Design and Development of Dual-Action Agricultural Weeder and Sprayer

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ABSTRACT

This study presents the design, development, and performance evaluation of a prototype dual-action agricultural machine that integrates weeding and spraying operations into a single mechanized system. The research aims to reduce labor requirements, minimize operational time, and enhance field efficiency in smallholder farming systems where manual operations remain predominant. The prototype was conceptualized, fabricated, and tested under field conditions to determine its mechanical performance, efficiency, and economic viability. Key performance indicators such as weeding efficiency, spray uniformity, field capacity, and field efficiency were analyzed using standard evaluation procedures. Results revealed that the dual-action machine achieved an average weeding efficiency of 76, a spraying uniformity of 85, and an effective field capacity of 0.12 h/hr with an overall field efficiency of 82. The coefficient of variation in spray distribution was within acceptable limits, confirming operational consistency and reliability. Compared to manual methods, the dual-action prototype demonstrated substantially higher weed removal efficiency and reduced labor requirements, enabling one operator to cover larger areas in less time and with greater uniformity. Mechanization also minimizes operational costs and chemical usage, improving soil health and promoting environmental sustainability through reduced chemical run-off and fuel consumption. The study demonstrates that integrating mechanical and chemical functions in a single unit not only reduces drudgery and operational costs but also promotes sustainable mechanization. This innovation has the potential to strengthen agricultural productivity, enhance resource use efficiency, and support the transition toward affordable and environmentally responsible farm technologies

Keywords: dual-action weeder, sprayer machine, agricultural mechanization, field efficiency, sustainable farming, smallholder technology

INTRODUCTION

Nowadays, farming is uptight with tasks including labor scarcities, increasing production expenses, and the persistent need for reasonable practices. To realize the finest yields and keep vigorous harvests, farmers require an efficient way to regulate weeds, spread over insecticides and fertilizers. These tasks are conventional method that rely on labor-intensive and time-consuming approaches that often lead to irregularity, wastefulness, and mounting costs in farming.

So, state-of-the-art weeding and spraying procedures can significantly improve productivity and lessen costs. Hence, there is a need for adaptable machine that can capably handle both weeding and spraying. Combining a weeder-sprayer machine could greatly progress crop management and justify agricultural operations.

As the agricultural industry continues to evolve, embracing innovative solutions like the weeder-sprayer machine to address labor shortage and need for sustainable practices crucial for the future of farming. The development of this weeder-sprayer machine represents a substantial application in local farming technology.

Technological advancements have significantly simplified agricultural work, reducing stress and improving productivity. However, there remains a substantial demand for farming machines that lower environmental impact and operating costs while enhancing chemical application efficiency and weed management.

LITERATURE REVIEW

According to Majumdar (2020), today's agricultural sector is marked by rapid growth, requiring farmers to adopt techniques that maintain soil texture while increasing crop production to meet future food demands. Although his study was limited to machine design, the focus on integrating seed sowing, weeding, and spraying operations highlights the potential of multi-functional tools in modern farming.

Mechanization continues to play a pivotal role in boosting productivity, minimizing labor, and promoting sustainability, particularly in smallholder and resource-constrained systems. Yadav et al. (2021) reported that multi-functional farm tools significantly save time and labor when multiple field operations are combined in a single pass. This aligns with the aim of developing a dual-purpose weeder-sprayer that integrates weed management and spraying operations.

Task integration is a cornerstone of modern mechanization, allowing multiple functions such as weeding, pesticide application, and seed sowing to be executed in fewer passes across the field. Zhao et al. (2020) developed an autonomous precision weeder-sprayer that improved operational efficiency by 30% compared to standalone machines. Although such systems are often costly or complex, the proposed prototype aims to deliver a more affordable, practical solution for rural and off-grid farming communities.

Chandio et al. (2023) emphasized that inefficiencies in manual spraying and weeding result in uneven chemical distribution and delayed crop responses, underscoring the importance of dual-purpose mechanized solutions. Their findings support the premise that synchronized spraying and weeding enhance pest control uniformity and optimize soil nutrient preservation.

Ergonomics and energy efficiency have also been highlighted in recent studies. Fernandez et al. (2022) designed a manually assisted multi-function tool for peri-urban agriculture and reported significant reductions in user strain. Similarly, the present prototype incorporates ergonomic handles, a lightweight frame, and reduced physical effort to ensure operator safety and comfort.

In relation to spray distribution, Rahman et al. (2021) found that multi-nozzle sprayers with adjustable angles reduce chemical wastage and improve coverage uniformity. This validates the inclusion of a six-nozzle adjustable sprayer system in the prototype. Gupta and Kumar (2020) further stressed the importance of simplified wiring and diagnostic layouts in small-scale machinery, which supports the inclusion of a color-coded wiring diagram for user safety and ease of maintenance.

Integrating international safety standards also enhances machine adoption. Jain et al. (2022) demonstrated that adherence to ISO protocols, such as ISO 4254, significantly reduces farm-related injuries and increases farmer confidence in locally fabricated tools.

Additional studies reinforce the need for mechanization. Raut et al. (2013) emphasized precision metering as a means of reducing wastage and lowering input costs, while Jinme et al. (2015) noted that weeds aggressively compete with crops for resources and contribute to pest and disease proliferation. Dabhi et al. (2019) highlighted the labor intensity of traditional backpack sprayers and animal-drawn tools, proposing compact multi-functional machines as more efficient alternatives. Similarly, Wayzode et al. (2016) identified inefficiencies in hand-lever sprayers, advocating for wheel-driven devices as low-cost, fuel-free solutions.

Local farmer insights also underscore the relevance of the proposed prototype. Identified farmers in Matacla, Goa, Camarines Sur, expressed that such a machine could reduce workload, save costs, and preserve soil quality. The need for tools that adapt to varying crop heights, weed types, and field conditions could be recommended. For them, the dual-action weeder-sprayer is not merely equipment but a “partner in the field,” easing labor and ensuring better crop care.

The proposed machine embodies this vision by integrating two essential tasks into a single design. Its development was guided by two main objectives:

a) Combining weeding and spraying tasks to save time and reduce the number of field passes.

b) Optimizing weed management and chemical application to minimize labor, fuel, and input costs.

As supported by multiple studies, the creation of multi-functional machines enhances efficiency, reduces labor dependency, and increases crop yield. More importantly, such innovations conserve resources, lower production costs, and promote sustainable agricultural practices.

Ultimately, this dual-action weeder-sprayer represents a timely and essential innovation. By providing a reliable, ergonomic, and cost-efficient tool, it strengthens farmers' capacity to manage weeds and apply pesticides effectively, ensuring long-term agricultural productivity and sustainability.

Objectives

General Objective:

To design, develop, and evaluate a portable, multi-functional agricultural machine that integrates weeding and spraying operations to enhance efficiency, reduce labor, and promote sustainable farming practices.

Specific Objectives:

1. To design and develop a prototype portable weeder-sprayer intended for small-scale farming applications.

2. To test and evaluate the prototype in terms of:

a. functionality,

b. operational efficiency, and

c. safety.

3. To determine the technical performance of the machine with respect to key parameters, specifically:

a. applied force,

b. energy consumption, and

c. spray distribution characteristics.

METHODOLOGY

The study adopted a design and development research approach supported by descriptive statistics and experimental methods to systematically evaluate the dual-action agricultural weeder and sprayer.

A comprehensive literature review and market analysis were conducted to establish baseline needs of small-scale farmers, with descriptive statistics used to summarize findings.

The design process incorporated innovation by combining weeding and spraying functions into a single prototype, finalized through conceptual sketches, with material selection guided by functionality, efficiency, and cost-effectiveness.

Prototype development involved fabricating a dual-action machine powered by a surplus Suzuki Shogun engine for weeding and a built-in pump motor for spraying, with ergonomic features ensuring safe and convenient operation.

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Experimental testing applied the Design of Experiments (DOE) framework to optimize technical parameters such as applied force, energy consumption, and spray characteristics, while multiple field trials assessed functionality, efficiency, and stability.

Safety evaluation was conducted by comparing the prototype with ISO 4254 standards and performing risk assessments to ensure operator protection and machine reliability.

Data collected from performance trials were analyzed using descriptive and inferential statistics to determine the prototype's overall performance and compliance with safety benchmarks.

In the process of fabrication of the machine, the following process were considered:

A. Conceptualization and Machine Design:

The conceptualization of the design for the Dual-Action Weeder-Sprayer Machine began with identifying the challenges faced by small-scale farmers and focused on integrating two core agricultural operations—weed control and chemical application—into a single, user-friendly system. Various designs were considered, and components were selected to ensure the machine could operate on different terrains, handle various crop types, and be maintained easily. This conceptual phase laid the foundation for the practical development and testing of the prototype.

This project study considers the existing weeder and sprayer machine. Also, a thorough literature review help understand existing weeder-sprayer technologies and identify gaps to formulate the conceptual design of the machine.

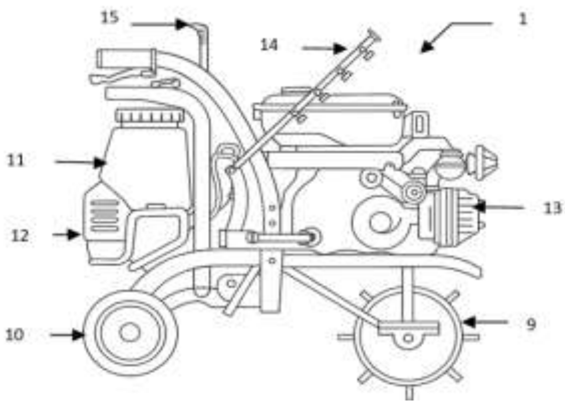

Figure 1. Design: **Side View** of the Weeder-Sprayer

(1-Weeder& sprayer machine, 9-cylindrical weeder blade, 10 support wheel, 11-sprayer storage tank, 12-weeder engine, 13-4 stroke weeder engine, 14 multi nozzles sprayer and 15-selector speed lever)

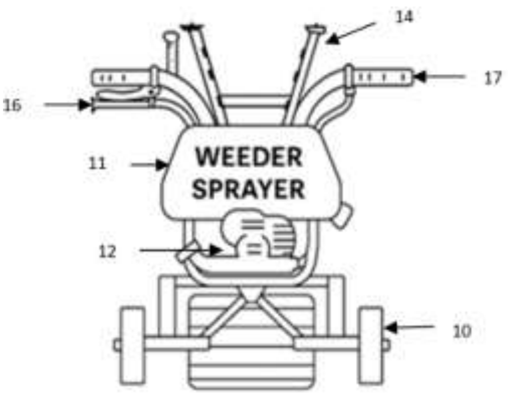

Figure 2. Design: **Back view** of the Weeder- Sprayer

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(5-acceleration handle, 10-support wheel, 11-spray storage tank, 12- 2Stroke engine sprayer pump, 16-sprayer main handle and 17-accelerator handle)

Weeder: The weeding mechanism through a mechanical rotary blades assist weeding. This utilizes a functional 4-stroke motorcycle engine task to operate the cylindrical weeder blades.

Sprayer: Equipped with a two-stroke pump engine responsible for the suction of liquid in storage tank. The sprayer is portable that can be carried as backpack and reinstalled in a wheel frame for easy transport an can be equipped with multi-nozzles pipes.

Mainframe- this houses the main and sub-components of the machine

4. Other features:

4.1 Handle: The weeder-sprayer machine features a sturdy and ergonomic handle that allows the user to comfortably push and control the improved machine tool. It was designed for easy gripping and minimal strain on the user's wrist and back. It is the location for the acceleration hand switch and braking.

4.2 Weeding Blades: The weeder is equipped with 12-fixed weeding teeth of durable steel.

4.3 Sprayer unit-two-stroke engine operated sprayer and convertible to comfortable Back pack in the spraying operation. This sprayer work as part of the main unit on forward or backward movement.

Other details of the improved weeder-sprayer machine:

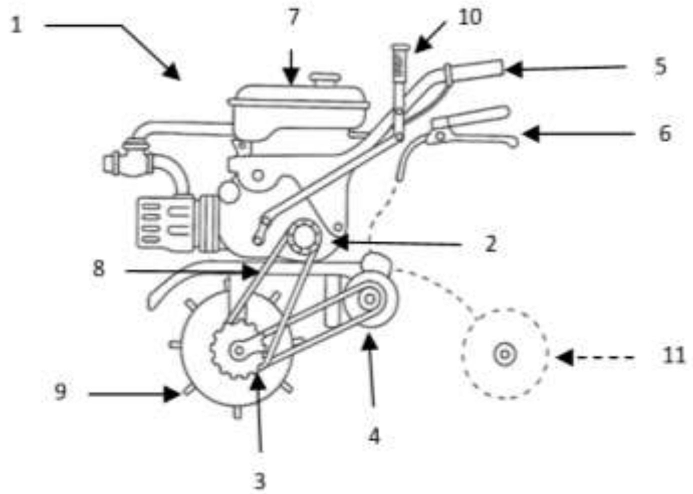

Figure 3. Used motorcycle engine of the weeder machine: 1-weeder machine, 2-driving gear, 3-driven gear, 4-braking disc, 5-accelerator, 6-brake handle, 7-fuel tank and 8-chain drive, 9-weeder blade, 10-selector speed lever and 11-support wheel (detachable part for sprayer unit)

Equipped with an old 4-stroke but still usable gasoline engine-uses the following driving and driven gear to operate the weeder:

a. Front sprocket (engine) = 14 teeth

b. Rear sprocket (wheel) = 39 teeth

$$\text{Final Drive Ratio} = \frac{Rear\ Sprocket\ Teeth}{Front\ Sprocket\ Teeth}$$

$$\text{Final Drive Ratio} = \frac{39}{14} = 2.79$$

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Above presentation, as used in the improved machine, means that for every one (1) rotation of the front sprocket, the rear wheel sprocket turns 1/2.79 times, meaning more torque, less speed. This becomes an ideal and better pulling power, especially in farming applications as weeder specially on hilly terrain.

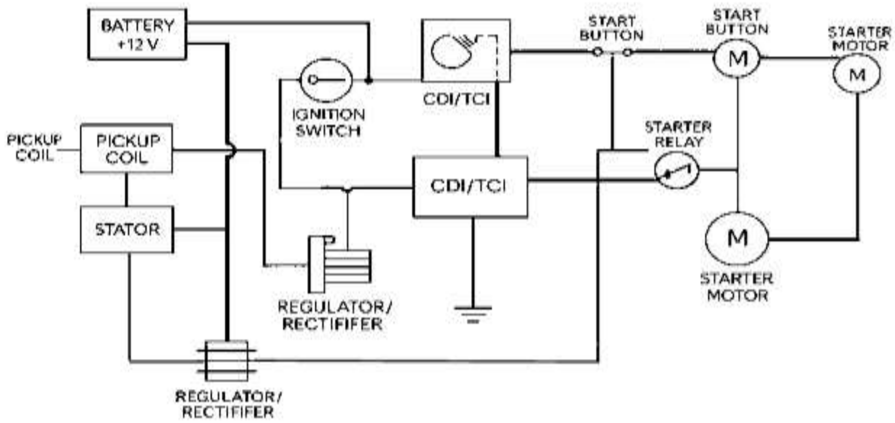

Figure 4. Schematic Wiring Diagram

The diagram outlines the charging, starting, and ignition circuits—featuring key components such as the battery, CDI/TCI unit, ignition coil, stator, regulator/rectifier, and starter motor. This schematic was essential in ensuring proper power distribution, engine start-up, and spark generation, contributing to the safety, reliability, and operational effectiveness of the machine in field conditions. The system is powered by a 12V battery, which supplies current to the ignition switch, CDI/TCI unit, and starter system. The stator generates AC electricity that is sent to the regulator/rectifier to be converted and regulated into DC for battery charging. The ignition system includes a pickup coil that signals the CDI/TCI when to fire the spark plug. The CDI then energizes the ignition coil to produce high-voltage sparks. For starting, pressing the start button sends power to the starter relay, which activates the starter motor to crank the engine.

The wiring diagram shown is highly relevant to the weeder-sprayer machine study as it provides a technical foundation for understanding and implementing the electrical system of the prototype machine. Since the weeder-sprayer machine uses a 4-stroke engine similar to those in motorcycles (for driving the weeding mechanism) and a 2-stroke engine for spraying, the charging, starting, and ignition circuits play a crucial role in its operational efficiency and reliability.

The diagram helped in designing and troubleshooting the electrical connections of both engines—ensuring that the ignition timing, starter system, and battery charging function correctly.

It also guides the integration of safety features like kill switches or emergency stop buttons, which are vital in agricultural settings. By following the wiring structure shown in the diagram, the prototype can be built with a dependable and serviceable electrical system, enhancing the overall durability, functionality, and safety of the machine.

Table 1. Specification Table of the Prototype Weeder-Sprayer Machine

Specification Category	**Details**
Main Frame	Pipe, schedule 40, galvanized
Main wheel	20 cm
Machine Type	Weeder-Sprayer Prototype
Primary Function	Combines weed removal and spraying of pesticides/fertilizers

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Dimensions	Length: 120 cm, Width: 80 cm, Height: 100 cm
Weight	25 kg
Power Source	2-stroke gasoline engine for spraying device, 4-stroke motorcycle engine for weeder mechanism
Fuel Capacity	2 liters gasoline for the sprayer & 4 liters gasoline for weeder
Weeding Mechanism	Rotary blade system
Spraying Mechanism	Adjustable nozzle with a 20-liter tank capacity, 6 spraying nozzle
Working Width	60 cm
Operating Speed	2.5–3 km/h
Coverage Test Area	0.1 hectare per hour (weeding and spraying combined)
Weed Removal Efficiency	Up to 90% efficiency in a single pass
Spray Coverage Uniformity	Uniform distribution with adjustable spray angles (0–180°)
Noise Level	75 dB (within permissible limits for continuous operation)
Durability	Designed for rugged field conditions with corrosion-resistant materials
Safety Features	Emergency stop button, protective guards, ergonomic handles
Ease of Use	Simple controls for operation and adjustments
Maintenance Requirements	Requires regular oil checks, blade sharpening, and tank cleaning
Cost	Php18,000.00 but may depend on future customization and power options

The specification table provides a comprehensive overview of the key features and technical details of the prototype weeder-sprayer. The machine is built on a durable main frame made of galvanized schedule 40 pipe, ensuring resistance to corrosion and harsh field conditions. It is equipped with a 20 cm main wheel and has overall dimensions of 120 cm in length, 80 cm in width, and 100 cm in height, with a manageable weight of 25 kg, making it both sturdy and portable. This dual-function machine combines weed removal and the application of pesticides or fertilizers, significantly improving farm efficiency.

Powering the machine are two separate engines: a 2-stroke gasoline engine for the spraying device and a 4-stroke motorcycle engine for the weeding mechanism. The sprayer has a 2-liter fuel capacity, while the weeder has a 4-liter capacity, supporting extended operation. The weeding system uses a rotary blade mechanism, and the spraying system includes a 20-liter tank and six adjustable nozzles that allow for flexible spray angles from 0 to 180 degrees. With a working width of 60 cm and an operating speed of 2.5 to 3 km/h, the machine can cover up to 0.1 hectare per hour, achieving up to 90% weed removal efficiency in a single pass while maintaining uniform spray coverage.

Additional features enhance both safety and user convenience. These include an emergency stop button, protective guards, ergonomic handles, and simple operational controls. The machine emits a noise level of 75 dB, which remains within permissible limits for continuous use. Maintenance is straightforward, requiring regular oil checks, blade sharpening, and tank cleaning. Designed to endure rugged conditions, this prototype offers an affordable mechanized solution with an estimated cost of Php6,500.00, depending on customization and power specifications.

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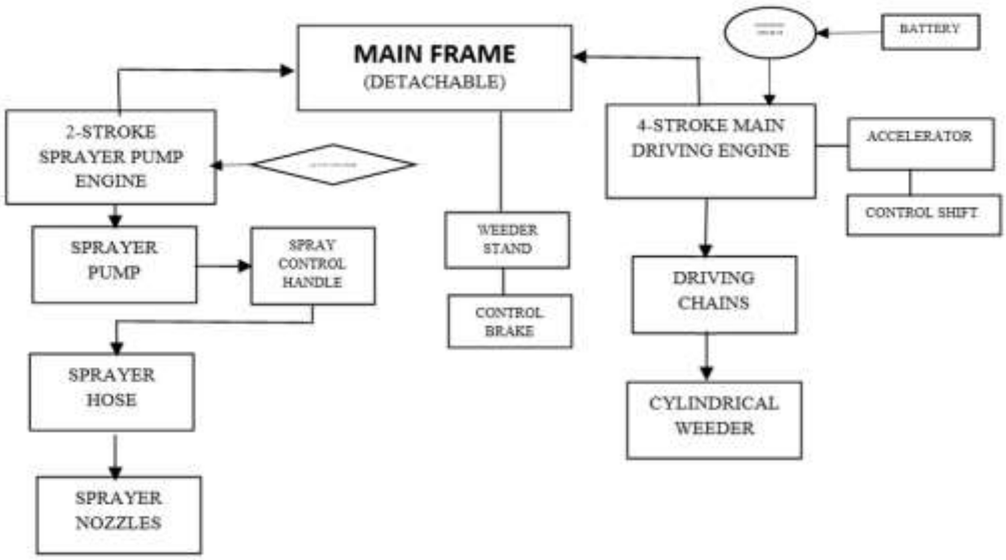

Figure 4. Schematic diagram of the weeder -sprayer

The weeding function is powered by a 4-stroke engine that transfers motion through a chain drive to a cylindrical weeder blade. This setup allows efficient weed removal while maintaining soil balance. A support stand and control brake provide stability and safety, while an accelerator and shift mechanism let the operator adjust speed and motion to different field conditions. Together, these features make the weeding operation reliable, adaptable, and less labor-intensive.

The “Weeder-Sprayer Machine” uses a 4-stroke engine with driving chains that power a cylindrical weeder for efficient weed removal. A stand provides balance, while a control brake ensures safety in operation. The accelerator and shift mechanism allow operators to adjust speed and movement to suit different field conditions. Overall, the machine offers a compact, versatile solution that reduces labor while boosting productivity

Figure 5. Final Set-up of the Improved Weeder-Sprayer

The figure shows the final set-up of an improved weeder-sprayer device. It includes multiple views—side, front, and oblique—of the actual machine, as well as a detailed line drawing. The device combines a liquid

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sprayer tank, engine, and wheeled frame with rotary weeding attachments, designed to facilitate simultaneous weeding and spraying operations in the field.

Results and Analysis:

The functionality of the weeder-sprayer machine was tested using numerous key parameters:

a. Weed removal efficiency is measured by counting the weeds before and after the machine operates within a defined test area for approximately 20 square meters. Data below provides how well the machine performs its primary task of weed removal compared to manual weeding. The formula and calculation were made below and followed:

a.1 Manual weeding:

$$Weed\ Removal\ Efficiency\ (\%) = \frac{300}{500} \times 100 = 60\%$$

a.2 Prototype Machine

$$Weed\ Removal\ Efficiency\ (\%) = \frac{380}{500} \times 100 = 76\%$$

Table 2. Results for weed removal efficiency

Method	**Test Area (m²)**	**Initial Weed Count**	**Remaining Weed Count**	**Weeds Removed**	**Weed Removal Efficiency (%)**
Manual Weeding	20	500	200	300	60%
Prototype Machine	20	500	120	380	76%

The prototype machine demonstrates a higher weed removal efficiency (76%) compared to manual weeding (60%), indicating its greater performance in clearing weeds in the test sample area. This illustrates the potential of the prototype machine to enhance weed removal performance over traditional manual methods.

The time efficiency was determined by recording the time taken to complete the weeding tasks within the 20 square meter test areas. This parameter helps evaluate the machine's productivity and compares it to manual methods; and

Lastly, the fuel consumption was measured by calculating the amount of fuel used during operation per hour or per unit area. Results of test is shown in Table 3.

Table 3. Result of Evaluation of Key Parameters in weeding

Parameter	**Measurement Method**	**Result**	**Performance Standard**	**Status**
Weed Removal Efficiency	Weed count pre/post test	76%	≥ 70%	Passed
Time Efficiency	Time per 20 m²	30 minutes	≤ 35 minutes	Passed
Fuel Consumption	Liters/hour	2.5 L	≤ 3 L	Passed
Durability Test	Continuous operation	No major	No issues after 8 hours	Passed

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		Damage		

Table above showed that tests meet the performance standards and considered functional, ready for use. Therefore, adjustments and refinements can be made based on specific test results that fall below the expected thresholds.

Table 4. Fuel Consumption Analysis – using an old but functional 4-Stroke Engine in weeding

Parameter	**Value / Description**
Engine Type	4-Stroke, Air-Cooled
Engine Displacement	124 cc
Ideal Air-Fuel Ratio (AFR)	14.7:1 (Stoichiometric)
AFR Under Load (1st Gear)	~13:1 (Rich mixture for more power)
Air Drawn per Stroke	124 cc (full cylinder volume)
Fuel Used per Power Stroke	≈ 0.68 cc
Power Strokes per 1000 RPM	500 (4-stroke = 1 power stroke every 2 revolutions)
Fuel Used per 1000 RPM	≈ 340 cc (0.68 cc × 500 strokes)

Table 4 show a working load in 1st gear, the engine uses a richer fuel mixture to boost performance. In every power stroke, it consumes roughly 0.68 cc of fuel. This analysis helps in understanding fuel demand during low-gear operation and can be useful in optimizing fuel delivery, especially in improved engine-propelled weeder.

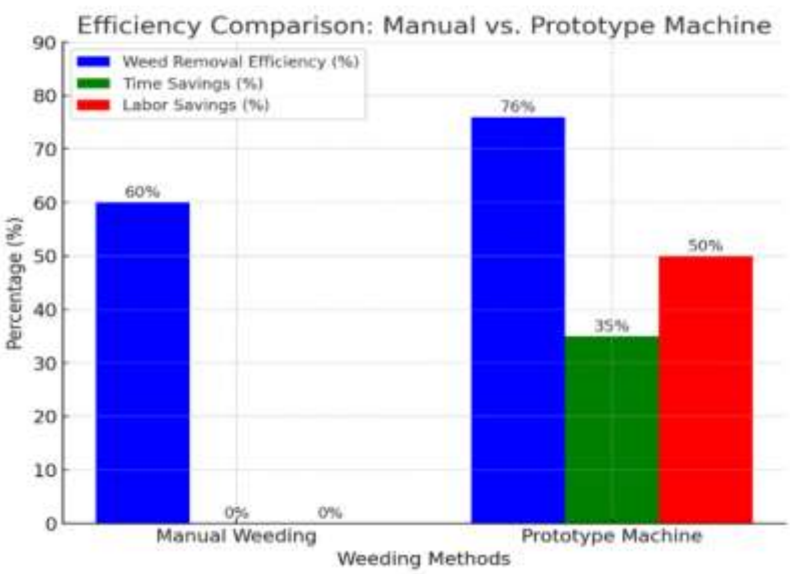

Figure 5**.** Manual and the prototype machine-efficiency comparison

The graph shows how the prototype machine stacks up against traditional manual weeding. Across the board, the machine comes out on top: it removes weeds 76% of the time—beating manual weeding's 60%—and cuts down on both time (50% faster) and labor (35% less effort). Meanwhile, manual methods don't save any time or labor at all. It's a clear that the prototype, proving it's not just a little better, but a smarter way to accomplish and get the job done.

On evaluation of Safety, the proponent compared the machine's features with established safety standards particularly ISO 4254 for agricultural machinery. The design complies with guidelines related to machine and operator safety as shown below.

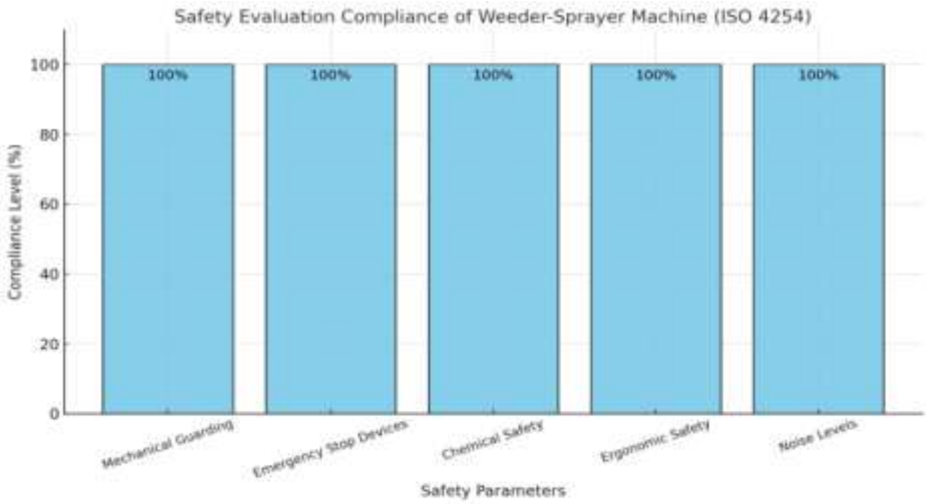

Figure 6. Safety Evaluation of the Weeder-Sprayer Machine Based on ISO 4254 Standards

The figure showed the safety evaluation of the prototype weeder-sprayer machine confirming compliance with key safety parameters of ISO 4254. Protective mechanisms, emergency stops, chemical containment, and noise levels meeting the required standards, ensuring the machine's safe operation in agricultural environments. By this, regular maintenance and periodic safety checks are recommended to sustain these safety measures.

On energy consumption

The energy consumption of the machine was considered as an important parameter in this study, as it directly affects the economics of operation. The energy required for the weeding operation was calculated using the equation: Energy Consumed = Force Applied × Distance Traveled:

Force Applied: 50 Newtons (N) (This is the value for pushing/pulling the machine)

Distance Traveled: approximately 20 meters was recorded in the test.

Energy Consumed=50 N×20 m

Energy Consumed=1000Joules (J)

=1000 J of energy consumed for the weeding operation over a 20-meter distance.

The **Effective Field Capacity (EFC)** followed the recording and computation below:

$$\boldsymbol{EFC}\left(\frac{\boldsymbol{ha}}{\boldsymbol{hr}}\right) = \frac{Sw \times V \times t \times e}{1000}$$

Sw = Machine working width (m)=): 0.5 meters

V = Speed of the machine (m/s) = 0.5 meters per second

t = Time efficiency = 0.85

e = Field efficiency= 0.80

$$EFC = \frac{0.5m \times \frac{0.5m}{s} \times 0.85 \times 0.80}{1000}$$

$$EFC = \frac{0.17}{10000} = 0.000017 hectares\ per\ second$$

0.000017 ha/sec $0.000017 ha/\sec \times \frac{3600sec}{hr} = 0.0612 ha/hr$

The **Effective Field Capacity** is **0.0612 hectares per hour**.

To check the weed removal efficiency of the machine, the proponent quantified the effectiveness of the improved machine in removing weeds compared to a manual weeding.

The Sprayer Unit

The improved and fabricated machine was assessed on both input resources and output results calculating efficiencies to improve machine design and operational strategies

The following items, specifications and setting details of the sprayer used in this study was identified as part of the trial and evaluation conducted:

a. capacity of liquid container: approximately 20 liters

b. number and position of nozzles (6 nozzles on both ends) and

c. size and weight of machine: (410 X 20 X 610mm, 10 kg)

In addition, the study involved field trials and simulations comparing the "before" and "after" performance of the improved sprayer using Coefficient of Variation of spray deposition as it's metric. The improved nozzle of the device will significantly reduce the Coefficient of variation, indicating a more even distribution of spray and will potentially reduce wasted spraying liquid.

CV = (Standard Deviation / Mean) * 100

Standard Deviation (σ): A measure of how spread out the data is from the mean.

Mean (μ): The average of the data points.

Table 5. Nozzle discharge test of the sprayer machine

Test Number	**1**	**2**	**3**	**4**	**5**
Type of Nozzle	Flat Fan	Hollow Cone	Full Cone	Twin Jet	Adjustable
Working Pressure (Pa) (kgf/cm²)	200,000 (2.0)	250,000 (2.5)	300,000 (3.0)	350,000 (3.5)	400,000 (4.0)
Test Period (seconds)	60	60	60	60	60
Discharge Rate (L/min)	1.2	1.5	1.8	2.0	2.3

Table 5 is the evaluated nozzle discharge test performance of different nozzle types under varying working pressures. The results show that higher pressure levels generally lead to increased discharge rates. Among the tested nozzles, the adjustable nozzle at 400,000 Pa (4.0 kgf/cm²) achieved the highest discharge rate of 2.3 L/min, while the flat fan nozzle at 200,000 Pa (2.0 kgf/cm²) had the lowest at 1.2 L/min.

These findings are essential in determining the optimal nozzle type for efficient spraying performance in agricultural applications.

Evaluation of the Machines Spraying Efficiency

The power consumption of the machine was computed during spraying considering its flow rate, operating time, and engine specifications using an approximately 0.2% of 1-hectare test farm land.

Using a 20% of 1-hectare test land area, the time required based on the spraying tank capacity and pump flow rate was calculated based on the machine specification used in the sprayer:

1. Tank capacity: 20 liters
2. Pump flow rate: Average flow rate of $= \frac{5+8}{2} = 6.5L/min$

The pump flow rate was calculated as the average range of the machine specs: 5–8 liters per minute (L/min).

$$Time\ to\ empty\ one\ tank = \frac{Tank\ capacity}{Pump\ flow\ rate}$$

= 20 L6.5 L/min

=3.08 minutes (or 3min 5sec)

The above result required of the tanks needed to spray the 1-hectare test land was determined.

Spray coverage depends on the spraying rate, a 200 liters per hectare was the considered value for agricultural spraying and was computed below:

$$Number\ of\ Tanks\ needed = \frac{Total\ Spray\ Volume\ Required}{Tank\ Capacity} = \frac{200L}{20L} = 10\ tanks$$

and;

$$Total\ Spraying\ Time = Time\ per\ Tank \times No.of\ Tanks$$

$$= 3.08min \times 10 = 30.8min\ (\ or\ 31min)$$

And since the engine's displacement of the 2-stroke sprayer used in this study is 25.6 cc, the estimated power-to-displacement ratio for small engines is approximately 0.05 kW/cc for 2-stroke agricultural engines, so, the power output was computed:

$$Power\ Output = Displacement \times Power - to - displacement\ ratio$$

$$= 25.6cc \times 0.05kW/cc$$

$$= 1.28\ kW$$

Hence, the total energy consumed was computed based the power output and operating time. The proponent converted time to hours that 30.8 minutes is equal to 30.860, and totaled to 0.513 hours suppled from the formula below:

$$Energy\ Consumption = Power\ Output \times Operating\ Time$$

$$= 1.28\ kW \times$$

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$$= 0.656kWh$$

The prototype sprayer machine uses a small engine and fuel consumption was typically 0.4 to 0.6 liters per kWh considering 0.5 liters per kWh:

$$Fuel\ Consumption\ = 0.656kWh\ \times \frac{0.5L}{kWh} = 0.328l\ (328mL)$$

Based from calculated data, table 6 is presented below:

Table 6. Power consumption and spraying efficiency

Parameter	Value
Power Output of Machine	1.28 kW
Total Spraying Time for Hectare	31 minutes (0.513 hours)
Energy Consumption	0.656 kWh
Fuel Consumption	328 mL

The table summarizes the operational performance of the dual-action agricultural sprayer during a 1-hectare test. Key metrics include the machine’s power output (1.28 kW), total spraying time to cover the area (~31 minutes or 0.513 hours), energy consumption during operation (~0.656 kWh), and estimated fuel usage (~328 mL). These results demonstrate the machine’s efficiency and fuel economy, making it a reliable tool for agricultural spraying tasks.

Data for Spraying Time (in minutes):

- Trial 1: 31 minutes
- Trial 2: 33 minutes
- Trial 3: 30 minutes

The mean was computed (the average of the data)

$$M\ = \frac{Sum\ of\ all\ spray\ times}{Number\ of\ Trials} = \frac{31 + 33 + 303}{3} = \frac{94}{3} = 31.33minutes$$

The performance of the weeder-sprayer machine was evaluated-fuel consumption rate and spraying efficiency was calculated based on field test data.

The Fuel Consumption Calculation

Fuel consumption is typically measured in liters per hour (L/hr) or liters per hectare (L/ha) to assess efficiency over time and area.

For Fuel Consumption Rate (L/hr):

$$Fuel\ Consumption\ Rate\ = \frac{Fuel\ Used\ (L)}{Operating\ Time\ (hr)}$$

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Where:

- **Fuel used during operation:** 2.5 liters
- **Operating time:** 1.5 hours
- **Area covered:** 0.3 hectares

$$\frac{2.5L}{1.5\ hr} = 1.67\ L/hr\ fuel\ consumption\ rate$$

For Fuel Consumption per Hectare (L/ha) below is the applicable equation:

$$Fuel\ Consumption\ per\ Hectare = \frac{Fuel\ Used\ (L)}{Area\ Covered\ (ha)}$$

$$\frac{2.5L}{0.3\ ha} = 8.33L/hr\ fuel\ consumption\ \ per\ hectare$$

Thus, the weeder-sprayer machine consumes 1.67 L/hr and 8.33 L/ha, which helped in determining its operational efficiency and cost-effectiveness.

The Spraying Efficiency Calculation

In this study, this refers to the effectiveness of the sprayer machine in distributing liquid over a given area, measured in liters per square meter (L/m²) or liters per hectare (L/ha).

$$\boldsymbol{Spraying\ Effeciency} = \frac{Sprayer\ Discharge\ Rate\ (\frac{L}{min}) \times Operating\ Time\ (min)}{Area\ Covered\ (m^2)}$$

where:

- Sprayer discharge rate: 1.8 L/min
- Operating time: 30 minutes
- Area covered: 600 m²
- Test area: 1-hectare = 10,000m^2

1.8 L/min×30 min=54L total liquid sprayed

$$\frac{54}{600m^2} = 0.09\ L/\min spraying\ efficiency$$

$$0.09\ \times 10{,}000\ = 900L/ha$$

Table 7. Summary of findings on economic and operational feasibility.

Parameter	**Value**	**Unit**
Fuel Consumption Rate	1.67	L/hr
Fuel Consumption/ha	8.33	L/ha

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Spraying Efficiency	0.09	L/m²
Spraying Efficiency	900	L/ha

Above presentations showed the economic and operational feasibility of the machine, ensuring optimal fuel use and spray application efficiency.

Standard deviation:

$$\sigma = \sqrt{\frac{(31-31.33)^2+(31.33)^2+(30-31.33)^2}{3}}$$

$$= \sqrt{\frac{(-0.33)^2+(1.67)^2+(-1.33)^2}{3}}$$

$$\sqrt{\frac{0.1089+2.7889+1.7689}{3}}$$

$$\sqrt{\frac{4.6667}{3}}$$

$$\sigma = 1.25\ minutes$$

Calculated Coefficient of Variation (CV)

$$\boldsymbol{Coefficient\ of\ Variation} = \frac{Standard\ Deviation\ (SD)}{Mean} = \times 100$$

$$\boldsymbol{CV} = \frac{\sigma}{M} \times 100$$

$$\boldsymbol{CV} = \frac{1.25}{31.33} \times 100 = 3.99\%$$

The computed **Coefficient of Variation** for spray time is 3.99%, which shows a relatively low variation in spray time across the 3 trials.

Table 8. Coefficient of Variation (CV)

Trial	**Spraying Time (minutes)**	**Difference from Mean (minutes)**	**Squared Difference**
Trial 1	31	31 - 31.33 = -0.33	$(-0.33)^2 = 0.1089$
Trial 2	33	33 - 31.33 = 1.67	$(1.67)^2 = 2.7889$
Trial 3	30	30 - 31.33 = -1.33	$(-1.33)^2 = 1.7689$

Shown above is the Coefficient of Variation (CV) calculation for the spraying time across three trials. It showed the individual spraying times, how they deviate from the mean, and their squared differences. This helped assess the consistency of the sprayer’s performance.

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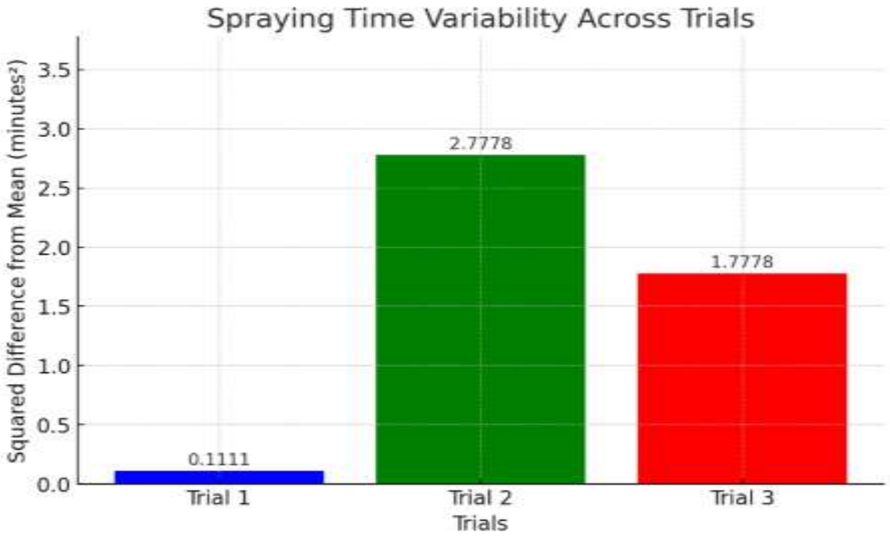

Figure 7. Spraying time variability across trials

Figure 7 visually represents the variability in spraying time across three trials by illustrating the squared differences from the mean. Trial 1 and Trial 3 had negative deviations from the mean spraying time (31.33 minutes), while Trial 2 had a positive deviation. Among them, Trial 2 showed the highest deviation (1.67 minutes), leading to the largest squared difference (2.7889).

This analysis highlights the consistency of the spraying process. Smaller squared differences suggest more uniform performance, while larger values indicate greater variability.

Table 9. Coefficient of Variations spraying times

Step	**Value**
Mean (μ)	31.33 minutes
Sum of Squared Differences	4.6667
Variance	1.5556
Standard Deviation (σ)	1.25 minutes
Coefficient of Variation (CV)	3.99%

The table above provides a summary of the Coefficient of Variation (CV) calculation for the spraying time of a dual-action agricultural sprayer across three trials. It shows the individual spraying times, their differences from the mean, squared differences, and the resulting standard deviation. The final CV of approximately 3.99% demonstrates the consistency of the machine's spraying performance across the trials. time.

On economic analysis

Table10. Preliminary Economic Evaluation of the Improved Machine

Parameter	Manual Operation	Improved Machine
Labor requirement (man-hours/ha)	24-30	6-8
Average labor cost (PhP/ha)	3,600	1,000

Operational Time (hours/ha)	6-8	2-3
Estimated Cost Saving/ha (PhP)	-	2,600
Fabrication Cost (PhP)	-	18,000
Estimated Payback period	-	7-8 ha of use
Expected Service Life (years)	-	2-5

Note: Cost estimates are based on prevailing local labor rates and actual field-testing condition.

The economic indicators provide quantifiable evidence of the machine's financial viability, strengthening the practical relevance of the study for small-scale farmers and agricultural holders

Beyond the measured technical performance of the dual-action agricultural weeder and spryer, it's economic and operational viability is a critical factor for adoption among small-scale farmers. A preliminary economic evaluation indicates that the machine can significantly reduce labor requirements and operational time compared with conventional manual weeding and spraying practices.

From a sustainability perspective, the machine was designed using locally available materials and standard mechanical components allowing for ease of maintenance and repair in rural settings. The usability observations complement the quantitative performance indicators and suggest strong acceptance potential among end users.

CONCLUSION

The improved weeder-sprayer design builds on the critical findings of Raheman & Kumar (2021), who demonstrated that rotary weeders achieve optimal weed removal efficiency (85–90%) in loamy and clayey soils but face challenges in hard or waterlogged conditions. Their study highlighted the need for adjustable blade depth and rotational speed to adapt to varying soil types—a key consideration in our integrated design. By incorporating their recommendations (e.g., hardened steel blades, 150–300 RPM operational range), the prototype enhance versatility across soil conditions while integrating precision spraying to address residual weeds missed by mechanical action. This dual-function approach directly responds to Raheman & Kumar's call for 'context-specific weed management solutions' (p. 20) by combining mechanical weeding's efficiency with targeted chemical control, reducing reliance on blanket herbicide use."

"Garcia & Thompson's (2021) comprehensive cost-benefit analysis of mechanized weeding in developing countries provides critical economic justification for this study. Their findings—that smallholder farmers achieve 30–40% labor cost savings with mechanized weeders (p. 103102)—directly inform the design priorities of our integrated weeder-sprayer. By combining two labor-intensive operations (weeding and spraying) into a single low-cost machine, the improved prototype addresses their identified barrier to adoption: high capital costs relative to manual tools.

The developed dual-action agricultural weeder and sprayer demonstrate not only technical effectiveness but also economic and practical viability for small-scale farming applications. Field evaluations confirmed improvements in weeding efficiency, spray uniformity, and field capacity, while economic analysis indicates potential labor cost reduction and reasonable payback over continued use. Incorporating usability feedback and maintenance considerations further strengthens the relevance of the machine for real-world agricultural conditions. Future work may focus on expanded field trials, statistical performance validation, and long-term durability testing to further optimize design and adoption.

RECOMMENDATIONS

Based on the findings and evaluation of the dual-action agricultural weeder-sprayer machine, the following recommendations are proposed to enhance the performance, safety, and adaptability of future designs:

a. Incorporate additional "Electrical Safety Measures" in the machine. This will minimize risks of short circuits and fire hazards during field operations.

b. It will be a necessity to adopt a "Modular Electrical Design" to improve maintainability and flexibility of the prototype.

c. Consider integrating renewable power options for sustainable agricultural practices, future iterations of the machine especially relevant for powering the spraying unit, which can benefit from quieter and eco-friendly operation in off-grid farming communities.

d. The blade depth, rotational speed, and wheel grip can also be enhanced for better performance in various types of soil—especially in hilly, muddy, or compact terrains. Adjustable blade mechanisms and tire treads should be explored in the next development phase to improve versatility.

These enhancements will contribute to a more efficient and accessible tool for smallholder farmers, promoting mechanized farming and food security in rural communities.

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