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

DESIGN AND DEVELOPMENT OF A LOW-COST AND EFFICIENT PORTABLE MINI WHEELED AND BATTERY-POWERED SPRAYING EQUIPMENT

BY:

MERCY SHUVAI JINYA

SUPERVISOR:

ENGINEER W. ZENDERA

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DECLARATION OF INDEPENDENT OF WORK

I, Mercy Shuvai Jinya, B202699B, 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.

Student´s Signature: Date: 06/21/2024

Project Coordinator´s Name: Isnel Rodriguez Signature:______________ Date: 06/21/2024

Academic Supervisor´s Name: Willard Zandera Signature: ______________ Date: 06/21/2024

ABSTRACT

Spraying is one of the key links in terms of reducing losses in farming since it directly affects the quality and quantity of produce as well as the marketing of produce. Self-propelled spraying machines are quite expensive and uneconomical to use over a small piece of land hence smallscale farmers in Zimbabwe cannot afford them. The main objective of this study was to design a spraying machine which is portable, efficient and cheap to make for local farmers. The design process involved identifying the requirements and constraints of the machine, selecting appropriate materials, and creating a prototype

ACKNOWLEDGEMENTS

Firstly, l would like to thank the Almighty God for in him all things became possible. Secondly, I would like to express my heartfelt gratitude to my main supervisors Eng W Zendera and Eng S Zhou, who helped me to sharpen this project with their input of brilliant ideas and their willingness to deliver information and spare their time for me.

My sincere gratitude also goes to my colleagues for standing with me throughout the project. Last but not least, my profound gratitude and appreciation goes to my mother and my great family for their unwavering day-to-day encouragement, financial support and love throughout my life. Without their support, I couldn't be here. Lastly, I would like to acknowledge my classmates, workmates and Mr Clemence for their input throughout my project.

DEDICATION

Special dedication goes to my father Mr P. Jinya for supporting me morally and financially throughout the process and not forgetting my work colleagues and boss who gave me brilliant ideas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 - INTRODUCTION

This chapter begins with the background information concerning the problem leading to the need for the mini-boom sprayer in Zimbabwe.

1.1 BACKGROUND

Finding cropping systems with the ability to lessen weed burden while increasing crop yields is necessary since weed management is one of the main obstacles affecting smallholder farmers in Zimbabwe and a major factor in their low yields. One of these farming approaches has been proposed: conservation agriculture. Southern African smallholder farmers have many difficulties, such as low income, a lack of technical expertise, limited land sizes (2.1 ha on average), and subpar farming equipment (Chamunorwa, 2010). Conventional tillage practices are abandoned, which increases the need to weed, particularly in the early years (Vogel, 1994b). However, there is not enough agricultural labour to effectively control weeds. In addition to causing a shift in the microenvironment and a shift in the weed flora, no-tillage in conjunction with residues under CA may exacerbate weed management issues (Derpsch, 2008). Hand hoes are a common tool used by smallholder farmers in Zimbabwe to manually pull weeds (Mandumbu et al., 2011). Due to residues, this labour-intensive approach slows down (Vogel, 1994b). For efficient weed control, hand hoeing may need up to four weeding sessions during the cropping season (Mashingaidze et al., 2012). Effective weed management techniques that minimize labour needs and work within the constraints of farmers' situations are thus necessary. Herbicides and hand weeding are two weed management techniques that help reduce the burden of weeds (Norsworthy and Frederick, 2005). According to CamalMaldonado et al. (2001), incorporating highly competitive cover crops made of green manure into farming systems may also lessen the pressure from weeds. At the farm level, however, there is a lack of adequate expertise regarding integrated weed control.

In addition to being prohibitively expensive, soya bean post-emergence herbicides also face the difficulty of resistant weeds. Herbicides are meant to destroy unwanted plants. Regrettably, attractive plants might be harmed or even killed by non-selective herbicides like paraquat. According to a 2005 survey by Ikuenobe, farmers in Nigeria are using more and more herbicides, particularly non-selective ones, as a means of controlling weeds. While paraquat can be applied as a post-emergence herbicide, it usually kills the necessary plants. According to Hayes and Steckel (2005), paraquat is a non-selective, broad-spectrum, contact herbicide that is used to control a wide variety of weeds in over 100 crops, including cereals, oilseeds, fruits, and vegetables that grow in all climates. Non-selective herbicides are sprayed using sprayer guards to protect crops from harm throughout the process.

A wheeled boom sprayer with guards is currently required in Zimbabwe to shield crops from herbicides that are not selective. Farmers in Zimbabwe utilize diquat, although it has been shown to harm crops in the process. For this reason, guards and a wheeled sprayer were developed to lessen operator backload and cut down on field time.

1.2 PROBLEM STATEMENT

The knapsack sprayer is traditionally carried on one's shoulders when operating it and this causes ergonomic challenges (back pain) to the operator due to constant pumping which results in muscular disorder. It also has a negative health impact on the operator as he or she is working within proximity to the chemical that is been sprayed. It also requires significant labour and time since only one spray nozzle is being used hence the need for a wheeled sprayer with several spray nozzles to cover more ground. There is a lot of spray drift hence the need for spray guards on this sprayer. Small farmers with limited land holdings simply cannot afford a tractor-mounted sprayer or a power sprayer both of which are widely available but prohibitively costly.

1.3 AIM AND OBJECTIVE

1.3.1 Main Objective

To develop resilient equipment (wheel driven and also battery powdered) that is going to benefit medium and small-scale farmers for the weeding and spraying operations.

1.3.2 Specific Objectives

- To design a wheeled mini boom sprayer for medium and small-scale farmers.
- To fabricate the wheeled mini boom sprayer.
- To test the performance of the wheeled mini boom sprayer.

1.4 JUSTIFICATION

An electric battery or a human pushing a lever may be used to power spray pumps for insecticides. Trolleys with a special mechanism that transforms rotating motion into reciprocating motion are used to drive push-operated spray pumps. This lever allows pesticides to be pushed up to a greater pressure. It saves time when spraying agricultural pesticides on the field. The sprayer is affordable and easy to use. It is not heavy as compared to the backpack knapsack sprayer. Uniformity can be achieved through a pressure regulator unlike in a backpack knapsack sprayer where one may use left or right hand or both hands to give pressure hence insufficient or over-application of chemicals.

In agriculture, a sprayer is designed to save both time and money. The mini boom spray acts as multipurpose equipment for both selective and non-selective herbicides as it will have removable guards for post-emergence spraying.

1.5 LIMITATIONS AND DELIMITATIONS

The limitations and delimitations of this project are discussed to analyse possible threats to the study's validity and focus on the study.

1.5.1 Limitations

Limited funds to access first-hand information from farmers.

Resources on the impact of sprayer guards in agriculture are limited.

1.5.2 Delimitations

The project is limited to medium and small-scale farmers.

1.6 CONCLUSION

Medium and small-scale farmers in Zimbabwe lack the tiny boom sprayers that would facilitate their spraying operations. This wheeled micro boom sprayer eliminates the need to wear a backpack over one's shoulder and has spray shields for post-emergence spraying. It also features a rechargeable battery, which simplifies work and allows it to cover a large area in a single tank.

CHAPTER 2 - LITERATURE REVIEW

2.1 INTRODUCTION

This chapter outlines literature on different methods of pest and weed control, the need for spraying, different types of spraying machines, and their advantages and disadvantages. The literature also underscores the need for a mini-wheeled boom sprayer for small-scale farmers in Zimbabwe.

2.2 PEST CONTROL METHODS

Many pesticides used to control weeds, insects, and diseases in field crops, ornamentals, turf, fruits, vegetables, and rights-of-way are applied with hydraulic sprayers. Tractor-mounted, pull-type, pickup-mounted and self-propelled sprayers are available from numerous manufacturers to do all types of spraying. Spray pressures range from near 0 to over 300 pounds per square inch (PSI), and application rates can vary from less than 1 to over 100 gallons per acre (GPA). All sprayers have several basic components: pump, tank, agitation system, flowcontrol assembly, pressure gauge, and distribution system. Properly applied pesticides should be expected to return a profit. Improper or inaccurate application is usually very expensive and will result in wasted chemicals, marginal pest control, excessive carryover, or crop damage. Agriculture is under intense economic and environmental pressure today. The high cost of pesticides and the need to protect the environment are incentives for applicators to do their very best in handling and applying pesticides. Studies have shown that many application errors are due to improper calibration of the sprayer. A North Dakota study found that 60% of the applicators were over or under-applying pesticides by more than 10% of their intended rate. Several were in error by 30% or more. A study in another state found that four out of five sprayers had calibration errors and one out of three had mixing errors. Applicators of pesticides need to know proper application methods, chemical effects on equipment, equipment calibration, and correct cleaning methods. Equipment should be recalibrated periodically to compensate for wear in pumps, nozzles, and metering systems. Dry flowable may wear nozzle tips and may cause an increase in application rates after spraying as little as 50 acres. (Vern Hofman Agricultural and Biosystems Engineering 2009)The management practices for pest control are physical, cultural, mechanical, legal, biological and chemical. The chemical method is widely preferred for pest control as chemicals are now reliable and accessible.

2.2.1 Biological control method

Biological control of insects and pests can be increased by conservation of existing natural enemies, introduction of existing enemies and periodic release of natural enemies that feed on the pests.

The manipulation of the practices for reducing and avoiding pest damage to crops is known

2.2.2 Cultural Control Practices:

as cultural control. Cultural control manipulations are based on habitat management and require a true understanding of different components at the Agroecosystem for instance: Cultural control manipulations are based on habitat management and require a true understanding of different components at the Agroecosystem.

Planting Time:

The manipulation of planting time helps to minimize past damage by producing asynchronous between the host plant and the pest or synchronous insect pest with their natural enemies. Example: in India, early planting has been found to reduce gall midge and leaf hopper damage in rice, Shoot fly and head bug damage in Sorghum and millets, white grub damage in groundnut and mustard, aphid damages in brassica crops.

Timely and synchronous planting has been found to reduce bollworm damage in cotton and stem borer damage in sugarcane the early and late sown cotton crop suffered higher damage due to pink and spotted bollworms.

2.2.3 Mechanical Method:

The reduction or separation of insect population utilizing manual devices is referred to as mechanical control. Examples include:

a.) Hand Picking:

Hand-picking destructions of large-size immature or mature stage of insects is the most ancient method hand picking is generally useful for the management of hairy caterpillars, leaf roller, cabbage butterfly, mustard sawfly, white grub etc.

b.) Trapping:

- Several types of mechanical devices are used for controlling insect pests.
- A hand net is usually used for collecting sugarcane leaf hopper when it migrated from wheat crop to sugarcane during March-April in North India.

c.) Clipping Pruning and Crushing:

- Pruning and destruction of infected shoots and floral part is effective in checking multiplication of scale insects of sugarcane mealy bug and gall midge attacking fruit
- Use of a high seed rate is recommended in those crops where removal of infected

2.3 WEED CONTROL METHODS IN ZIMBABWE FARMING SYSTEMS

2.3.1 Mechanical methods

The main tools that are used to control weeds are hand hoes, ox cultivators, ploughs, and spike tooth harrows. The proportion of farmers who use hoes, ploughs, cultivators, and harrows was 96%, 76%, 23%, and 14 %, respectively in six districts surveyed in Zimbabwe (Chatizwa and Nazare, 1994). Handhoes have wooden handles which are attached to metallic blades. The metal blade is pushed rearward after being placed into the ground to weed. This usually gets rid of weeds at their roots. On the weeds, it produces a shaving effect. To make sure that large weeds don't regrow, they are manually removed and shaken. It takes multiple hand-wearing strokes to completely eradicate the weeds. This approach, which is employed in farming systems, is a laborious procedure. One hectare of weeding would frequently take the farmers several days to do, depending on the available labour force. There are often fields that are left unweeded because farmers are too busy to pull weeds. This is the most popular way of weed control, but it is difficult to weed on time. Most farmers possess hoes. These hoes can be made by blacksmiths from scrap metal. The kind and moisture content of the soil affects how well hand hoeing works. Wet circumstances make hand hoeing less effective since weeds may return a few days after the weeding procedure. By interrupting tuber dormancy, this approach appears to boost the infestation of Cyperus rotundus. But occasionally, it improves the tubers' desiccation, which helps to better regulate Cyperus species. Sand soils are typically easier to hand hoe than soils with a lot of clay.

2.3.2Chemical Weed Control

Herbicides are employed in chemical weed control, which has primarily been applied in largescale commercial farming areas. Large-scale commercial farms began using 2,4-D and MCPA in the early 1940s to control weeds in their wheat and maize crops. But in Zimbabwe, just approximately 5% of smallholder farmers use herbicides to keep weeds under control. Currently, Zimbabwe has permitted the use of various herbicides on a range of crops. In Zimbabwe, herbicides can be purchased at Agricura, Windmill, and ZFC depots. Applying herbicides doesn't take a lot of work. Unlike mechanical weed control approaches, they also destroy weeds in moist situations. Farmers have been unable to use herbicide technology due to a lack of sufficient knowledge. A rudimentary understanding of the herbicides that farmers must apply to their crops is necessary.

2.4 CHEMICAL APPLICATION METHODS FOR HERBACEOUS WEEDS

Several herbicide application methods are available to land managers for herbaceous weed control. Roughly speaking, these techniques fall into two categories: directed and broadcast applications. Herbicides must be applied consistently and at the appropriate rate, regardless of the technique. Inadequate use of pesticides can lead to chemical waste, inadequate weed control, excessive runoff, and harm to attractive flora.

2.4.1 Broadcast Herbicide Application

Using a spray solution, the entire treated area is covered consistently in broadcast applications. Herbicides are often either soil-active or selective, such as aminopyralid on rangeland. Broadcast applications are particularly successful for controlling weeds and are safe for nontarget plants when (1) herbicides are sprayed following label instructions and (2) equipment is operated correctly.

2.4.2 Directed herbicide application

Directed applications, as opposed to broadcast applications, focus on specific plants. This lessens the chance that less selective herbicides like glyphosate, imazapyr, or triclopyr will damage non-target vegetation when applied directly to individual plants. Targeted medicines, however, are only practical when the target plants are unique enough to need customized care.

2.5 SPRAYERS

Various spray ingredients, including insecticides, fungicides, and herbicides for pre-emergent and post-emergence applications, are frequently applied using a sprayer. Sprayers are now essential in modern agriculture for managing and protecting crops. Achieving the best yields requires sprayers to be effective and efficient. Many other kinds of sprayers are available, each with its benefits and drawbacks, including boom sprayers, air blast sprayers, and electrostatic sprayers. Their performance is affected by nozzle design, spray quality, and application rate, among other factors. The most crucial farming practice for increasing production is applying pesticides. Sprayers and weed eaters come in a range of configurations these days, such as selfpropelled, tractor-mounted, animal-drawn, and manually operated variants (Ambaliya *et al*.,2022). Spray nozzles, liquid tanks, sprayer pumps, pressure regulators, valves, fluid plumbing, and spray guns are some of the parts of agricultural sprayers. These agricultural sprayers are available in a range of shapes, sizes, and functionalities. Different spraying applications, such as gardening, crops, trees, fruit, animal needs, and weed control, call for different types of sprayers. Pesticides are crucial to the agricultural sector's ability to maintain crop health and, by extension, the stability of farmers' profits. For a range of farming jobs throughout the crop production cycle, these equipments are perfect. These incredible farming implements are available in a range of shapes and sizes, from enormous trailed or mounted sprayers to sophisticated atomizers, and they start with hand-held and manual sprayers. In modern agriculture, sprayers are crucial equipment for applying fertilizer, herbicides, and pesticides. Because sprayers are so good at minimizing crop damage and increasing yields, their use has grown dramatically in the last few years (Aktar *et al.* 2009) [1]. There are many different kinds of sprayers on the market, each with special features and functions intended for particular uses. Sprayers of all kinds are used by farmers to control diseases and pests in their crops. Choosing the appropriate plant protection equipment is essential for effective pest control and high crop yields. Plant protection equipment should be chosen with several aspects in mind, such as economy, effectiveness, ergonomics, and ecologyTNAU(2015). Ergonomics is the process of choosing equipment that minimizes operator fatigue and injury by making it simple and comfortable to operate. Choosing equipment that is economical to buy, maintain, and repair is influenced by economic reasons. Choosing equipment that can efficiently apply the right amount of insecticide to the intended area is essential to efficacy. When choosing equipment for pesticide application, ecological factors must be taken into account. This includes limiting spray drift and chemical runoff. Farmers can efficiently manage pests while reducing their negative effects on the environment and boosting crop yield by using the proper plant protection tools and methods (Pankaj and Shashidhar 2018). For crop protection and higher yields, agricultural usage of pesticides and herbicides is essential. However, conventional pesticide application techniques frequently rely on fossil fuels and have a negative influence on the environment. Creating ecologically safe and sustainable pest management solutions has drawn more attention in recent years. In the agriculture sector, one such device that has attracted a lot of interest is remote-controlled boom sprayers that run on solar power that is drones. This kind of sprayer minimizes chemical exposure to humans and requires less fossil fuel because it can be operated remotely and runs on solar power for its electric motors. Gill et al 2017.

Numerous varieties of spraying machines exist, each with a unique or similar operating mechanism. While some are best suited for medium- and small-scale farming, others can only be utilized profitably in commercial farming.

2.5.1 Self-Propelled Sprayers (Tractor Mounted Sprayer)

These energy sprayers use hydraulics. The sprayer's pump is run by the tractor's PTO motor. There are two configurations for the spray boom: one overhead and one on the ground. The tall field crops that are intended for the overhead spray boom are planted with a gap of approximately 2.5 meters between each plant to allow for tractor operation. As a result, a planted strip may be between 18 and 20 meters wide, and a fallow strip must be left for tractor use after each planted strip. Planting for a ground spray boom requires that you work in rows while bearing in mind the tractor's track width. It works well when the crop is tiny. The sprayer is composed of a fibreglass or plastic tank, a pump assembly, a strainer-equipped suction pipe, a delivery pipe, an air chamber, pressure gauges, pressure regulators, and a spray boom with nozzles. The complete sprayer is mounted on 3-point linkages of the tractor. It uses highpressure and high-discharge pumps as the number of nozzles may be up to 20 depending upon the crop and make of the sprayer. Krishi Bhavan 2017

Advantages

- They cover a large area over a short period
- A large tank can be used hence reducing the number of times one goes for a refill

Disadvantages

- It is expensive hence small-scale farmers cannot afford it.
- High maintenance cost

Figure 1: Tractor Mounted Sprayer Krishi Bhavan 2017

Figure 2: Boomsprayer (Krishi Bhavan 2017)

2.5.2 Knapsack Sprayer

The Knapsack sprayer consists of a pump and an air chamber permanently installed in a 9 to 22.5-litre tank. It is feasible to pump with one hand and spray with the other thanks to the pump's handle extending over the operator's shoulder or under their arm. The pump can be kept running continuously to maintain uniform pressure. (E Lambrecht, 2019).

Advantages

- Medium and small-scale farmers can utilize this sprayer since it is affordable
- It is easy to use hence does not require any expertise

Disadvantages

- The operator needs frequent refills
- The tank is heavy on the operator's back and this results in backache High labour intensity

Figure 3: Knapsack sprayer (Toe and Kinane 2004)

2.5.3 Battery-powered volume knapsack spinning disc sprayer

The sprayer consists of a plastic tank, a grooved spinning disc, a fractional horsepower DC motor to spin the disc at very high speed, a 12-volt power supply source which can be a dry battery or lead acid battery, and a lightweight handle on which the spray head is mounted. The handle has a provision to adjust the angle of the spray head. The spinning disc is also made of fine quality plastic, which has very fine radial grooves.' For operation, the spray liquid in minimum dilution is filled in the tank, which flows in the form of drops at the centre of the spinning disc. The disc is attached to the motor, which rotates it at a very high speed. The spray liquid travels in the grooves of the disc and gets fragmented into very fine droplets when it leaves the periphery of the disc. The droplets are thrown outwards due to centrifugal force. (Lakshman Chandra Patel 2023)

Advantages

- Easy to use
- An efficient tool for small-scale farmers Disadvantages
- It is costly
- Tedious to use

Figure 4: Low-volume knapsack spinning disc sprayer (https://search.app.goo.gl/fwnbTzi)

2.5.4 Blower Sprayer

These are tractor-mounted or trailed air carrier type of sprayers for spraying in orchards. The spray volume can be controlled making it a high-volume, low-volume, or ultra-low-volume sprayer depending on the requirement. The sprayer mainly consists of a high-pressure piston pump, which atomizes the spray solution, an axial or centrifugal fan to produce a stream of air, interchangeable and orientable spray heads, a high-capacity spray tank, and other control attachments. All the sub-assemblies are mounted on the frame and can be attached to a 3-point linkage of the tractor or mounted on a trailer. The spray heads are mounted radially to cover the 2-rows of the trees. The spray heads can be oriented upwards for spraying the tall trees. In the case of spraying individual trees, the spray heads can be exactly adjusted to the form of a tree. The volume of spray and the air stream velocity and volume can also be adjusted as per the requirement. For operation, the spray liquid is filled in the tank. The tractor power is used to drive the fan and pump. The pump sucks and sends the liquid to the spray head, which atomises the liquid, and at the same time, droplets meet the air stream to carry them to the target. (Caffini 2023)

Advantages

- They can be used over a small area
- They are easy to use

Disadvantages

- High cost of fuel
- It is expensive

Figure 5: Blower sprayer https://search.app.goo.gl/4QF2v4C

2.5.5 Drones and planes in agriculture

The rising population is also increasing the demand for food. The traditional methods used by the farmers are unable to fulfil the requirements. This creates a demand for the development of new automated technologies that can manage agriculture efficiently and increase productivity. In this endeavour Drones, also known as Unmanned Aerial Vehicles (UAVs) can be highly beneficial. In general, UAVs are equipped with cameras and sensors for monitoring crops and sprayers are used for spraying fertilizers, weedicides, pesticides, etc. Drones can fly autonomously with dedicated software which allows making a flight plan and deploying the system with GPS and feed in various parameters such as speed, altitude, ROI (Region of Interest), geo-fence and fail-safe modes (Dutta and Goswami, 2020). Drones successfully and effectively monitor plant growth by collecting and delivering real-time data from the moment of plant emergence to harvest. With the help of fast and accurate GPS (Global Positioning

System) or GNSS (Global Navigation Satellite System) technology, a highresolution camera, and variable flying speeds and altitudes, drones can provide a wealth of information on the condition of every half square inch of crop or soil. The use of drones in United States agriculture is relatively new, but the global use of drones in agriculture has increased significantly in the past 10 years and is likely to continue growing in the near future. According to a report by *Fortune Business Insights*, “the global agriculture drone market is projected to grow from $4.98 billion in 2023 to $18.22 billion by 2030, at a compound annual growth rate of 20.3% during the forecast period” (Fortune Business Insights, 2023).

Advantages of drones and planes

- They monitor soil characteristics (type, moisture content, and nutrient content)
- Location of drainage tiles
- Crop nutrient stress level
- crop emergence or stand count
- Weed species and infestation level
- Detection of insects and diseases

Disadvantages of drones and planes

- Expensive to purchase
- High maintenance cost
- Uneconomical to use over a small space of land
- Uncontrolled spray drift
- Needs technical expertise to use

Figure 6: Drones (http://www.croptracker)

Figure 7: Plane (https://en.wikipedia.org/wiki/PZL-101_Gawron)

2.6 CONCLUSION

In a nutshell, weed management in farming is of utmost importance. It is necessary to develop a mini-wheeled boom sprayer with spraying guards to protect crops from non-selective herbicides. This wheeled mini boom sprayer is not only affordable but it rules out the carrying of the knapsack sprayer on the farmer's shoulders hence protecting the farmers from backache. The mini-wheeled boom sprayer is inexpensive compared to other spraying machines available on the market. The mini-wheeled boomsprayer mimics the tractor-mounted boomsprayer covering a swath of 6 metres therefore reducing time spent on spraying operations as compared to using the backpack knapsack sprayer.

CHAPTER 3 – DESIGN ANALYSIS AND METHODOLOGY

3.1 INTRODUCTION

This chapter describes the procedures by which the project was undertaken to solve the existing problem and accomplish the outlined objectives in Chapter 1. A modified general engineering research design procedure was followed by the designer as outlined in Figure 3.1 below:

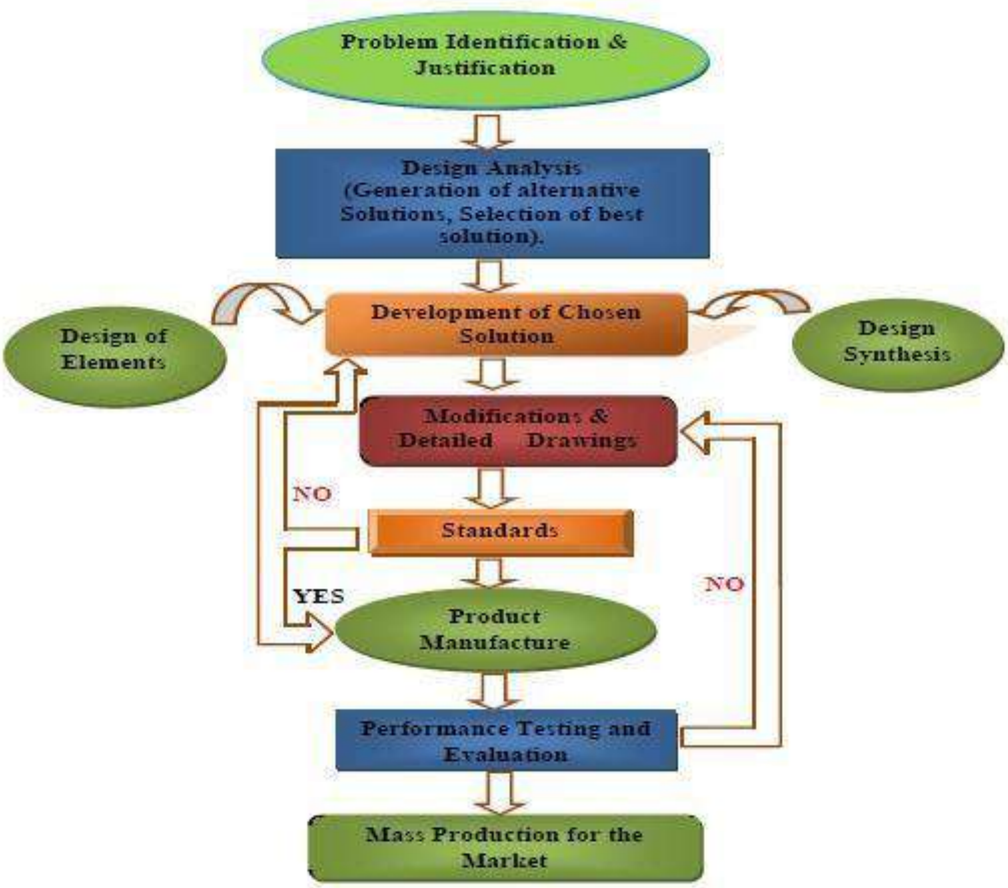


Figure 8: Engineering Research Design Procedure (Source; Yue Wu et al, 2012)

3.2 DESIGN ANALYSIS

With the help of different spraying equipment designs, the researcher was able to;

- Generate detailed possible design solutions
- Selected the best solution using solution criteria

3.3 CONCEPT GENERATION

Three possible solutions were produced using AutoCAD 2016 and SOLIDWORKS and the best solution was selected using a solution matrix and data was collected and analysed using Excel. Engineering and experimental design principles, optimisation and prototype construction were also used.

The mini-wheeled boom sprayer adopts its working principle from deep cycle pumps by sucking up spraying chemical from the tank and transporting it to the nozzles through the delivery pipe. It uses energy from the 12V battery which is alternatively charged by solar panels. From an engineering point of view, the prototype was able to fulfil the following requirements:

- ✓ ***Power requirements*****:** this defines the total amount of power required in the spraying operation.
- ✓ ***Cost*****:** the retail cost is affordable to medium and small-scale farmers
- ✓ ***Functionality*****:** the mini-wheeled boom sprayer performed at desired spraying efficiency and reduction in drudgery.
- ✓ ***Reliability*****:** the spraying equipment should impress the target group to the extent that it becomes a necessity in the farm operations of the farmer. It was designed for a longer service life.
- ✓ ***Aesthetics***: the harvester contains a splendid and pleasing appearance.
- ✓ ***Ethics and social impact*****:** the implementation should be socially acceptable despite different ethical beliefs between the farmers.
- ✓ ***Manufacturability***: the prototype was easy to produce, excluding the need for high-value materials.

3.4 DESIGN REQUIREMENTS

Material Selection

Analysis of material performance requirements of the spraying equipment was done considering:

- ✓ **Functional requirements of the sprayer**: the functional characteristics of the sprayer correspond with measurable material properties being selected for wear resistance, thermal expansion coefficient, durability and reliability.
- ✓ **Processing**: it is the measure of the ability of the selected materials to be worked and shaped into a finished product.
- ✓ **Cost**: it is an important factor considered when evaluating materials to be used so as not to exceed the cost limit.
- ✓ **Reliability**: it is the probability that the selected materials for the sprayer will perform the intended function for the expected life without failure.
- ✓ **Resistance to service conditions**: the environment in which the sprayer is going to operate plays an important role in determining the material performance requirements for example corrosive environment. The materials should be strong enough to add a longer physical life to the harvester.

Weight Requirements

The weight of the mini-wheeled boom sprayer is important because it is a contributing factor to the general efficiency of the machine. The design focused on reducing the weight of the sprayer to make it more affordable to the end user and reduce the time spent on spraying operations by making it a multi-nozzle spraying machine.

Manufacturability Requirement

Manufacturing capability is one of the primary considerations in designing this mini-wheeled boom sprayer. Limiting the design to available materials, techniques, tools and manufacturing machines, makes the harvester possible to be manufactured around Zimbabwe. This is advantageous because it allows the country to use its indigenous labour resources rather than importing parts. Replacement parts and skilled craftsmen familiar with spraying machines will be available and will not experience lengthy downtime, and expert repairs will give units longer life expectancies.

3.5 POSSIBLE SOLUTIONS

The researcher came up with three different design solutions explained in detail below, clearly showing the advantages and disadvantages of each design

3.5.1 Design Solution 1 – battery powered mini boom sprayer

Figure 9: battery powered mini boom sprayer

In this design solution, a battery-powered knapsack is mounted on a wheelbarrow frame with a wheelbarrow wheel. The mini boom sprayer is controlled and pushed by an operator. A battery-powered knapsack consists of a battery that powers the pump inside the knapsack tank. This pump pumps the loaded herbicides to the spraying system, which consists of multiple nozzles that will allow an even distribution of the loaded herbicides to the targeted weeds. In cases where non-selective herbicides are used, spray guards will protect the crops. The battery can be easily charged by the solar or on a socket power source. This system uses a solar charger controller to keep the battery from overcharging by regulating the voltage and the current that is coming to the battery from the solar panel.

3.5.1.1 Advantages

1. The operator does less work
2. The mini boom sprayer can spray even its stationary
3. It is light therefore reducing ergonomic challenges for the farmer
4. It uses a renewable source of energy
5. Less maintenance is needed

3.5.1.2 Disadvantages

1. It has a chemical holding capacity of 16 litres only which means the farmer will need several refills.

3.5.2 Design Solution 2 – Animal-Powered Mini Boom Sprayer

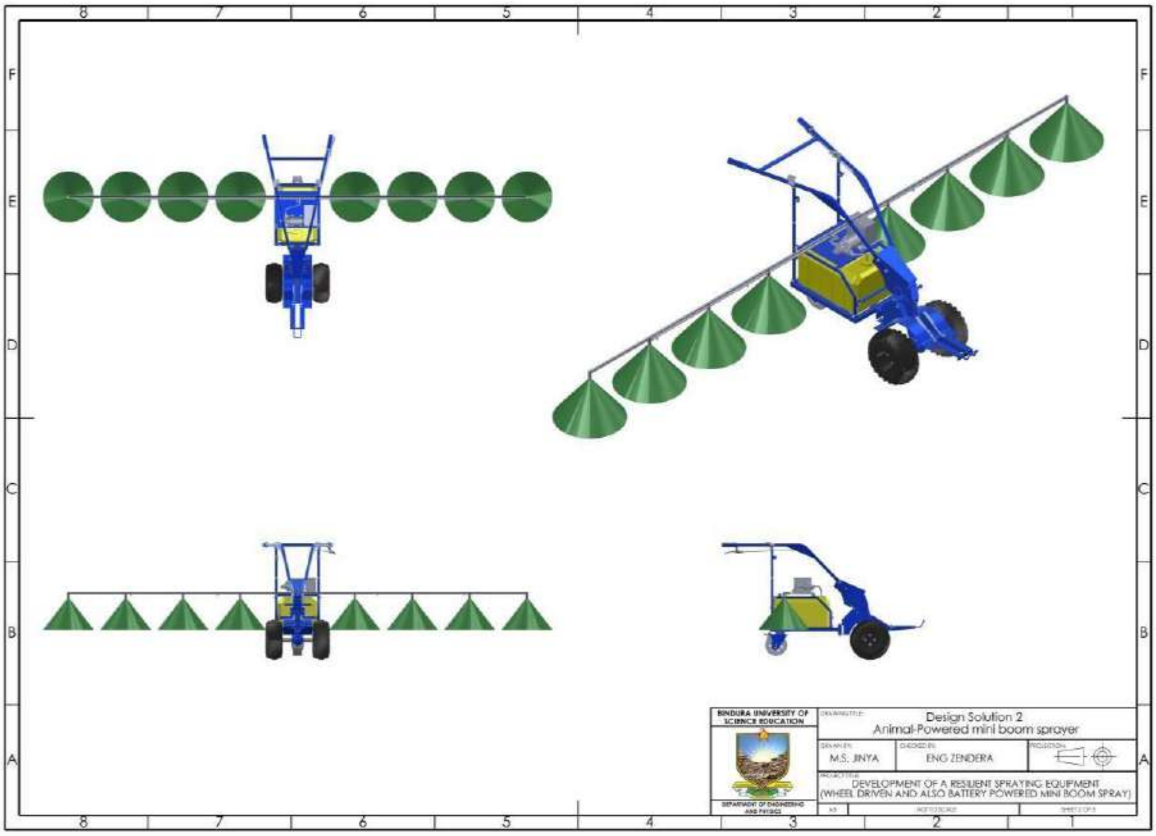


Figure 10: Animal-powered mini boom sprayer

In this design solution, a huge tank is mounted on the frame with 3 wheels. The mini boom sprayer is animal-powered and is controlled by an operator. The design consists of a pump that is powered by a DC battery. the pump sucks the herbicides and feeds them to the spraying system which consists of multiple nozzles that will allow an even distribution of the loaded herbicides to the targeted weeds. In cases where non-selective herbicides are used, spray guards will protect the crops.

3.5.2.1 Advantages

1. Saves herbicides
2. The spraying system is automated
3. Little work is done by the operator

3.5.2.2 Disadvantages

1. Difficult to manufacture
2. It is only animal-powered
3. More expensive

3.5.3 Design Solution 3 – Human automated mini boom sprayer

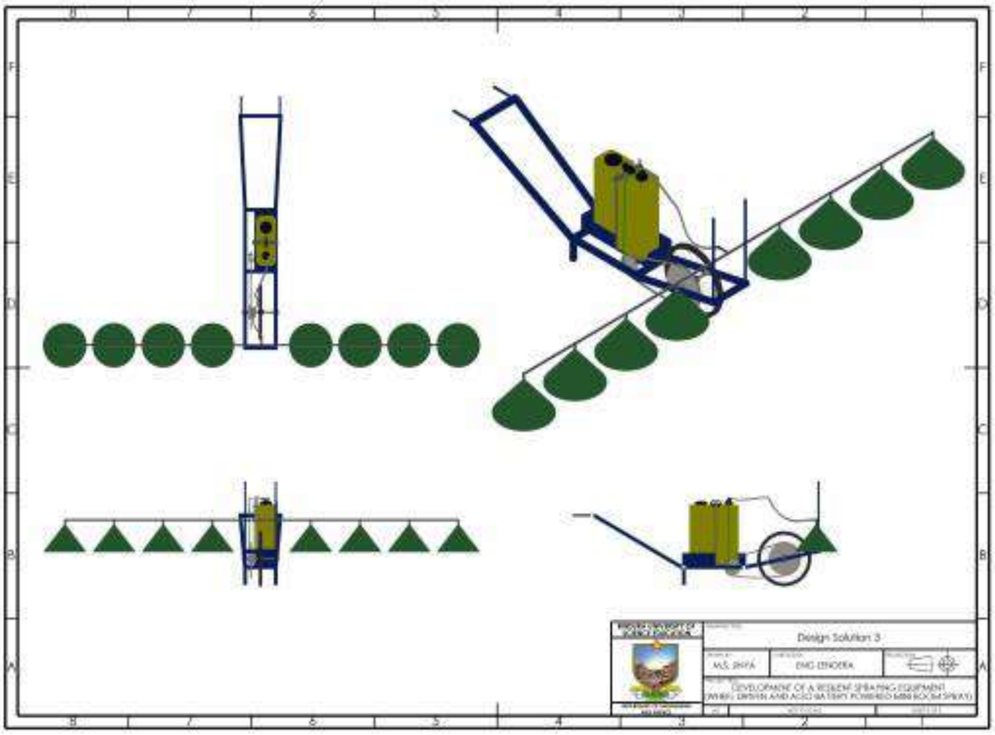


Figure 11: Human automated mini boom sprayer

In this design solution, a traditional knapsack is mounted on a wheelbarrow frame with a wheelbarrow wheel. The mini boom sprayer is controlled by an operator. The rotational motion generated by the DC motor is transferred to the wheels by a chain and sprocket mechanism, thereby causing the mini boom sprayer to move. The rotational motion of the DC motor is also transferred to a Scotch York mechanism which changes the rotational motion to linear motion. The linear motion will be used to move the manual pump. The pressure generated pumps the loaded herbicides to the spraying system, which consists of multiple nozzles that will allow an even. This pump pumps the chemicals stored in the tank as solution or liquid through multiple nozzles that will allow an even distribution of the loaded herbicides to the targeted pests and weeds. In cases where non-selective herbicides are used, spray guards can be used on the crops.

3.5.3.1 Advantages

1. Saves herbicides
2. The spraying system is automated
3. Uses renewable sources of energy

3.5.3.2 Disadvantages

1. The system does not spray when it is stationary
2. Difficult to manufacture
3. Consist of many mechanisms

3.6 BINARY SOLUTION MATRIX KEY

Most effective	**A**
Safety	B
Ergonomics	C
Reliability	D
Cost efficiency	E
Function	F
Ease of maintenance	G
Ease of manufacture	H
Simplicity of layout	I
Quality	J
Weight	K
Lifespan	L

Table 1: Binary Solution Matrix Key

	A	B	C	D	E	F	G	H	I	J	K	L	TOTAL
A	/	1	1	1	1	1	1	1	1	1	1	1	11
B	0	/	1	0	1	1	1	1	1	1	1	1	9
C	0	0	/	0	0	0	0	0	0	0	1	0	1
D	0	1	1	/	1	1	1	1	1	1	1	1	10
E	0	0	1	0	/	0	1	1	1	1	1	1	7
F	0	0	1	0	1	/	1	1	1	1	1	1	8
G	0	0	1	0	0	0	/	1	1	1	1	1	6
H	0	0	1	0	0	0	0	/	1	0	1	0	3
I	0	0	1	0	0	0	0	0	/	0	1	0	2
J	0	0	1	0	0	0	0	1	1	/	1	0	4
K	0	0	0	0	0	0	1	0	0	0	/	0	1
L	0	0	1	0	0	0	0	1	1	1	1	/	5

Table 2: Binary solution matrix

		Concept rating			Concept weight		
CRITERIA	WEIGHT	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 1	DESIGN 2	DESIGN 3
Most effective	**11**	10	8	8	110	88	88
Safety	**9**	7	7	7	63	63	63
Ergonomics	**1**	1	1	1	1	1	1
Reliability	**10**	10	7	7	100	70	70
Cost efficiency	**7**	7	7	5	49	49	35
Function	**8**	7	6	6	56	48	48
Ease of maintenance	**6**	5	3	2	30	18	12
Ease of manufacture	**3**	2	2	1	6	6	3
Simplicity of layout	**2**	2	2	1	4	4	2
Quality	**4**	3	1	2	12	4	8
Weight	**1**	1	1	1	1	1	1
Lifespan	**5**	4	4	3	20	20	15
TOTAL					**452**	**372**	**346**

Table 3: Concept selection table

Therefore, from the above binary dominance matrix, it can be concluded that concept 1 has the largest total hence it is the chosen solution. In addition, although it is fairly expensive to manufacture it provides greater efficiency and at the same time is more reliable and durable to use. Solution 2 on the other hand possesses all of these attributes but it has more complicated mechanisms than other designs. Furthermore, although the production costs for solution 3 are favourably low it is less reliable. Henceforth, the chosen solution was developed further to meet the requirements for the development of the mini-boom sprayer for small-scale farmers

3.7 EVALUATION METHODS FOR THE PROTOTYPE

The primary goal of calibration is to determine the actual rate of application of the spraying equipment and then make adjustments where necessary. The following are the steps which were taken to achieve the goal and these are:

- Ensure that nozzles are in good working condition that is there are no damaged nozzles. If there are any, they should be replaced.
- Fill the tank with clean water.
- Three specific measurements should be taken and these are

- Actual ground speed
- Distance between nozzles
- Nozzle flow rate per given time

These measurements are taken using:

- A stopwatch
- Measuring tape
- Calibrated measuring cup

A distance of 100m was measured

Ground speed is measured by allowing the operator to walk at a steady speed over a distance of 100m. Ground speed is calculated by determining how long it takes for the operator to walk a distance of 100 metres.

Ground speed=Distance(m)/Time(sec x 1.47)

The operator would walk twice and average the time taken to cover the course.

The application rate would then be calculated by collecting spray into metric-calibrated vessels for 1 minute. The quantity collected is added and then divided by the number of spray nozzles to get the application rate per minute.

Equation 1

$$\text{lpm} = \frac{lph\ x\ mph\ x\ w}{5940}$$

- **lpm** = litres per minute, the nozzle flow rate
- **lpha** = litres per hectare, a decision made based on label recommendations, field
- conditions, spray equipment and water supply
- **mph** = the ground speed you select, metres per minute
- **w** = bandwidth or spacing between nozzles in metres
- **5940** = A constant to convert litres per minute, metres per minute, and nozzle spacing in metres to litres per hectare

Where swath width is the spacing between nozzles.

The above steps were carried out to determine the need and efficiency of the battery-powered mini boom sprayer. The operator covered 33 metres over 1 minute. The operator managed to cover a distance of 100 metres covering 4 rows of crops in a space of 3mins. The prototype proved to be time-saving as compared to the backpack knapsack sprayer where there is only one nozzle which translates to 3 minutes over 100-metre length.

3.8 PROPOSED SOLUTION

The proposed mini boom sprayer design was developed from the chosen solution in the previous sections. The proposed solution does not affect the working mechanism of the batterypowered knapsack and it is also subject to further developments for future purposes.

3.9 Feasibility assessment

To come up with a chosen design, a feasibility assessment was employed to determine whether this project could move on or continue to the design stage. The assessment was based on an achievable idea that fell within cost limits. This criterion was very important because batterypowered mini boom sprayers have not been developed in Zimbabwe and as a result, it was very important to develop low-cost and resilient spraying equipment that is affordable to medium and small-scale farmers in the country.

3.9.1 Design requirements

The success of the spraying equipment design was measured by considering and quantifying certain requirements and goals that the sprayer had to achieve and these included safety, readily available and cheap fuel source, portability, ease of construction and manufacturability. Energy source, eco-friendliness and portability were the most critical design factors, which were considered.

3.10 Conclusion

From the analysis made above, Conceptual Design 1 had the highest percentage (%), which makes it the most appropriate solution to the addressed problem.

CHAPTER 4 - DEVELOPMENT OF CHOSEN SOLUTION

4.1 INTRODUCTION

The design consists mainly of the tank made of plastic, pump assembly, suction pipe with strainer, delivery pipe, spray boom fitted with nozzles, equipment frame, solar charger controller, solar panel and a 12V battery. The solar charger controller is used to regulate voltage and current when photovoltaic panels are used to charge the battery. Without this component, the batteries can be damaged by overcharging. Inside the knapsack tank, there is a pump that sucks the spray chemical from the tank to the nozzles. The frame is made of steel square tubes. The solar panel (28W) has the following specifications:

- Voc:22.32v
- Vmp:18v
- Imp:1.55A
- Isc:1.85A
- Size:450*350mm
- The boom swath is 2 metres with 3 stages of boom height to cater for a range of different crop heights.

4.2 PRODUCT FABRICATION

The fabrication process was carried out as illustrated by the flow diagram in Figure below.

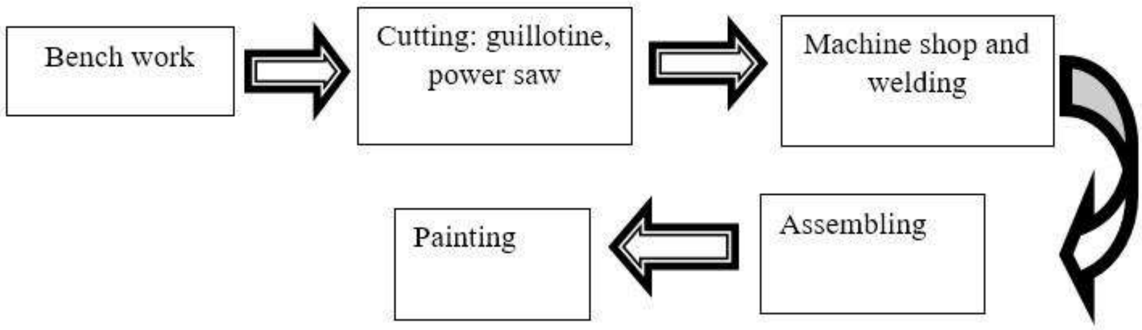


Figure 12: Fabrication flow diagram

4.2.1 Fabrication Technologies

Fabrication of the harvester was done at the Crown Brass Mechanical Engineering workshop in Harare. The design incorporates basic tools found in most Zimbabwean machine shops. Techniques used considered that the spraying equipment will be mobile. Thus, supporting materials have to be light in terms of weight and stable to withstand the load through proper measuring and metal developments, cutting, machining, drilling and welding.


MURIMI


MURIMI

4.2.1.1 Benchmarking

This refers to all work which was done on the bench which includes marking out steel square tubes and filling.

4.2.1.2 Cutting

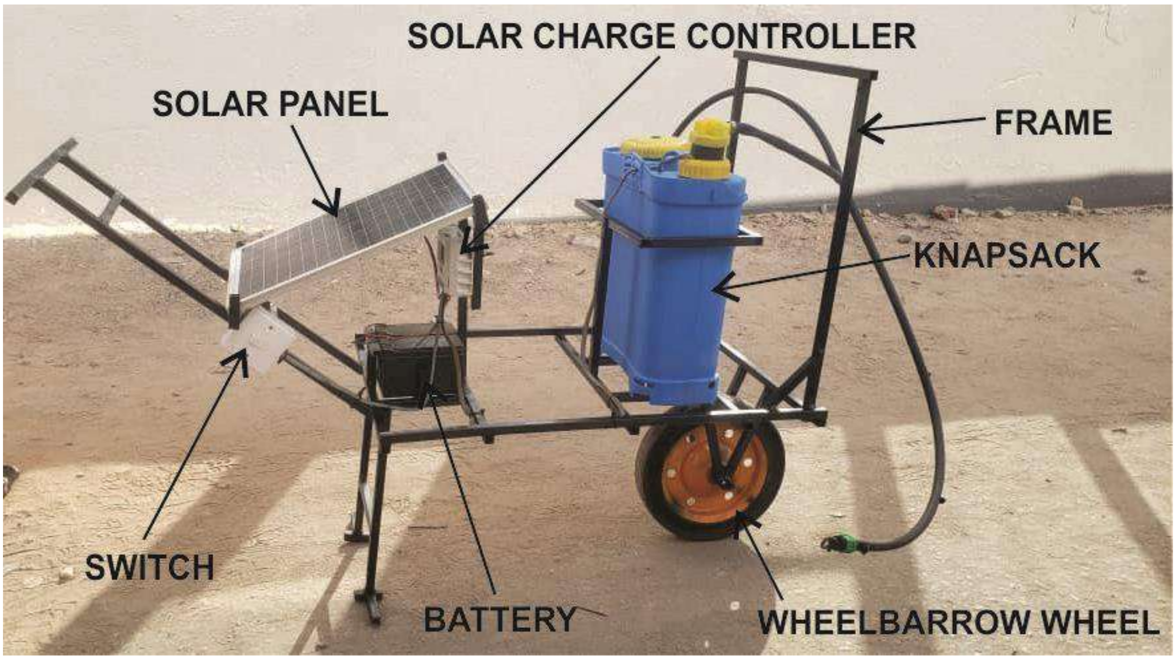
The cutting of the square tubes was done using a hacksaw, guillotine and cutting disks.

4.2.1.3 Drilling

To use bolts and nuts to join the main frame to the boom; drilling of holes was done using a vertical drilling machine and hand drill. The drilled holes ran through mating pieces, at relatively similar positions to save time and for easy alignment. Drill bits used for the complete machine ranged from 2mm to 30mm.

4.2.1.4 Welding

Most of the joints of the mini-wheeled boom sprayer were arc welded using Vitemax welding rods. Extensive welding was done on the main frame.



4.3 MACHINE PERFORMANCE TESTING

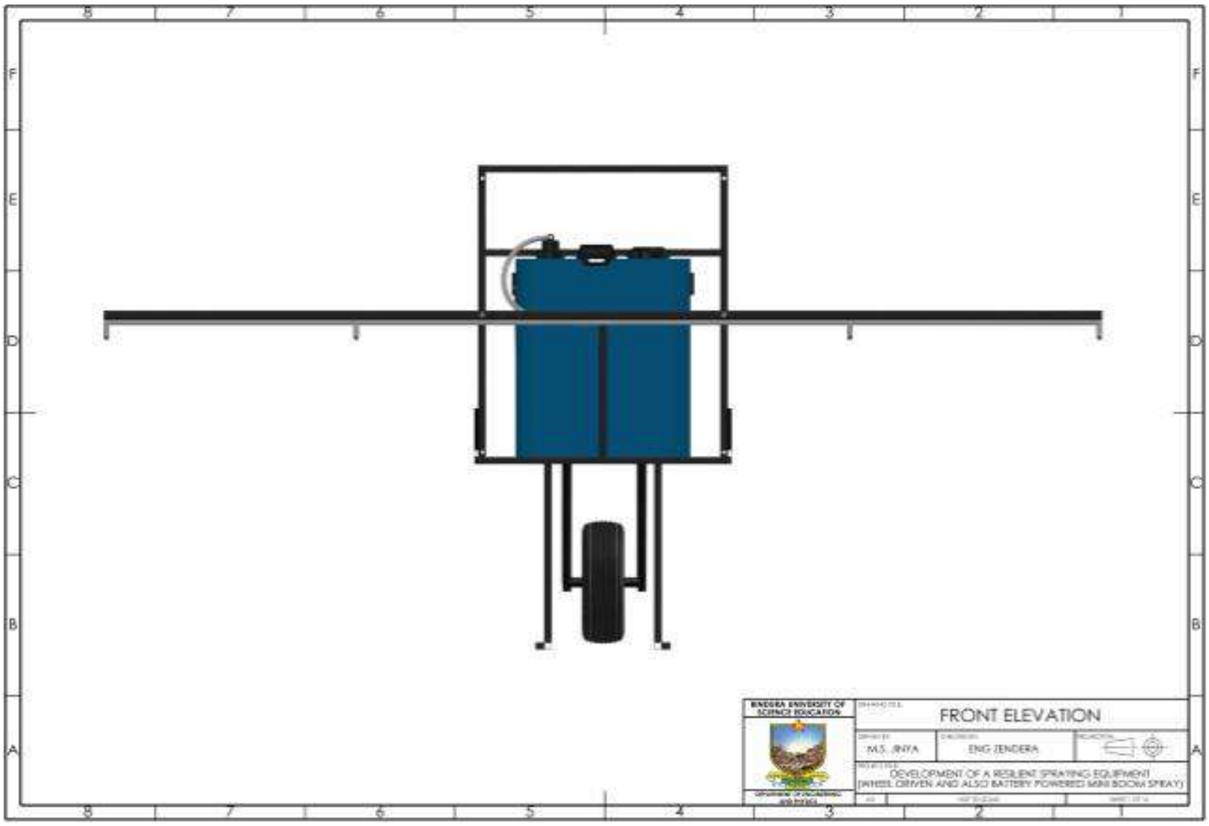
After the design and construction of the mini wheeled boom sprayer, testing was done to assess;

- Time taken to spray an area of 1hectare
- Sprayer application rate and efficiency
- Total weight of spraying equipment when loaded with spraying chemical Appreciate the level of success in the development of the sprayer

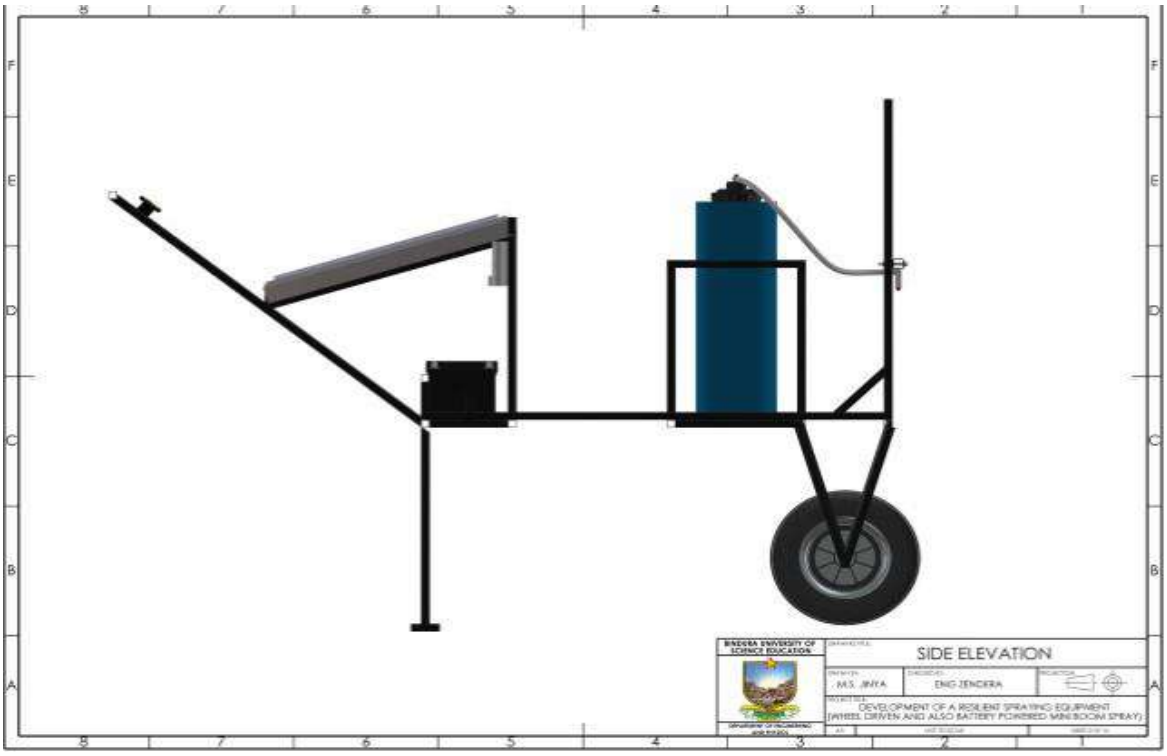
4.4 TESTING SITE

Field testing of the mini-wheeled boom sprayer was carried out at Pickstone Horticulture Farm in Chegutu. Scouting of pests was done first. After spraying operations it was noticed that the pest population had decreased to 30%.

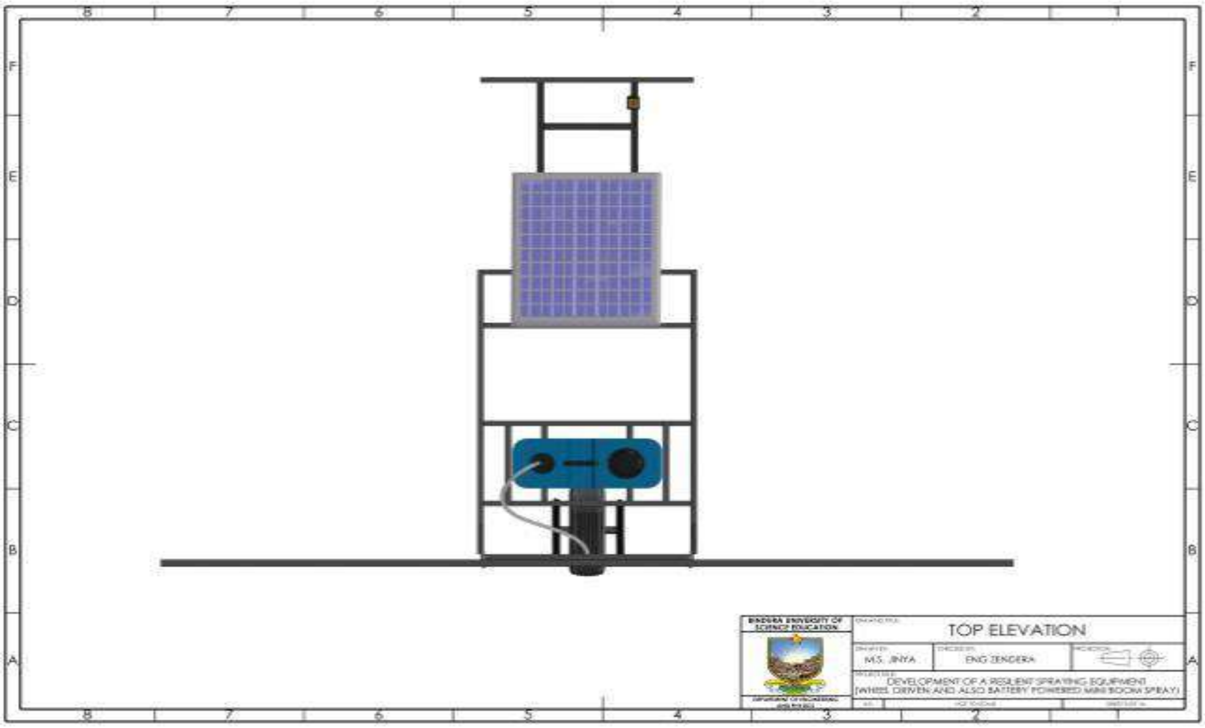
.1 Front Elevation



4.4.2 Side Elevation

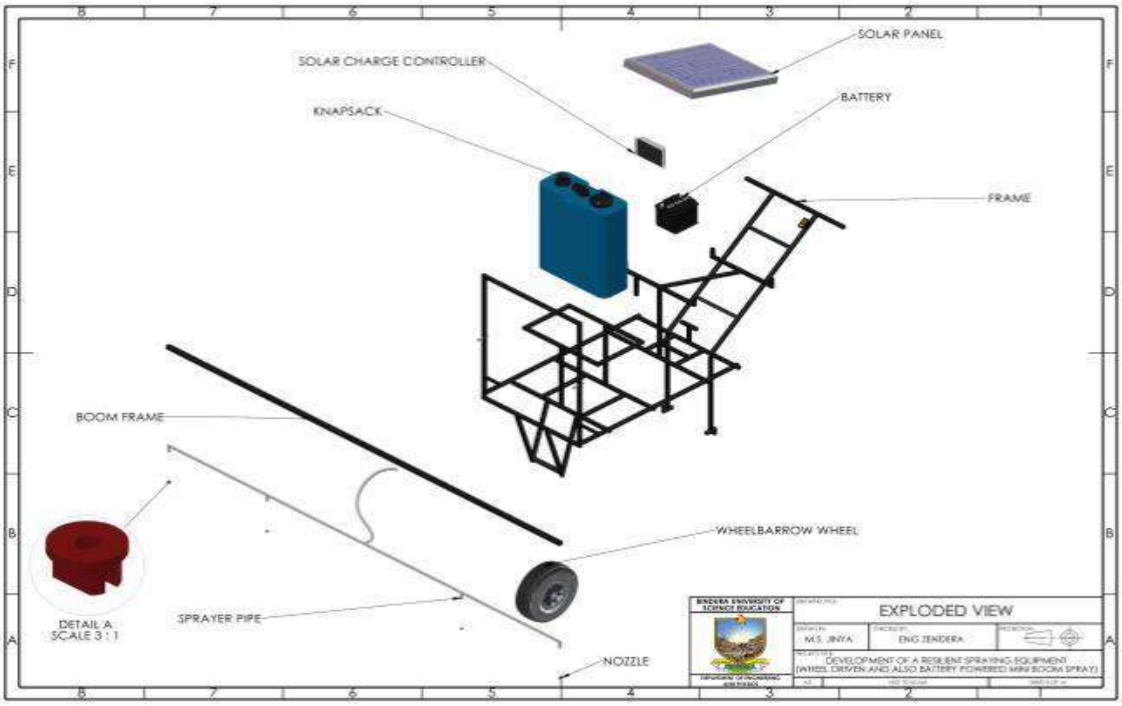


4.4.3 Plan Elevation

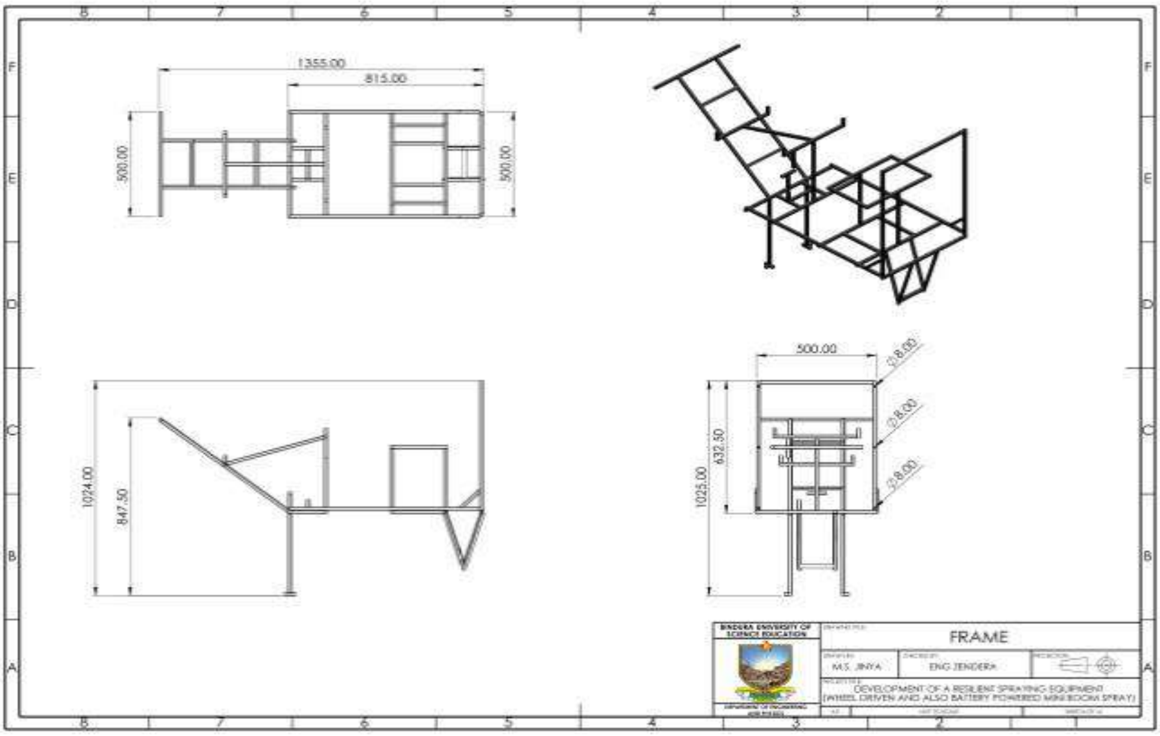


.4 Isometric View

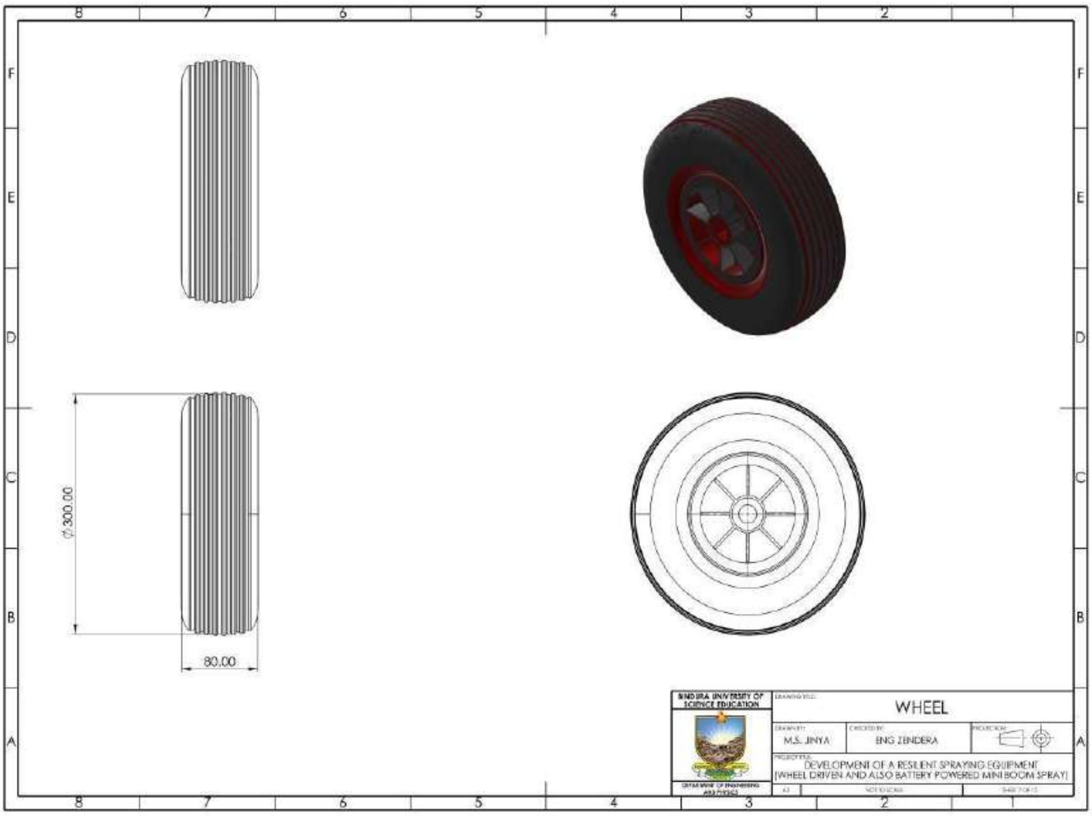
4.4.5 Exploded View



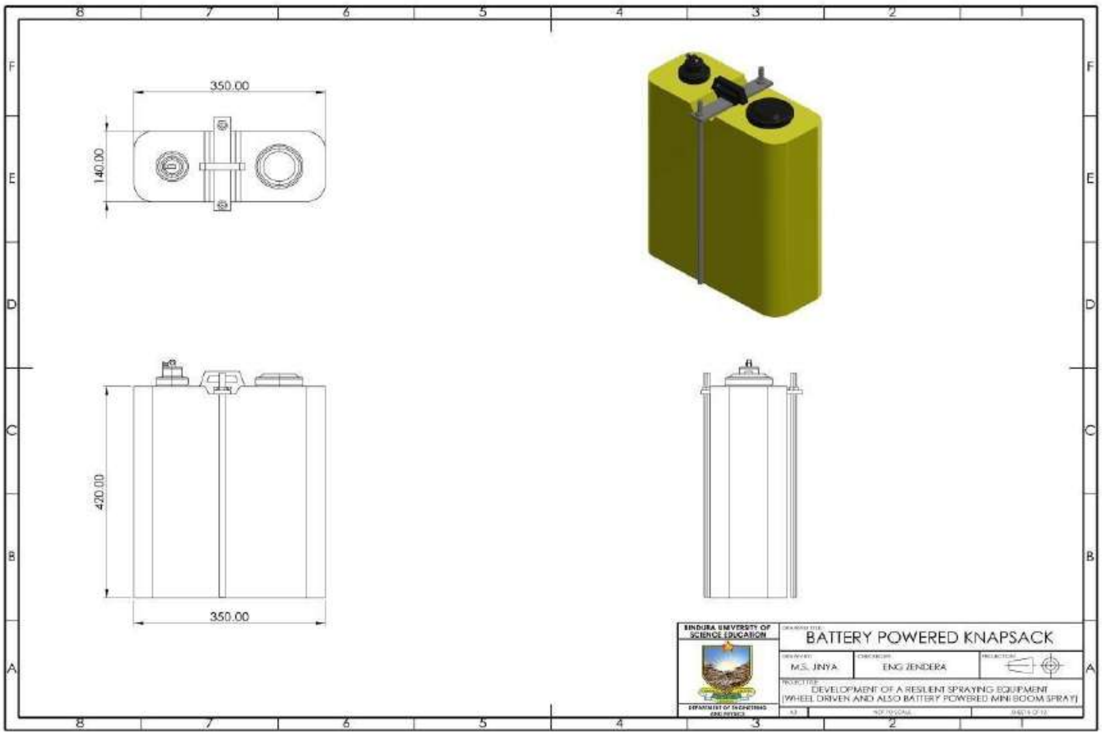
4.4.6 Frame



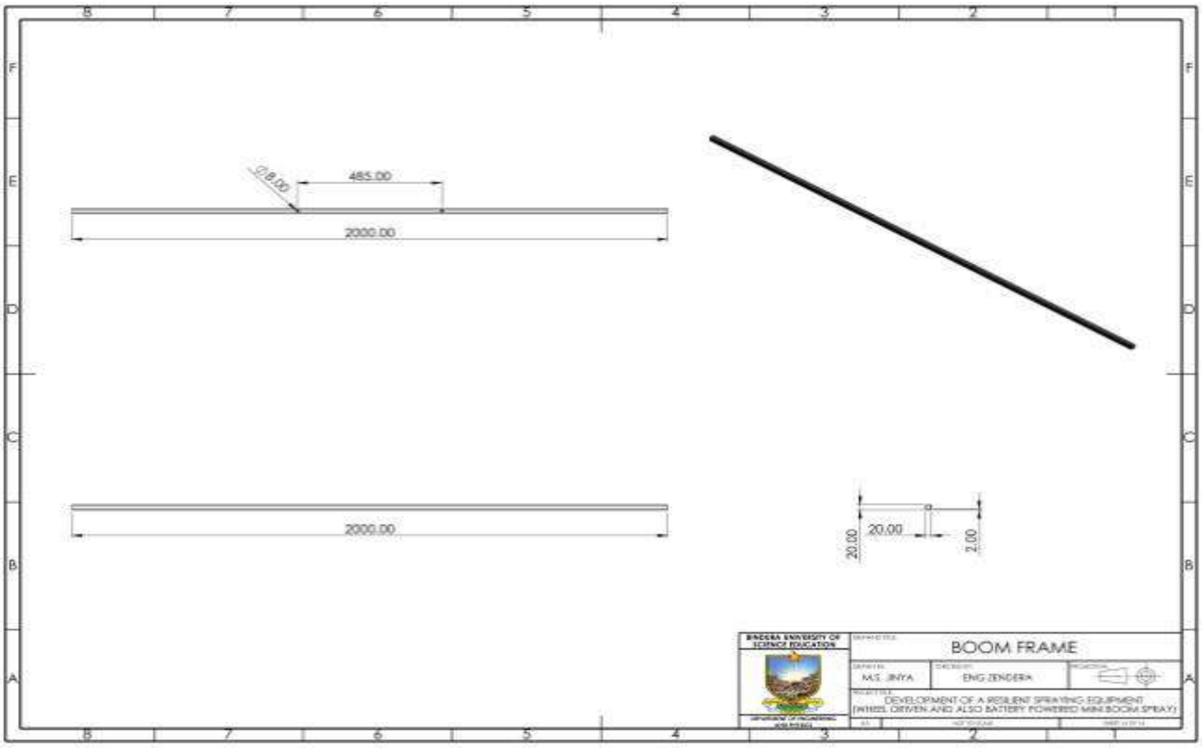
4.4.7 Wheel



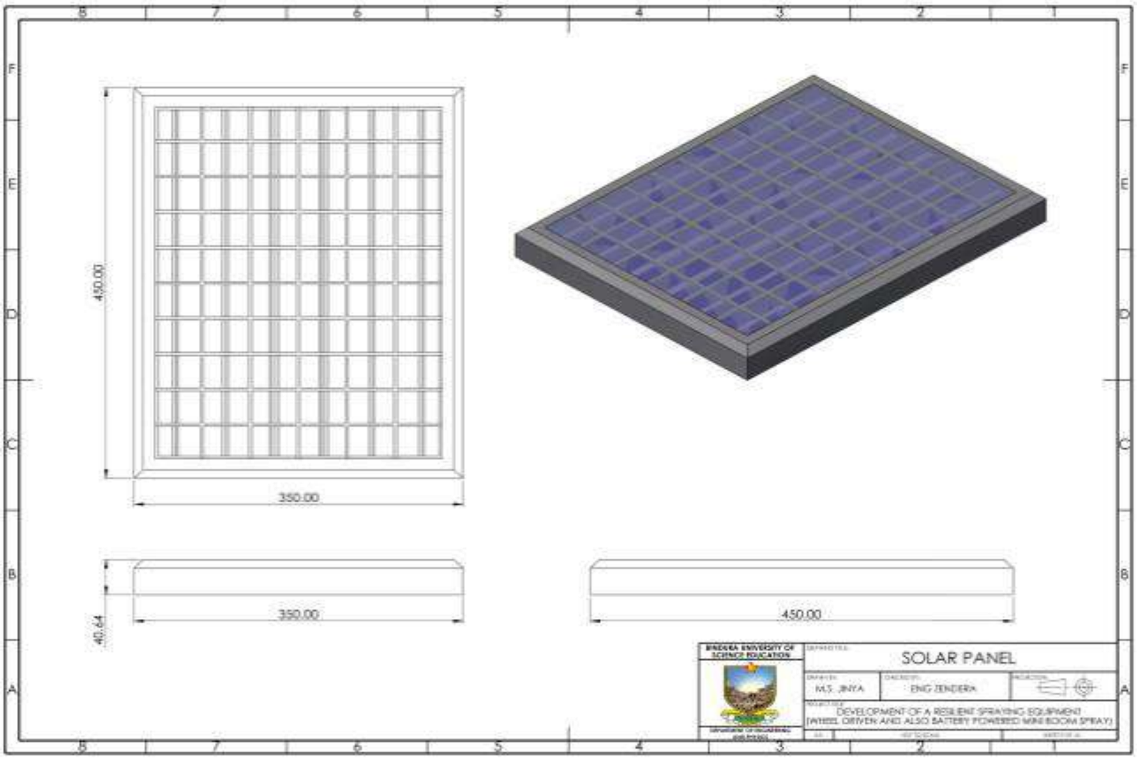
4.4.8 Battery-Powered Knapsack



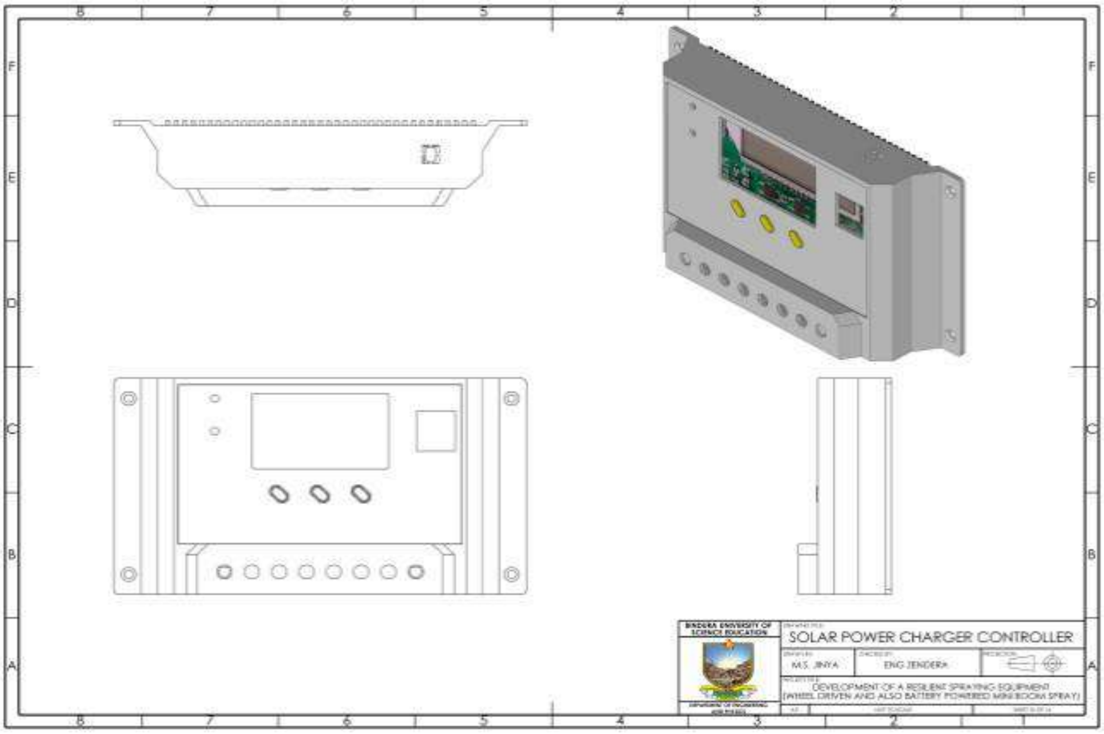
4.4.9 Boom Sprayer Frame



4.4.10 Solar panel



4.4.11 Solar charger controller



4.4.12 Nozzle

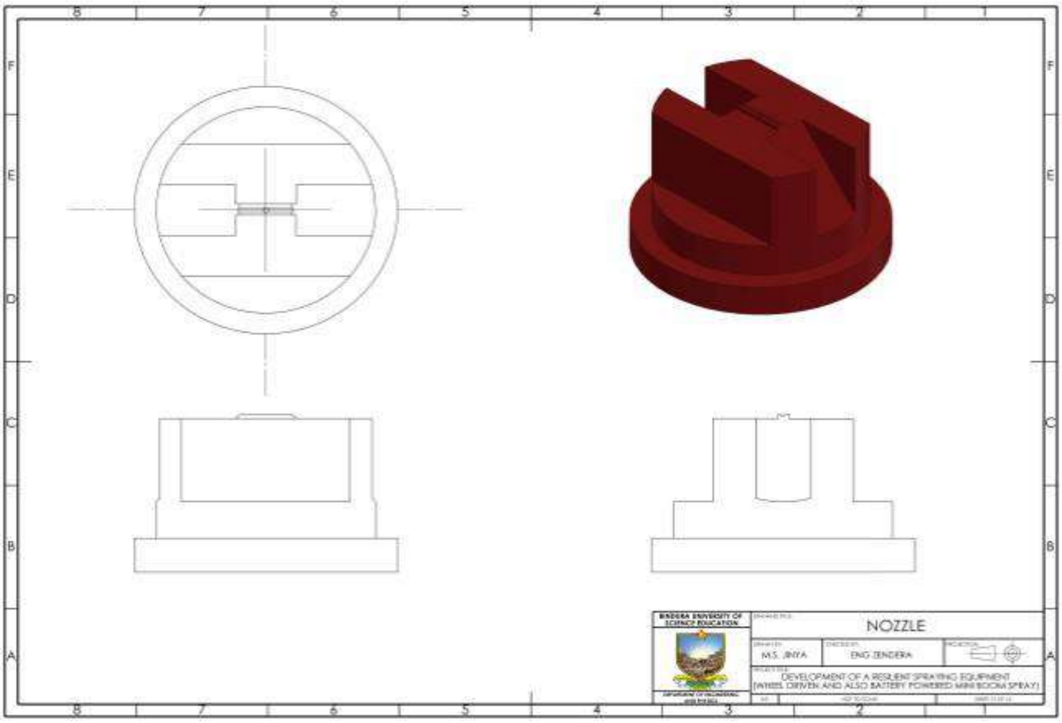
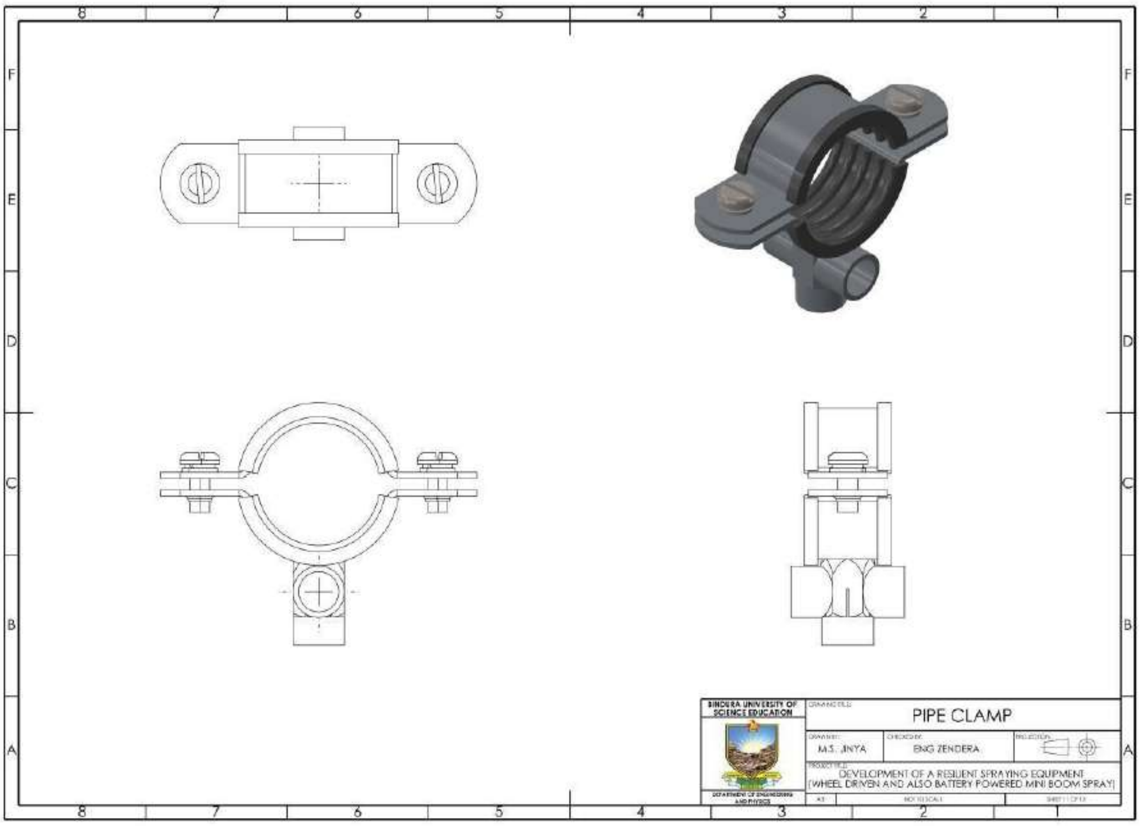


Figure 24: Nozzle

4.4.13 Pipe Clamp



4.5 DESIGN CALCULATIONS AND ANALYSIS

4.5.1 Design of frame (Deshpande, 2017)

a) Length of frame

$$L = \text{Diameter of front wheel} + \text{width of tank} + \text{excess space of operator}$$

$$L = 300 + 340 + 500$$

$$L = 1140mm$$

b) Height of frame

$$H = 940mm$$

c) Width of frame

$$W = 500\text{mm}$$

4.5.2 Selection of Wheel (Deshpande, 2017)

Factors to consider on selecting the wheel

a) Width of frame

- the width of the wheel must be smaller than the width of the frame

b) Environment conditions

- The wheel must have a reasonable width to provide more surface area in muddy areas
- The wheel must be smooth to avoid mud build-up on the wheel

c) Type of wheel rim

- The rim must have a solid design with no sprockets that would destroy the crops

With these factors above, the ideal wheel for the project is a wheelbarrow wheel

4.5.3 Selection of knapsack sprayer

A battery-powered knapsack sprayer was selected to power the spraying system with the following specifications:

a.) 16L tank capacity

For the prototype, a 16-litre tank was used because it is light and easier to push around and in between vegetable beds without destroying the plants.

b.) Battery size 12V/8Ah

This battery is best suited for the size of the pump which was used in the mini boom spray as it requires 12V to power the pump.

c.) Pump 12V, 0.65MPa

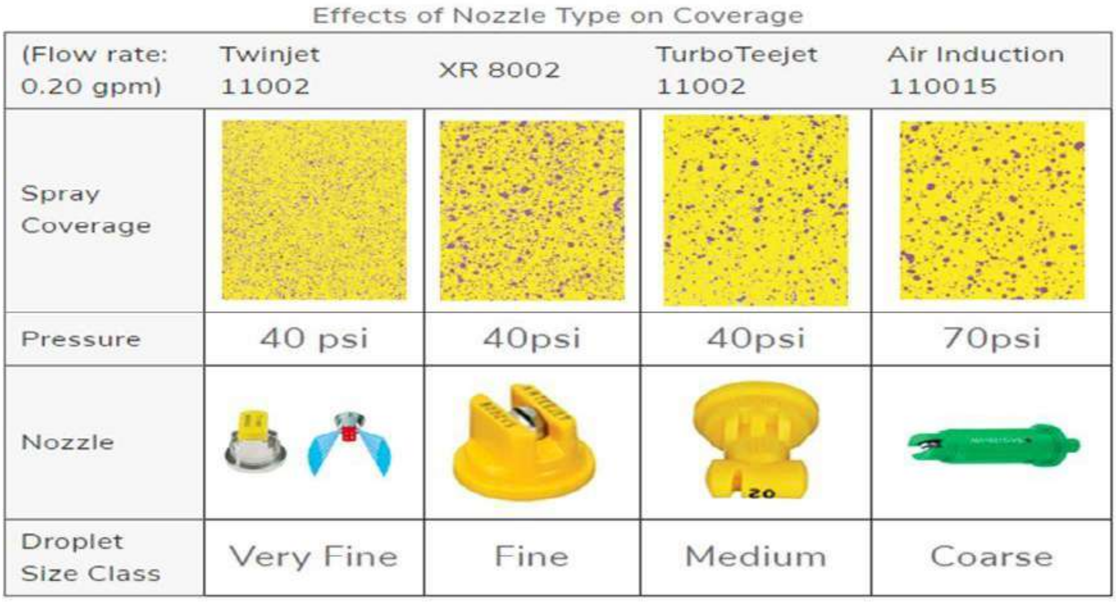
The pump can handle abrasive and corrosive chemicals at high pressures. This pump was selected as an alternative to the mini diaphragm pump which normally is used for spraying purposes as it can achieve the same purpose as the latter.

d.) Dimensions

(L x W x H): 385 x 213 x 490

4.5.4 Selection of nozzle

The flat fan nozzle type produces spray patterns with heavy spray volume discharged at the centre as the volume tapers off at both ends of the triangular-shaped pattern. This results in adjacent nozzles overlapping to get a uniform distribution across the whole swath.



Effects of Nozzle Type on Coverage

(Flow rate: 0.20 gpm)	Twinjet 11002	XR 8002	TurboTeejet 11002	Air Induction 110015
Spray Coverage				
Pressure	40 psi	40psi	40psi	70psi
Nozzle				
Droplet Size Class	Very Fine	Fine	Medium	Coarse

Average working pressure = 0.3MPa

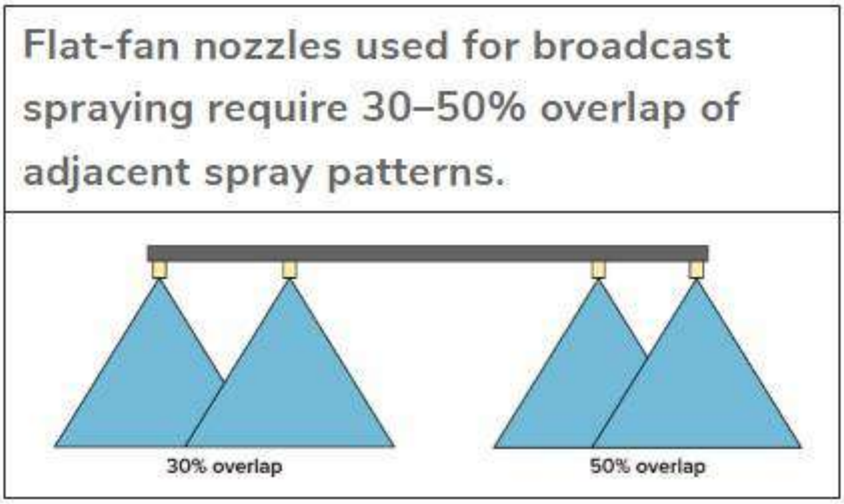
Flowrate from pump =33.3ml/s

Number of nozzles = 4

Flow rate at each nozzle =

$$= \frac{33.3\text{ml/sec}}{4}$$

$$= 8.33\text{ml/s}$$



4.5.5 Sprayer boom's pipe

The boom is made of LD pipe 14mm knapsack hose with a total length of 4m. The boom pipe has a thickness of 2mm. it has a nozzle spacing of 0.5m. The boom swath is 2 metres. The boom height can be adjusted in 3 stages

4.5.6 Design and development of the frame for holding the sprayer boom

A frame is made of steel square tubes. It is 2m long. This frame is fixed at the front of the implement main frame. The boom is adjustable at 3 stages using a bolt and nut to a height of the nozzle-crop requirement

4.5.7 Design and development of the frame for holding the tank

A frame is made of steel square tubes forming a box (300 x 370 x 225.0) for fixing the batterypowered knapsack with the main frame. The tank will be attached at the centre of the main frame

4.6 DOCUMENTATION

The table below shows the applications that were used in this project and their specific use.

Name of software	Icon	Use
Microsoft Word		• Project documentation • Making questionnaire forms
Microsoft PowerPoint		• Making presentation slides
Microsoft Excel		• Data analysis • Creating Gantt Chart
SOLIDWORKS		• 3D modelling • Simulations • Engineering drawings
CorelDRAW		• Block Diagrams

4.7 PROJECT MANAGEMENT

The researcher used a weekly Gantt Chart to plan work and properly allocate time to different chapters. The Gantt chart helped to maintain a bird's eye view of the project

START DATE		END DATE							
04 MARCH 2024		**29 MAY 2024**							
Task Name	Number of days	11/03/2024	25/03/2024	8/04/2024	22/04/2024	6/05/2024	13/05/2024	20/05/2024	27/05/2024
Introduction	7	■							
Literature review	21		■	■					
Design solution, analysis and synthesis	28			■	■				
Design manufacture, assembly and maintenance	28				■	■	■		
Project evaluation	21						■	■	■
Recommendations, further work and conclusions	2								■

4.8 MAINTENANCE SCHEDULE FOR THE SPRAYING EQUIPMENT

- Remove and clean nozzles and filters
- Inspect and clean the tank lid gasket**.** Look for cracked or missing gaskets and replace them as needed.
- Flush the tank hose and wand with clean water. You can save rinse water for future use but be careful not to contaminate your herbicide if you are using different types of herbicides as this may lead to compatibility issues.
- Always leave the strainer in place when adding water to the tank
- Clean the tank breather valve
- Inspect for cracks and always clean the tank lid casket
- Tighten clamps
- Check battery power before using of sprayer and always keep the battery charged.
- When you're not spraying your crops always drain your sprayer of any water completely.

CHAPTER 5 - PROJECT COST AND EVALUATION

5.1 INTRODUCTION

This chapter comprises the bill of quantities and the cost per unit of the materials and items or components used. The overall cost of manufacturing is also included to come up with the total cost of the mini-wheeled boom sprayer. Request for quotations for materials was sent to several Engineering companies including J. Mann, Steelmate, Electric Hardware and Farm Supplies.

5.2 TOTAL MANUFACTURING COSTS

Based on the design of the best-chosen solution, a bill of quantities was constructed.

ITEM	DESCRIPTION OF ITEM	QUANTITY	UNIT PRICE	TOTAL PRICE
Solar panel	28W 18V	1	$20	$20
Battery	12V 12AH	2	$10	$20
Knapsack sprayer	16litres	1	$12	$12
Solar charger controller	12V/24V	1	$9	$9
Wheel	Diameter 300mm	1	$15	$15
LD pipe	15mm	6m	$1.6	$9
Nozzles		5	$0.25	$1.25
End plugs	15mm	2	$0.2	$0.4
Pump	12V	1	$30	$30
LD Tee	15mm	1	$0.5	$0.5
Thread tape		1	$0.18	$0.18
Electric cables	mm	2	$0.5/m	$2
Flex cable	mm	3	$3	$9
On and Off switch		1	$1	$1
TOTAL COST				**153.33**

Table 4: Total Manufacturing Costs

5.3 OPERATING AND LABOUR COST

Labour cost is shown in the table below

OPERATION	TIME TAKEN(Hr)	COST/HOUR $US/Hr	TOTAL COST $US/Hr
Mounting solar, solar charger controller and battery	1	8	8
Welding	8	7	56
Painting and drilling	1	10	10
Cutting and grinding	2	14	28

TOTAL COST			102

Table 5: Operating And Labour Cost

5.4 COST OF CONSUMABLES

The operating cost includes all the costs of consumables or necessities that are needed to carry out fabrication processes. The estimated costs are as below:

DESCRIPTION	QUANTITY	UNIT PRICE (US $)	TOTAL COST(US $)
Welding rods	1kg	1	1
Cutting disks	1	3	3
Grinding disks	1	3	3
Electricity			10
Paint	1.5L	1.07	3.5
Total			21.5

Table 6: Cost of consumables

5.5 TOTAL MANUFACTURING COSTS OF THE MINI WHEELED BOOM SPRAYER

The total cost of fabrication was calculated by adding the material cost, labour and operating costs and the cost of consumables shown below:

COST CATEGORY	COST (US $)
Material cost	153.33
Labour and operating costs	102
Cost of consumables	21.5
GRAND TOTAL	276.83

Table 7: Total cost of fabricating the mini wheeled boom sprayer

5.6 MACHINE SELLING PRICE

To determine the machine selling price the following assumptions were considered:

Assumptions:

1. Value added tax = 15%
2. Profit Margin of the manufacturer = 15%

Selling price = Total manufacturing costs + Value added tax + Profit margin

= $276.83+ (0.15*276.83) + (0.15*276.83)

= $359.88

5.6.1 Cost-benefit analysis

Knapsack sprayers have very low field capacity whilst tractor-operated sprayers are costly. Economic analysis of the mini-wheeled boom sprayer was evaluated in the present study. The fabrication cost of the mini-wheeled boom sprayer was about 276.83. In comparison to using a knapsack sprayer, this mini-wheeled boom sprayer saves spraying time. The study concluded that the mini-wheeled boom sprayer was economically feasible as it saves time and reduces drudgery in comparison to the backpack knapsack sprayer.

5.7 CONCLUSION

The selling price of the harvester is **$359.88** which is quite affordable for most medium and small-scale farmers.

CHAPTER 6 - SUMMARY CONCLUSION AND RECOMMENDATIONS

This Chapter summarizes the tests carried out as explained in the Methodology section. The data collected during field testing and evaluation was analysed to determine the field capacity, field efficiency and spraying efficiency of the mini wheeled boom sprayer.

6.1 CONCLUSIONS

In conclusion, the main objective of this project was achieved. The ergonomic challenges that the farmers have been experiencing due to carrying the backpack sprayers on their backs have been altered. It reduces human fatigue and less time is spent on spraying leaving the farmer with more time to do other farm activities. Sprayers can be used on different heights in crops. The mini-wheeled boom sprayer is light and hence can be manoeuvred throughout the whole field easily. The mini-wheeled boom sprayer is affordable for medium and small-scale farmers. There is no use of fossil fuel therefore no fuel costs are incurred. The spraying equipment has more nozzles which means it covers the maximum area of spraying in a minimum space of time and at a maximum rate.

6.2 RECOMMENDATIONS

For a more efficient mini wheeled boom sprayer it should be equipped with a 12V mini diaphragm pump which is normally used in battery-powered knapsack sprayers.

6.2.1 Future Scope

- For use on harsh terrain, the wheels can be further upgraded
- It can be equipped with space to carry agricultural tools and equipment
- The machine can be equipped with a bigger tank to hold chemical
- The swath can be increased up to 8 metres
- A 12V mini diaphragm pump can be used instead

6.2.2 Problems encountered

Unavailability of the 12V mini diaphragm pump part in Zimbabwe. It came as a whole batterypowered knapsack sprayer and was costly to buy and dismantle. The accuracy of the prototype to the generated drawing slightly differed due to poor workmanship. Fabrication time was increased due to power cut-offs at the workshop the prototype was produced

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