International Research Journal of
SCIENCE, TECHNOLOGY, EDUCATION, AND MANAGEMENT
P-ISSN: 2799-063X — E-ISSN: 2799-0648

Volume 5, No. 2 | June 2025

Development of portable electrostatic nozzle for sugarcane pesticide application

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ABSTRACT

Agriculture remains a critical sector in the Philippine economy, with sugarcane ranking fifth among the most cultivated crops. However, pest infestations significantly reduce crop yield and quality. Conventional pesticide application methods are labor-intensive, inefficient, and contribute to health and environmental risks due to excessive spraying. This study aims to design, development and evaluate the portable electrostatic nozzle designed to improve pesticide application efficiency in sugarcane farming. The prototype incorporates a high-voltage arc generator using a 5-stage Walton-Cockcroft voltage multiplier, producing 14.09 kV to electrostatically charge pesticide droplets from a conventional sprayer. Utilizing ImageJ software for data gathering, an independent t-test was employed to compare its performance with traditional sprayers. Results demonstrated a significant increase in droplet deposition, with "back" leaf surface coverage improving from 1.048% to 21.421%, and "front" coverage increasing by 13%. Overall spray efficiency improved from a range of 18.344% - 20.374% in the control group compared to 34.444% - 34.661% in the experimental group, resulting an average of 20% greater coverage of pesticide using the electrostatic nozzle. It consumed 11.397 watts of power and operated for 1.5 hours per charge using a 3.9Ah Li-ion battery. The electrostatic nozzle consistently outperformed the conventional sprayer. Further research should focus on optimizing the electric field distribution, incorporating protective battery circuitry, and conducting field validation under practical agricultural conditions. These findings support the potential of electrostatic spraying technology as a sustainable solution for improving pesticide application in crop production.

ARTICLE INFO

Received : Apr. 24, 2025
Revised : June 5, 2025
Accepted : June 30, 2025

KEYWORDS

Electrostatic, Portable nozzle, Pesticide, Sugarcane

Suggested Citation (APA Style 7th Edition):

Espeleta K., Acero B. I., Deroy S. A., Geraga K., Loraez J., Mandate J. R., Nabalitan S., Panilan S., Tabuada A. N., Maligaya J., Golingay J., & Gabutero M.W. (2025). Development of portable electrostatic nozzle for sugarcane pesticide application. *International Research Journal of Science, Technology, Education, and Management*, 5(2), 62-74. https://doi.org/10.5281/zenodo.15904514

INTRODUCTION

Sugarcane stands as a cornerstone of Philippine agriculture, ranking as the fifth most widely cultivated crop in the country (Mojica-Sevilla, 2021). Yet, behind its economic importance lies a sector grappling with persistent issues, such as, outdated technologies, inefficient practices, and increasing pest-related losses (Phil Seed, 2023). Among the most pressing challenges is the threat posed by pests such as insects, nematodes, rodents, and various crop diseases, which severely compromise yield and product quality (Akoijam et al., 2014). In response, pesticide use has become a standard defense, acting as a crucial tool to curb infestations and ensure stable food production (Damalas & Eleftherohorinos, 2011). However, conventional pesticide application methods are often wasteful and imprecise, leading to over spraying, chemical runoff, and long-term risks that could slowly impact ecosystems and the health of communities. In this context, electrostatic spraying technology emerges as a promising alternative. By charging pesticide droplets with a positive electrical charge, electrostatic sprayers enhance droplet attraction to plant surfaces especially those with neutral or negative charges resulting in more efficient, even coverage and a distinctive "wrap-around" effect (Patel et al., 2024). Despite their proven benefits, commercially available electrostatic sprayers remain largely out of reach for many farmers due to their high costs and limited field adaptability. To bridge this gap, this study introduces a cost-effective and practical electrostatic nozzle designed with farmers' needs in mind. This innovation not only optimizes pesticide use by ensuring uniform deposition and reduce spray drift but also contributes to sustainability goals by minimizing chemical waste and soil contamination. Furthermore, the improved droplet size and targeted delivery system enable more effective pest and disease control while cutting down on overall pesticide consumption. Ultimately, the development of an affordable electrostatic spraying system aligns with broader efforts to modernize Philippine agriculture, enhancing productivity, safeguarding farmer health, and protecting ecosystems. A thoughtfully engineered solution such as this holds the potential to redefine pest control practices, placing efficiency, safety, and environmental responsibility at the forefront of agricultural progress.

OBJECTIVES OF THE STUDY

This study intends to develop a portable electrostatic nozzle device, which is an accessory compatible with the existing sugarcane pesticide sprayer, that is efficient and cost-effective, helping farmers reduce human labor, costs, and time. The nozzle seeks to improve the transfer efficiency of pesticides by electrostatically charging droplets as they pass through an electric field, ensuring they are attracted to an electrically neutral target, in this case, sugarcane. This natural attraction minimizes over-spraying, reduces soil degradation, and prevents contamination.

The study specifically focuses on designing, fabricating, and developing the portable electrostatic nozzle and test its functionality. The tests will evaluate the uniformity of spray coverage on both the front and back surfaces of the target and compare the efficiency of the prototype to conventional spraying methods based on the percentage of area coverage. This innovation is expected to enhance pesticide application practices while addressing environmental and economic concerns.

MATERIALS AND METHODS

This study adopts a quantitative approach, utilizing an experimental and developmental research design. The experimental research method is selected for its ability to systematically observe and measure variables under controlled conditions. This approach is essential for evaluating the effectiveness of the newly developed portable electrostatic nozzle designed for pesticide application on sugarcane plants. The primary objective of this study is to assess the prototype's performance and efficiency in an agricultural setting.

Design Criteria

Figure 1 The design model of the portable electrostatic nozzle for sugarcane is integrated as a nozzle on a spraying device. This portable nozzle is designed to be rechargeable and configured to charge liquid particles through electrostatic induction. It houses the main components of the device, including the electrostatic circuit, batteries, IR sensor, and control circuit, all enclosed within its compact structure to ensure functionality and portability.

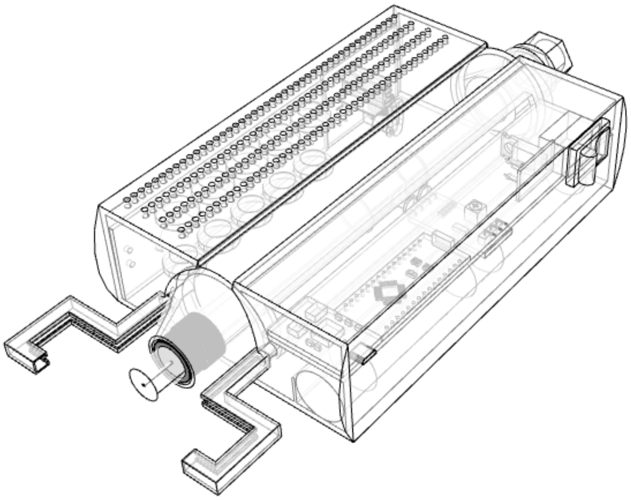

Figure 1. X-ray View of the Portable Electrostatic Nozzle

Figure 2 The flowchart illustrates the operational process of the prototype. The rechargeable battery supplied power to the entire circuit and was connected to the charging module. Once the IR sensor detected the presence of fluids, the microcontroller activated the high-voltage electrostatic generator. This, in turn, energized the Walton-Cockcroft circuit (electrostatic generator), producing an electrostatic discharge that charged the nozzle and the pesticide droplets.

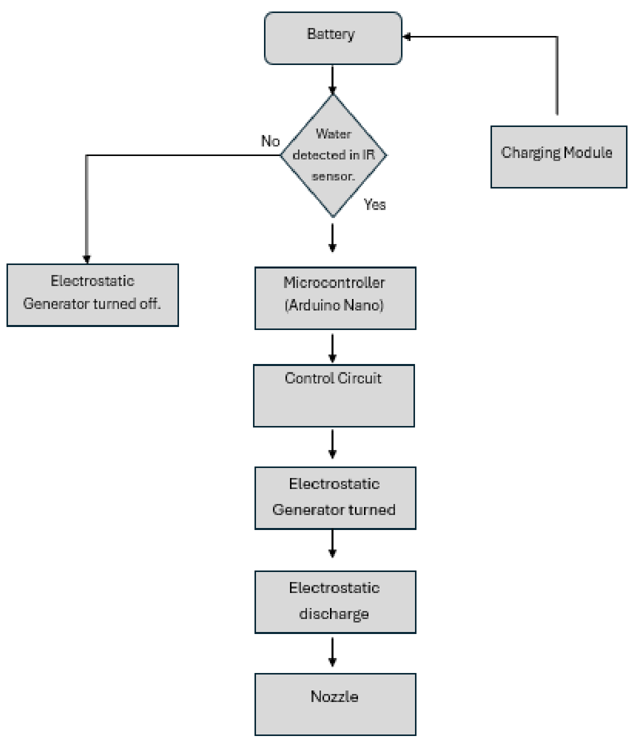

Figure 2. Flow Chart of "Portable Electrostatic Nozzle"

Electrostatic Supply Assembly

Configured the 20kV capacitor and 2CL77 diode into 5 stages of the Cockroft -Walton voltage multiplier into the PCB.

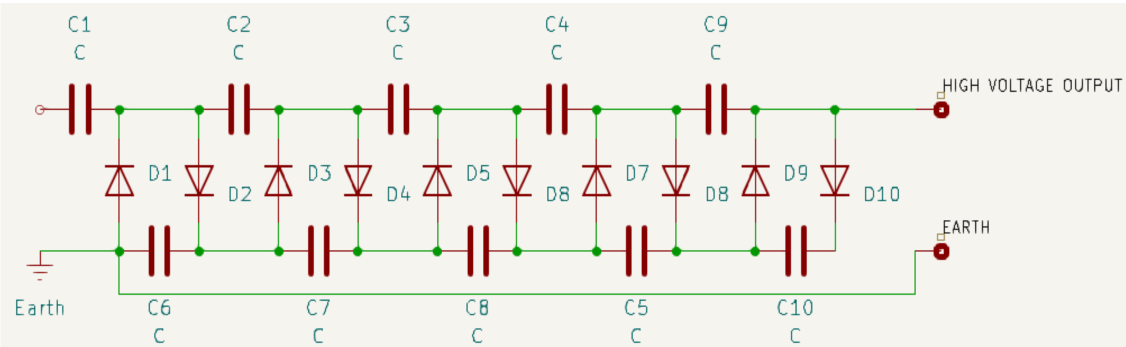

Figure 3. Schematic Diagram of Cockroft -Walton Voltage Multiplier

Calculation Formula

The output voltage (\(V*{out}\)) of a Cockcroft-Walton multiplier can be approximated using the formula:*
***[V*{out} = 2 x N x Vpeak]**

Where:
- N = Number of stages
- *Vpeak* = Peak input AC voltage

Calculation:
Vout = 2 × 5 × 1500 = **15000V**

Theoretically, the output of Cockroft-Walton multiplier with 5 stages and peak input voltage of 1500 volts was 15000 volts or 15 kV.

Data Collection Procedure

The testing process was conducted in four stages to ensure the systematic evaluation of the electrostatic nozzle. First, six sugarcane plant samples were collected from the field, with three samples designated for the control group (using a conventional nozzle) and three samples for the experimental group (using the electrostatic nozzle). This setup allowed for a direct comparison of the two methods under similar conditions. A controlled environment was prepared to minimize external variables such as humidity and airflow that could influence the results. To evaluate the spray coverage, a fluorescent dye was added to the spray mixture, and UV light was employed as a visualization tool, providing a clear assessment of the spray distribution on the target. The testing procedure, which included three trials, each consisting of one experimental and one control sample. The distance between the developed electrostatic nozzle and the target sugarcane was maintained at two feet to standardize the application process. After spraying, the samples were left undisturbed for 10 minutes to allow the spray mixture to settle, avoiding any external contact or vibrations that could affect the accuracy of the results. Then, the researchers cut four 6-inch leaves from each sample, specifically from the front-facing side of the target, to analyze the spray coverage. Furthermore, droplets deposited on the ground beneath the target were measured to calculate the eccentricity of droplet deposition. Image analysis was performed using ImageJ, a widely used open-source software for visualizing, inspecting, and quantifying scientific image data (Schroeder et al., 2021). This comprehensive approach ensured reliable data collection and accurate evaluation of the nozzle's performance.

Data Analysis

The researchers used an independent t-test as a statistical tool to test significant differences in total coverage for both the front and back parts of the leaves between the electrostatic and conventional nozzle. Independent t-test is also used to determine significant differences between the droplet deposition based on the eccentricity of the electrostatic and conventional nozzle.

RESULTS AND DISCUSSION

The results from multiple trials comparing a conventional sprayer with an electrostatic nozzle revealed that the electrostatic nozzle consistently outperformed the conventional sprayer in terms of droplet dispersion uniformity on leaf surfaces. At a standard distance of 2 feet (60.96 cm), the electrostatic nozzle achieved significantly higher spray coverage percentages, as determined through ImageJ software analysis and statistical tests assessing droplet coverage and uniformity. These findings demonstrate the superior effectiveness of the electrostatic nozzle in delivering charged droplets to plant surfaces. The improved performance of the developed electrostatic nozzle is attributed to its higher transfer efficiency, which maximizes the attraction between charged droplets and plant surfaces. This improvement not only ensures more efficient pesticide application but also suggests the potential for reduced pesticide usage, contributing to cost savings and environmental benefits. Notably, the electrostatic nozzle demonstrated a marked improvement in spray coverage on the "back" surfaces of leaves, a critical factor in applications where thorough coverage is essential for pest and disease control. Although the improvements in "front" surface coverage were less pronounced, they still indicate an overall enhancement in droplet deposition. These results highlight the electrostatic nozzle's capability to achieve comprehensive and uniform coverage, underscoring its potential as a highly effective tool for agricultural pesticide application.

Table 1. Total Front and Back Leaf Coverage in Terms of Area in cm^2

GROUP	LEAF No.	BACK (area in cm^2)	FRONT (area in cm^2)	TOTAL AREA COVERAGE (%)
Control 1	1	0.419	42.250	21.334
Control 1	2	0.849	58.339	29.594
Control 1	3	0.876	47.271	24.073
Control 1	4	1.438	44.153	22.795
Control 2	1	1.037	39.499	20.268
Control 2	2	5.693	8.282	6.987
Control 2	3	0.248	78.909	39.578
Control 2	4	0.227	57.071	28.649
Control 3	1	0.165	43.743	21.954
Control 3	2	0.093	56.480	28.287
Control 3	3	0.120	24.030	12.075
Control 3	4	1.411	50.053	25.732
Experiment 1	1	26.118	71.333	48.726
Experiment 1	2	15.174	88.348	51.761
Experiment 1	3	30.343	41.752	36.047
Experiment 1	4	22.152	37.521	29.837
Experiment 2	1	16.674	31.453	24.064
Experiment 2	2	34.515	72.120	53.318
Experiment 2	3	26.447	71.720	49.084
Experiment 2	4	10.094	67.637	38.866
Experiment 3	1	33.675	17.349	25.512

Experiment 3	2	11.597	54.505	33.051
Experiment 3	3	10.857	36.651	23.754
Experiment 3	4	19.411	28.954	24.183

Group	N	Mean total area coverage	Std.Dev. of total area coverage	p-Value	t-Value	Significance level (α)	Interpretation
Control	12	23.444	8.375	0.004448	3.1686	0.05	**Significant**
Experiment	12	36.517	11.581				

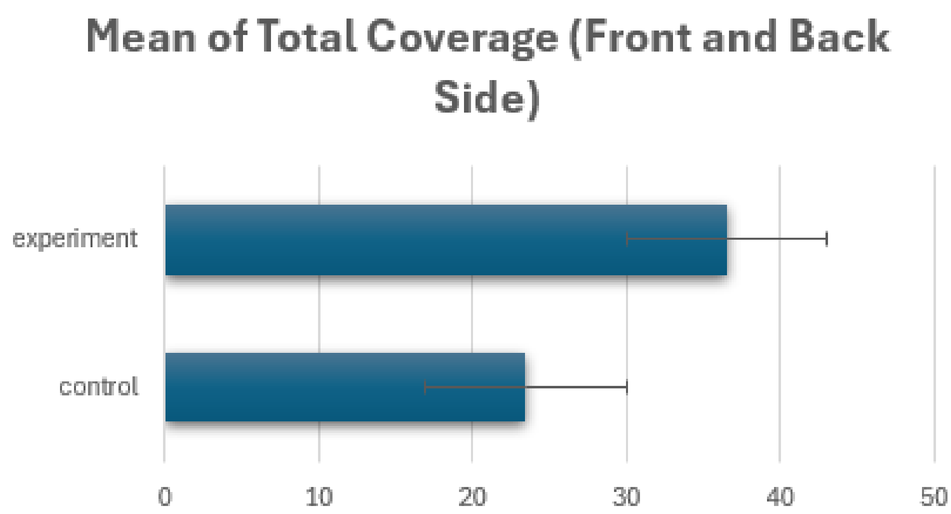

Figure 4. Average of Total Coverage Both Front and Back.

Table 1 and **Figure 4** shows the significant difference in uniform coverage between the experimental and control groups, as assessed using an independent t-test. The computed t-value of 3.1686 was obtained, and the null hypothesis was rejected, as the p-value (0.004448) was less than the alpha level of significance (0.05).

The results clearly indicate a significant difference between the post-test total area coverage of the experimental group, which utilized electrostatic nozzles, and the control group, which employed conventional sprayer. This suggests that the electrostatic nozzle was notably more effective in achieving uniform coverage across the total area, as demonstrated by the post-test data.

Table 2 Waste Pesticide Droplet Deposition Based on the Major and Minor Axes of the Control and Experiment Groups.

Group	Minor axis	Major axis	Eccentricity
Control 1	36	59	0.7923
Control 2	32	59	0.8401
Control 3	40	59	0.7351
Experimental 1	35	64	0.8372
Experimental 2	35	60	0.8122
Experimental 3	37	65	0.8222

Table 2 shows the waste pesticide droplet deposition based on the major and minor axes shows that the experimental group demonstrated that droplet deposition forms more circular pattern compared to control group under the sample, which may indicate less pesticide wastage.

Table 3 Statistical Data of Off-Target Pesticide Droplet Deposition Based on the Eccentricity of the Control and Experiment Groups.

Group	N	Mean	Std.Dev.	p-Value	t-Value	Significance level (α)	Interpretation
Control	3	0.7892	0.0526	0.3288	1.1112	0.05	Not Significant
Experiment	3	0.8239	0.0126				

df=4

Table 3 analysis revealed no significant difference in off-target pesticide droplet deposition between the experimental and control groups, as assessed using an independent t-test. The computed t-value was 1.1112, and the p-value (0.3288) was greater than the alpha level of significance (0.05). As a result, the null hypothesis was not rejected, indicating that there was no statistically significant difference between the experimental and control groups in terms of off-target pesticide droplet deposition.

The data indicates that there was no significant difference in the post-test results for off-target pesticide droplet deposition based on the major and minor axes between the experimental group (using electrostatic nozzles) and the control group (using conventional sprayers). While electrostatic charging of droplets enhanced uniform coverage on the sugarcane target, the results align with previous studies suggesting that smaller droplets, which are more prone to drift, may adhere to surfaces beyond the intended target area (Liang et al., 2020). This phenomenon occurs because charged droplets tend to attract to nearby surfaces with an opposite charge. Consequently, while electrostatically charged droplets exhibited a higher off-target deposition rate, the difference was not statistically significant, indicating that this factor did not notably affect the overall spray application.

Table 4 Mean of Spray Efficiency for Each Trial/Group

Group	Spray Efficiency (%/ mL)
Control 1	20.374
Control 2	19.892
Control 3	18.344
Experiment 1	34.661
Experiment 2	34.444
Experiment 3	22.188

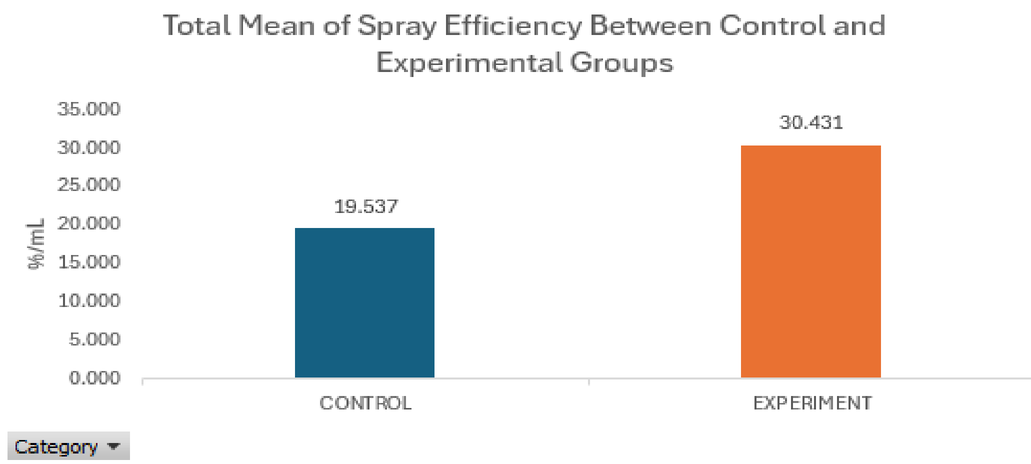

Figure 5. Total Mean of Spray Efficiency Between Control and Experimental Groups

Table 4 and **Figure 5** presents spray efficiency by coverage percentages per milliliter for both control and experimental groups. The control group shows relatively consistent values, ranging from 18.344% to 20.374%. In comparison, the experimental group generally demonstrates higher spray efficiency, with Experiments 1 and 2 achieving values around 34.444% to 34.661%. However, there is an evident drop in Experiment 3, where the efficiency falls to 22.188% One of the reasons might be prolonged energy consumption from the battery source due to high voltage discharge thus reducing the electrostatic effect of the nozzle or a sudden change in environmental conditions. Overall, the experimental treatments show increase in spray efficiency compared to the control.

Table 5 Test Result of Power Consumption of the Portable Electrostatic Nozzle

Description	Rated Voltage(V)	Rated Current (A)	Total Power (W)
Electrostatic Power Supply	7.4	1.54	11.396
Control Circuit	7.4	0.00143	0.01

Total Power: 11.397 W

Table 5 measured total battery power capacity is 7.4V x 3.9Ah = 28.86Wh. The device computed operation time is 28.86Wh / 11.397W which is estimated at an average of **2.5 Hours.**

Table 6 Test Result of High Voltage Electrostatic Charge

High Voltage Electrostatic Charge	**14.09 kV**

Table 6 demonstrates the utilization of a high-voltage arc generator and with the 5-stage Walton- Cockroft voltage multiplier, the prototype has an output high electrostatic voltage of 14. 09 kV with 1.5 cm distance of the two probes. According to Dipak (2016), the recommended voltage is 5kV with spark gap distance of 5mm for optimum electrostatic spraying; however, the researchers increased the spark gap between the two probes to compensate for the higher voltage output, and to reduce arcing that drains and damages the battery. The theoretical calculation for 5-stage Walton-Cockroft voltage multiplier in this prototype is 15kV while the actual measurement of high voltage electrostatic charge is at 14.09kV; it is off by 6% or almost 0.91 kV.

Table 7 Total Weight of the Portable Electrostatic Nozzle

Weight	Portability (Yes or No)
396g	Yes

Table 7 shows the measured weight of the portable electrostatic nozzle at 396g. The average weight of spray gun nozzles can vary based on the type and design of the spray gun. Generally, the entire spray gun typically weighs between 1 to 3 pounds (approximately 0.45 to 1.36 kg) which is manageable to carry with little wrist or arm strain. (Björing & Hägg, 2000).

CONCLUSION AND RECOMMENDATIONS

The portable electrostatic nozzle for pesticide application in sugarcane cultivation addresses critical concerns within the agricultural community, particularly related to the inefficiency in application of pesticides, environmental harm, and health risks to operators, farmers and community. The electrostatic nozzle was designed to be lightweight and ergonomic, ensuring ease of use and minimizing strain, making it suitable for prolonged agricultural usage and applications. The prototype incorporated a high-voltage arc generator and a 5-stage Walton-Cockcroft voltage multiplier, producing 14.09 kV with a 1.5 cm spark gap. The power consumption was measured at 11.397 watts, and the device lasted for 1.5 hours during testing, shorter than the anticipated 2.5 hours maybe due to high-voltage transient losses. The experimental group demonstrated a significant improvement in coverage, with "back" surface values reaching 21.421% compared to 1.048% in the control group, approximately 20 times higher. The "front" surface coverage also increased by 13%, from 45.840% in the control group to 51.612% in the experimental group, indicating enhanced droplet coverage on both surfaces. Overall, the experimental group showed higher spray efficiency, with coverage ranging from 34.444% to 34.661% in two trials, compared to 18.344% to 20.374% in the control group. However, experiment 3 exhibited a drop in efficiency to 22.188%, possibly reason to this is the prolonged energy consumption of the battery source or a change in environmental conditions during the testing. Despite these fluctuations, the experimental group generally demonstrated improved spray efficiency.

These results suggest that the portable electrostatic nozzle enhances droplet deposition and improves overall pesticide coverage on sugarcane plants, supporting its potential as a possible effective solution to the identified concerns in sugarcane farming. The use of an electrostatic power supply to generate high voltage for charging the liquid droplets helps decrease and regulate droplet size, ensuring uniform distribution and efficient operation of the spraying mechanism.

Based on the findings, several areas for further research are recommended. Future studies could investigate the use of a sphere-shaped probe to evaluate its impact on the uniformity of the distribution of electric field that charges the droplets. Furthermore, the design of a protective circuit to safeguard the battery from electrical surges due to the high current of the electrostatic circuit should be explored. Finally, conducting field tests in real-world conditions would help assess the nozzle's performance and effectiveness in practical agricultural scenarios.

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APPENDIX

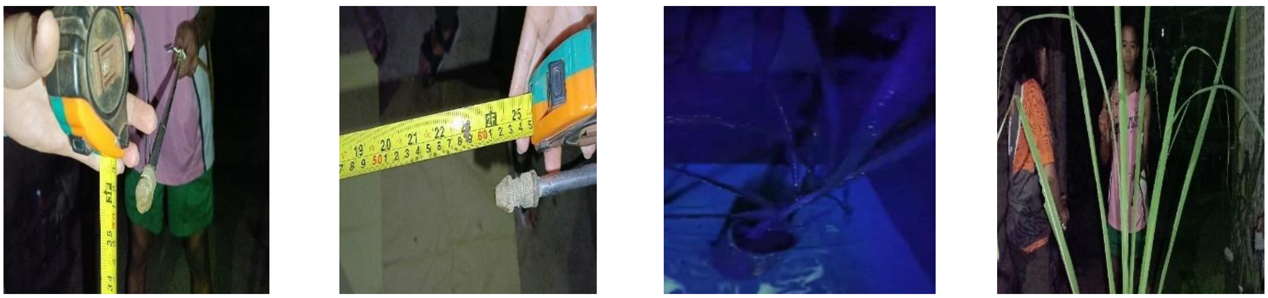
Testing Procedure Documentation

Control 1




Control 2

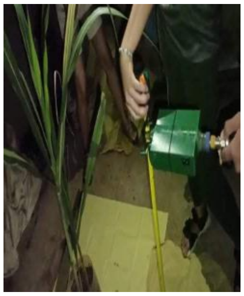
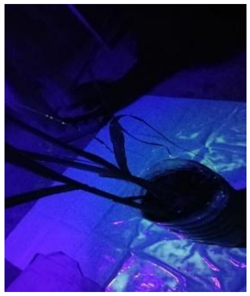
Control 3



Experiment 1

Experiment 2

Experiment 3

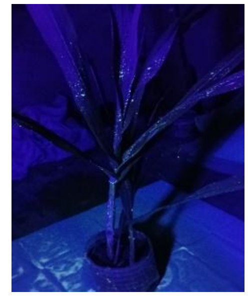
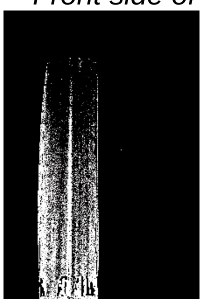
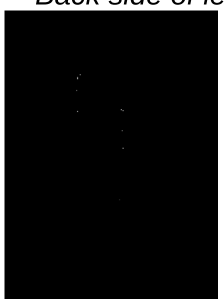
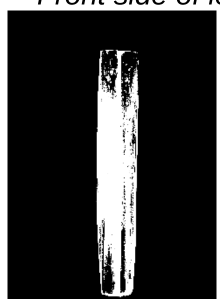


Image J post-test image data

Trial 1

Conventional Sprayer — *Electrostatic Nozzle*

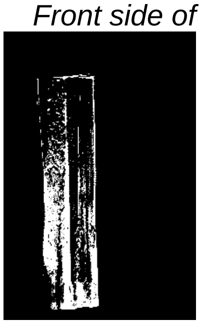
Front side of leaves — *Back side of leaves* — *Front side of leaves* — *Back side of leaves*

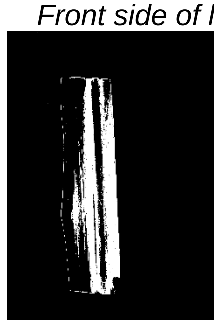
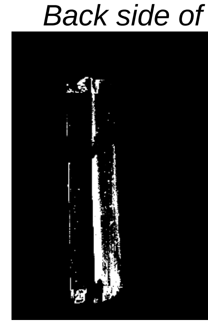





Trial 2

Conventional Sprayer — *Electrostatic Nozzle*

Front side of leaves — *Back side of leaves* — *Front side of leaves* — *Back side of leaves*



Trial 3

Conventional Sprayer — *Electrostatic Nozzle*

Front side of leaves — *Back side of leaves* — *Front side of leaves* — *Back side of leaves*