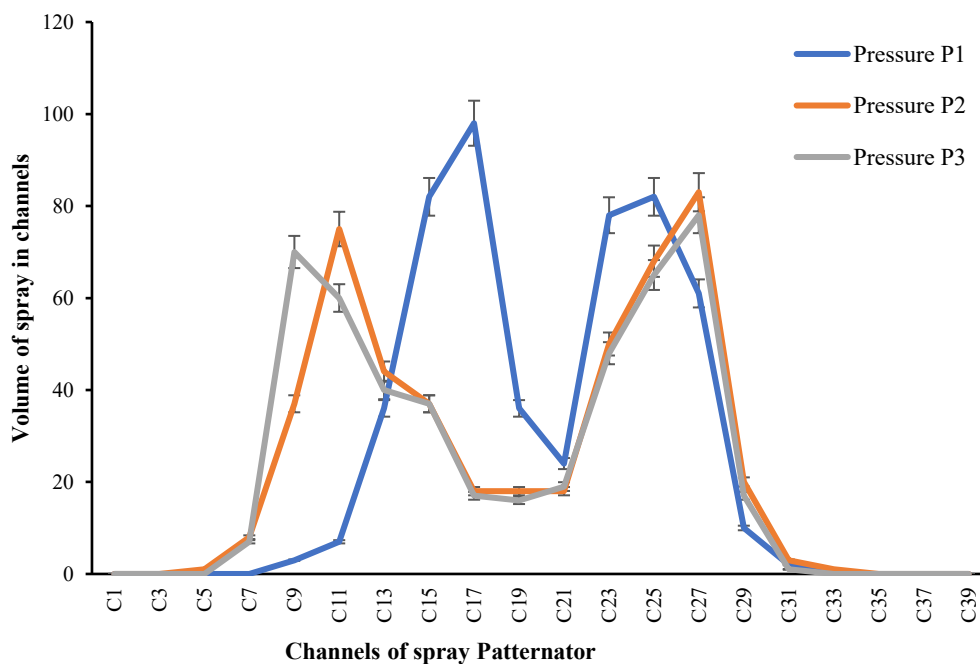


Figure 4 Effect of operating pressure on spray pattern of nozzle in all treatment combinations

Table 6 Effect of forward speed, pump operating pressure and boom height on average droplet size of spray

	S1				S2				Overall Mean	
	P1	P2	P3	Sub Mean	P1	P2	P3	Sub Mean		
H1	r1	0.96	2.30	0.00	1.54	0.99	1.78	0.00	0.91	1.225
	r2	4.95	5.69	0.00	3.54	5.47	4.33	0.00	3.26	3.4
	r3	8.01	10.14	0.00	6.05	9.80	9.06	0.00	6.28	6.165
	r4	10.37	12.71	0.00	7.69	12.44	14.19	0.00	8.84	8.265
	r5	1.77	8.09	3.90	4.58	11.52	18.01	2.01	10.51	7.545
	r6	0.00	7.30	4.98	4.09	2.46	17.57	4.78	8.27	6.18
	r7	0.00	5.74	17.01	7.58	0.00	8.84	20.25	9.69	8.635
	r8	0.00	0.00	19.25	6.41	0.00	3.20	26.47	10.89	8.65
	r9	0.00	0.00	10.46	3.48	0.00	0.00	21.22	7.07	5.275
Sub Mean	3.04	5.77	6.17	4.99	4.73	8.55	8.63	7.30		
H2	r1	2.62	1.91	0.00	1.51	1.18	2.77	0.00	1.29	1.285
	r2	5.77	4.81	0.00	3.52	5.74	5.31	0.00	3.68	4.71
	r3	9.21	9.25	0.00	6.15	8.95	10.63	0.00	6.52	7.735
	r4	9.99	14.51	0.00	8.16	13.52	13.72	0.00	9.08	11.3
	r5	9.63	16.94	4.34	10.30	9.58	17.84	1.91	9.77	9.675
	r6	12.18	12.57	7.62	10.79	9.67	22.26	12.15	14.69	12.18
	r7	2.8	2.99	16.90	7.56	0.00	16.83	26.04	14.29	7.145
	r8	0.00	0.00	19.46	6.48	0.00	3.22	29.47	9.89	4.945
	r9	0.00	0.00	13.74	4.58	0.00	0.00	21.08	7.02	3.51
Sub Mean	5.80	6.99	6.89	10.28	5.41	10.28	9.73	8.47	7.52	
Overall Mean				5.78				7.89		

Table 7 Effect of forward speed, boom height and pump operating pressure on average leaf coverage area (μm^2) for top, middle and bottom positions of the plant

	S1			S2			Mean
	H1	H2	Sub Mean	H1	H2	Sub Mean	
P1	1407.92	1501.02	1454.47	1979.94	2039.47	2009.70	1732.08
P2	1311.88	1413.47	1362.67	1888.18	1936.99	1912.58	1637.63
P3	852.71	907.51	880.11	1046.64	1121.24	1083.94	982.08
Mean	1190.83	1274	1232.45	1638.25	1699.23	1668.74	

The smallest mean droplet size, measuring $0.96 \mu\text{m}$, was observed.

3.5 Droplet density (number of drops per cm^2)

The quantification of droplets dispensed onto the upper, middle, and lower positions of the plant was meticulously conducted. The subsequent calculation yielded the average number of droplets per square centimeter for each of these positions. Among the various conditions tested, the lowest recorded average number of droplets per square centimeter stood at 3.33. This was observed when the forward speed was set at 0.75 km h^{-1} , the boom height was maintained at 150 cm, and the pump operated at a pressure of 1.20 kg cm^{-2} . In contrast, the most substantial recorded average number of droplets per square centimeter reached 18.21. This specific outcome transpired under the conditions of a forward speed of 0.61 km h^{-1} , a boom height of 135 cm, and a pump operating pressure of 1.45 kg

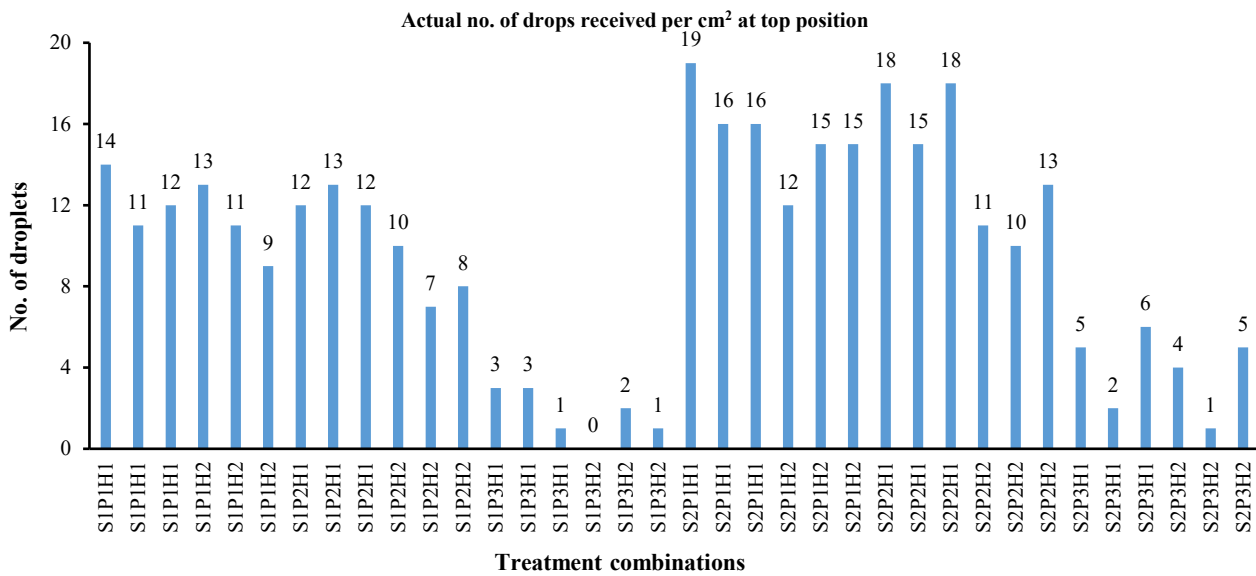
cm^{-2} . Significantly, across all experimental configurations, the central portion of the plant exhibited the highest receptivity to droplet deposition during the spraying process. This central area consistently contributed the most to the cumulative count of droplets received by the plant as a whole. Notably, the maximum observed count of droplets per square centimeter was 58, achieved when the forward speed was 0.61 km h^{-1} and the pump operated at a pressure of 1.45 kg cm^{-2} . Conversely, the minimum observed count, measuring 6 droplets per square centimeter, materialized during conditions featuring a forward speed of 0.75 km h^{-1} and a pump pressure of 1.20 kg cm^{-2} (Figure 5).

3.6 Average leaf coverage area

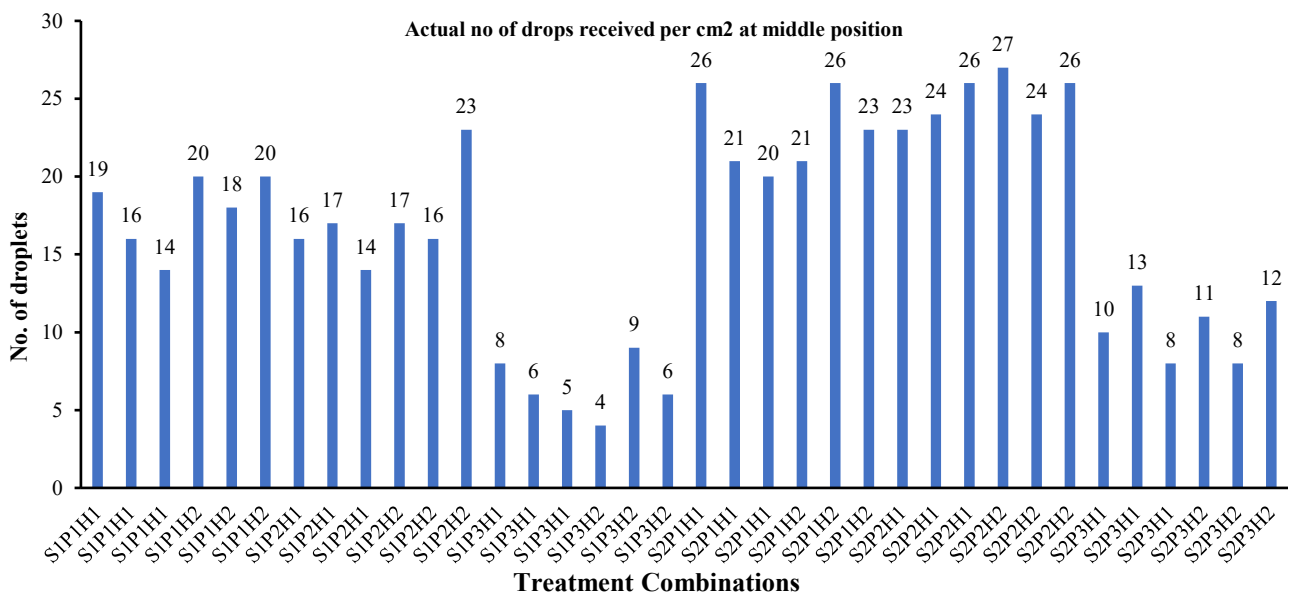
The investigation entailed a meticulous analysis

of the average leaf coverage across the upper, middle, and lower segments of the plant. In the majority of instances, a notable trend emerged wherein the sprayer’s efficacy in covering leaf surfaces was most pronounced in the middle portion of the plant. This phenomenon could be attributed to the greater concentration of droplet deposition during spraying in this central area. Remarkably, the smallest recorded mean leaf coverage area was $852.71 \mu m^2$, observed under conditions involving a forward speed of 0.75 km h^{-1} , a boom height of 150 cm , and a pump operating pressure of 1.20 kg cm^{-2} . Conversely, the most

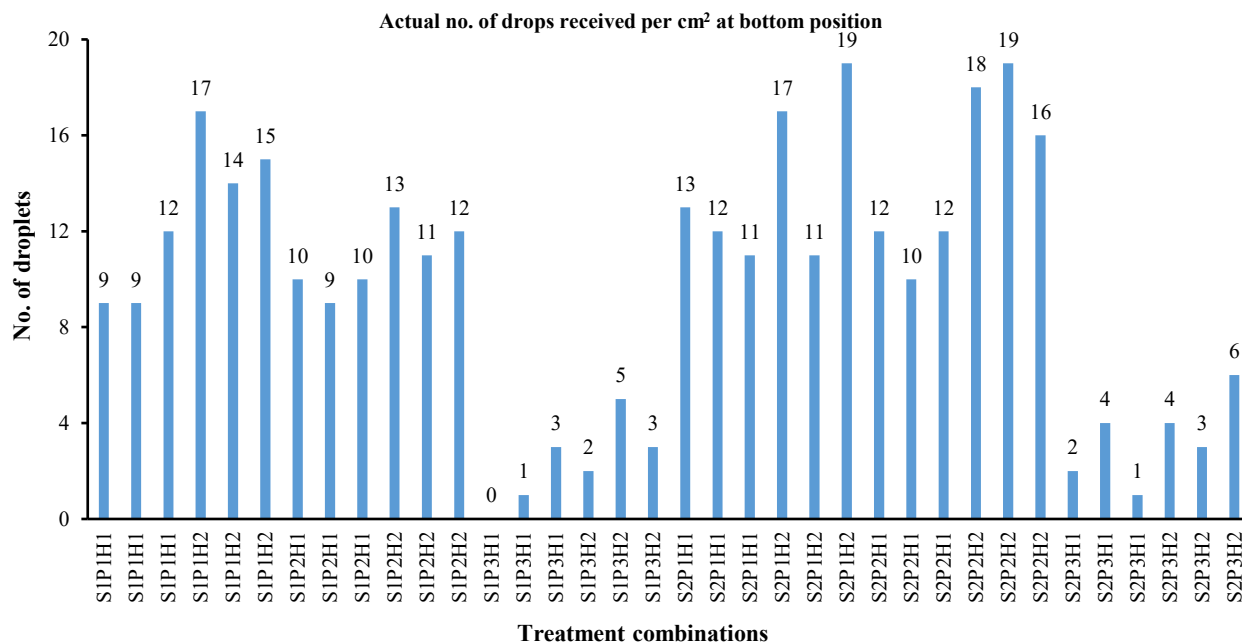
substantial mean leaf coverage area of $2039.47 \mu m^2$ was documented during trials with a forward speed of 0.61 km h^{-1} , a boom height of 135 cm , and a pump operating pressure of 1.45 kg cm^{-2} (Table 7). Furthermore, rigorous statistical analysis underscored the undeniable impact of the sprayer’s forward speed on the cumulative leaf coverage area for the upper, middle, and lower portions of the plant. A conspicuous pattern emerged where decreased forward speed correlated significantly with augmented leaf coverage across various plant segments. The smallest mean droplet size, measuring $0.96 \mu m$, was observed.



(a) Top position of plant



(b) Middle position of plant



(c) Bottom position of plant

Figure 5 Effect of speed, boom height and pump operating pressure individually on actual droplet density (actual no. drops.cm⁻²) of spray at different position of plant

Table 8 Effect of forward speed, boom height and operating pressure of pump on VMD of sprayed droplets

	S1			S2			Mean
	H1	H2	Sub Mean	H1	H2	Sub Mean	
P1	2.55	3.43	2.99	3.78	3.02	3.40	3.19
P2	6.31	3.65	4.9	4.04	3.16	3.60	4.25
P3	6.88	5.20	6.04	4.80	4.79	4.79	5.41
Mean	5.24	4.09	4.64	4.20	3.65	3.92	4.29
Factor Means	H1: 4.72			H2: 3.87			

Table 9 Effect of forward speed, boom height and operating pressure of pump on NMD of sprayed droplets

	S1			S2			Mean
	H1	H2	Sub Mean	H1	H2	Sub Mean	
P1	3.54	5.24	4.47	5.90	5.38	5.64	4.92
P2	5.80	6.41	6.10	7.08	5.81	6.44	6.27
P3	6.52	6.72	6.62	7.32	5.99	6.65	6.63
Mean	5.28	6.12	5.73	6.76	5.72	6.24	5.98
Factor Means	H1: 6.02			H2: 5.92			

3.7 Uniformity coefficient

The investigation revealed a consistent trend wherein both the VMD and NMD exhibited a decrease in magnitude as the operational pressure of the pump increased (Table 8 and 9). The findings highlighted a discernible range for the VMD and NMD of droplets, averaging between 3 μm and 7 μm. Notably, across all combinations of forward speed, pump operating pressure, and boom height, the uniformity coefficient ranged from 0.52 to 0.94. Specifically, the lowest VMD

was attained when the pump operated at a pressure of 1.45 kg cm⁻², while the highest VMD was associated with a pump pressure of 1.20 kg cm⁻². The uniformity coefficient achieved its minimum value of 0.52 under the conditions of a forward speed of 0.61 km h⁻¹, a boom height of 135 cm, and a pump operating pressure of 1.35 kg cm⁻². The highest elevated mean uniformity coefficient was registered at forward speed of 0.75 km h⁻¹, the boom height reached 150 cm, and the pump’s operating pressure was 1.35 kg cm⁻² (Table 10).

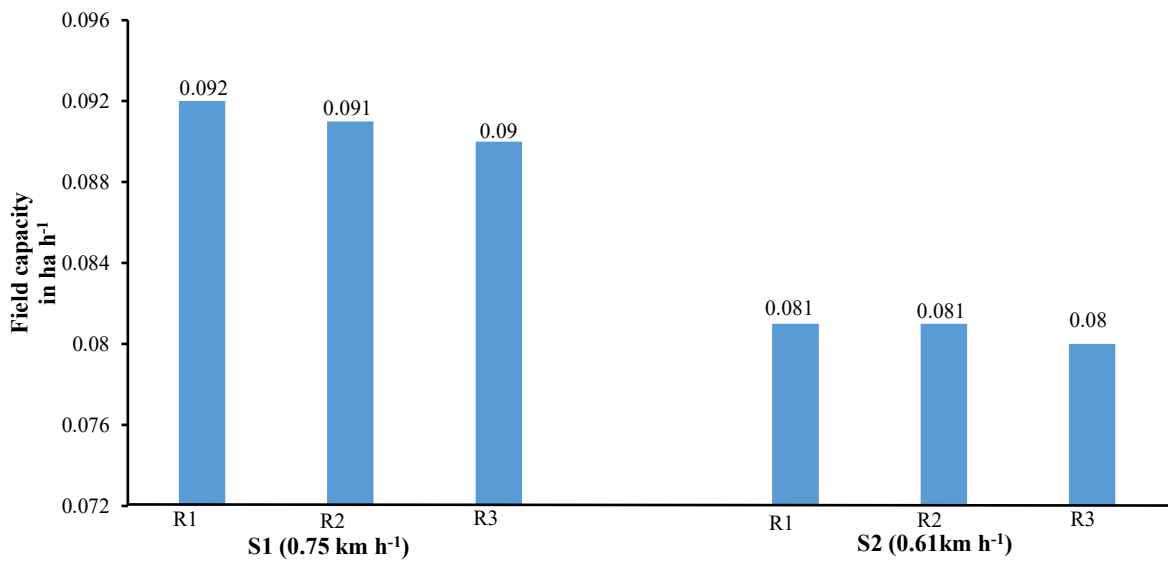
3.8 Field capacity and efficiency

The theoretical field capacity was found to be 0.11 and 0.097 ha h⁻¹ at forward speeds (S1 and S2). The

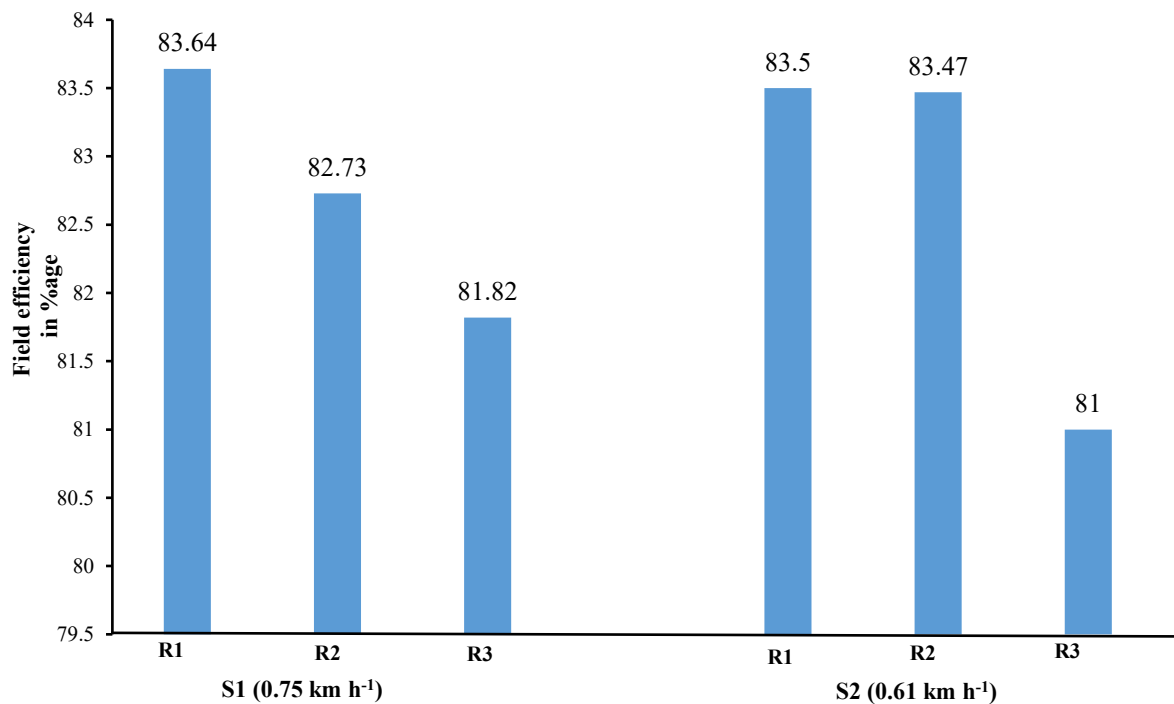
effective field capacity is plotted in Figure 6 a and field efficiency of the sprayer (Figure 6b) was found to be ranging from 82.12% to 82.73%.

Table 10 Effect of forward speed, boom height and operating pressure of pump on uniformity coefficient

	S1			S2			Mean
	H1	H2	Sub Mean	H1	H2	Sub Mean	
P1	0.94	0.53	0.74	0.53	0.93	0.73	0.74
P2	1.14	0.73	0.93	0.60	0.52	0.565	0.74
P3	0.63	0.73	0.68	0.73	0.70	0.71	0.70
Mean	0.91	0.66	0.79	0.62	0.72	0.67	
Factor Means	H1: 0.76			H2: 0.69			



(a) Effective field capacity of the developed sprayer for 3 replications at 02 different forward speeds of sprayer



(b) Field efficiency of developed sprayer for 3 replications at 02 different forward speeds of sprayer

Figure 6 Effective field capacity and field efficiency of the developed sprayer at different forward speeds

4 Conclusion

The evaluation of a developed sprayer encompassed the significant impacts of forward speed, boom height, and pump pressure on droplet attributes. Enhanced pressure corresponded with reduced droplet size, while diminished boom height correlated with larger droplets. Moreover, slower forward speed resulted in larger droplets. Notably, the optimal conditions for mean droplet size were observed at $0.96 \mu\text{m}$ (top) and $29.47 \mu\text{m}$ (bottom). Notably, reduced speed and elevated pressure yielded more droplets. Leaf coverage displayed analogous trends, with the middle section manifesting the highest coverage due to more droplets. Uniformity coefficients, ranging from 0.5 to 0.94, fluctuated with droplet size variations and revealed optimal conditions at specific parameter combinations. Discharge rate primarily responded to pressure variations, while swath width and rate of work increased with heightened pressure and boom height. Field efficiency ranged from 82.12% to 82.73%. In conclusion, optimized parameters encompassing a forward speed of $0.61 \text{ km}\cdot\text{h}^{-1}$, boom height of 135 cm, and pump pressure of 1.45 kg cm^{-2} yielded superior performance in terms of various attributes and overall efficiency.

Acknowledgement

The authors would like express their sincere appreciation to the faculty associates of College of Agricultural Engineering and Technology, SKUAST-K for their precious suggestions and guidance.

Conflict of interest

The authors declare that no conflict of interest exists.

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