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A PROJECT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BSc IN AGRICULTURAL ENGINEERING

DESIGN AND FABRICATION OF A WHEELBARROW SPRAYER

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DECLARATION

I, **<u>Faggy Ngulube</u>**, **<u>B201578B</u>**, I declare that, with the exception of what is noted in the acknowledgement and references, all of the research and work for this study was done by me. According to my knowledge NO other university has received this project, in whole or in parts.

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DEDICATION

I dedicate this project to my mother for her unwavering financial and moral support throughout my life. Her continuous encouragement has been instrumental in keeping me motivated and focused on achieving my goals since childhood up until the present day. This project is a testament to her enduring commitment to my success and personal growth.

ACKNOWLEDGEMENT

I'm grateful to my supervisor, Prof. Wilfredo, for his guidance, encouragement, continuous feedback, and unwavering support that helped me complete this project. I thank Redemption Zengenene from my class for his assistance throughout the fabrication process. I also appreciate the farmers who shared their perspectives. Additionally, I acknowledge the entire Engineering faculty for their leadership and guidance over the years.

ABSTRACT

Agriculture is a vital economic activity in Africa, employing around two-thirds of the continent's working population. Much of this agricultural work involves subsistence farming, where the available machinery requires significant manual labour. This leads to farmers accumulating health problems and experiencing low production capacity. Subsistence farmers who engage in crop spraying often rely on knapsack sprayers, which can cause back problems. High costs prevent the adoption of alternative solutions like drone sprayers.

This study presents the design, fabrication, and testing of a low-cost wheelbarrow spraying device that reduces the manual labour required. The device features a single-wheel frame that the user pushes, carrying a tank. A gear-chain system automatically operates the pump's lever. Experimental testing of the prototype carried a 16-litre tank while requiring only 32% of the manual load effort under firm mud conditions, staying below the 50% load limit for loose sand. Appropriate gear sizing was confirmed to enable the desired flow rate of 0.5L/min while the user walks at a regular speed of 1.45 m/s.

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LIST OF ACRONYMS AND ABBREVIATIONS

FAO: Food and Agriculture Organization

DC: Direct current

USD: united States Dollar

CAD: Computer Aided Design

RPM: Revolutions Per Minute

N_{rpm}: Angular Velocity

N: Newton

PPE: Personal Protective Equipment

PVC: Polyvinyl Chloride

HDPE: High Density Polyethylene

CM: Centimetres

MM: Millimetres

KG: kilograms

M: Meters

CHAPTER ONE

1.1 Introduction

Crop yields in many agricultural regions of Zimbabwe tend to be low, and it is unclear how much individual factors contribute to this issue. Insects, pests, and diseases are significant contributors to the reduction of crop yields. Environmental conditions like prolonged rainfall and cloudy weather can create a suitable environment for faster growth of insects, pests, and diseases. Therefore, the use of pesticides is essential to meet the demand for high-quality and high-quantity crop production. Additionally, crops need spraying of growth-enhancing nutrients and fertilizers to increase productivity. Hence, an effective sprayer is necessary to spray different substances and ensure maximum productivity of crops.

1.2 Background of the Study

In many regions of Zimbabwe, agricultural productivity is often suboptimal, and the specific factors contributing to this issue are not entirely clear. One of the significant challenges faced by farmers is the infestation of crops by insects, pests, and diseases, which significantly reduce crop yields.

Environmental conditions, such as extended periods of rainfall and overcast weather, can exacerbate these problems by creating an environment conducive to the rapid proliferation of these pests and diseases. As a result, the use of pesticides becomes a critical component in the fight against these yield-reducing factors, aiming to ensure both the quantity and quality of crop production meet the demand.

In addition to pest control, crops also require the application of growth-enhancing nutrients and fertilizers to boost their productivity. This necessitates effective spraying methods to distribute these substances evenly and efficiently.

Spraying methods in agriculture encompass a range of techniques, each presenting its own unique set of challenges and advantages. One such method is manual spraying, which involves using handheld sprayers operated by individuals. While manual spraying offers the benefits of being cost-effective and easy to use, it can be demanding in terms of labour and time, particularly when dealing with larger farms. Furthermore, the efficacy of manual spraying is influenced by factors such as the operator's skill level and fatigue, which can impact coverage and effectiveness.

On the other hand, mechanized spraying provides a more efficient alternative. These sprayers are typically mounted on tractors or other vehicles, enabling them to cover larger areas in less time compared to manual methods. Mechanized sprayers can be equipped with various nozzle types to cater to different spraying requirements. However, they necessitate a substantial initial investment and ongoing maintenance. Additionally, operators must carefully manage factors like wind speed, nozzle type, and spray pressure to achieve optimal coverage and minimize wastage. These considerations are crucial for ensuring the effectiveness of spraying operations.

Aerial Spraying is a widely used method in agriculture that utilizes aircraft to efficiently distribute pesticides or fertilizers over large areas. This approach offers significant advantages in terms of speed and coverage. However, it also comes with certain requirements and challenges. Aerial spraying demands substantial investment in aircraft and specialized equipment, making it a significant financial commitment for farmers. Additionally, proper management of drift caused by wind is crucial to ensure that the spray reaches the intended target area and does not disperse unnecessarily. Precise application techniques must be employed to minimize wastage and prevent environmental contamination, as any excess spray that drifts beyond the target area can have adverse effects on non-target organisms and ecosystems.

Drip Irrigation Spraying is a precise and efficient method that involves applying water-soluble pesticides or fertilizers directly to the plant roots through a drip irrigation system. This approach significantly reduces waste and minimizes the environmental impact associated with conventional spraying methods. However, it requires a well-maintained drip irrigation system to ensure optimal functionality. Regular maintenance and careful management are necessary to prevent clogging of the drip emitters, which can hinder the effective delivery of the spray. By directly targeting the plant roots, drip irrigation spraying maximizes the uptake of nutrients or pesticides, enhancing their efficiency and minimizing their release into the wider environment.

Fogging and Misting methods are specifically designed to provide thorough coverage and penetration, particularly in dense crop canopies. These techniques employ specialized equipment to create a fine mist or fog of the spray material, ensuring that it reaches all areas of the plants, including the undersides of leaves and other hidden surfaces. Fogging and misting methods are particularly effective in situations where uniform coverage is critical. However, their efficacy can be influenced by environmental conditions such as wind and humidity. To overcome these challenges, careful management is essential to adjust the application parameters and ensure that the spray is effectively delivered to the target areas.

When choosing between these spraying methods, farmers must consider their specific needs, available resources, and environmental conditions. Factors such as the size of the area to be treated, the type of crops, and the presence of sensitive ecosystems nearby should all be taken into account. It is important to select the method that not only meets the spraying requirements but also minimizes potential negative impacts on the environment. Regardless of the chosen method, consistent and attentive management practices, including regular monitoring, adjustment, and maintenance, are crucial to ensure effective spraying and maximize crop productivity. By implementing these measures, farmers can optimize the efficiency of their spraying practices while minimizing potential risks to both the environment and their agricultural operations.

Small-scale farmers are mainly affected when it comes to using sprayers as most of the machinery used they can't afford and hence they end up using mechanical methods of spraying. Small-scale farmers need to have access to affordable machinery which they can use for the propagation of their farmland. Mechanical machinery such as the knapsack has so many challenges in usage which include back and shoulder strains which can cause physical damage in the long run of usage to the operator. Setting aside physical strain one of its small size results in low efficiency on a large scale land and lack of pressure control results in Variable Flow Rates where the sprayer may deliver inconsistent dosages of chemical preparations due to fluctuating pressure and Inconsistent Spray Patterns and Droplet Size where Uneven pressure affects the spray coverage and chemical performance.

While boom sprayers are an effective way of spraying crops, they tend to be quite expensive and require a significant investment, making them unsuitable for small-scale farmers who may not have the budget to afford them.

1.3 Statement of the Problem

The traditional knapsack, while functional, is riddled with a multitude of issues that make it less than ideal for regular use. One of the primary concerns is its weight. The heaviness of the knapsack, especially when filled, can lead to fatigue even after short periods of use. This, in turn, can cause strain on the back and shoulders, making it uncomfortable and potentially harmful over time. In addition to its weight, the size of the old knapsack presents another challenge. Its small capacity limits the amount of materials or items that can be carried, which can hinder efficiency and productivity. This is particularly problematic in operations that require a larger carrying capacity. In the realm of agriculture, there are alternatives such as boom sprayers. These devices, which are operated on a commercial scale, are capable of covering large areas of land quickly and efficiently. However, they come with a hefty price tag, making them inaccessible for medium and small-scale farmers.

1.4 Objectives

1. To design a cost effective wheelbarrow sprayer with increased spraying distance.
2. To construct a prototype of the wheelbarrow knapsack sprayer.
3. To evaluate the efficiency of the system in comparison with the old knapsack.

Main objectives

To design and develop an agriculture wheel sprayer which is economical, well adaptable and efficient.

Specific objectives

1. To design a wheelbarrow sprayer.
2. To develop and test the wheelbarrow sprayer.
3. To determine the efficiency of the wheelbarrow sprayer.

1.5 Justification

The wheelbarrow sprayer is an essential tool in modern agriculture, offering numerous benefits that justify its use. Firstly, the wheel sprayer significantly increases efficiency and productivity. It allows for the rapid and uniform application of pesticides, herbicides, or fertilizers over a large area. This not only saves time but also ensures that all plants receive an equal treatment, leading to more consistent crop growth and yield. Secondly, the wheel sprayer is cost-effective. Although there is an initial investment, the increase in productivity and reduction in wasted resources can lead to significant cost savings in the long run. Additionally, the durability and low maintenance requirements of the wheel sprayer mean that it will serve reliably for many years, providing excellent value for money.

Thirdly, the wheelbarrow sprayer can help to reduce the environmental impact of farming. By ensuring a precise application of chemicals, it minimizes runoff and overspray, reducing the amount of chemicals that end up in the soil and waterways. This not only helps to protect the environment but can also lead to cost savings by reducing the amount of chemicals needed. Finally, the wheel sprayer can improve health and safety on the farm. By automating the spraying process, it reduces the risk of farmers coming into direct contact with potentially harmful chemicals. Furthermore, the wheel sprayer's design can be ergonomically optimized to reduce physical strain on the operator, further enhancing safety.

1.6 Limitations

1. Technical Constraints: The design of the wheelbarrow sprayer may be limited by technical constraints such as the availability of materials and technology. For example, certain materials may be too expensive or not durable enough for use in a wheel sprayer.
2. User Requirements: The design must meet the needs of the end-user, which can limit the design options. For instance, if the user requires a lightweight sprayer, this could limit the size and capacity of the sprayer.

1.7 Development Limitations

1. Manufacturing Constraints: The development of the wheelbarrow sprayer may be limited by manufacturing constraints. For example, certain design features may be difficult or costly to manufacture.
2. Time and Budget: The development process may be constrained by time and budget limitations. This could impact the quality of the final product if corners are cut to save time or money.

1.7.1 Efficiency Evaluation Limitations

1. Testing Conditions: The efficiency of the wheelbarrow sprayer may vary under different conditions. For example, the sprayer may perform differently in different weather conditions or on different types of terrain. This can make it difficult to accurately evaluate its efficiency.
2. Measurement Error: There may be errors in the measurement of the sprayer's efficiency. For example, it may be difficult to accurately measure the amount of area covered by the sprayer or the uniformity of the spray distribution.

CHAPTER 2

Literature review

2.1 Introduction

Hall et al. (2017) The United Nations Food and Agriculture Organization (FAO) has pointed out that a quarter of Africa's population does not have sufficient food for a healthy lifestyle. Furthermore, it is projected that Africa will experience the most rapid population growth, with numbers expected to rise from 1.1 billion in 2015 to 2.4 billion by 2050. This necessitates investment in agriculture to meet the needs of both the existing population and the anticipated growth.

Baiphethi et al. (2009) given the central role of subsistence farming in Africa's economy, enhancing production is crucial for improving food security. This section examines existing crop spraying equipment, except the knapsack sprayer, to glean insights that could aid in the development of an affordable and effective crop sprayer.

2.2 Related work

SIDEK et al. (2022) undertook a fascinating project involving the development of a Wheel sprayer. They aimed to design and create an ergonomic machine, resulting in a device measuring 168cm in length, 110cm in height, and 50cm in width. The sprayer utilised a reciprocating pump with a single sliding crank mechanism, cleverly employing the wheel gears as a crank. Two sprockets were mounted on separate axles, with one directly attached to the wheel axle. The connecting rod was connected to the other sprocket axle through a disc. By rotating the wheel, power was transmitted to the reciprocating pump piston. The connection link engaged with the sprayer pump piston, allowing it to move back and forth, generating pumping action and increasing pressure within the pump. When the valve on the sprayer pipe was opened, the increased pressure was utilised to spray pesticide.

Furthermore, the design incorporated two nozzles at the front of the sprayer, adding efficiency to the spraying process. As the device moved, pressure was generated, activating the pump to spray onto the plants. However, the researchers encountered challenges in their work. They recommended the addition of extra nozzles to increase the coverage area per unit of time and noted that their design did not account for variations in plant heights. Nevertheless, the system proved to be efficient.

Shambhu Singh et al. (2020) worked on a similar project the sprayer was tested both in the laboratory and field for application and the field for application uniformity, discharge rate field capacity and field efficiency. The sprayer managed to maintain an average nozzle pressure of 1.8 bars during both the field and laboratory tests at an average speed of 1.4km/hr. The average nozzles discharge rate variation along travel distance reduced and attained an optimum discharge rate at the nozzles 30 m distance. On the other hand, the sprayer had a 16-litre tank and could only cover 0.075ha at a time and would require to refill the tank 14 times to cover an entire hectare this then meant that more time would be required to cover a single hectare. I believe the variation in the discharge of the nozzle was due to the low building up of pressure in the system and this problem can be counteracted if different gear modules are used so that pressure builds up fast in the system.

Shailesh et al. (2016) worked on the Design and Development of Multipurpose Pesticides Spraying Machine. The machine was driven by a rear-connected permanent magnet DC motor via a roller chain drive. This provided the necessary torque to operate on uneven terrains. The battery supplied power for spraying purposes and for the motor and a solar panel was supplied to the battery. A controller regulated the current supplied to the battery. The battery was removable and could be fully charged before being placed in the sprayer. The spray pattern of the pesticides could be controlled using a speed variable switch provided at the spraying unit. This allowed for precise spraying on crops. The authors were successful and stated that the spraying coverage increased per unit of time. However, although the machine was a success the use of batteries and motors made the machine more expensive to build. It can result in a lot of problems for those operating in different areas of farming making it more expensive. He also suggests the use of hollow coned nozzles for better performance and increased spraying efficiency.

In 2021, Kiran and his team embarked on the design and development of a wheeled sprayer. Their prototype, a wheel-operated sprayer, proved effective for dispensing spray solutions on vegetables. The sprayer is composed of a mainframe, a 16-litre knapsack tank, a wheel, driving and driven sprockets, a boom assembly, three nozzles, a chain and sprocket, a piston pump, a hose, a shaft, a bearing, and a connecting rod. The sprayer operates through two types of motion transmission within the system. A chain drive facilitates the transfer of rotational motion between two sprockets, and the rotary motion obtained from the chain drive is transformed into the reciprocating motion of the piston via a connecting rod. As the sprayer is propelled forward, the nozzles release the spray fluid onto chili plants. Despite the success of their project, the authors acknowledged some limitations and proposed future enhancements. These include increasing the number of nozzles from 3 to 6 to enhance field capacity, adjusting the sprayer according to plant size, installing a cut-off valve, and adding two supporting wheels for easier navigation and turning on wet and clay soils.

2.3 Conclusion

Diverse teams have executed numerous designs and developments, each yielding unique results. While solar-powered machines are efficient, their manufacturing costs are high and they require regular maintenance for prolonged product life. On the other hand, the mechanized wheel sprayer offers a plethora of benefits and is economically feasible for small to medium-scale farmers. However, recent advancements in wheel sprayers have certain drawbacks, such as a limited number of nozzles, restricted tank capacity, absence of a shut-off valve, and inconsistent nozzle discharge.

CHATPER 3
METHODOLOGY

3.1 Introduction

This chapter outlines the systematic approach taken to achieve the objectives of this project, which are to design, construct, and evaluate the efficiency of a wheel sprayer. The methodology is crucial as it provides a detailed roadmap of the procedures and techniques that will be used, ensuring the research is replicable and verifiable.

This chapter will detail the design process, including the principles and considerations that guide the creation of the wheelbarrow sprayer. It will also describe the construction process, detailing the materials used, the assembly process, and any challenges encountered. Finally, it will outline the methods used to evaluate the efficiency of the wheel sprayer, including the metrics for evaluation and the experimental setup.

3.2 User Requirements

To determine the user requirements, I conducted a survey of farmers in the Mashonaland area. The survey aimed to understand the challenges they face in spraying their crops and the methods or ways they would like to reduce their workload. The questions I asked included:

1. What are the limitations of using a knapsack sprayer?

2. Are drone sprayers or tractors easily accessible?

3. What are your suggestions for improving the spraying process?

4. What is your willingness to pay for a crop spraying device?

The responses from the interview highlighted the following user requirements:

1. The device requires less effort to operate.

2. Uniform spraying and simultaneous coverage of significant ground.

3. Minimum maintenance.

4. The cost should not exceed USD 50.

Additionally, during the farmer interviews, I asked about the crops they mostly grow and how often they need to spray.

3.2.1 Spraying Requirements for Sprayers

Knapsack sprayers are essential tools in agriculture, used to apply pesticides, herbicides, and fertilizers efficiently across a variety of crops. Their targeted application minimizes chemical wastage, reduces environmental impact, and enhances the effectiveness of pest control measures (Unveiling the Versatility of Knapsack Power Sprayers in Agriculture, 2024). The design and performance criteria for knapsack sprayers include lever-operated knapsack sprayers, motorized knapsack sprayers, compression sprayers, motorized mist blowers, and rotary atomizer sprayers. These requirements focus on operator safety, sprayer efficiency and durability, and minimizing environmental contamination risks.

Successful application with a knapsack sprayer necessitates clean water, the sprayer itself, chemical containers, liquid fertilizer/herbicide/fungicide, and the appropriate Personal Protective Equipment (PPE), including overalls, rubber boots, chemical-resistant gloves, and a face shield.

3.2.2 Target Crops for Knapsack Sprayer

Knapsack sprayers are specifically designed for crops under 100 cm tall, such as young tomato plants, cotton, sorghum, potatoes, sweet potatoes, rice, maize, wheat, barley, oats, soybeans, cassava, and sugar beet. They are primarily used for horticultural pesticide applications. These sprayers are ideal for selectively treating young crops that cover only a small portion of the land. For instance, at the critical stage of head formation in cabbages, knapsack sprayers can be both effective and economical. Additionally, they are suitable for spot spraying, particularly when individual plants are infested with pests, thereby preventing the need to treat the entire field.

3.3 Objectives

4. To design a cost effective wheelbarrow sprayer with increased spraying distance.
5. To construct a prototype of the wheelbarrow knapsack sprayer.
6. To evaluate the efficiency of the system in comparison with the old knapsack.

3.4 Conceptual design

The conceptual design phase involves CAD modelling and simulation to ensure the structural integrity of each component, as determined by analytical calculations. AUTOCAD is utilized to design and conduct finite element analysis, enabling the assessment of the wheelbarrow sprayer design's structural properties.

Figure 1 displays the CAD design of the wheelbarrow sprayer, providing a visual representation of its three-dimensional model. Additionally, the assembly drawing in Figure 2 showcases all the individual parts of the crop sprayer, offering a detailed overview of their arrangement and composition.

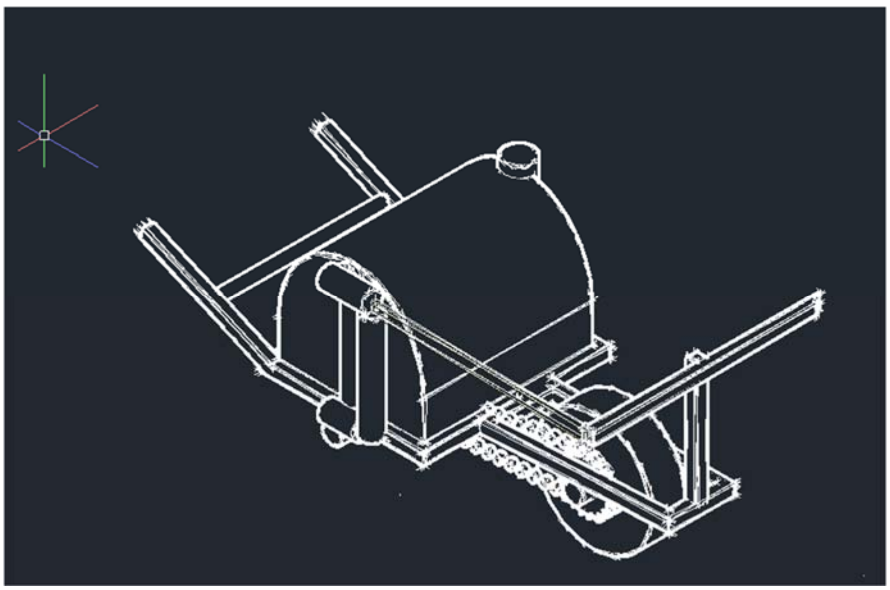

Figure 1 Design of the wheelbarrow sprayer

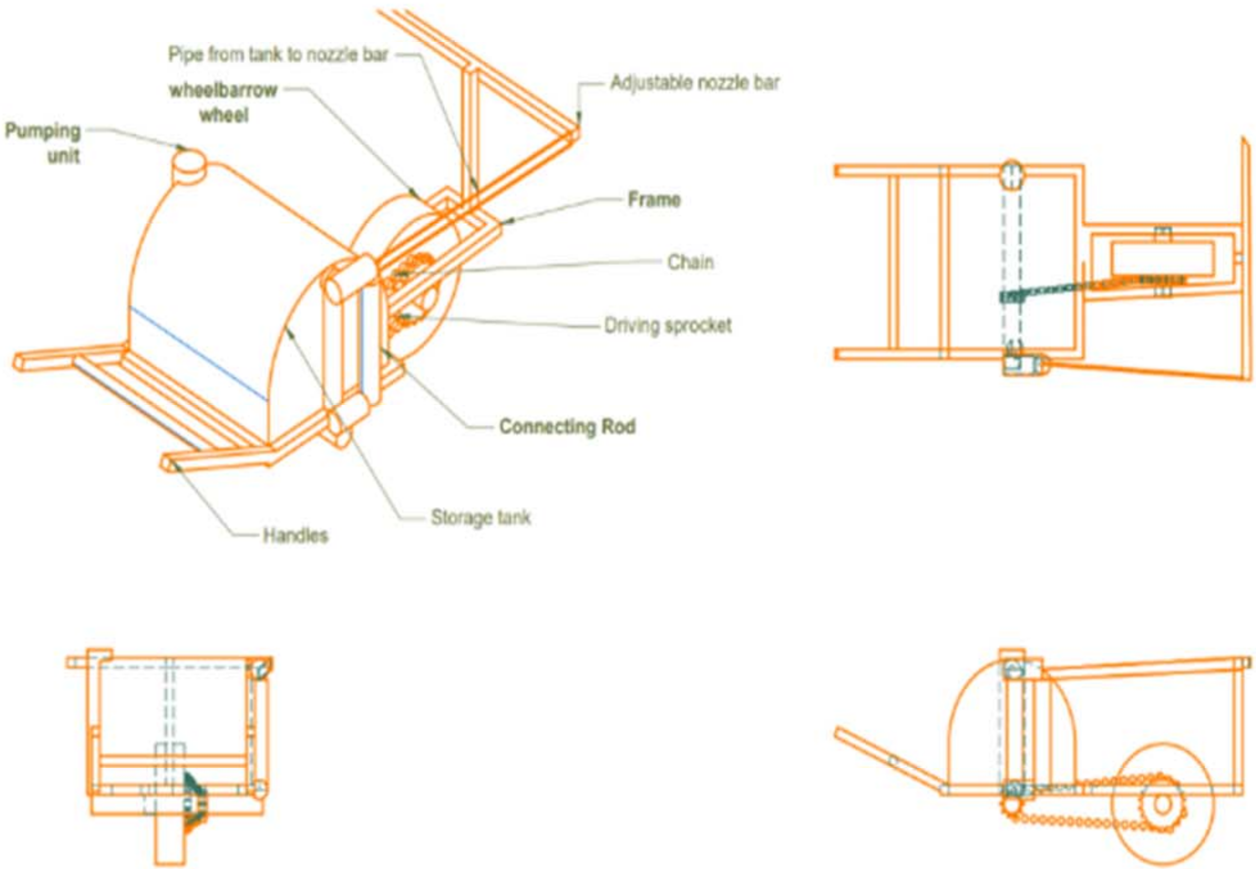

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Figure 2 Assembly drawing of the wheelbarrow sprayer

3.5 Detailed design and engineering

The hardware requirements play a crucial role in selecting the appropriate design from the proposed solutions. This project specifies the following specifications based on the reviewed literature and interviews with the farmers:

i. The device must be able to propel itself over rough terrain.

ii. The device should require a minimum manual effort to operate, less than 50% of the total load.

iii. Automatic pump and spray mechanism.

iv. Adjustable nozzle height and orientation.

v. Durability.

The wheel sprayer will cover a length of 2m and have 6 nozzles, which can be interchanged to meet the spraying requirements for droplet size and application rate. In addition to the outlined design parameters, other factors like the lack of electricity, maintenance shops, service stations, and knowledge capacity in rural areas are considered in designing the crop sprayer device.

The proposed device must be entirely manual, without the need for a charge or fuel to pump and propel the system. However, the device should require minimum manual labour and have an automatic pumping system capable of developing adequate pressure. The manual knapsack sprayers currently used by farmers require 100% lift effort and continuous rocking of the pump lever, which causes back pain and muscle fatigue. Therefore, the solution should address the shortcomings of knapsacks at an affordable rate.

The design is, therefore, focused on a wheel-driven crop sprayer with a gear-chain mechanism to operate the pump's lever. The wheeled frame reduces the required labour per load carried, and the gear-chain system can operate the pump's lever. The wheel-driven crop sprayer design requires the operator to apply a push or pull to move the device. The driving gear is attached to the rotating wheel, and it translates the motion to the driven gear via the chain. The driven gear then rocks the pump's lever. Thus, the continuous motion will pump and automatically spray the fluid. The rate of application is affected by the gear sizes and operating speed, hence the need to put multiple gears for easy adjustments.

3.5.1 Components sizing

This section outlines the critical components of the selected design to achieve the expected outcomes. The spraying pump, in particular, should achieve the desired flow rate, thus the gear-chain system is designed to provide sufficient pumping.

3.5.2 Gear Sizing

The wheelbarrow sprayer is designed to produce a desired test flow rate of 0.5 L/min while the operator moves at a regular walking speed. Research indicates that 51 pump strokes achieve 1.977 L/min. Therefore, this study estimates that 11 pump strokes reach a flow rate of 0.5 L/min.

To configure the gear sizes that provide sufficient rotation to produce the specified 11 pumping strokes, the operating speed of 1.4 m/s is converted to revolutions per minute. Given the 340 mm diameter wheel, the linear operating speed translates to a rotational speed that can be used to determine the appropriate gear ratios.

The gear-chain system is designed based on this analysis to ensure the spraying pump can achieve the targeted 0.5 L/min flow rate as the operator moves the wheelbarrow sprayer at a regular walking pace. The linear operating speed offers a rotational speed given by:

78.64 *Equation 1*

The driving sprocket is attached to the 340 mm diameter wheel, causing it to rotate at 79 revolutions per minute based on the 1.4 m/s operating speed. To achieve the target 0.5 L/min flow rate, the design requires 11 pumping strokes per minute. This means the driven gear needs to rock the pump's lever at 11 revolutions per minute. Therefore, the size of the driven gear must be selected to reduce the 79 RPM wheel rotation down to the required 11 RPM for the pump lever. This is calculated by determining the appropriate gear ratio:

7.2 *Equation 2*

An 18-teeth gear is specified as the driving gear from the available components. Thus, the gear ratio determines the size of the driven gear to be a 32-teeth gear.

3.5.3 Determining the connecting rod diameter

A small cylindrical rod connects the pump's lever to the driven gear. The size and material of this connecting rod need to be specified to ensure it does not fail under the applied stresses of rocking the pump's lever.

Research indicates the pump's lever requires a rocking force of approximately 75 N to create the sufficient pumping pressure. This force alternates between 0 N and 75 N during the pump's up-and-down pumping cycle. As a result, the connecting rod experiences repeated loading with alternating stresses. Let's define the variables:

Xmin = Minimum stress during the cycle (0 N)

Xmax = Maximum stress during the cycle (75 N)

The design must account for this alternating stress on the connecting rod to prevent failure. The size, material, and any other relevant specifications of the connecting rod need to be carefully selected based on the expected loading conditions.

Alternating loading $X_a = 0.5x\ (X_{MAX} - X_{MIN})$ *Equation 3*

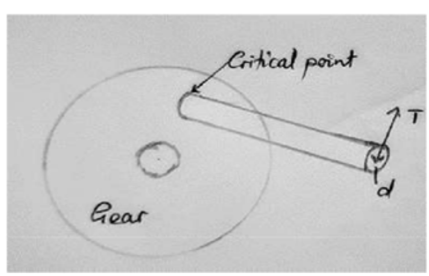
Mean loading $X_m = 0.5(X_{min} + X_{max})$ *Equation 4*

The diameter of the connecting rod needs to be determined based on the specified material, length, and an appropriate safety factor. This can be calculated using the Modified Goodman design equation:

Design against yield ط ض / ي يث ي *Equation 5*

Design against fatigue پ/ص ي/ض ي/ض *Equation 6*

Table 1 : Summary of pin sizing calculation

Parameter	Equation	Evaluation
Load Analysis	Bending, T~(0,75N) $P_m = P_a = \frac{72.6N}{2} = 37.5N$ L = 40mm $M_m = M_a = 1452Nmm$	

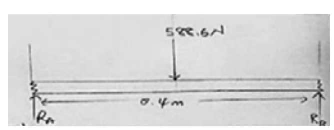
Stress Analysis	CP: At the weld attaching the rod and gear	$\sigma_a = \sigma_m = \frac{32M}{(\pi d^3)} = \frac{32(1452)}{\pi d^3} = \frac{14790}{d^3}$
Material Properties	Stainless steel 1020, CR	S_{ut} = 470 MPa; S_{yt} = 390 MPa S_{ys} = 0.577S_{yt} = 225 MPa S_f = 0.5S_{ut} = 235 MPa
DE and Solution	Modified Goodman	Operating Point P = $(\frac{14790}{d^3}, \frac{14790}{d^3})$ FOS n = 2
Design against yield	$n_y = \frac{S_y}{\sigma_m + \sigma_a}$; $2 = \frac{225}{2(\frac{14790}{d^3})}$	d = 6.41 mm
Design against fatigue	$\frac{1}{n_f} = \frac{\sigma_m}{S_{ut}} + \frac{\sigma_a}{S_e}$	d = 5.74 mm
Deduction	Failure by yielding	
Size selection	Standard size d = 6.5mm	N(actual) = 2.1

3.5.4 20mm square tube size for frame design

The wheelbarrow sprayer design calls for using a 20 mm square steel tube as the structural frame. The specific outer and inner dimensions of this square tubing need to be specified to ensure it can support the maximum expected load without yielding.

Table 3.2: Summary of 20mm square tube Estimation

Table 2: Summary of 20mm square tube Estimation

Load Analysis	Normal bending, T = 588N	
Stress Analysis	Normal bending stress	$\sigma_x = \frac{32 d_o M}{(\pi(d_o^4 - d_i^4))}$

Material Properties	Low-grade steel 1020, CD	S_{ut} = 470 MPa; S_{yt} = 390 MPa
Minimum size	Outer diameter d = 13.7mm	Thickness = 6.35mm

3.5.5 Complete List of Components

The analytical calculations have determined the appropriate sizes, materials, and specifications for the critical components of the wheelbarrow sprayer design. The following table summarizes the key details for all the parts:

Table 3.3 Component size and specifications

Table 3: Component size and specifications

Component	Dimensions	Material	Material specs
Frame	**400mm x 1200mm**	**20mm square tube heavy gauge**	**High strength, Lightweight**
Storage Tank	16L knapsack sprayer	PVC plastic	Impermeable, durable
Nozzle	0.5l/min nozzle Standard flat fan nozzles	PCV plastic	Lightweight, cheap
Wheelset	340mm diameter	Wheelbarrow wheel	Lightweight, readily available, and cheap
Gear set	18 T driving gear 24T driving gear 32 T driven gear	Steel	Lightweight and durable
Wheel Axle	12mm x 190mm	Steel	Durable
Nozzle bar	20mm x 2000mm	Square tube	Lightweight
Chain ring	3.175mm width	Steel	Durable

3.6 Prototype manufacturing

3.6.1 Materials used

Square tube and steel pipe

When designing and constructing a wheelbarrow sprayer, the choice of materials is critical to ensuring the device is durable, sturdy, and able to withstand the demands of agricultural use. Two key materials that offer significant advantages are square tube metal and 34mm steel pipe.

Square tube metal provides excellent structural integrity for the frame of the wheelbarrow sprayer. Compared to round tubing, the square shape offers greater resistance to bending and twisting forces, making it well-suited to bear the weight of the sprayer tank, pump, and other components. The uniform cross-section also allows for easy attachment of other parts through welding or fasteners. Additionally, square tubing has a high strength-to-weight ratio, enabling the construction of a lightweight yet robust frame.

The use of a 34mm steel pipe, particularly for the wheelbarrow's axle and handles, further enhances the durability and longevity of the design. Steel is an inherently strong and resilient material that can withstand the rigours of rugged terrain and heavy loads. The 34mm diameter provides ample load-bearing capacity to support the overall weight of the sprayer, while still maintaining a manageable size and weight for manual operation. Steel pipes are also corrosion-resistant, ensuring the critical structural components of the wheelbarrow sprayer can withstand exposure to chemicals, moisture, and other environmental factors encountered during agricultural use.

Together, the square tube metal and 34mm steel pipe create a stable, sturdy, and long-lasting framework for the wheelbarrow sprayer. This combination of materials helps to ensure the device can reliably and safely transport and dispense agricultural chemicals, even in challenging field conditions. The inherent strength and durability of these components contribute to the overall robustness and service life of the wheelbarrow sprayer, making it a practical and dependable tool for farmers.

Figure 3: 20mm square tube gauge and 34mm steel pipe

3.6.2 Tank Selection and Materials

For the sprayer tank, the design leverages an existing knapsack sprayer system. This provides several benefits - the knapsack sprayer already includes an integrated pumping mechanism and agitation system, reducing the complexity of the overall wheelbarrow sprayer design.

The knapsack sprayer tank itself is constructed using high-density polyethylene (HDPE). This material is an excellent choice for the application, offering a range of advantageous properties. HDPE is highly versatile, making it one of the most widely used plastics in the world. It is relatively low-cost and easy to process, allowing for straightforward fabrication of the tank component. Importantly, HDPE also demonstrates excellent chemical resistance, enabling it to safely contain and dispense the agricultural chemicals used with the wheelbarrow sprayer without risk of degradation or leaching.

In addition to its cost-effectiveness and compatibility with the target chemicals, HDPE provides good flexibility and impact resistance. This helps the tank withstand the bumps and vibrations encountered during field operations, without becoming brittle or cracking. The material's availability is another key benefit - HDPE is readily accessible, making replacement or repair of the tank a simple matter if needed over the lifespan of the wheelbarrow sprayer.

By integrating the proven knapsack sprayer tank design, constructed from the durable and cost-effective HDPE material, the wheelbarrow sprayer can leverage an existing, reliable liquid containment and delivery system. This streamlines the overall development process while ensuring the tank component meets the necessary performance and safety requirements for the application.

Figure 4 knapsack sprayer tank

3.6.3 Alloy Steel Driving System Components

The driving system at the heart of the wheelbarrow sprayer's operation relies on several key components constructed from alloy steel. This specialized material provides a combination of strength, durability, and cost-effectiveness that makes it ideally suited for this application.

For the wheelbarrow sprayer's driving system, the sprockets - both the driving sprocket connected to the wheel and the driven sprocket that powers the pump - are fabricated from alloy steel. This material choice ensures the sprockets can reliably transmit the rotational forces from the wheels to the pump linkage, even under the strain of heavy loads or rugged terrain. The inherent strength and wear resistance of alloy steel help maintain the precise alignment and engagement of the sprocket teeth over the lifespan of the device.

Complementing the alloy steel sprockets is the roller chain that forms the mechanical link between the two sprockets. Again, the use of alloy steel provides the necessary durability to withstand the repeated cycling and tensile forces experienced as the chain rotates. The chain's robust construction helps prevent elongation, kinking, or premature failure that could compromise the driving system's performance.

By strategically employing alloy steel for the sprockets and chain, the wheelbarrow sprayer's design capitalizes on the material's advantageous properties. This not only ensures the reliable and efficient operation of the driving system but also does so in a cost-effective manner compared to higher-end stainless steel alternatives. The result is a durable, practical, and economical powertrain that seamlessly translates the operator's manual input into the pressurized spray output required for effective agricultural applications... Alloy steel material is shown in Fig below

Figure 5: Driving gear

Figure 6: Driven gear

Figure 7: Chain

3.7 Development of wheelbarrow sprayer

The components of developed wheelbarrow sprayer are main frame, sprayer tank, wheel, driving and driven sprockets, boom assembly, nozzle, chain, piston pump, hose, shaft, Plummer block bearing and connecting rod.

3.7.1 Main Frame Design and Fabrication

At the core of the wheelbarrow sprayer's structural integrity is the main frame, which serves as the foundation for supporting the entire assembly. This critical component is fabricated using 20mm square steel tubing of a heavy gauge thickness, ensuring the frame can withstand the substantial loads and stresses it will encounter during operation.

The choice of 20mm square tubing provides several key advantages. Firstly, the uniform cross-section of the square profile allows for easy attachment and integration of the other system elements, such as the wheel assembly, tank, and pump. This uniform geometry simplifies the welding and assembly process compared to using round tubular stock.

Importantly, the heavy gauge thickness of the 20mm square tubing imparts exceptional strength and rigidity to the frame. This robust construction enables the main frame to reliably carry the full weight of the sprayer's components, including the tank when filled with liquid, without succumbing to bending, twisting, or other structural deformation. The frame's ability to maintain its integrity is crucial for preserving the proper alignment and functionality of the entire sprayer system.

To fabricate the main frame, the 20mm square tubing sections are carefully cut to length and then joined together using arc welding. This welding technique ensures a durable, permanent connection between the frame members, creating a unified structure that can withstand the dynamic loads and impacts experienced during field use.

In designing the frame's dimensions, the length and width were selected based on the overall sprayer system requirements. The final dimensions of 140cm length and 40cm width provide ample space to accommodate the tank, pump, and other components while still maintaining manoeuvrability. Importantly, the frame was also designed with ergonomic considerations in mind, positioning the handles at a comfortable height for the operator to push or pull the sprayer.

By anchoring the sprayer's architecture to this robust, well-engineered main frame, the overall design ensures the device can reliably and safely perform its essential agricultural spraying functions, even in demanding field conditions. The frame's structural integrity is a fundamental aspect that enables the wheelbarrow sprayer to deliver efficient and durable service to its users.

Figure 8: Main frame with wheel

3.7.2 Wheelbarrow Wheel Design and Integration

A critical component of the wheelbarrow sprayer's mobility and functionality is the wheel assembly. Rather than using a standard pneumatic tire, the design leverages a wheelbarrow-style wheel, which offers several key advantages.

The wheelbarrow wheel is typically constructed from a durable, solid rubber or polymer material that is highly resistant to punctures, cuts, and other damage that could result from navigating rugged terrain. This solid construction eliminates the need for air-filled tires that may be prone to flats or require periodic maintenance and repair. The robust nature of the wheelbarrow wheel ensures the sprayer can be easily maneuverer across uneven ground, through mud, over rocks, and other challenging field conditions without concern for tire-related issues.

The wheelbarrow wheel selected for this design has a diameter of 35.6 cm (14 inches). This generous size provides ample ground clearance and smooth rolling characteristics, allowing the sprayer to be pushed or pulled with minimal effort by the operator. The large wheel diameter also helps to distribute the weight of the full sprayer system over a wider area, reducing the risk of the unit sinking into soft soil or getting stuck.

Importantly, the driving mechanism that powers the sprayer's pump is directly integrated with the wheelbarrow wheel. A driving gear is welded directly onto the same axle shaft as the wheel, creating a unified assembly. As the wheel rotates when the sprayer is moved, this driving gear transfers the rotational motion to the pump's input, providing the necessary mechanical power to operate the spraying function.

This streamlined integration of the wheel and driving gear not only enhances the system's overall efficiency but also simplifies the design and assembly process. By avoiding the need for additional mechanical linkages or transmissions between the wheel and pump, the design minimizes complexity, potential failure points, and maintenance requirements.

The robust construction of the wheelbarrow wheel, combined with its seamless incorporation into the driving system, makes it a pivotal element in the wheelbarrow sprayer's mobility, reliability, and user-friendly operation. This thoughtful design choice helps to create an agricultural tool that can withstand the rigors of field use while remaining easy for the operator to manoeuvre and control.

Figure 9: wheelbarrow wheel

3.7.3 Sprayer Tank Design and Specifications

At the heart of the wheelbarrow sprayer's functionality is the tank that holds the liquid spray solution. Given the need to maximize the sprayer's capacity and versatility while minimizing overall weight, the design incorporates a standard 16-liter plastic tank commonly used in knapsack-style sprayers.

The choice of a plastic tank material offers several key benefits. Firstly, the inherent low weight of plastic helps to keep the total loaded weight of the sprayer manageable, allowing for easier manoeuvring and reduced operator fatigue during use. Additionally, plastic tanks are well-suited to withstand exposure to the agricultural chemicals and pesticides that will be stored and dispersed by the sprayer.

The specific tank selected for this design measures 420mm in length, 360mm in width, and 180mm in depth. This compact yet sizable 16-liter capacity provides ample volume to hold a sufficient quantity of spray solution for effective coverage of agricultural fields or plantings, while still maintaining overall sprayer dimensions that are easy for the operator to handle.

The tank's dimensions were carefully chosen to optimize the sprayer's balance, stability, and ergonomics. The length and width measurements allow the tank to be positioned centrally on the main frame, distributing the weight evenly over the wheel assembly. Meanwhile, the 180mm depth provides enough vertical clearance to accommodate the pump, plumbing, and other components without making the overall sprayer unit overly tall or top-heavy.

By integrating this standardized plastic tank into the wheelbarrow sprayer design, the engineers have successfully blended proven components with thoughtful dimensional planning. This approach ensures the sprayer can carry a meaningful volume of spray solution while maintaining a compact, manoeuvrable, and user-friendly form factor.

The figure below illustrates the specific tank that has been selected and integrated into the overall wheelbarrow sprayer system. Its dimensions and capacity make it well-suited to fulfil the spraying requirements while complementing the other design elements for a cohesive, functional agricultural tool.

Figure 10: Knapsack sprayer tank

3.7.4 Tank Support Frame Design and Fabrication

In addition to the main structural frame of the wheelbarrow sprayer, the design incorporates a specialized secondary frame to securely hold and position the spray tank. This supplementary frame is fabricated using flat metal stock with a diameter of 31mm.

The tank support frame is constructed in a rectangular shape, with dimensions of 350mm in length and 230mm in width. This size and configuration allow the frame to encompass approximately one-third of the overall footprint of the 16-litre spray tank, providing a stable and robust platform to house the liquid container.

To fabricate this secondary frame, seven individual metal rods, each with a diameter of 6mm, are carefully welded together. The use of multiple, smaller-diameter rods, as opposed to a single larger-diameter piece, enhances the frame's structural integrity and resistance to deformation under the weight of the filled tank.

The tank support frame is then securely welded to the main sprayer frame, integrating it as a cohesive unit. This integrated design ensures the spray tank is firmly anchored in place, preventing any unwanted shifting or movement during operation that could adversely affect the sprayer's performance or stability.

The figure below illustrates the fabricated tank support frame, showcasing its rectangular shape and the individual 6mm metal rods that comprise its construction. This thoughtful design feature, combined with the robust main frame, creates a holistic structural system capable of safely and reliably carrying the spray tank, even when it is filled to its 16-liter capacity.

By incorporating this dedicated tank support frame, the wheelbarrow sprayer design demonstrates an attention to detail and engineering principles that prioritize the system's overall stability, durability, and functionality. This thoughtful approach helps to ensure the sprayer can fulfil its intended agricultural applications with efficiency and dependability.

Figure 11: Frame and tank mounted

3.7.5 Spray Boom Assembly and Integration

A critical component of the wheelbarrow sprayer's spray delivery system is the boom assembly. This assembly consists of a pipe that is outfitted with multiple nozzles to distribute the liquid spray solution from the tank across a wider coverage are of 2m.

The boom assembly selected for this design features six individual nozzles spaced along the 320mm length of the flexible pipe attached to a steel bar. This configuration allows for more uniform and effective application of the spray solution to the target crops or plantings.

The boom is securely mounted to a vertical frame that is allows for height adjustment. This allows for a wide range of crops of different height to be sprayed. The figure below illustrates the spray boom assembly and its integration into the overall wheelbarrow sprayer design:

Figure 12: Boom assembly

3.7.6 Spray Nozzle Selection and Integration

A critical element of the wheelbarrow sprayer's spray delivery system is the selection and integration of the nozzles. These components play a vital role in converting the pressurized liquid from the tank into a precisely dispersed spray pattern, ensuring the spray solution is applied effectively to the target plants or crops.

For this design, six interchangeable plastic nozzles have been selected and fitted onto the brass boom assembly. These nozzles are spaced at regular 320mm intervals along the 800mm boom length. The use of multiple nozzles helps to provide uniform coverage across a wider swath as the sprayer is maneuverer through the field.

The plastic construction of the nozzles offers several key benefits. Plastic nozzles are lightweight, durable, and resistant to the corrosive effects of the agricultural chemicals and pesticides that will be used in the sprayer. This material selection helps to maximize the lifespan and reliability of the nozzle components, which are critical to the overall performance and longevity of the sprayer system.

To further protect the nozzles and ensure they remain in optimal condition, each one is outfitted with a plastic cap. These protective covers shield the nozzle orifices from debris, damage, and premature wear, helping to maintain the sprayer's spray pattern consistency and efficiency over extended periods of use.

The interchangeable nature of the nozzles is an important design feature, as it allows the operator to easily swap out individual components if they become worn or clogged. This facilitates simple maintenance and troubleshooting, enabling the sprayer to continue operating at peak performance levels throughout its service life.

By carefully selecting and integrating these specialized nozzle components, the wheelbarrow sprayer design ensures the pressurized liquid spray is transformed into a fine, precisely distributed mist that can be accurately applied to the target crops or plantings. This attention to detail in the spray delivery system is a key contributor to the overall effectiveness and efficiency of the sprayer in agricultural applications.

Figure 13: 0.5L/min nozzles and pipe

3.7.7 Connecting rod

This is used to connect the piston of sprayer pump to the shaft. Connecting rod is made of mild steel. Length is measured using measuring tape. Connecting rod is attached to the piston pump by using a pin and locked to avoid the detachment from the sprayer assembly. The length of connecting rod is 400mm. Fig below

Figure 14: Connecting from tank pump to shaft

3.8 Assembly and integration

Working principle

3.8.1 Motion transmission by chain and sprockets arrangement

Chain drive is a way of transmitting mechanical power from one place to another especially when the distance between the centres of the shafts is short such as in bicycles, motor cycles, agricultural machinery, road rollers, etc. No slip takes place during chain transmission (Poratkar*et.al*, 2013).A roller chain which is extremely strong and simple in construction is used for the development of wheel sprayer. It gives good service under severe conditions. Sprocket with integral hub is used in chain drive.

3.8.2 Slider crank mechanism

A slider crank mechanism is used to convert straight-line motion to rotary motion, as in a reciprocating piston engine, or to convert rotary motion to straight-line motion, as in a reciprocating piston pump (Poratkar*et.al*, 2013).

In the developed wheel sprayer, rotary motion obtained to crank from chain drive is converted into reciprocating motion of the piston with the help of connecting rod. Thus the desired pressure is achieved by compression and spray solution is discharged from the nozzle. The crank is attached to one of the rotating wheel and other end is attached to the reciprocating pump. The wheels are fixed on main axle and cranking is on the other axle which pushes the piston rod in and out of the cylinder, pumping the air pressure into the tank. The spray tank fitted on the frame consists of spray solution and is connected on the protruded rod and jet is set for the required pitch. Operator by holding the handles of wheel sprayer, it is being pushed which causes the wheel to rotate. The chain sprocket arrangement is driven by the wheel, which in turn rotates the slider crank, creating pressure in piston pump. The final outcome of the machine is that the push force of the operator is converted finally to the pressure energy and the fluid is sprayed. This equipment has an air pump which compresses air into the tank and pressurizes the spray mixture. The pressure slowly drops as the liquid is sprayed. The amount of pressure created causes the spray solution to flow out of the tank. The spray solution propel out through the nozzle and sprayed on plant surface

3.8.3 Working of wheel sprayer

The operator pushes the handle of the developed wheel sprayer in forward direction. When the wheel rotates then the gear sprocket mounted on wheel also rotate at same speed. The chain drive transfers the motion of driving sprocket to driven sprocket. The driven sprocket and connecting rod is mounted on either side of same shaft. The rotary motion of shaft is converted into the reciprocating motion of pump with the help of crank and connecting rod mechanism.

The reciprocating motion of piston pump produces desired pressure for spraying the spray solution through nozzles. Since the wheel, sprockets and chain are of bicycle type, the spraying of the pump occurs only in the forward motion of developed wheel sprayer by the operator. When the wheel sprayer moves in the forward direction, the piston pump reciprocates which causes the spray solution to discharge through the boom assembly and droplets are sprayed on plant surface by the spray nozzles.

FLOW CHART OF WORKING PRINCIPLE OF MACHINE

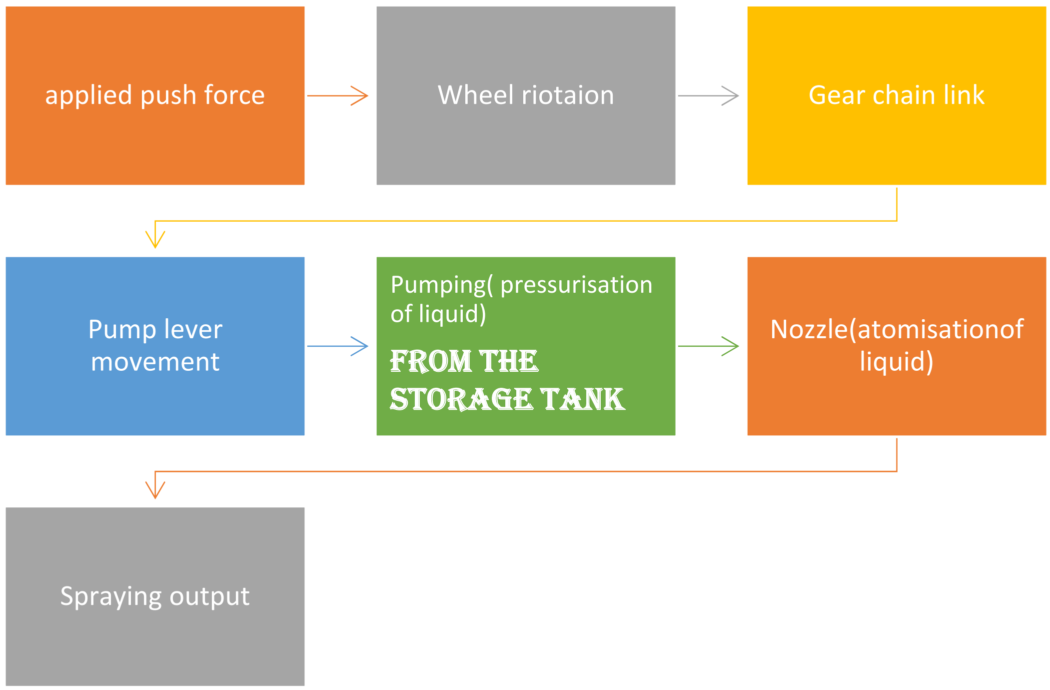


Figure 15: Flow chart of working principle of machine

3.9 Testing and evaluation

3.9.1 DESIGN CONSIDERATIONS FOR THE WHEEL BARROW SPRAYER

The design of the wheelbarrow sprayer aims to achieve specific performance criteria. These include minimizing the manual effort required for pushing the sprayer, ensuring it remains below 50% of the load (not exceeding 250 N). Analytical calculations indicate that a manual push equivalent to 27% of the load is necessary to move the sprayer through firm mud. Additionally, the design accounts for a lift force equal to 46% of the load, measured from the wheel axle.

To optimize fluid delivery, the selected gear sizes result in a flow rate of 0.5L/min at an operating speed of 1.4 m/s. Experimental testing will validate these design requirements, particularly assessing the achievable flow rate and the manual labor needed to operate the device effectively.

Table 4: Table of expected outcomes

Parameter	Expectation
Max manual push	≤ 60%
Manual push in firm mud condition	27% of the load
Lift force requirement	30%
Flow rate	0.5L\min
Operating speed	$1.4ms^{-1}$

Experimental Procedure Experimental testing was done to determine the flow rate of the wheelbarrow sprayer at average walking speed. The outflow from the two end nozzles was collected using transparent bottles as the sprayer was pushed across a 75-metre distance. Five pumping strokes were allowed to create enough pressure before releasing the flow trigger. The sprayer was moved at different speeds, timing each interval. The total collected volume in each test was measured using a measuring cylinder. At least 25 trials were performed for this procedure. The obtained flow rate readings were plotted against the operating speeds to determine the required speed for the desired test flow rate of 0.5L/min.

3.10 Bill of quantises

Table 5: Bill of quantises

ITEM	QUANTITY	PRICE USD
20MM SQUARE TUBE	6M	7
DRIVEN SPROCKET	1	3
DRIVING SPROCKET	1	3
CHAIN	1	2
KNAPSACK SPRAYER TANK	1	11
WHEELBARROW WHEEL	1	5

34MM STEEL PIPE	3M	5
NOZZLES	6	3
TOTAL		39

CHAPTER 4

Analysis and Presentation of Data

4.1 Overview

In this chapter, we delve into the comprehensive study carried out on farmers utilizing pesticides and herbicides in their crop spraying practices. The primary aim of this study was to develop an innovative spraying product that would surpass the limitations of manual backpack sprayers by delivering substantial time savings and enhanced efficiency. The development process involved careful consideration of crucial factors such as safety, ergonomics, and technological feasibility to ensure optimal outcomes.

4.2 Inclusive Design Considerations

The design of the spraying machine was driven by the objective of creating a product that could be utilized by a wide range of individuals, including women, young children, and people with disabilities, with utmost ease and minimal exertion. Inclusive design principles were embraced to ensure accessibility and usability for all users.

Ergonomics constituted a key aspect of the design, with a focus on reducing strain on various parts of the operator's body, including the legs, arms, shoulders, lower back, and knees. The sprayer was ergonomically optimized to promote comfortable handling and operation. Efforts were made to minimize physical exertion and fatigue, allowing operators to perform spraying tasks for extended periods without discomfort or undue strain.

By prioritizing inclusive design considerations, safety, and ergonomics, the wheelbarrow sprayer achieved a user-friendly and accessible design. The aim was to empower a diverse range of individuals, regardless of age, gender, or physical abilities, to utilize the machine effortlessly and efficiently.

4.3 Technological Considerations for the Wheelbarrow Sprayer

The design of the wheelbarrow sprayer was specifically tailored to align with the technological capabilities of the immediate Zimbabwean environment. This approach ensured that the sprayer could be easily manufactured, assembled, cleaned, and repaired, taking into account the available resources and infrastructure.

In terms of manufacturing, the design of the wheelbarrow sprayer was optimized for efficient production processes. The components and materials selected were readily available and suitable for local manufacturing capabilities, enabling cost-effective production.

Cleaning and maintenance of the nozzles and machinery were also key considerations in the design. The wheelbarrow sprayer was designed with accessible parts and components that could be easily disassembled for cleaning and maintenance purposes. This facilitated regular upkeep and ensured the longevity of the sprayer, reducing the need for frequent repairs or replacements.

By tailoring the design to the technological capabilities of the local environment, the wheelbarrow sprayer provided a practical and efficient solution for farmers and gardeners in Zimbabwe. The emphasis on easy manufacture, assembly, cleaning, and repair enhanced the accessibility and usability of the sprayer, contributing to its overall effectiveness and long-term sustainability.

4.4 Performance Evaluation of the Wheelbarrow Sprayer

The performance evaluation of the wheelbarrow sprayer encompassed various factors to assess its effectiveness and efficiency compared to manual knapsack sprayers. The evaluation considered the following key aspects:

1. Spraying Efficiency: The sprayer's ability to deliver the intended spray coverage and distribution was evaluated. Factors such as spray pattern, droplet size, and uniformity of application were assessed to determine the sprayer's efficiency in delivering the desired amount of liquid onto the crops.

2. Manual Push Effort: The amount of effort required to push the wheelbarrow sprayer during operation was measured. This evaluation aimed to determine the level of physical exertion needed by the operator, considering factors such as weight distribution, ease of manoeuvrability, and terrain adaptability.

3. Lift Effort: The evaluation also assessed the effort required to lift the wheelbarrow sprayer when needed, such as during transportation or manoeuvring over obstacles. The design aimed to minimize the lifting effort for the operator, ensuring ease of use and reducing physical strain.

4. Uniform Spraying Coverage: The evaluation examined the sprayer's ability to achieve uniform coverage across the target area. This included assessing factors such as spray drift, overlapping, and

potential areas of under or over-application. The goal was to ensure consistent and effective spraying throughout the crop field.

5. Operational Variables: Various operational variables were considered during the evaluation, including spray pressure, nozzle selection, and calibration. These factors influenced the sprayer's performance and were analysed to optimize its efficiency and effectiveness in different spraying scenarios.

Through the performance evaluation, the wheelbarrow sprayer was compared against manual knapsack sprayers, with the assumption that the machine would provide higher efficiency and improved performance. The evaluation aimed to validate these assumptions and provide insights into the advantages and benefits of using the wheelbarrow sprayer over manual alternatives in terms of spraying efficiency, operator effort, uniform coverage, and other operational aspects.

4.5 Evaluation

The use of wheel sprayers is an effective solution for crop control, saving time, and reducing costs compared to manual methods. Wheel sprayers contribute to increased crop productivity. Proper planning, including farm design, is essential for smooth operations with wheel sprayers. The dependence on manual labour is minimized, resulting in cost savings. Although wheel sprayers require a higher initial investment, the return on investment is obtained quickly and proves more profitable in the long run.

4.5.1 Fabrication of the Wheelbarrow Sprayer

To fabricate the wheelbarrow sprayer, the following steps were taken:

1. Frame Construction: A sturdy frame was constructed using a 20mm square tube steel, measuring 400mm x 1200mm. This frame provided the foundation and structural support for the entire sprayer assembly.

2. Wheel and Axles: Two axles were added to the frame to support the wheel and driven sprocket. These axles allowed for smooth rotation of the driven sprocket, ensuring easy pumping and spraying of the sprayer.

3. Drive Mechanism: A driving sprocket was incorporated into the design and connected to the driven sprocket using a chain. This drive mechanism enabled the rotation of the driven sprocket, which played a crucial role in the sprayer's operation.

4. Detachable Nozzle Bar: A detachable nozzle bar was bolted to the frame. This bar could be adjusted in height to accommodate different spraying needs. It allowed for varying the nozzle height from ground level up to 1 meter.

5. Knapsack Sprayer Tank: A single 16-liter knapsack sprayer tank was securely fitted onto the frame. This tank served as the main reservoir for holding the liquid to be sprayed. Its placement on the frame ensured stability during operation.

6. Pumping Lever: The pumping lever, connected to the driven gear, was integrated into the design. This lever allowed the operator to build up pressure within the sprayer tank by leveraging the rotational movement of the driven gear.

7. Pipes, Nozzles, and Flow Trigger: The necessary pipes, nozzles, and flow trigger were also attached to the sprayer assembly. These components facilitated the flow of liquid from the tank to the nozzles, which were responsible for dispersing the spray. The flow trigger allowed the operator turn the flow on and off, and maintain desired pressure build-up before spraying.

By following these fabrication steps, the wheelbarrow sprayer was successfully assembled. Its construction included the frame, wheels, drive mechanism, detachable nozzle bar, knapsack sprayer tank, pumping lever, pipes, nozzles, and flow trigger. This fabrication process resulted in a versatile and efficient sprayer, offering adjustable nozzle height, controlled flow, and proper pressure management for effective crop spraying. The figure below depicts the wheelbarrow sprayer:

Figure 16: Image of the wheel barrow sprayer

4.5.2 Manual Push Testing:

To assess the manual effort required to move the wheelbarrow sprayer, a series of tests were conducted on three different field types: mud, loose sand, and lawn grass. The purpose was to evaluate the ease of pushing the sprayer across various soil conditions.

For each soil type, a representative sample was prepared outside to mimic the conditions of a crop field. The wheelbarrow sprayer was placed on each sample, and an operator pushed the sprayer to simulate movement across the field. The manual effort required to push the sprayer was carefully observed and recorded during each test.

The purpose of conducting these manual push tests was to gauge the sprayer's manoeuvrability and assess its performance in different soil conditions. By evaluating the effort needed to push the sprayer across mud, loose sand, and lawn grass, valuable insights were gained regarding its usability and adaptability to various field types.

The results of these manual push tests provided valuable data for understanding the sprayer's performance characteristics and determining its effectiveness in different agricultural settings. This information helps users make informed decisions when utilizing the wheelbarrow sprayer for crop spraying tasks.

The key variables measured and recorded during the experimental testing of the wheelbarrow sprayer design include:

Flow Rate: The volumetric fluid discharge rate from the two nozzles, measured in litres per minute.

Manual Push Force: The amount of force required to manually push the wheelbarrow sprayer device when loaded with a 20 kg payload.

Lift Force: The effort needed to raise the filled sprayer to the desired operational height.

These variables provide important performance data points that characterize the sprayer's functionality and ease of use. The flow rate indicates the system's pumping capacity and spraying output. The manual push and lift forces quantify the physical effort required by the operator to transport and deploy the sprayer in the field.

Measuring and analysing these variables through the experimental procedures helps validate the design's performance against the target specifications and user requirements. This data can then be used to optimize the sprayer's ergonomics, pumping efficiency, and overall usability in real-world agricultural applications.

4.6 Testing observations

During the experiment conducted to examine the relationship between flow rate and operating speed of the wheelbarrow sprayer, the following observations were made:

1. Flow Rate and Operating Speed: It was noted that as the operating speed of the sprayer increased, the flow rate also increased. This implies that higher speeds resulted in a greater amount of liquid being sprayed onto the crops.

2. Atomization of Fluid: Additionally, the atomization of the fluid at the nozzles was observed to increase with higher operating speeds. This means that the liquid was being converted into finer droplets, potentially enhancing spray coverage and effectiveness.

3. Excessive Spray Drift: However, the testing revealed that the wheelbarrow sprayer exhibited excessive spray drift at higher speeds. Spray drift occurs when the spray is carried away by the wind, leading to inaccurate application and potential wastage.

4. Windy Conditions: The spray drift was particularly pronounced during tests conducted in windy conditions, especially when the nozzles were positioned at their maximum height. The increased nozzle height exposed the spray to stronger wind currents, causing it to be blown away.

5. Challenges in Windy Conditions: These observations indicate that applying agrochemicals using the wheelbarrow sprayer can be challenging in windy conditions. The wind can significantly affect the spray pattern and result in inefficient application. Special precautions and adjustments are necessary to overcome these challenges.

6. Normal Spray Drift at Walking Speed: On the other hand, when the sprayer was operated at an average walking speed, the spray drift was within acceptable limits. This suggests that maintaining a moderate speed during operation can help reduce spray drift and ensure more accurate targeting of the intended areas.

These testing observations provide valuable insights into the behaviour of the wheelbarrow sprayer under different operating speeds and wind conditions. They emphasize the need for careful speed control and consideration of environmental factors to optimize spraying results while minimizing spray drift.

4.7 Results and analysis:

This section presents the findings from the conducted experimental tests, along with an analysis of the results. Additionally, the challenges encountered during each test will be highlighted to provide context for the obtained results. The analysis will also evaluate the success criterion of achieving the desired flow rate.

4.7.1 Flow Rate Results

The results of the flow rate variation with operational speed are displayed in the accompanying figure. The figure illustrates that as the operational speed and pumping stroke frequency increase, the flow rate also increases. A regression model was fitted to the plotted measurements, indicating that 97% of the measurements align with the model. Although some variations can be observed in the figure, the majority of the data follows the predicted model.

It was determined that the desired test flow rate of 0.5L/min was achieved at an operating speed of 1.45 m/s. The gear sizing was designed to attain this flow rate at an average walking speed of 1.4 m/s. Therefore, the obtained speed was 3.5% higher than the expected value. The difference between the predicted and experimental values can be attributed to factors such as extra volumes collected after interval timing ceased, inconsistencies in timing, and pressure fluctuations resulting from challenges in maintaining a consistent speed during each interval.

However, the overall results demonstrate that the selected gear sizes were successful in achieving the desired flow rate at an average walking speed. Despite the slight deviation from the expected value, the analysis confirms the viability of the gear sizing approach for achieving the desired flow rate.

The analytical evaluation of the results provides valuable insights into the relationship between operational speed and flow rate. It validates the effectiveness of the chosen gear sizes to achieve the target flow rate, despite some technical challenges and minor deviations.

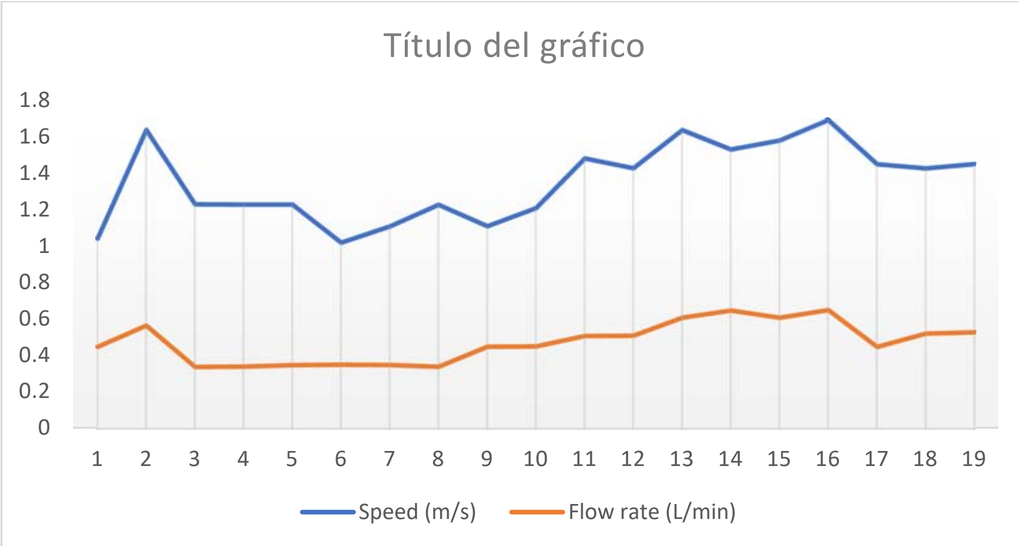


Figure 17: Flow rate of the sprayer with relative to the speed

4.7.2 Manual push results

The figure presented illustrates the manual push required to move the wheelbarrow sprayer across three different soil samples. The figure indicates a slight variation in the recorded manual push readings. However, it is determined that the average manual push adequately represents the effort needed to move the wheelbarrow sprayer in each soil type.

The figure depicts that the manual push readings remained below the 250 N limit, which corresponds to 50% of the load. This suggests that the wheelbarrow sprayer can be easily pushed in the tested field conditions. Notably, the manual push required for loose sand is significantly higher compared to the other soil types, nearing the 250 N limit.

Under firm mud conditions, it was estimated that a manual push equivalent to 27% of the load is sufficient to propel the device. However, experimental results indicate that the average manual push corresponds to 32% of the load in such conditions. It should be noted that the specific composition of the mud and the type of rubber tire used to estimate rolling resistance were not specified in the reference text. Additionally, experimental errors, such as inconsistencies in the applied push force and the gradual degradation of the compacted soil's firmness, may contribute to the observed deviation in the results.

Nevertheless, the overall findings suggest that the wheelbarrow sprayer requires a relatively low manual effort, as it remains below 50% of the carried load. This indicates that the sprayer can be easily maneuverer by the operator, ensuring efficient operation in agricultural fields.

Figure shows the manual push required to move the device across three soil samples, and the actual collected data is in Appendix A.8. The figure shows a small deviation in the obtained readings of the applied manual push. Thus, the average manual push can fully describe the effort required to move the crop sprayer in each soil type. The figure depicts that the manual push stayed below the 250 N limit (50% of the load); thus, the crop sprayer can be pushed easily in the tested field conditions. However, loose sand requires significant manual push close to the 250N limit compared to the other soil types. It was estimated that a manual push equivalent to 27% of the load is sufficient to propel the device under firm mud conditions. Experimentally, the average manual push is equivalent to 32% of the load carried under firm mud conditions. However, the referred text did not specify the mud composition and the type of rubber tire used to estimate the rolling resistance. Also, experimental errors, including inconsistently applied push and the gradual degradation of the rammed soil's firmness, contribute to the deviation of the results. However, the results show that the crop sprayer requires a reduced manual effort which is less than 50% of the carried load.

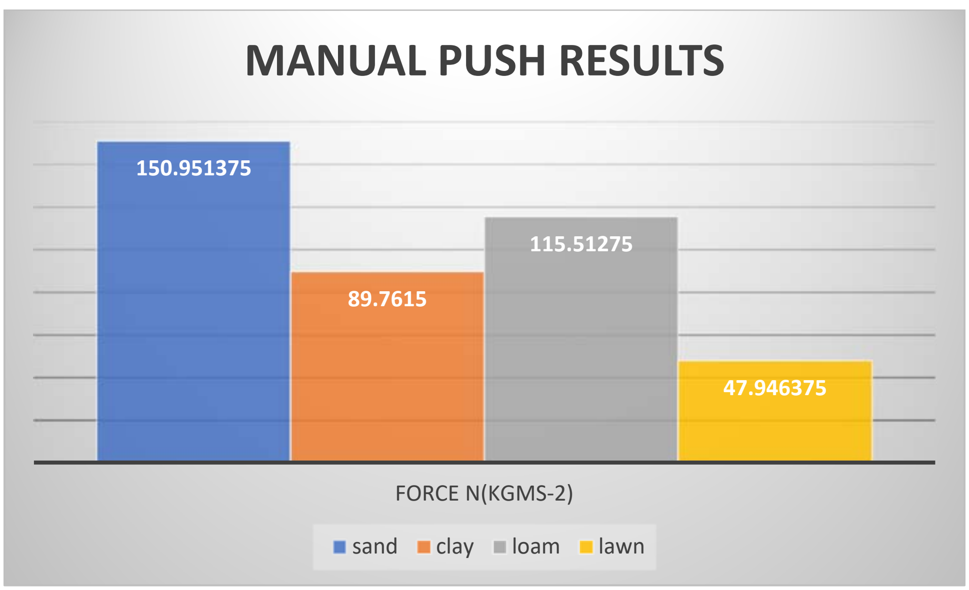


Figure 18: Manual push results on different grounds

4.8 Area Coverage Efficiency of the Wheelbarrow Sprayer

The analysis has shown that the designed wheelbarrow sprayer can cover an area of 927.42 m2 in 5.33 minutes when walking at an average speed of 1.45 m/s. This equates to a coverage rate of 0.927 hectares per sprayer tank refill.

Comparatively, using a traditional knapsack sprayer walking at a similar average speed of 1.24 m/s with a 0.5 L/min discharge rate would only cover 0.075 hectares per tank refill.

Therefore, the wheelbarrow sprayer design demonstrates significantly improved area coverage efficiency compared to the knapsack sprayer. This is due to its higher discharge rate and larger tank capacity, which reduces the number of refill stops required to cover a given area.

To further enhance the ground coverage, the wheelbarrow sprayer's tank size could be increased to carry more volume and minimize refill frequency. This would allow the user to cover even larger areas without interruption, improving overall spraying productivity and efficiency in the field.

In conclusion, the wheelbarrow sprayer design offers a substantial improvement in area coverage rate compared to a typical knapsack sprayer, making it a more effective solution for agricultural spraying applications.

CHAPTER 5

Conclusions

5.1 Achievements

A manual crop sprayer device was designed, built, and tested, achieving the desired flow rate of 0.5L/min at an average walking speed. Compared to a traditional knapsack tank, which requires 100% effort to lift and move, the new design requires only 40% of the lift force and less than 50% of the manual push effort, significantly reducing the manual effort needed. The device has a 16-liter tank capacity and features an effective automatic pump, eliminating the need for manual lever operation.

The crop sprayer is equipped with six nozzles, allowing it to spray six crop rows simultaneously. The height of the nozzles can be adjusted, enabling it to spray crops of different sizes, thus enhancing efficiency and reducing manual labour. The total cost of materials for the prototype was $39, with all components selected to ensure structural integrity. The gear sizing was optimized to achieve the required flow rate at an average walking speed.

Stakeholder farmers specified a maximum cost of $100 for a crop sprayer with these capabilities, making the design cost-effective and attractive for subsistence farmers. This new device offers a viable option for efficiently applying agrochemicals, significantly reducing manual labour and improving crop spraying efficiency.

5.2 Limitations

Obtaining timely feedback from engaged farmers was challenging, slowing the project's progress as their input was crucial for understanding their challenges and demands. However, using platforms like WhatsApp simplified the process, making it easier to share valuable insights. Procuring requested parts for fabrication was also difficult, causing delays of several weeks. Alternative materials and parts were secured to ensure continued prototyping and testing.

The project initially aimed for a 40-litre tank with a fitted manual pump, but it could not be purchased in time, so a single knapsack was used as an alternative. Additionally, required components for testing were unavailable and could not be shipped in time. The project needed strain gauges to determine manual labour requirements, but instead used a digital scale and high-speed camera to measure the manual push effort, similar to a crash test experiment. The flow rate was manually determined by collecting a timed nozzle discharge and measuring the quantity with a cylinder. While the operational pressure could not be verified, the device achieved the desired flow rate.

5.3 Future Work

After fabricating and testing the prototype, valuable feedback was received. One suggestion was to add an electric motor to drive the device, which would further reduce the manual push effort and enable the device to operate effectively in rough field conditions. In conclusion, future crop spraying designs should strive to balance cost and efficiency by developing technologies that cater to the needs of all farmers.

5.4 Suggestions for Modifications

- Adjust the height of the spray boom relative to crop height using sliding slots with a nut and bolt arrangement.
- Install a cut-off valve in the boom assembly closer to the operator to stop the spray solution discharge while making turns at headlands.
- Install interchangeable nozzles for different pesticide applications and easy cleaning.
- Design and fabricate a larger tank with its own pumping and agitation unit.
- Install a controlled motor to assist with pumping, reducing the effort required for pushing and increasing spraying uniformity.

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