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Development of intra canopy vertical boom sprayer for maize (*Zea mays*) crop under hill farming conditions

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ABSTRACT

The study was carried out during 2022–2024 at College of Agricultural Engineering and Post-Harvest Technology Central Agricultural University, Imphal, Manipur), Ranipool, Sikkim to determine discharge rate, swath width, spray angle and CV at different pressure and height combinations of three commercially available nozzles. The flat fan nozzle was selected with lowest CV of 30.26% at operating pressure of 150 kPa and 400 mm nozzle height. The selected nozzle was used in a vertical boom and tested under simulated conditions in the laboratory at different pressures and forward speeds to access the intra canopy spraying on test maize (*Zea mays* L.) plants at different positions (Adaxial and Abaxial) and the optimum speed and pressure was found to be 0.42 m/s and 150 kPa. Then a small, lightweight manually guided power sprayer for intra canopy spraying in maize crop was developed and evaluated in the field conditions. The experiment was laid out in a completely randomized design (CRD) with 16 treatments (4×4) and total of 48 experiments with three replications of each treatment. Good above leaf and under leaf deposition with 70.81 and 58.66 deposits/cm^2 respectively were observed in field trials. The volume deposition above leaf and under leaf were found to be 70.35 and 58.14 µL/cm^2, respectively. The sprayer had a field capacity of 0.11 ha/h with field efficiency of 73.33%. The cost of developed sprayer was ₹22,600. The benefit cost ratio and payback period of developed sprayer was estimated to be 1.56 and 1.7 years, respectively. The sprayer can be adopted by small farmers in the NEH region under terrace farming conditions.

Keywords: Intra canopy, Plant protection, Sprayer, Spray characteristics, Water sensitive paper

India's agricultural sector has been a cornerstone of its economy, sustaining livelihoods and ensuring food security for its vast population. In 1951, agriculture accounted for 57.7% of the GDP and employed 69.4% of the workforce (Anonymous 2019). However, with rapid industrialization and the diversification of the economy, agriculture's contribution to GDP has drastically reduced, reaching to just 14% by 2019, even though nearly half of the country's workforce remains engaged in this sector (Dolli and Divya 2020). One of the key challenges in agriculture, particularly in hill farming, is the effective management of plant diseases and pests (Shankar and Abrol 2017). To elevate the mechanization level to an estimated 75% by the year 2047, it is projected that average farm power availability will need to be enhanced to approximately 7.50 kW/ha. Despite the relatively moderate mechanization level of 47% at present, Indian farmers have demonstrated substantial adoption of advanced agricultural machinery across a range of operations, including seedbed preparation, sowing, planting and transplanting, crop protection, irrigation, harvesting, and threshing (Mehta *et al.* 2024). The conventional use of tractor-operated boom sprayers for pest and disease control is largely ineffective for crops with tall and dense canopies, such as maize. These sprayers primarily target the upper surfaces of leaves and plant stems, leaving the undersides of leaves and lower parts of the plant inadequately covered. This is a significant limitation, as pests like stem borers and shoot flies often lay their eggs or infest the lower canopy, resulting in suboptimal pest control. Additionally, uneven pesticide application leads to wastage of chemicals and increased environmental contamination, which is a growing concern in sustainable farming practices (Pramod *et al.* 2023, Miao *et al.* 2023).

Maize (*Zea mays* L.), a versatile crop grown across diverse agro-climatic zones, holds substantial importance in Sikkim's agricultural landscape. Accounting for 35–40% of the total cultivable area, maize is cultivated on approximately 36,000–40,000 ha, with a production of 67.94 thousand tonnes in 2020–21 with an average productivity of 1,769.68 kg/ha (Anonymous 2021). As a tall field crop, maize requires

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multiple pesticide applications typically 3 to 4 times during its growing stages, such as the knee-high stage and silking stage, to combat pests like stem borers (*Chilo partellus*), pink borers (*Sesamia inferens*), shoot flies (*Atherigona soccata, A. naquii*), and shoot bugs (*Peregrinus maidis*). Among these, stem borers are particularly destructive, posing a major threat to maize production. The height of maize plants, ranging from 1.2–2.5 m, combined with their large canopy, poses challenges for effective pesticide application using conventional horizontal boom type or manually operated sprayers. To address these challenges, there is a pressing need for a sprayer capable of effectively targeting both the top and bottom surfaces of the plant canopy. An intra-canopy vertical boom sprayer designed specifically for maize crops in hilly terrains offers a promising solution. This type of sprayer can deliver fine droplets of pesticide solution to all parts of the plant; top and bottom; ensuring efficient pest and disease control while minimizing chemical wastage and environmental impact (Satyanarayan *et al.* 2019). Furthermore, a lightweight, manually guided design with horizontal and vertical spraying capabilities would make it suitable for use in hill farming conditions, where mechanized equipment may face operational constraints due to steep slopes and limited accessibility (Agrawal *et al.* 2013). In hilly regions, farmers face significant challenges in pest and management due to the limitations of existing spraying equipment. Most commercially available sprayers are designed for flat and accessible terrain, making them unsuitable for steep slopes and narrow pathways typical of hill farming. Mechanized options, such as tractor-mounted or drone-based sprayers, are often impractical due to high costs, limited manoeuvrability, and poor accessibility in remote or fragmented farms. Currently, there is a lack of lightweight, manually guided spraying systems that are specifically for use in hilly conditions, particularly those capable of both horizontal and vertical spraying. This underscores the need for innovative equipment that can be operated efficiently in terrace farming conditions, offering better coverage, reduced labour input, and improved safety for smallholder farmers in these challenging environments. This research focuses on the development of an intra-canopy vertical boom sprayer for maize crops under hill farming conditions. Such a sprayer aims to enhance the efficiency of pesticide application, reduce labour and chemical input costs, and improve pest and disease management outcomes, contributing to sustainable and profitable maize cultivation in terrace farming conditions in the north east hill region.

MATERIALS AND METHODS

The laboratory experiments were conducted to evaluate the spray characteristics of nozzles for selection of appropriate nozzle. The selected nozzle was then used to develop a vertical boom and the intra canopy spraying performance was studied under simulated conditions in the laboratory to optimize the operating conditions. Then a manually guided, power sprayer was developed for intra canopy spraying and evaluated in the field conditions.

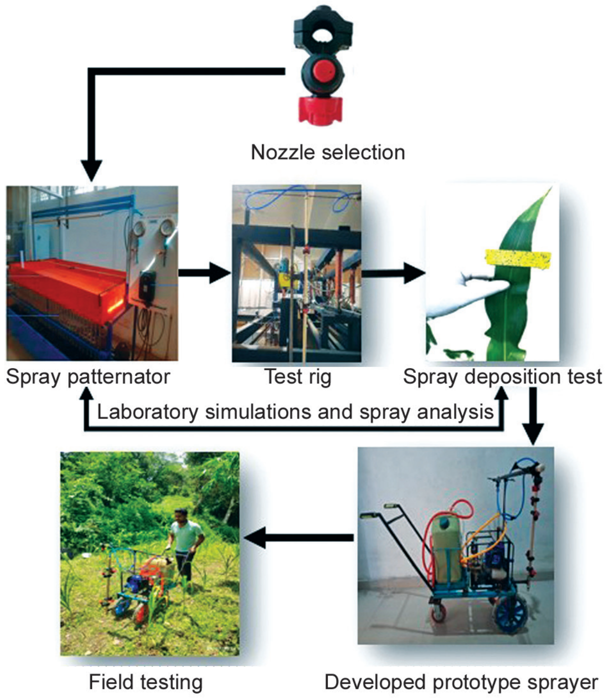

Fig. 1 Activity flow chart for development of intra canopy boom sprayer.

The study was carried out at the College of Agricultural Engineering and Post-Harvest Technology, Ranipool, Sikkim during 2022–2024. The activity flow chart is shown in Fig. 1 and detail methodology of the research is explained below.

Study of the spraying characteristics of nozzles: Spraying characteristics is one of the most important parameters for nozzle selection. The type and material of nozzle affects not only the amount of spray applied to a particular area, but also the uniformity of the applied spray, the coverage obtained on the sprayed surfaces, and the amount of drift that can occur (Klein and Kruger 2011). Each nozzle type has specific characteristics and capabilities and is designed for use under certain application conditions. The nozzle types which are commonly used for application of agricultural pesticides like flat-fan, solid cone, and hollow cone nozzle were considered for the study is presented in Table 1.

Experimental procedure: A spray patternator test rig of size 2032 mm × 1000 mm was used for testing of nozzle as per the guidelines of Indian standards test code IS: 3652-1995 (Bureau of Indian Standards 1995). The test rig

Table 1 Specification of the nozzles

Nozzle	Spray pressure	Spray angle	Discharge cc/min	Make and model
Flat-fan Nozzle	40 psi	100°	1400	ASPEE-QCN/PD
Solid cone Nozzle	10 psi	60°	500	ASPEE-SCN/PA
Hollow cone Nozzle	40 psi	60°	250	ASPEE-HCN/ PA

consisted of a water tank, pump, pressure regulator, on-off valve, pressure pipe, pressure gauge, nozzle, patternator table with V-shaped channels and liquid collection tubes. The nozzle was mounted above the patternator table at the centre through a custom-made fixture and directed vertically downward. The height of the nozzle could be adjusted by sliding the fixture over the mounting frame. The nozzle was connected to the water supply through a pressure pipe of 10 mm diameter and a pressure gauge was provided to check the pressure level. Experiments were conducted at various pressures (150, 200, 250, and 300 kPa) and nozzle heights (200, 300, 400, and 500 mm). The volume of liquid collected in the tubes was measured using a measuring cylinder of 100 ml capacity and the data was recorded (Dowlati *et al.* 2022). The CV of the volumetric distribution was determined for assessing the spray pattern uniformity and one nozzle was selected having the least coefficient of variation.

Study of intra canopy spraying characteristics of vertical boom: The test set-up for study of performance of nozzle spray characteristics in vertical boom under simulated conditions was developed in the Soil Dynamics Laboratory. A boom was made using CPVC (Chlorinated Polyvinyl Chloride) pipe and two numbers of the selected nozzle were mounted on the boom with nozzle spacing of 400 mm. The boom was mounted in vertical position through a frame on the Soil Bin carriage in the Soil Dynamics Laboratory. The vertical boom forward speed of operation could be controlled and maintained at desired level by controlling the speed of the soil bin carriage through the digital control panel of the soil bin test rig. The nozzle pressure was controlled by a pressure regulator fitted on the supply line. Maize plants grown in pots were kept over a custom-made platform by the side of the boom at desired distance.

Experimental plan and statistical analysis: The spray pressure is crucial in spraying operation and affects spray droplet size, effective spray penetration and deposition on various parts of the plant in the canopy. In a sprayer, the adequate deposition of pesticides on the target surfaces of the plant is also affected by the speed of operation of the sprayer. If the speed is too high then it may lead to inadequate deposition, while too slow speed may lead to excessive deposition of chemicals on the target surfaces. The spray characteristics were studied at different pressures (150, 200, 250, and 300 kPa) and speeds of operation (0.13, 0.27, 0.42, and 0.56 m/s) and the experiments were planned in a completely randomized statistical design with 16 treatments (4×4) and total of 48 experiments with three replications of each treatment. The physical arrangement of leaves and the canopy can significantly impact how well the spray penetrates and covers different parts of the plant. Therefore, the spray deposition was assessed for both above leaf and under leaf positions by placing water sensitive paper of size 26 mm × 76 mm at different positions on the plant. After spraying the sample papers were taken out and dried in ambient conditions. The sample papers were then analyzed using Deposit Scan software for determination of droplet density, percentage coverage under leaf, percentage coverage above leaf and droplet diameter. The statistical analysis was done in Jupyter notebook with python-3 programming language.

Spray analysis by deposit scan software: Deposit Scan is a portable scanning programme for spray deposit qualification that can quickly evaluate spray deposit distribution on water sensitive paper or kromokote paper etc. These programmes consist of a set of custom plugins used by an image processing program to produce a number of measurements expressing spray deposit distribution. The Deposit Scan program offers a convenient solution for on the-spot evaluation of spray quality even under field working conditions (Zhu *et al.* 2011).

Methodology and sample of spray analysis in Deposit Scan software: A, The sample water sensitive paper was scanned using a desktop scanner at 600 DPI and the image was stored in the computer. B, The image to be analysed was selected from the File Menu option followed by open. C, The image opens in the software. D, After the image opens, select the image option then type and select the 8-bit grayscale for the spray analysis of the water-sensitive paper. E, After this process, select the AA (USDA Automatic Paper Analysis Tool) option to set the threshold and measure the spray parameters. The data was exported in the Excel sheets and saved for further use.

Development of vertical boom intra canopy sprayer: While the design and development of the intra canopy vertical boom sprayer, the primary focus was on achieving simplicity in fabrication, utilizing locally available materials, making it lighter and minimizing the overall cost of the machine so that it will be suitable for small farmers in the NEH region. The sprayer width was based on the row spacing in maize crop. The pump input power was estimated based on the designed flow rate and pressure requirements. The designed pump input power was found to be 362 W and the corresponding required engine power was obtained to be 0.8 hp. As per the market availability a 2-stroke petrol engine of 1.13 hp with pump was selected for the sprayer.

The developed intra canopy boom sprayer is manually guided, and powered by petrol engine. The sprayer consisted of sprayer boom (horizontal and vertical), tank, two front wheels and one rear caster wheel for steering, pump with pressure gauge, engine, frame and handle**.** The horizontal boom height was adjustable according to the plant height and the nozzles on the boom could be shifted laterally along the boom for proper positioning above the plants. The vertical boom height and forward position from the frame could be adjusted for proper positioning with respect the the plants. The developed sprayer is suitable for row crops for spraying from top as well as sides of the plant. In one pass, the sprayer covers one side of two rows and complete spray in a row achieved in the second pass. The developed sprayer was aimed at reducing labour requirements, higher field coverege and optimum spray coverage on the whole plant canopy. The brief specification of the sprayer is presenetd in Table 2.

Table 2 Specification of developed intra canopy boom sprayer

Particulars	Details
Name of equipment	Manually operated intra canopy boom sprayer
Pump	HTP (Horizontal triplex pump)
Power source	
(a) movement of sprayer	(a) Manually operated
(b) Spraying	(b) Petrol engine
Fuel required	Petrol
No. of nozzles	Six
Type of nozzles	Flat fan
Tank capacity	20 liters
Material of tank	Plastic
Spray boom	Vertical, Horizontal
Material of frame	M.S. Square Pipe
Boom height (cm) (Adjustable)	105
Material of boom fabrication	CPVC
Overall dimensions, (L×W×H) (mm)	(1300×1030×1040)
Weight, kg (Without water)	29.7
Cost of machine (₹)	22,600/-

Performance evaluation of developed sprayer under field conditions: The developed sprayer was evaluated in the field conditions in maize crop at farmers field in Samlik village, Sikkim. The machine was tested in a test plot of about 200 m^2 area for 0.5 h duration. The spray deposition on maize plants was assessed by using water sensitive paper and following the similar methodology adopted in the laboratory study. The agronomic parameters like plant-to-plant distance, plant height, row to row spacing, and the number of leaves were recorded during the field test. The field capacity and efficiency of the sprayer were determined in the field study.

RESULTS AND DISCUSSION

The results of the study of nozzle spray characteristics and vertical boom in the laboratory under simulated conditions are discussed. The performance of the developed sprayer in field conditions for maize crop is also discussed.

Spray characteristics of selected nozzle: The volumetric distribution of flat fan nozzle at different pressures and heights are shown in Fig. 2. The distribution implies that the spray nozzle achieves effective coverage, with the majority of droplets concentrated near the centre and a gradual decline toward the edges. This pattern is desirable for ensuring consistent application while minimizing overspray or uneven deposition. The volumetric distribution along the spray width was found to vary significantly with change in pressure and height of nozzle. It was observed that, with increase in pressure at constant height the peak discharge at any channel increased along with total discharge (Elwakeel *et al.* 2021). Similar distribution curves were also obtained for other nozzles. CV was at its lowest value (30.26%) in case of flat fan nozzle at operating pressure of 1.5 kPa and height of 400 mm, which was acceptable as 25–35% CV values are considered optimum (Bhabani *et al.* 2020).

Analysis of nozzle with dependent parameters: The analysis of the nozzle performance in flat fan nozzle showed a wider range of spray angles, indicating more variability in their spray patterns. The flat fan nozzle has the widest distribution of swath widths, indicating broader coverage, while solid cone and hollow cone exhibit narrower and more consistent swath width. Hollow cone has the broadest range in CV showing variability in output, whereas solid cone has the most consistent and narrow range, indicating uniform output.

Spray performance of the selected nozzle on vertical boom under simulated condition: The evaluation of selected nozzle was done in soil bin test rig under simulated condition in the Farm Machinery Testing Laboratory, Department of Farm Machinery and Power Engineering, CAEPHT, Ranipool, Sikkim. The tests were conducted to assess the

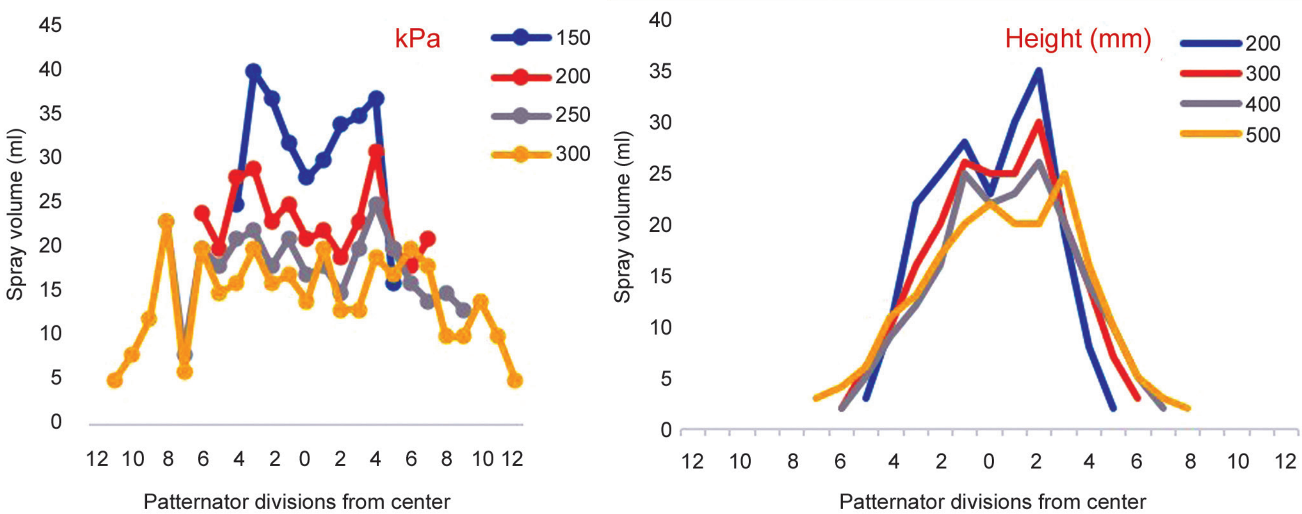

Fig. 2 Effect of different height on spray volumetric distribution of flat fan nozzle at 150 kPa pressure and effect of different operating pressures on spray volumetric distribution of flat fan nozzle at 400 mm height.

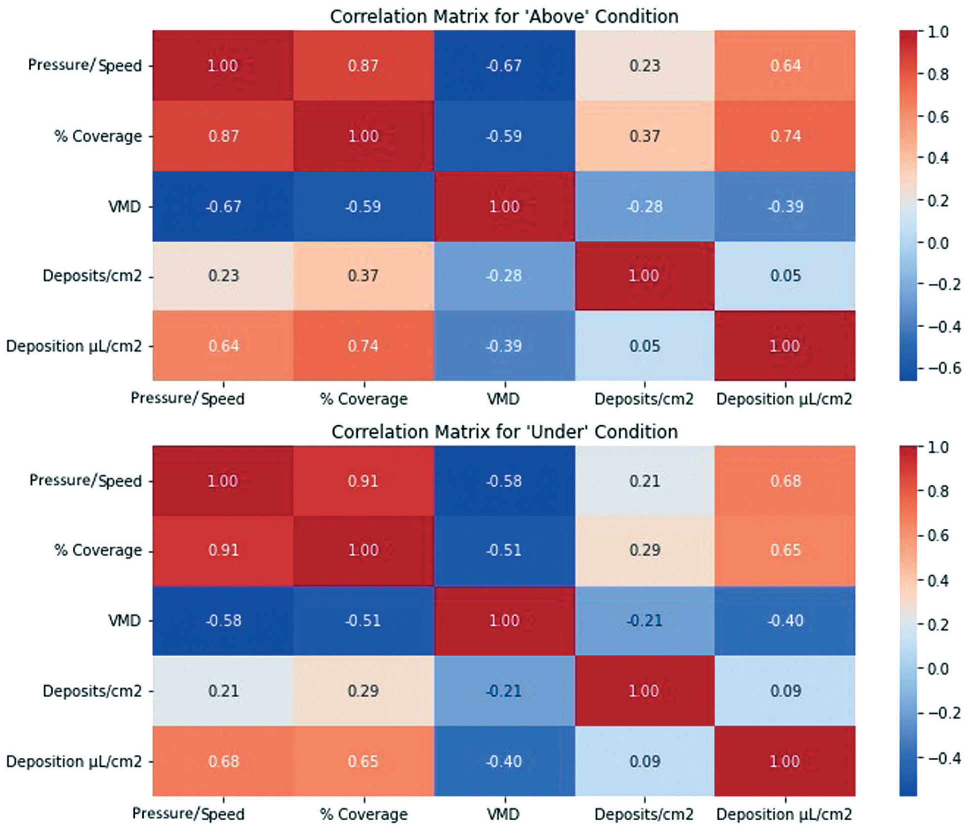

Fig. 3 Correlation heatmap analysis of leaf position.

different spray parameters such as per cent coverage, VMD, deposits/cm^2 and deposition/cm^2 with respect to leaf position (above and under). The selected nozzle was operated at different operating pressure and speed. The results of the laboratory tests in soil bin test rig under simulated condition are shown in correlation heatmap matrix analysis with the leaf position in Fig. 3, respectively.

Correlation heatmap analysis for above leaf position: The first variables pressure/speed and second variables % coverage have a high positive correlation (0.87), indicating that they tend to increase together. The first pressure/speed and fifth variables deposition µL/cm^2 share a moderate positive correlation (0.64), indicating some level of dependence.

Correlation heatmap analysis for under leaf position: The first pressure/speed and second variables % coverage show an even stronger positive correlation (0.91) compared to the under-leaf matrix. The fifth variable deposition µL/cm^2 remains moderately positively correlated with the first pressure/speed (0.68) and second % coverage (0.65) variables, similar to the under-leaf matrix

Analysis for different dependent variable with leaf position: The median % coverage for the "Above" leaf position is higher than for the "Under" leaf position, with a wider interquartile range (IQR) for above position. Similar to the other plots, the "Above" leaf position shows a higher median number of Deposits/cm^2 compared to the "Under" condition. There is less variability in the "Under" leaf position, as shown by the smaller IQR, while the "Above" leaf position has more spread-out values. The working pressure significantly affects all four variables for above leaf positions (% coverage, VMD, deposits/cm^2, and deposition µL/cm^2), with very high F values and extremely low p values, showing its dominant role in spray characteristics. The working speed has a significant impact on VMD and deposits/cm^2, but it does not significantly affect % coverage or deposition µL/cm^2. Pressure's influence is considerably stronger than speeds across all variables, with much higher, especially in % coverage and VMD. The laboratory evaluation clear that the optimum speed and operating pressure for field trial experiment was at 0.42 m/s and 150 kPa after analysis of the spray deposition from the plant canopy.

Field performance evaluation of the developed sprayer: The field performance evaluation of developed sprayer was conducted at farmers field in Samlik village, Sikkim. The machine was tested in a test plot of about 200 m^2 area for 0.4 m/s duration. The machine was tested in maize crop and the various performance parameters were recorded. The results indicated good above leaf and under leaf deposition with 70.81 and 58.66 deposits/cm^2 respectively. The volume deposition above leaf and under leaf were found to be 70.35 and 58.14 µL/cm^2, respectively. In field evaluation, the field capacity and efficiency were found to be 0.11 ha/h and 73.33% respectively. The cost of developed sprayer was ₹22,600. The benefit cost ratio and payback period of developed sprayer was estimated to be 1.56 and 1.7 years, respectively.

REFERENCES

Anonymous. 2019. Sector-wise contribution of GDP of India. Retrieved on July, 9, 2020 from Statistics Times: http:// statisticstimes. com/economy/sectorwise-gdp contribution-of-india. php

Anonymous. 2021. Annual Report. Food Security & Agriculture Development Department, Government of Sikkim.

Agrawal K, Narang Suresh and Singh R. 2013. Development of power tiller operated intra canopy sprayer for cotton and pigeon pea crops. *Agricultural Engineering Today* **37**: 17–22.

Bureau of Indian Standards. 1995. *IS 3652 (1995): Crop Protection Equipment - Foot Sprayer*, IVth Revision, pp. 1–26.

Dash Bhabani, Kumar Arun, Modi Rajesh and Namdev Sharad. 2020. Design and performance evaluation of self-propelled intra-canopy boom spraying system. *Journal of Agricultural Engineering India* **57**. 195-209. 10.52151/jae2018551.1715

Dolli M and Divya K S. 2020. A study on present Indian agriculture: Status, importance, and role in Indian economy. *Zenith International Journal of Multidisciplinary Research* **10**(3): 30–34.

Dowlati M, Khoshnam F, Namjoo M and Mirshahi E. 2022. Analysis of nozzle spray distribution for different nozzle height and pressure. *Agricultural Engineering International: CIGR Journal* **24**(1): 61–67.

Elwakeel Abdallah, Ahmed Saad, Eldin Abdalla and Nasrat Loai. 2021. Effect of spraying height, pressure, and nozzle type on flow characteristics of a field sprayer. *Al-Azhar Journal of Agricultural Engineering* **1**: 29–38. 10.21608/azeng.2021.209946

Klein R N and Kruger G R. 2011. Nozzles-selection and sizing. University of Nebraska-Lincoln Extension (EC141).

Miao Y, Chen X, Gong Y, Liu D, Chen J, Wang G, and Zhang X. 2023. Design and test of powerful air-assisted sprayer for high stalk crops. *Frontiers in Plant Science* **14**: 1266791.

Mehta C, Bangale Rashmi, Chandel Narendra and Kumar Mohit. 2024. Farm mechanization in India: Status and way forward. *Agricultural Mechanization in Asia, Africa and Latin America* **54**(2): 75–88.

Pramod P P, Raosaheb G N, Kashinath K J and Madhukar N S. 2023. Performance evaluation of tractor mounted boom sprayer on chilly crop. *Environment Conservation Journal* **24**(2): 61–69.

Satyanarayan K V, Prakash M, Anantachar M, Veerangouda, Satyanarayana Rao and Sreenivas A G. 2019. Performance evaluation of air assisted intra canopy sprayer in cotton crop. *International Journal of Current Microbiology Applied Scienes* **8**(11): 159–166.

Shankar U and Abrol D P. 2017. Pest Management Problems and Strategies in Hill Farming. *Technological Innovations in Integrated Pest Management Biorational and Ecological Perspective* **79**.

Zhu H, Salyani M and Fox R D. 2011. A portable scanning system for evaluation of spray deposit distribution. *Computers and Electronics in Agriculture* **76**: 38–43.