



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(8): 344-349
Received: 14-05-2026
Accepted: 18-06-2026

Pulla Nagajyothi
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

Satyanarayan
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

P. Jhansi
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

T Saketh
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

T Anusha
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

J Chaitanya
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

A Naresh
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

Corresponding Author:
Pulla Nagajyothi
Department of Farm Machinery and Power
Engineering, College of Agricultural
Engineering, Professor Jayashankar
Telangana, Agricultural University
(PJTAU), Kandi, Sangareddy, Telangana,
India

Development and performance evaluation of a push type canopy sprayer for field crops

Pulla Nagajyothi, Satyanarayan, P Jhansi, T Saketh, T Anusha, J Chaitanya and A Naresh

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i8Se.6321>

Abstract

In agricultural production, applying pesticides effectively and consistently is crucial for tall and dense-canopy crops where traditional spraying techniques failed to cover the inner and lower parts of the plant canopy. While traditional knapsack and tractor-operated sprayers may result in poor spray penetration, higher chemical use, operator drudgery, and crop loss. In order to alleviate all this issues, the study has been carried out on the design, develop, and assessment of a Push Type Canopy Sprayer for field crops. Laboratory and field analysis have been carried out by considering biometric parameters such as crop height, row spacing, crop stage and canopy characteristics to evaluate performance of sprayer. In laboratory analysis it was observed that the discharge increased with an increasing in operating pressure. It was observed at 14 kg cm⁻², the average total discharge was 3.8775 L min⁻¹, while the average operator travel speed was 1.53 km h⁻¹. Field evaluation of the developed sprayer in maize crop resulted in a theoretical field capacity of 0.306 ha h⁻¹, effective field capacity of 0.251 ha h⁻¹ and field efficiency of 82.02 per cent. The developed sprayer covered four rows compared with two rows for the conventional power sprayer used for comparison. The total fabrication cost of the Push Type Canopy Sprayer was ₹17,250, while the estimated operating cost was ₹103.67 h⁻¹, including fixed, labour and fuel costs. The study concluded that the developed Push Type Canopy Sprayer provides a practical alternative for efficient and timely pesticide application. Its adjustable spraying arrangement facilitates better adaptation to crop conditions and can improve spraying efficiency while reducing operator drudgery and unnecessary chemical application.

Keywords: Field capacity, field efficiency, nozzle, pesticide application, push type canopy sprayer, spray discharge

Introduction

Agriculture plays a vital role in the Indian economy and provides livelihood and employment to a large proportion of the population. A substantial proportion of Indian farmers operate small and marginal holdings, and improvement in the efficiency and timeliness of agricultural operations is therefore important for enhancing farm productivity and profitability. The predominant concern in maintaining high productivity is protecting yield from pests, weeds etc. to mitigate these issues, pesticides were applied that includes chemicals such as insecticides, herbicides, fungicides, acaricides, molluscicides and nematicides, which are used on plants, soil and water for controlling pests and diseases. The use of pesticides for preventing pre-harvest and post-harvest losses has assumed considerable importance in modern agriculture. Chemicals are widely used for controlling diseases, insects and weeds in crops. They can protect crops from pest attack only when applied at the appropriate time and in an effective manner. Consequently, farmers require suitable machines for applying liquid and dust formulations of insecticides, herbicides and fungicides. The Indian farmers, particularly small and marginal farmers, commonly use lever-operated backpack sprayers. A backpack sprayer generally consists of a tank of about 10–20 litre capacity carried on the operator's back. Continuous pumping is required to maintain pressure, which can result in considerable operator fatigue, low field capacity and non-uniform spraying (Rao S and Sreenivas AG., 2019) ^[28]. According to (Rao S and Sreenivas AG., 2019) ^[28] production inputs must be complemented by adequate crop protection measures to realize potential yield increases. It has been observed that a substantial

proportion of agricultural production is lost due to insect pests, diseases, weeds, nematodes and rodents. Crop yield losses due to insect-pests, diseases, weeds, nematodes and rodents range from 15–25 per cent in India, amounting to considerable economic losses annually. Although pesticide use per hectare is comparatively low in India, the effectiveness of pesticides depends strongly on their timely and appropriate application. The Agro-Chemical Policy Group reported that agricultural produce lost in India due to pests was about Rs. 1.40 lakh crores in 2007 (kalikar *et al.*, 2013) ^[15]. Therefore, improving pesticide application efficiency is important not only for achieving effective pest and disease control but also for reducing unnecessary chemical expenditure, operator exposure and environmental contamination and also circuitously Mechanization of critical crop production operations can reduce human drudgery, improve timeliness and facilitate more precise application of agricultural inputs. Application of pesticides is one of the most important operations in agricultural production. Efficient application of agricultural chemicals is a major social, economic and environmental concern (Al-Gaadi, 2010) ^[12]. Inaccurate application can result in chemical drift, inadequate target deposition and increased farming costs (Narang *et al.*, 2013) ^[19]. Generally, tractor-operated boom sprayers fitted with spray nozzles carry out spraying mostly over the upper surface of plant stems and leaves. Fine spray droplets may provide inadequate coverage of the underside of leaves and lower portions of the plant. Especially in the crops of cotton and pigeon pea due to its large canopy. Hence a suitable canopy-oriented spraying system should improve deposition on stems, leaves and branches throughout the plant canopy. The introduction of an intra-canopy or canopy-oriented spraying system involves appropriate positioning of spray nozzles and, where required, air assistance to improve spray penetration. Incorporation of air assistance can improve deposition within the canopy and facilitate movement of droplets towards lower and inner canopy regions (Mathews *et al.*, 1992) ^[18]. The fine droplets generated under pressure, when combined with an appropriate air stream, can penetrate foliage and improve deposition on different surfaces of leaves and branches. (Gupta *et al.* 2004) ^[10] demonstrated that air velocity, leaf area density and forward speed significantly affected spray deposition in a simulated crop canopy. The development of a suitable canopy sprayer is therefore particularly relevant for crops having considerable plant height and dense canopy structure. A machine capable of moving through crop rows while maintaining appropriate nozzle position can potentially improve spray coverage without causing excessive crop damage. In addition, a properly designed machine can reduce operator drudgery associated with repeated manual spraying. Farmers frequently use manually operated knapsack sprayers, which require continuous human effort and generally have limited field capacity. In crops having tall plants and dense canopies, achieving adequate spray penetration using conventional manual spraying becomes more difficult. Cotton and pigeon pea may attain considerable plant height and canopy development, making it difficult to obtain uniform deposition on the upper, middle and lower portions of the plant using conventional top-directed spraying systems.

Tractor-operated boom sprayers can cover large areas within a relatively short period, however, their operation within standing crops may cause crop damage depending on crop height, row spacing and machine dimensions. Furthermore, conventional boom arrangements generally direct spray downward from above the crop, which may not provide adequate coverage of the

lower and inner portions of a dense canopy.

An alternative spraying mechanism is therefore required that can move conveniently between crop rows, minimize crop damage, provide adjustable nozzle positioning and improve spray deposition throughout the target canopy. A push-type canopy sprayer offers the possibility of combining a relatively simple ground-driven chassis with a power spraying system and adjustable spraying attachment. Such a system can be particularly useful for small and medium farmers because of its comparatively simple construction and operation. The need for such equipment is also consistent with international recommendations that pesticide application equipment should be safe, reliable, durable and capable of efficient operation under practical field conditions. FAO guidelines further emphasize the importance of engineering measures and appropriate equipment design in reducing operator and environmental risks associated with pesticide application. Considering all the above concerns the study was conducted to develop a Push Type Canopy Sprayer for selected field crops with the aim of improving the efficiency and timeliness of pesticide application. The developed machine was intended to provide better adaptation to crop height and row spacing, improve spray coverage, reduce operator drudgery and facilitate efficient utilization of spray liquid. The research work pertaining to the Push Type Canopy Sprayer was undertaken with the following objectives:

1. Study of biometric parameters of selected crops.
2. Development of Push type Canopy Sprayer.
3. Performance evaluation of Push type Canopy Sprayer in the laboratory and in field conditions.
4. Cost Economics of Canopy Sprayer.

Materials and Methods

Design and Construction of Push Type canopy sprayer

The study was conducted at the College of Agricultural Engineering (CAE) in Kandi, Sangareddy, India (17.63° N, 78.08° E; 516 m AMSL). Spraying operation has been performed on two variety of crops such as the cotton (Hybrid: Bt cotton hybrid MRC - 7351) and pigeon pea (variety: Maruthi ICP 8863) which were grown in the nearby villages of College of Agricultural Engineering Sangareddy. Push type Canopy sprayer consists of Power sprayer which was driven by the ground wheels and it was placed in a separate cabin. The ground wheel was placed Infront of the equipment attached to frame for easier operation. It was also provided with nozzle height adjustment provision. The main frame of the sprayer was fabricated using 3 mm thick L angle sections with dimensions of 125 mm width and 600 x 400 mm. The frame accommodated the 20 L spray tank, boom assembly, nozzle tubes and on-off control valves. A horizontal boom carrying four nozzles at center and 2 at top was provided to facilitate spraying over four crop rows in a single pass. A T-shaped handle was designed for convenient pushing and pulling of the sprayer during the field operation. A hollow circular rod of 1150 mm in length and 25 mm in diameter was used to construct the handle, which had an adjustable height arrangement. The handle was supported during operation by a supporting member that was positioned around 150 mm above the ground. A 4-stroke ASPEE power sprayer was used as the spraying unit. The sprayer had a 20L tank with dimensions of approximately 420 x 330 mm and was mounted on a frame of 610 x 470 mm. The tank was placed approximately 660 mm from the handle. Spray pressure was generated by the power sprayer and regulated using the engine accelerator. Hose pipes were used to transport pressurised spray liquid from the pump outlet to the nozzles. To make filling,

inspecting, and cleaning easier, a detachable strainer was installed at the tank opening.

The sprayer had a boom assembly with six nozzles that was held aloft by vertical parts that were 1000 mm long. The boom was made to allow for height and orientation adjustments based on crop height and canopy structure. Depending on the situation, it could be placed either vertically or horizontally. Using hose

pipes and nozzle holders, three nozzles were positioned on either side of the boom and connected to the spray line. To achieve circular spray coverage and appropriate penetration into the crop canopy, hollow-cone nozzles were utilised. The nozzle configuration was chosen to deliver medium-sized spray droplets that would sufficiently cover the target crop canopy.

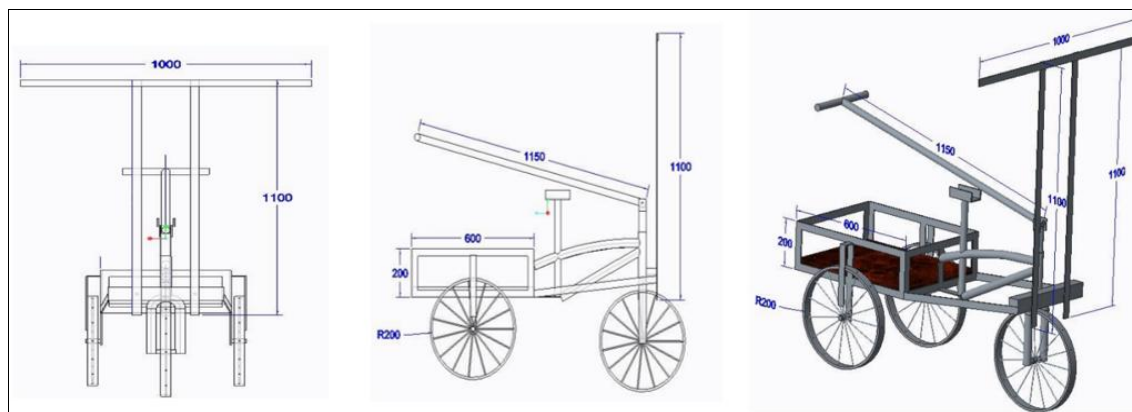


Fig 1: Experimental setup a) Front view b) Side view c) Complete design of PTCS

Crop parameters

The spraying methods used for the field trials are mostly influenced by crop factors. Variety, crop stage, row spacing, crop height, and crop canopy are among the biometric agricultural metrics. Standard methods were used to measure the crop parameters for the chosen field crops, such as cotton and pigeon pea.

Performance evaluation of Push type Canopy Sprayer

Field Evaluation and Laboratory evaluation

Discharge rate and spray uniformity has been evaluated

a) Discharge rate

Three operational pressures were used to measure the sprayer's discharge. The experiment was done three times, collecting the discharge at each of the six nozzles. The final discharge value was determined by summing the discharge values. In the field, the discharge rate was also calculated by running the sprayer for an hour at various forward speeds while taking into account the discharge rates of each nozzle.

b) Spray uniformity

spray uniformity has been assessed by using a spray patternator at specific variable levels. The nozzle was positioned 500 mm above the patternator (Padmanathan and Kathirvel, 2007)^[20] and sprayed liquid onto the patternator's collecting pipes. The amount of liquid from each channel was measured and recorded. Various operating pressures were used to record the data. The following formula was used to calculate the coefficient of uniformity. (Elhussiny *et al.*, 2023)^[6].

$$C_U = \frac{\sum X}{(1-mn)} \times 100$$

C_U = coefficient of uniformity, percent

X = absolute numerical derivations of the individual observations from the average applications, mm

m = average of all observations, mm

n = total number of the observations

Testing procedure

Evaluation of push type canopy sprayer

The total spray output, travel speed, swath width, and application rate of the sprayer were calculated in order to estimate the required spray application rate for the plant, soil, and insect. The spray tank was filled with clean water, and a measuring jug was positioned beneath each nozzle separately in order to measure the total spray production ($L \min^{-1}$). The amount of water gathered from each nozzle was measured and noted after the sprayer ran for a minute. The process was repeated for each nozzle, and the overall spray output of the sprayer in $L \min^{-1}$ was calculated by adding the individual nozzle discharges.

Travel speed (km/h)

100m distance is measured on ground, with marking the start and finish positions with pegs.

The time taken to cover 100m is measured in seconds. The travel speed is calculated by the following equation.

$$\text{Travel speed (km/h)} = 100(m) \times 3.6/\text{time(seconds)}$$

Spray Application Rate (L/ha)

The width of the swath was measured. The swath width for band spraying was defined as the sum of the widths of each individual spray band. The application rate is calculated by using the following formula (Gatkal *et al.*, 2026)^[7]

$$\text{Application rate (l/ha)} = \frac{600 \times \text{output}}{\text{swath width} \times \text{travel speed} \left(\frac{\text{km}}{\text{h}} \right)}$$

NOTE: Swath width is taken as number of nozzles multiplied by nozzle spacing.

Field Capacity

The field capacity of a farm machine is the rate at which it performs its primary function, such as the area of land tilled per hour or the quantity of material processed per hour. Measurements or estimates of machine capacity are useful for

scheduling field operations, determining power and labour requirements, and estimating machine operating costs. Field capacity of agricultural machinery is commonly expressed in terms of the area covered per hour of operation. (Shubham *et al.*, 2018)^[27]

$$\text{Theoretical field capacity (ha/h)} = \frac{\text{width (m)} \times \text{speed } \left(\frac{\text{m}}{\text{h}}\right)}{10^4}$$

The effective field capacity of a machine can be calculated by dividing the actual area covered by the total time taken to complete the operation. (Shubham *et al.*, 2018)^[27]

$$\text{Effective field capacity} = \frac{\text{width (m)} \times \text{speed } \left(\frac{\text{m}}{\text{h}}\right)}{10^4} \times \eta$$

$$\text{Field efficiency}(\eta) = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$$

Area rate of Power sprayer

A test plot was used to assess the power sprayer. The power sprayer was used to spray the test plot, and the amount of time needed to cover the whole plot area was noted. The power sprayer's field capacity was calculated using the measured area of the test plot and the spraying time. (Shubham *et al.*, 2018)^[27]
Area of test plot = length × breadth (m²).

$$\text{Rate of area of sprayer} = \frac{\text{Area of test plot (ha)}}{\text{time taken (h)}}$$

Patternator method

The nozzle spray pattern was measured by using the patternator test rig. The pressure was set as per the requirement Sprayer. The test was carried out at three different pressure ranges of 14 kg/cm², 21 kg/cm², 28 kg/cm² for 6 hollow cone nozzles by using pressure gauge of 2bar has been used for measuring pressure at different stages of spraying. Each trial on set pressure was recorded in four replications and the average reading graph was plotted on the basis of liquid collected in the tubes. Typically, the patternator has 16 channels, each of which is 25 ± 0.25 mm wide and can be any suitable length as long as it covers the spray area. The measuring tubes were positioned beneath each channel where the spray swath reached during the calibration of the spray pattern and stop watch was used to record the time. After that, gather the samples and produce the graph to display the spray pattern across the swath width.

Volume rate and application rate has been calculated by using the following formulas (Shubham *et al.*, 2018)^[27] The patternator test is depicted in the following figure fig 2.



Fig 2: Spray Patternator Test

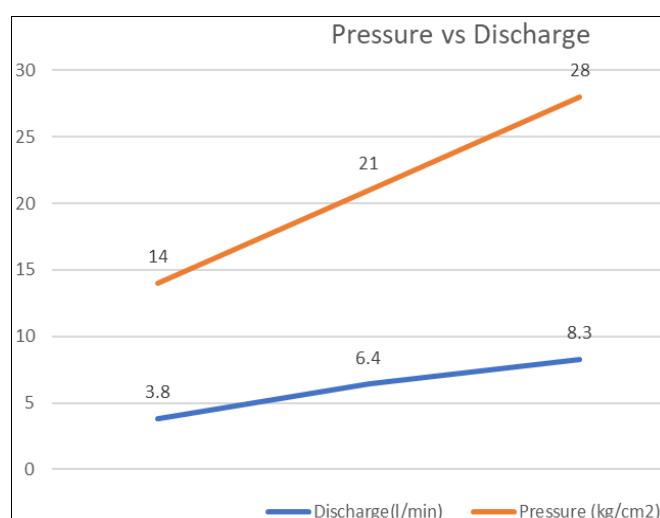
$$\text{Volume rate(l/h)} = \frac{\text{volume collected (l)}}{\text{time (h)}}$$

Application rate: Application rate of the Power sprayer is being measured by considering the above results, which is given by

$$\text{Application Rate(l/ha)} = \frac{\text{volume rate } \left(\frac{\text{l}}{\text{h}}\right)}{\text{area of rate of sprayer(ha/h)}}$$

Results and Discussion

The performance evaluation of the push type canopy sprayer was evaluated by using laboratory and field methods. It was observed that the increasing of pressure increasing the discharge rate of hollow cone nozzles as shown in the graph 1. The discharge rate is higher at the pressure of 28 kg/cm² and the travel speed was 1.53 km/h. In case of comparison of push type canopy sprayer with power sprayer, power sprayer covering only 2 rows but push type canopy sprayer covering 4 rows in single pass. The discharge rate was observed 2.39 l/min and application rate was 170 l/ha. As per table 1,2 and 3 it was noticed that at 14kg/cm² the discharge rate was 3.8 l/min, at 21 kg/cm² the discharge rate was 6.4 l/min, at 28 kg/cm² the discharge rate was 8.3 l/min. After performing field evaluation, it was observed that the theoretical field capacity is 0.306 ha/h, effective field capacity is 0.251 ha/h and the obtained field efficiency was approximately 82.02%.



Graph 1: Graphical representation of Discharge vs pressure

Performance of Push type Canopy Sprayer

Discharge of push type canopy sprayer has been calculated at

three different operating pressure. The discharge calculated at the different pressures were shown in the Table 1,2 & 3.

Table 1: The discharge calculated at the pressure 14 kg/cm²

Replications	Time (min)	Nozzle discharge (ml)						Overall discharge(ml)	Calibrated flow (ml/min)
		1	2	3	4	5	6		
1	1	520	510	680	685	750	735	3880	3880
2	1	515	520	690	675	745	740	3885	3885
3	1	505	510	675	680	730	750	3850	3850
4	1	520	515	685	690	745	740	3895	3895
		Average						3877.5	

The average discharge value is 3.8 l/min

Table 2: The discharge calculated at the pressure 21 kg/cm²

Replications	Time (min)	Nozzle discharge (ml)						Overall discharge (ml)	Calibrated flow (ml/min)
		1	2	3	4	5	6		
1	1	900	890	1100	1090	1200	1180	6360	6360
2	1	910	910	1110	1105	1210	1205	6450	6450
3	1	915	900	1080	1100	1205	1200	6400	6400
4	1	900	905	1095	1105	1200	1200	6405	6405
		Average						6403.7	

The average discharge value is 6.4 l/min

Table 3: The discharge calculated at the pressure 28 kg/cm²

Replications	Time (min)	Nozzle discharge (ml)						Overall discharge(ml)	Calibrated flow (ml/min)
		1	2	3	4	5	6		
1	1	1150	1170	1400	1390	1640	1620	8370	8370
2	1	1160	1165	1410	1400	1620	1630	8385	8385
3	1	1165	1160	1420	1450	1610	1620	8390	8390
4	1	1160	1155	1415	1400	1630	1625	8385	8385
		Average						8382.5	

The average discharge value is 8.3 l/min

Table 4: Comparison of performance of push type canopy sprayer and power sprayer

S. No.	Particulars	Power sprayer	Push type Canopy Sprayer
1.	Crops	All crops at pre-emergence stage	All crops at pre-emergence stage, when only top spray is required
2.	Discharge	1.873lit/min	2.39 lit/min
3.	Pressure	21 kg/cm ²	14-28 kg/cm ²
4.	Application rate	280 l/ha	170 l/ha
5.	Field capacity	0.196ha/h	0.306ha/h
6.	No of rows covered	2	4
7.	Height	Based on crop	Based on crop
8.	Speed of operator	2.8km/h	1.53km/h

Conclusion

It was concluded by using three distinct nozzle types and varying working pressures, the Push Type Canopy Sprayer was successfully designed, manufactured, and tested in both lab and field conditions. Improved spray penetration and deposition within the crop canopy, especially on the lower and inner parts of plants, was the goal of the created sprayer. According to the study, spray discharge varied depending on the type of nozzle and rose as operating pressure increased. A 250 L ha⁻¹ application rate was attained using the developed sprayer. Because of its greater orifice size, the flat-fan nozzle had the maximum discharge of all the nozzles that were studied. With an increase in operating pressure, spray uniformity also improved. The total fabrication cost of the Push Type Canopy Sprayer was ₹17,250, while the estimated operating cost was ₹103.67 h⁻¹, including fixed, labour and fuel costs.

Authors' contribution

Conceptualization of research work and designing of experiments (PN, SN); Execution of field/lab experiments and

data collection (PN) Analysis of data and interpretation (PN, SN); Preparation of manuscript (PN, SN).

Acknowledgements

The authors sincerely thank the Department of Farm machinery and power engineering, College of agricultural engineering, Professor Jaishankar Telangana Agriculture University, for providing lab facilities.

References

1. Ashfaq M, Manzoor J, Afzal M. Comparative studies on the efficacy of electrodyn spray system with different flow rates and application techniques against insect pests of cotton. Pak Entomol. 2006;28(2):11-14.
2. Al-Gaadi KA. Effect of nozzle height and type on spray density and distribution for a ground field sprayer. J Saudi Soc Agric Sci. 2010;9(1):1-12.
3. Babasaheb G, Ravi M. Field evaluation of tractor operated boom sprayer of cotton crop. Int J Agric Eng. 2013;6(2):372-374.

4. Cooper JF, Jones KA, Moawad G. Low volume spraying on cotton: a comparison between spray distribution using charged and uncharged droplets applied by two spinning disc sprayers. *Crop Prot.* 1998;17(9):711-715.
5. Debouche C, Huyghebaert B, Mostade O. Simulated and measured coefficients of variation for the spray distribution under a static spray boom. *J Agric Eng Res.* 2000;76(4):381-388.
6. Elhussiny KT, Hassan AM, Habssa AA, Mokhtar A. Prediction of water distribution uniformity of sprinkler irrigation system based on machine learning algorithms. *Sci Rep.* 2023;13(1):20885.
7. Gatkhal NR, Nalawade SM, Shelke MS, Deshmukh MS, Bhanage GB, Sahni RK, *et al.* Effect of UAV operational parameters on target and non-target spray deposition and efficacy of spider mites and thrips control in cotton. *Smart Agric Technol.* 2026;102258.
8. Pergher G, Gubiani R. The effect of spray application rate on foliar deposition in a hedgerow vineyard. *J Agric Eng Res.* 1995;61:205-216.
9. Gimenes MJ, Carlos GR, Mario HFADP, Evandro PP, Rafel SC, Denis TR. Air assistance in spray booms which have different spray volumes and nozzle types for chemically controlling *Spodoptera frugiperda* on corn. *J Plant Prot Res.* 2012;52(2):247-253.
10. Gupta P, Sirohi NPS, Rengasamy S, Vidhu KP. Effect of air assistance, leaf area density and forward speed on spray deposition in simulated crop canopy. *J Agric Eng.* 2004;41(2):25-30.
11. Gupta P, Sirohi NPS, Kashyap PS. Effect of nozzle pressure, air speed, leaf area density and forward speed on spray deposition in simulated crop canopy. *Ann Hortic.* 2011;4(1):72-77.
12. Gupta P, Sirohi NPS, Mishra IM. Air flow characteristics of an air-assisted sprayer through horizontal crop canopy. *Int J Agric Biol Eng.* 2012;5(1):1-6.
13. Gurpreet S, Shiv SK, Anoop D, Manes GS, Arshdeep S. Spray distribution pattern of different sprayers on cotton using droplet analyzer. *J Res.* 2011;10(1):33-40.
14. Jamar L, Mostade O, Huyghebaert B, Pigeon O, Lateur M. Comparative performance of recycling tunnel and conventional sprayers using standard and drift-mitigating nozzles in dwarf apple orchards. *Crop Prot.* 2010;29:561-566.
15. Jan A, Jorgen A, Herman R. Design optimization for the vertical suspension of a crop sprayer boom. *Biosyst Eng.* 2005;90(2):153-160.
16. Kalikar VK, Prakash KV, Veerangouda M, Sushilendra S. Performance evaluation of bullock cart mounted engine operated sprayer. 2013.
17. Khuram E, Abdul RT, Faizanulhaq K, Tariq CM. Performance evaluation of modified self-leveling boom sprayer. *Int J Agric Biol.* 2004;6(4):636-638.
18. Khurana R, Kumar S, Dixit F. Nozzle spacing on sprayer boom. *J Agric Eng.* 2007;44(3):1-5.
19. Mathew VJ, Dash SK, Das DS, Pradhan SC. Development and testing of a power tiller operated boom sprayer. *Agric Mech Asia Afr Lat Am.* 1992;23:25-27.
20. Narang S, Agrawal KN, Singh RC. Development of power tiller operated intra canopy sprayer for cotton and pigeon pea crops. *Agric Eng Today.* 2013;37(2):17-22.
21. Padmanabhan PK, Kathirvel K. Performance evaluation of power tiller operated rear mounted boom sprayer. *Res J Agric Biol Sci.* 2007;3(4):224-227.
22. Patil BV, Bheemanna M, Ram TK, Hugar PS. Evaluation of spray schedule against cotton insect pest complex. *J Cotton Res Dev.* 1995;9:247-249.
23. Pergher G. Field evaluation of a calibration method for air-assisted sprayers involving the use of a vertical patternator. *Crop Prot.* 2004;23:437-446.
24. Praat JP, Maber JF, Manktelow DWL. The effect of canopy development and sprayer position on spray drift from a pipfruit orchard. *N Z Plant Prot.* 2000;53(8):241-247.
25. Sandeep H, Poratkar K, Raut DR. Development of multinozzle pesticides sprayer pump. *Int J Mod Eng Res.* 2013;3(2):864-868.
26. Satyanarayana C, Patil BV. Evaluation of different types of nozzles used in cotton insect pest management. *Karnataka J Agric Sci.* 1998;13(2):451-453.
27. Sehsah EME, Ganzelmeier H. Comparison study on low pressure EMTF nozzles based on droplet size characteristics. *J Agric Eng.* 2010;27(1):122-140.
28. Zilpilwar SR, Kalbande SR, Gahane MV, Daharwal N. Field and laboratory studies of Solarcum hand operated hybrid knapsack sprayer. *Int J Curr Microbiol Appl Sci.* 2018;7(3):2932-2945. doi:10.20546/ijcmas.2018.703.339.
29. Rao S, Sreenivas AG. Performance evaluation of air assisted intra canopy sprayer in cotton crop. 2019;8(11).