UNIVERSITY OF EDUCATION, WINNEBA

EXPERIMENTAL ANALYSIS OF A MULTI-PURPOSE CULTIVATOR

ABUKARI ABDUL-SOMED

2021

UNIVERSITY OF EDUCATION, WINNEBA

EXPERIMENTAL ANALYSIS OF A MULTI-PURPOSE CULTIVATOR

ABUKARI ABDUL-SOMED

(200029762)

A Thesis submitted to the Department of MECHANICAL AND AUTOMOTIVE TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education Winneba, Kumasi in partial fulfillment of the requirements for the award of a Master of (Philosophy in Mechanical Engineering Technology) Degree

DECEMBER, 2021

DECLARATION

STUDENT'S DECLARATION

I, Abukari Abdul-Somed, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for any other degree elsewhere.

SIGNATURE:…………………………………

DATE:……………………………….…...............

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: **DR. SHERRY KWABLA AMEDORME**

SIGNATURE:…………………………………

DATE:……………………………….…...............

ACKNOWLEDGEMENT

I am most grateful to the Almighty God for His knowledge, strength (physical and spiritual) and His wisdom giving me throughout my course work.

I wish to express my profound gratitude to my supervisor, Dr. Sherry Kwabla Amedorme of the Automotive and Mechanical Technology Department, University of Education Winneba- Kumasi. I deeply appreciated his dedicated support, directions and constructive criticism throughout the writing of the research work.

My sincere gratitude goes to my family most especially my lovely wife Memunatu and children; Faridah, Abdul- Haleem, Ayisha and Raaha.

To everyone who supported me, but their names could not be mentioned, I say God bless you all.

Finally, to Alhaji Abukari Abass may Allah bless you.

DEDICATION

I dedicated this work to my lovely wife and children.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A mechanical multi-purpose cultivator was designed, fabricated and tested in a series of experiments bearing in mind basic engineering principles with other field requirement using locally available materials. The research work aimed at producing a mechanized tool with newest features to aid Small scale farmers to take advantage of the improved weeding tool for weeds management on farms that is advantageous than the existing tools. This cultivator was produced as a complement if not substitute for the use of the traditional equipment and methods such as manual weeding with tools such as cutlasses and hoes require high drudgery, time consuming and high labour force needed. The machine was modeled using AutoCAD and imported into COMSOL Multi-physics version 5.2 for the analysis. Stationary and Eigen frequency studies were performed to deter mine the stresses and displacements that the frame and handle are subjected to respectively, experiment test was carried out to find comparative performance of the soil interacting tools designed to the cultivator for which the result was immediately observed. The field efficiency was found maximum for Earthing disc (84.18%) followed by Worm Rotary cutter (81.02%) Strip blades rotary cutter (76.47%) and Float weeder (77.26%). The higher field efficiency of the unit was because of the minimum time loss such as turning time and other time during operation. The experimental test revealed that engine powered performance could be useful equipment in modernizing agriculture for small farm holders. The theoretical or effective field capacity (TFC) was determined to be 24m/h, plant damage was found to be 89.95% as the percentage of weeds that will be damaged therefore the machine proves to be effective in weed management. The new cultivator to introduce must be simple, modified with mechanisms that beeves up speeds at the slightest move of the operator to enable all the proposed weeding units function manually at a comparable low price to than traditional devices. Therefore, these conditions would be

resolved by introducing a prototype of new cultivator to blacksmiths and mechanical engineering institutions so that they could modify and fabricate it from local materials which might make it affordable and easier to introduce to farmers. This Project will help people to understand the relevance of mechanized weeding, which is not a huge time consuming and significantly improves weeding efficiency as well as the quality of weeding.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

There is an increase in technological methods in all aspects our daily activities. This is done to improve the efficiency, quality and cost reduction of products and methods. Many manufacturers and scientist tries to be up-to-date in their products for weed management in our farm lands without thinking of the effects on their customers and the environment. Although it is good for customers to have the latest version of particular products but if the interest of their valued current customers is to be put into consideration there should be a stand-by solution to their previous products improvement to suit the latest version to some extent if not one hundred percent. Various farm implements designs and chemicals are introduced to solve the need for weed management which leaves endless problems on the human and their environment or high cost of products. This has been one of the major problems of companies nowadays because their equipment and machines are very expensive and the manufacturers should not expect the customers to buy the new products anytime they are released due to inability of most farmers to afford the cultural practices in their farms as weeding and fertilizer applications.

Weeding requires huge labour force in the field of agriculture. In part of Ghana, this operation is mostly performed with cutlass or hoe and obsolete equipment that require high labour input, tedious and it is a time-consuming process. Weeds have very fast growth rates compared to other crops, and if not treated and managed properly may dominate the field. Weeds affect crop yield due to competition to acquire plant nutrients and resources (Slaughter et al., 2008; Weide et al., 2008). Weed management is a strategy that makes a desired plant population successful in a particular agro ecosystem using knowledge of the ecology of the undesired plants, which is the weeds (Ghersa et al., 2000). Oni (1990) reported that 50 to 70% of yield reduction is caused by poor weed control. Weeding and hoeing is generally done 15 to 20 days after sowing. The weed should be controlled and eliminated at their early stage. Depending upon the weed density, 20 to 30 percent loss in grain yield is quite usual which might increase up to 80 percent if adequate crop management practice is not observed. Rice and groundnut are very sensitive to weed as reported by Goel, et al (2008). The use of herbicides adversely leads to desert encroachment and intensive application of pesticides contributes significantly to environmental pollution (Gobor & Lambers, 2007).

Presently, there are many types of weeders available from simple to complex and motorized weeders. Several innovative and cost effective designs were developed and experimented according to the requirements of the farmers and soil conditions. Efforts are still on to reduce the drudgery in weeding operation (Thiyagarajan, et. al, 2006).

1.2 Statement of the Problem

Utilization of hand tool technology is one of the major tools some farmer especially Northern part of Ghana largely employ, which causes major problems of poverty in the rural areas. Nganilwa et al. (2003) opined that a farmer using only hand hoe for weeding would find it difficult to escape poverty, since this level of technology tends to perpetuate human drudgery, risk and misery. The most common methods of weed control are mechanical, chemical, biological and cultural methods. Out of these four methods, mechanical weeding either by hand tools or mechanical weeders are most effective in both dry land and wet land. Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity. In parts of Ghana where weed growth rate is high, farmer spent so much money for controlling weeds every year, in the production of major crops. Poor weed control leads to loss of several tones of major food grains every year. Therefore, timely weeding is very much essential for a good yield and this can only be achieved by using mechanical weeders which perform simultaneous job of weeding and tilling that reduce the time spent on weeding (man hour), cost of weeding and drudgery involved in manual weeding.

At present, weed control process, tools and machineries used has renewed interest not only due to labour and mechanization issues but due to some negative impacts that surface in the future. The most popular traditional method of controlling weeds in this country is the use of hoes and cutlasses which involves intensive labour and is time consuming. Since these tools are very slow during operations, weeds cause harm to farmlands before they are weeded, farmers hire more labour to enable them control the weeds on time before the crops are affected. In view of the problems farmers face in weed eradication, there is the need for a fast and versatile cultural practice tool which is easy and less costly to operate.

1.3 Aim and Objectives of the Study

The main aim of this research work is to redesign and examine a multi- functioning cultivator, to provide the best opportunity for crop farmers to acquire lest costly but highly efficient tool, as far as total cost of production is concerned.

1.4 Specific Objectives

The specific objectives targeted to achieve the research goals are summarized as:

1. To redesign a multi-purpose cultivator with new design parameters
2. To experimentally examine the cultivator and its weeding units
3. To perform comparative test analysis of the new design and existing design.

1.5 Justification

Currently in every part of Ghana, weeding with simple tools such as cutlasses, hoes etc is labour intensive and time consuming. Thus, there is a need for the design of manually operated weeder for intensive and commercial farming system in this country. One of the problems in crops and large plantation is poor weed control; hence there is need of mechanical weeder to increase the production of these products. The cost for employing manual labour when using simple tools is very high in commercial farming system. This can be reduced using mechanical cultivators.

Realizing that some of the methods and tools used in controlling weeds on our farm lands inhibit the production of crops in this country. Therefore, there is the need for a very fast and efficient weeding tool to be introduced to replace the use of traditional hoes in controlling weeds.

The introduction of the manual weeder will reduce the number of labour and cost drastically since a person can work on a very large farm size within a very short time with the use of the weeder as compared to the use of traditional hoes and cutlasses.

The use of the manual weeder will conserve soil against erosion, since the disc does not stir the soil; it only slashes the target down to the ground level.

It reduces direct use of human energy as compare to weeding by pulling with the hand, which is very tiring and time consuming.

As the tool reduces the human effort, farmers can increase their farm size that they can easily manage which will go a long way to increase crop production.

The use of the tool (Manual Weeder) will reduce the use of chemicals on our farmlands, which posse's health hazards to man and the environment and causes of soil compaction.

1.6 Scope of the Study

The research work was limited to the design concept of the machine and its attachments (weeding units), examine and test of all the designed units for efficiency and comparative performance of the weeding units. The overall research work was done at the university education Winneba-Kumasi and Tamale Technical university campuses and workshops.

1.7 Organization of the Study

This thesis is organized into five chapters, the introduction, which is the subject of chapter one, which consist of the background, the specific objectives, justification, material and method, scope of the study and the organization of the work. Chapter two contains the review of related work done on cultivators such as weeders and planters used for cultural practices in the field of farming, types of weeding methods adopted by farmers, intended design of the cultivator. Chapter three describes the method and material used for the design, fabrication and testing of the work. Chapter four discusses the experimental results and analyses of the results. Chapter five gives conclusions and recommendation of from the research work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter concerns itself with the review of existing literature on the key themes of the study. It also discusses the weed control management methods employed by farmers, views of authors that have contributed to the topic under study both in theoretical and empirical perspectives.

2.2 Weed Management Methods Employed by Farmers

Basically farmer in the entire glob use various cultural practices to manage weed in the crop environment, these cultural practices vary from place to place depending on the nature of the plant environment and resources available, (Lemerle et al. 2001).

Liebman and Davis (2000) states that controlling weeds in forage crop production may involve a wide range of techniques. Nevertheless, virtually all weed control methods may be classified into one or more of five main categories. The 5 general categories of weed control are:

1. Preventative Weed Control; 2. Cultural Weed Control; 3. Mechanical Weed Control;

4. Biological Weed Control; 5. Chemical Weed Control.

2.3 Preventative Weed Control

According to Bàrberi and Mazzoncini, (2001) Preventative weed control refers to any control method that aims to prevent weeds from being established in a cultivated crop, a pasture or a greenhouse. Examples of preventative weed control would be using certified weed free seed, only transporting hay that is weed free, making sure farm equipment is cleaned before moving from one location to another and screening irrigation water to prevent weed seeds from traveling along irrigation ditches.

Teasdale and Mohler (2000) states that when cover crops are used as dead mulch (i.e. they are left to decompose on soil surface), weed suppression seems mostly to be the result of the physical effects of the mulch. The action influences light extinction through the mulch and consequently weed seed germination. Timely sowing of cover crops is very important to enhance biomass production and hence to increase their weed suppression potential, Liebman and Davis (2000). Cover crops can also interact with other biota; for example, they promote the establishment of vesicular-arbuscular mychorrhizae, which in turn may shift weed flora composition by favouring mychorrhizal plant species at the detriment of non-mychorrhizal species (Jordan *et al.* 2000).

2.4 Cultural Weed Control

According to Spandl et al. (1998) Cultural weed control refers to any technique that involves maintaining field conditions such that weeds are less likely to become established and/or increase in number. Examples of cultural weed control would be crop rotation, avoiding overgrazing of pastures or rangeland, using well-adapted competitive forage species, and maintaining good soil fertility.(Lemerle et al. 2001) states that Crop sowing time and spatial arrangement can be manipulated in a special mannerto enable crops escape competing for nutrients at certain stages of the crop life's span.In some cases, modification of crop sowing date, density and pattern can reduce weed emergence and/or increase crop competitive ability (Mohler, 1996), although this effect is very much dependent on crop species and environment. Spandl et al. (1998) observed that, compared to autumn-sown wheat, control of Setariaviridis in the spring-sown cereal was favoured because the weed emerged in a single flush instead of several flushes, thus being more vulnerable to direct weed control methods (herbicides or cultivation). In cases like this, the crop sowing date can be used by the farmer as a cultural weed management method. In other crops (e.g. vining pea and potato), an increase in seeding rate may turn into higher competitive ability against weeds, but this is often to the detriment of yield because of higher intra-specific competition between pea plants (Lawson and Topham, 1985), or decreased tuber quality and increased potato susceptibility to diseases (Litterick *et al.* 1999).

2.5 Biological Weed Control

Biological Weeding: Biological control involves the use of insects or pathogens that affect the health of the weed. It includes the use of living organisms for suppressing or controlling the weeds. Plant, animal or micro-organisms may be used for destruction of weeds. The goal of biological control is not eradication, but the use of living agents to suppress vigour and spread of weeds. Such agents can be insects, bacteria, fungi, or grazing animals such as sheep, goats, and cattle or horses. Grazing produces results similar to mowing and bacteria and fungi are seldom available for noxious weed management. Biological control is most commonly thought of as insect bio control.

Biological weed control is a weed control method using specialized natural herbivorous enemies of problematic plants in agricultural or natural environments (Gite, 2003). Heraux et al., (2005) used all chemical-releasing organisms, which are organisms that release a chemical substance that can suppress or stimulated other organisms, to control weeds in transplanted vegetable fields. Agricultural research (2011) also reported several well-known examples of biological control of weeds, such as the control of an Australian weed, prickly pear cactus, using a moth that originated from South America. This biological approach for weed control has its successes and failures, and some inconsistencies that make it difficult to adopt in practice.

As part of biological the farmers themselves controls weeds by physical hand pulling to eliminate them from the desired plants which is termed as manual weeding.

Basically this method uses a technique that involves the use of natural enemies of weed plants to control the germination of weed seeds or the spread of established plants. This is a rapidly expanding area of weed control with many examples. Examples of biological weed control include the use of sheep to control tansy ragwort or leafy spurge, cinnabar moth and the tansy flea beetle to control tansy ragwort, the chrysolira beetle to control St. John's Wort, and the use of goats to control brush on rangeland.

2.6 Manual Weed Control

Sylestre et al., (1983) observe that weed competition was more under broadcast situation. Hand weeding gave the highest weed control efficiency (89.74%) and higher grain yield (63.55qt/ha) compared to the herbicidal treatments.

Singh, (2012) found that the hand weeding twice, one at 15 days and other at 30 days gave the highest control efficiency and the maximum grain yield.

Manual Weeding: Manual control is the use of the hands or handheld tools to deal with weeds. Extensive amount of cheap manual labor is necessary for manual weeding. Manual weeding is commonly employed by smaller framers for weed removal. The earliest and the simplest of all technologies was manual weed control. Manual weed control started with farmers using their hands to uproot the weeds. The technology then advanced to hand tools, from using a stick to using a hand-hoe (Cloutier et al, 2007).

According to Chatizwa, (1997) and Hanson et al, (1992) Manual weeding (hand hoeing) is very expensive and it may be difficult to find labor. Additionally, it is strenuous and physically demanding and can cause overload injuries. However, it requires less or no initial cost of equipment, and therefore be used on small areas (Hansen et al., 2004) or in developing countries where hand labor is readily available at a relative low cost. Manual weeding using human hands, provides a very effective weed control, but requires substantial human effort and energy. From the study by Agarwal and sigh (2011), asparagus required the lowest time for hand weeding, 12 hours per hectare, and onions require the highest time for hand weeding operation, 158 hours per hectare. A cause for this low weeding rate for onions compared to other crops like asparagus was that have a smaller crop canopy, which allows more sunlight to penetrate onto the soil, thus creating a higher probability for emergence weeds, Weed Society of America (WSA) and American Farm Bureau Federation (AFBF). Sule, (1983) indicated that hand weeding eliminated only 65-85% of the weeds for cotton production, mainly due to workers mistaking weeds for crop plants or missing weeds. It was also reported that manual weeding using long-handled hoes would damage the crops while also missing some of the weeds (Spliid & Helweg, 2007). Hoeing is also time consuming and can lead to back injuries to workers.

Earlier in Ghana, manual hoes were used primarily for weeding most vegetable crops. Farm workers complained of suffering permanent back injury due to the extended periods of hoe weeding. Donkoh et al, (2016) conducted a National Organic Farmer's Survey and concluded that organic farmers cited weeds as one of the major causes of reduced profit after weather-related losses, high input costs and high labor costs, in that order. Earthbound Farms, the largest organic producer in North America, mentioned that weed control was a time consuming and very costly part of their operations since they depended on mechanical cultivation and hand weeding. Their farmers had to spend up to $1000 per acre to control weeds (Reza, 2011).

2.7 Chemical Weed Control

Chemical weeding: Chemical control involves the use of herbicides. Herbicides control weed plants either by speeding up, stopping or changing the plant's normal growth patterns; by drying out the leaves or stems; or by making it drop its leaves. Chemical control with herbicide application can provide the most effective and time-efficient method of managing weeds. Numerous herbicides are available that provide effective weed control and are selective in that grasses are not injured. Weed removal is one of the major activities in agriculture. Chemical method of weed control is more prominent than manual and mechanical methods. However, its adverse effects on the environment are making farmers to consider accept mechanical methods of weed control. Chemical weeding is the most extensively used method of weed removal. But these chemical used for weeding are harmful to living organisms and toxic in nature. (Bowman, 1997; Cloutier et al., 2007 Weide et al., 2008).

In the mid-20th century, the use of mechanical weeders decreased as herbicide spraying was introduced in North America and Europe (Cloutier et al., 2007; Hakansson, 2003). The usage of herbicides became more favorable because labor becomes limited and more expensive. After World War II in the U.S., labor costs increased and labor workers become scarce, as workers were more eager to work in the cities rather than staying in the rural areas. As a result, labor rates increased from \$0.10/hour in 1940s to \$0.50/hour in 1950s and \$1.00/hour in 1960s.in addition, the cost of herbicide application was more economical and helped to reduce yield loss compared to standard practices such as mechanical cultivation or manual weeding (Gianessiand Reigner, 2007). Gianessi and Reigner (2006) reported that the herbicide cost for vegetable crops increased slightly from 2001 to 2005. They also reported that manual weeding costs alsoN increased, with hand weeding costs increasing from \$8.75/hour in 2001 to \$10/hour in 2005.

Mechanical cultivation costs also increased from \$4.5/acre to \$5.84/acre. Herbicide application cost was slightly lower, estimated at \$4.00/acre in 2001 and increased slightly to \$5.21/acre in 2005, based on an 18.3 m (60ft) self-propelled boom sprayer. These costs provide one reason why vegetable farmers tend to use chemical weeding, because of the cost advantage over manual weeding.

Chemical weeding, not only protects the crop from weed competition, but it also helps to reduce crop yield loss compared to mechanical cultivation. Mechanical cultivation has always had difficulties in performing cultivations in a timely manner, due to issues such as wet fields hindering tractor and equipment entry, leading to weed competition for crop plant nutrients

(Hakansson, 2003).Gianessi and Reigner (2007) presented historical data indicating increases in yield due to chemical weeding. Researchers have also shown statistically that herbicides contribute to improved corn and soybean yield.

However, renewed interests in chemical weed control alternatives have grown due to environmental concerns, the growing consumer demand for pesticide-free produce and also growing herbicide resistance in weeds (Mc Coornick and sander, 1982). Herbicide application is also becoming more constrained with increasing pesticide use regulations, consumer concerns and a growing interest in organic foods (Slaughter et al., 2008). Most of these non-mechanical methods at long run make use of the mechanical equipment to render services such as spraying and transport of materials for the exercise.

2.8 Mechanical Weeding

Mechanical Weeding: Mechanical control is the use of powered tools and machinery to manage weeds. It is suitable for larger infestation because it reduces the weed bulk with less manual effort. Mechanical control consists of methods that kill or suppress weeds through physical disruption. Such methods include pulling, digging, disking, ploughing and mowing.

As agriculture becomes more mechanized, weeding tools developed that were pulled by draft animals such as buffaloes and horses were evolved and were adapted to tractors as the source of draft. There are many types of mechanical weeders in the market that can use three main physical techniques for controlling weed: (1) burying weeds, (2) cutting weeds and (3) uprooting weeds. Burial of weeds is accomplished through the action of tillage tools (Pawar, 2003) and is usually done during land preparation when soil conditions are enhanced through tillage. The goals of tillage include reducing the soil strength, covering plant residue, rearranging aggregates and also removing weeds. Cutting and uprooting weeds are performed by mechanical tearing and breaking the weeds from the soil and usually done by mechanical cultivation after the crop is planted and has emerged. The majority of the manufactures, who sell mechanical weeders, produced weeders that are designed to control weeds between rows, or in the inter-row region (Cloutier et al, 2007). There are only a few machines that are designed to do within crop row weeding, or intra-row weeding.

2.9 Intra-row Weeding

This type of weed control is generally widespread and used by farmers who do not use herbicides. The objective of inter-row cultivation is to cultivate as much of the inter-row area as possible without damaging the crop. Cultivation can destroy weeds by completely or partially burying weeds, uprooting and breaking the weed root contact with the soil. However, there are limitations using this method. Weed control can only be done during the early crop stages because limited tractor and cultivator ground clearance and machine-plant contact may potentially damage the crop foliage at later growth stages (Cloutier at al 2007). However, in spite of these limitations, there is a wide selection of cultivation implements that can be used for mechanical inter-row weeding.

Inter-row cultivators are the most common machine used for mechanical weed control. This agriculture implement consist of cultivating tools mounted on a toolbar that either rotate or sweep to move soil, bury, cut or uproot the weeds. The sweeping type cultivators use triangular-shaped or duck –foot-shaped blades that are swept under the soil surface. The blades vary in width, from as small as 5.1 cm (2 in.) to as large as 71.1 cm (28 in.). This type of cultivator does not require any PTO power. Recommended travel speeds for sweep type cultivators such as rotary are 6.4km/h to 11.3 km/h. Another type of cultivators are rotating type cultivators such as rotary tilling cultivators and rotary tillers, which are commonly used for inter –row weed control. However, the latter machine is more expensive, since it has been designed for multiple functions including other tillage applications such as strip-planting into crops and preparing permanent plant beds. These rotary tillage implements use individually suspended inter-row gangs or blades, which are mounted on circular discs with parallel linkages. The cutting blades or knives vary in width, from 12.7cm to 152.4 cm (5 in 60 in), and in configuration. Metal housings can be used to cover the tolling blades to prevent crop damage. Recommended forwards speeds for rotating type cultivators are 4 km/h (2.5 mile/h) to 8 km/h (5 mile/h) (Bondwan, 2001).

Mechanical intra-row weeders control weeds within the crop rows. These weeders accomplish their goal using two different approaches depending on the crop density. The first approach is to use selective machines or add-on tools that can perform weed control close to the crop, without damaging the crop itself. The second approach is to use machines that have weeding tools that move sideways to conduct weed control around the crop canopy. Below are some of the machines that have been reported to be effective in weed control.

The torsion weeder is another machine available for intra-row weed control. Torsion weeders use spring tines connected to a rigid frame and that are bent so that two short tine segments are parallel to the soil surface and meet near the crop plant row. This arrangement allows crop plants to pass through the tine pairs. The coiled spring tines allow the tips to flex with soil contours and around established crops. These weeders have been tested in Europe and North America for horticultural crops with very good results. The weeder also reduced the weed density to 60-80% of the original weed population. However, it also requires very accurate steering with relatively low forward velocities, and hence has a low working capacity. Torsion weeders are often used together with precision cultivators to perform efficacious weeding (Bowman, 1997; cloutier et al., 2008).

2.10 Review and Evaluation of Existing Weeders

Brain (2002) studied the design and evaluation of animal-drawn weeders in Mexico and found that, evaluation of weeders performance depends on the categories of information required for a particular purpose and it should include both technical and socio-economic parameters. Evaluation parameters includes soil type and condition, crop, weed type and population, effectiveness of weed control, crop damage, implement draft, forward speed and power requirement. All these have to be taken into consideration as far as the multi-purpose cultivator is concerned. Parida (2002) modified IRRI conical weeder and evaluated its field performance in paddy field. He revealed that under experimental conditions, field capacity and field efficiency of the weeder were found to be 0.2 ha h^{-1}. Senthilkumar (2003) compared the use of rotary weeder (five times with ten-day intervals from 20 days after transplanting until booting stage) with the conventional hand weeding (three times) for wet season, and chemical weeding and two times hand weeding for dry season. In both seasons, mechanical weed control significantly increased grain yields. Weeders use alone increased the plant height and enhanced the grain yield by 10.9% as compared to manual weeding.

Tajuddi (2006) has designed, developed and tested the engine operated weeder powered by a 2.2kW petrol start kerosene run engine. The rated engine speed of 3300 rpm at load was reduced to 60rev/min of ground wheels by belt pulley and sprocket – chain mechanisms in three steps. A sweep type weeding blade was designed for structural strength. The power weeder was evaluated in the field in terms of field efficiency and weeding efficiency in cotton crop. The machine was found useful for weeding by this machine comes to only – third of the weeding cost by manual labours. Mynavathi et al, (2009) studied the effect of manually operated weeders on growth and yield of irrigated maize. The treatments consisted of four manually operated weeders viz., crescent hoe (T1), multi tine weeder (T2), wheel hoe (T3) and rotary peg weeder (T4) and weeding twice on 25 and 45 days after sowing.

The above treatments were compared with hand weeding twice on 25 and 45 DAS (T5), pre-emergence application of atrazine 0.5 kg ha-1 on 3 DAS with one hand weeding 45 DAS (T6) and un weeded control (T7). Efficacy of mechanical or manual weeding in controlling the weeds at critical crop-weed competition at 45 DAS in maize might be the reason for better growth of maize in mechanical or manual weeding as reported by Perron et al. (2001). The study revealed that pre-emergence application of atrazine 0.5 kg ha^{-1} on

3 DAS with hand weeding on 45 DAS (T6) and hand weeding on 25 and 45 DAS (T5) for higher grain yield. Among the manual weeders, higher grain yield could be obtained by weeding with either wheel hoe (T3) or multi tine weeder (T2) on 25 and 45 DAS.

Manuwa et al., (2006) designed and fabricated an engine powered row crop mechanical weeder and tested at the Federal University of Technology, Akure, Nigeria. The main features of the weeder were: a 5 hp Internal Combustion (IC) petrol engine as prime mover, power transmission system, and three sets of weeding blades, main frame and ground wheels. The width of cut of machine was 0.24 m, while the speed of the cutting blades was 800 rpm. The average fuel consumption of the engine was 0.7 Lh^{-1} at maximum speed. Field tests showed that under most field condition, the weeding efficiency was 95% and effective capacity was 0.053 ha h^{-1}. The cost of producing the model weeder was estimated at about US$ 285 in 2007.

Allender, (1991) studied the comparative performance of different power weeders in rain fed sweet sorghum crop. The study found that, the weeding efficiency of 'L' shaped blade power weeders was found to be 91%, whereas 'C' type and Sweep type blade power weeder were 87% and 84% respectively. The performance index of 'L' shaped, sweep shaped and 'C' type blade weeder were observed to be 169.84, 153.23 and 114.30 respectively. The field capacity of sweep type weeder was 0.12 ha/hr which is more than 'C' and 'L' type weeder and plant damage observed minimum as compared to other two.

Berling, (1992) studied the design power weeder for low land paddy cultivation in Sri Lanka with the main objective of design and fabrication of a power weeder. Optimization of weeding ability was done by mechanize simultaneously in three rows. The machine was designed to use in the field cultivated by using mechanize seeder or mechanized transplanter. The double action weeding drum was driven by a small 1.3 KW gasoline engine that can enable removal of weeds drum simultaneously facilitating the forward motion of the machine. In addition, the conical shaped weeding drum was also designed to loose-up soil without harming the paddy. Totally six drums will be used in such a way rear drums have high angular velocity with respect to the front drums.

2.11 Automated Technology in Weeders

Automation is defined as the technique, method, or system of operating and controlling a process or mechanical device without human intervention and continuous input from an operator, Tang et al. (2000).

Automation also optimizes the power provided by the machine, and thus often represents the substitution of energy input into a process with electronic hardware, sensors, actuators and software (Chancellor, 1981). Weed control, particularly within the crop row is a process that benefits greatly from the intelligence represented in manual weeding, but also from the higher work rates associated with mechanical weeding. Automation technology also been applied to weed control to combine the advantages of manual and mechanical approaches. By using automation, a machine offers the possibility to determine and differentiate the crop plants from weed plants, and at the same time, remove the weed plants with a precisely controlled device (Bakker, 2009). Slaughter et al. (2008) in a review on autonomous robotic weed control systems identified four core technologies needed for automated weed control: (a) guidance, (b) detection and identification, (c) precision in-row weed control and (d) mapping. He also described several intra-row weed removal mechanisms for robotic actuation. One of the mechanical-based designs was using mechanical knives that can rapidly position in and out of the crop row.

Detection and identification of weeds and crop, is a very challenging task to conduct in real time.

Weed identification techniques rely on machine vision systems and image processing techniques described by Gonzales et al. (2004) such as biological morphology, spectral characteristics and visual structure. Steward and Tian, (1999) used Environmentally Adaptive Segmentation Algorithm (EASA) to develop real-time machine vision weed detection for outdoor lighting conditions. Tang et al. (2000) used color image segmentation using a binary-coded Genetic Algori (GA) for outdoor field weed identification under different lighting conditions. Precision intra-row weed control can use mechanical, chemical or electrical approaches.

Mechanically automated weed control such as the automated thinners use mechanical knives that travel in and out of the crop row or use a rotating hoe that could be height adjusted (Astrand and Baerveldt,(2002). Automated chemical weed control such as precision spraying system was developed using independent spray ports for spraying weeds in a spray map generated by vision systems (Lee et al., 1999). Electrical weed control was developed by applying high voltage (15-60 kV) electrical discharge or continuous current to small weeds using precise probe position control (Diprose and Benson, 1984; Blasco et al., 2002). Precision thermal weed control involves the usage of sensors to detect weeds and automatically opens the flame nozzle to burn the detected weeds (Mattsson, 2011).

2.12 Automated Weeders

Parish, (2008) tested a weeding machine using computer vision to detect plants. This automated intra-row weeder used a rotating half circle disc that rotated to avoid contacting the crop plants during weeding. A camera was mounted centrally on the implement at a height of 1.7 m looking ahead and down such that the bottom of the field of view was vertically below the camera and the full-width of the bed was visible over a length of approximately 2.5 m. the position of the plants along the crop row and their location relative to the rotating disc were detected using computer vision. An experiment on a cabbage plot was conducted using an intra-row crop plant spacing of 0.3 m and a forward velocity of 1.8 km/h (0.5 m/s). Weeding treatments were conducted at 16, 23, and 33 Days after Transplanting (DAP). The best results were obtained at 16 and 23 days after planting, with 77% and 87% reduction in the number of weed plants, respectively. However, after 2 weeks of subsequent weed re-growth and new germination, the number of weed plants after the 16 DAP weeding treatment was still reduced by 74%, while number of weed plants after the 23 DAP were still reduced by 66%. Under the experimental conditions, it was shown that performing weed control at an early stage succeeded in controlling later weed re-growth and new germination. This machine was commercialized under the name Robo crop, Agricglance,(2014). Augustin et al., (2002) developed an agricultural mobile robot with vision-based perception for weed detection and subsequent control. This machine required two cameras, one gray-scale camera with a near-infrared filter to obtain high-contrast images located at the front to identify the crop row location and direction, and a color camera to identify crop plants, located at the center of the machine, facing downwards towards the soil. A weeding tool, which was a rotating wheel oriented perpendicular to the crop row, was located at the rear of the machine. The tool was lowered using a pneumatic cylinder when gap between crop plants was detected and provided some tilling action in the inter-crop plant area. At a speed of 0.2 m/s, the weeding robot showed good perception performance. The crop row detection camera was able to recognize crop rows based on a row-recognition algorithm with a ±2 cm error. The crop detection color camera successfully detected crops with using image segmentation techniques to classify weeds and crops using color and shape features. However, the weed control efficacy of the machine was not reported. The research focused more the perception system for crop row and crop detection, and not on weed control in particular.

Cloutier et al, (2007) reported on the in-row hoe weeder developed by a France firm. This automated weeder sensed reflected light from the field surface to detect crop plants and used a control system to control the motion of a hoe around the crop plants. It was originally developed for transplanted crops and can only be operated when the weeds are substantially smaller than the crop plants. This is usually the condition with conventional weeding, in which weeds are controlled while they are still small compared to the crop plants. The working speed of the prototype was reported to be 3 km/hr. Farmers Guardian (2007) reported that the Dutch Applied Plant Research organization is continuing to develop this prototype, hoping to achieve an operating speed of 4-6 km/h and to effectively control higher population weeds between the crops. Dryden et al. (2006) developed an autonomous intra-row weeder based on RTK (Real-Time Kinematics) GPS to locate the weeder relative to crop seed maps that were developed at the time of crop seeding. This weeder used a rotary weeding mechanism that is rotated using an electro-hydraulic motor. The mechanism consisted of eight tines with tine tips having an outer diameter of 0.234 m. These tines can be controlled individually to follow two different tine trajectories.

The non-activated tine trajectories can be described as a cycloid curve, where a curve traced by a point on the circumference of a circle as the circle rolls on a straight line. The other trajectory is where the tine moves in and out of a crop row. The research claimed that the rotor weeding mechanism has the ability to control weeds inside the crop row and till the soil as close as possible to the crop plants without damaging them. The weeding effect of these tines is accomplished through uprooting, weed soil coverage and root cutting. The parameters to achieve a particular tillage effect are the ratio of forward speed to rotational speed, the diameter of tine rotation, the number of tines, the shape and design of tine tips and the lateral offset to crop rows. The machine was attached to an autonomous tractor driven and the lateral shift of the weed mechanism and the activation of the rotor tines were based on seed maps from the previous sowing operations.

Harrowing is the most effective non-chemical control method on gravel surfaces and can be carried out at relatively low cost (Ramamoorthy and Blasubramanian, 2000). In Denmark, the use of chemicals was banned on churchyards in 1992 and harrowing the gravel surfaces has been the most used weed control method in these areas (Gupta., 1981). However, it is important that the gravel surface consists of a district, compact base layer that has no large bb stones embedded in it. The surface layer has to be loose and easy to treat. The treatment should be carried out when the weeds are at an early developmental stage, as large weeds would need to be removed after the harrowing.

2.13 Animal Operated Weeder

Yadav (1980) gave details of serrated blade for hoe and harrow, bullock drawn blade cum tine hoe for weeding and intercultural operations in dry land farming. The serrated blade of different size may be fitted in to the traditional blade or blade harrow (Bakhar, 2014). The serrated blades easily penetrate into the soil and help in moisture conservation.

Murthy et al., (1996) evaluated the performance of a bullock drawn blade hoe for 3 different approach angles (120, 130, and 140 degrees) to determine the most effective angle with respect to implement draught, soil moisture conservation, weeding efficiency and crop (finger millet)yield under dry land conditions. The overall performance of the blade hoe was best with an approach angle of 140 degrees with respect to the formation of ridges and furrows, soil moisture conservation and yield but the draught was significantly higher (19.5kg).

Biswas et al., (1999) reported that the animal drawn weeder works between crop row spacing, the weeds leftover a long row may be removed manually. However, due to clogging of the straight edges, the output is adversely affected. So, there is need to study and use improved blades.

2.14 Ergonomic Considerations

Murrel (1979) stated that ergonomics is scientific study of the relationship between man and his working environment. The goal of ergonomic is to design the task so that its demand stays within the capacities of workers. Its object is to increase the efficiencies of human activities by removing those features of design which are likely to cause inefficiencies or physical disability in the long term and thus to minimize the cost operation. He further stated that to achieve maximum efficiency a man machine system must be designed as whole.

Gite (1985) gives scientific study about ergonomic consideration. Ergonomic study gives the criteria for ergonomic design like design within the capability of human worker, use of proper posture of the operator for most efficient performance of the tool at a lesser fatigue, suitability of the tool for workers of varying age and body dimension.

Geetha and Tewari, (2000) gave the study on an anthropometry of Indian female agricultural workers and implication on tool design. With a view to generation anthropometric data based for women agricultural workers in southern region of India, an anthropometric survey was conducted. Different body dimensions of the subjects having direct implication on agricultural tool/implement design were collected from 37 female workers during the survey.

The data compared with that of the male worker of the region as well the data of females from other ethnic groups. Remesan et al, (2007) study revealed that both the weeders selected for the study has its own strengths and limitations. Rotary weeder can be recommended in the later stages of weed growth as the better weeding efficiency, more turning of the soil and uprooting of weeds overrules the higher cost of operation. Cono weeder performed the task with comparatively higher field capacity, better performance index in the early stages of weed infestation.

2.15 The Development of a Multi-function Cultivator

In view of the above reviewed literature of weeders, the researcher opts to design the very latest and unequal machine to perform multi-purpose task as far as farming and gardening is concerned. The machine comes with several desirable new features to render multi-purpose task. The wheel, 11 inches diameter can be set to 9 or 11.5 inches apart for narrow rows and 4 inches apart when used as single wheel hoe, the frame is malleable, with quick change device so the position of the tools may be changed with ease. The versatile frame is to be made to accommodate a variety of weeding tools or cutter including seeding and fertilizer application systems with little or no adjustment. The machine is very simple, quickly adjusted, light, durable and works to perfection, the source of power can be manually, motorized or electrical powered. It is unequal garden implement with an affordable price and can easily be constructed.

CHAPTER THREE

METHODS AND MATERIAL

3.1 Introduction

This chapter presents the methods and material used for the design realization and test of the multi-purpose cultivator.

3.2 Method

This research work employs AutoCAD and COMSOL for the modeling and the use of morphological matrix in which the principles of solution were combined in order to generate at least one best conceptual design for this study.

For the selection of the most promising concept, one technique selection was applied for a feasibility judgment on the designs were successful carried out. In the judgment of viability of the designs, it was noted on the basis of number of task, flexibility, and sum of ranking and high score of each individual conception was conditionally feasible presented. The concept that had more positive responses than negative responses was chosen as indicated in table 3.1 hence new concept was born, as the positive characteristic of the selected concepts was promising. The principles applied in the discarded concepts were also taken into consideration based on the need for the research work. In this investigation, structural analysis such as static and tensile test experiment was carried out and analyzed on the frame and the shaft, the behavior of the designed chassis was reviewed under various situations. Thus, the severity of any undesirable outcome was estimated and an attempt was made to examine the need for any necessary modifications on the design. Shown in appendix A.

The research starts with the literature survey and ends with the result evaluation as indicated in figure 3.1 that shows the design processes of the proposed cultivator.

Design process of the cultivator

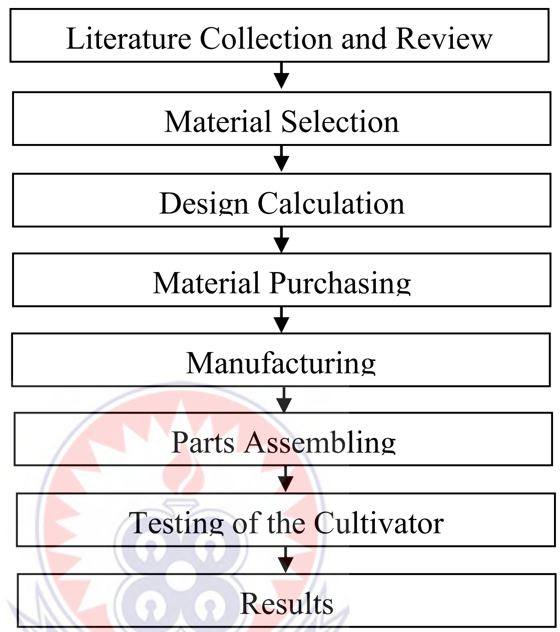


Figure 3.1: Design process of the cultivator

3.3 Material

Design for manufacture and assembly was achieved based on Material suitability, Material suitability was one of the considerations that was studied and selected for the various components of the machine. Galvanized steel pipe was considered for the frame and handle of the machine, the materials used for the various components were selected based on their availability, durability and affordability. The implement was constructed with the desire to have minimum labour input for its operation. One or at most two persons are needed to use the implement for any task. The mechanical cultivator was puts into consideration, the basic engineering principles and the properties of the materials and soil where the attached units will operate. The maximum power output from the machine combined with functional requirements and cost are combined to achieve the designed objectives. The designs parameters were established after studying some literatures and employing the assessed engineering properties of soil on which destruction of weeds will take place. Power transfer device was sprockets and chain mechanism which is made of stainless steel which, the operators are familiar with in terms of use, adjustments, repairs and maintenance.

The chassis design process was efficient and effective, and helps detect high or low-stress situations in different members at testing conditions. In this study, steel pipes with a wall thickness of 3 mm and an outer diameter of 45.5 mm have been used to make the frame. This material has been chosen due to its weight reduction capability and beneficial properties.

3.4 Design Constraints and Requirements

1. The cultivator will be designed for single row weeding on vegetable crops fields, since weed control is challenging for mechanical weeding systems
2. The design is targeted for small scale vegetable crop producers, since it will only have single cutting action that will operate on the same crop row.
3. The machine will be targeted to achieve intra-row weed control efficacy of 80% or more reduction in the number of living weed plants after a weeding operation, since the literature shows that mechanical weeders can obtain this range of efficacies.
4. The machine should be able to control weeds with minimal crop plant damage.

5. The machine will be designed to target early growth stage weed control, because they are easily discriminated at early growth stages.
6. Overall dimensions of the machine must not too bulky, as it will operate only in the area around one crop row.
7. The machine can be pulled using live aided (an animal or a person) or a small tractor (e.g. 40 kW) because it is does not require any power from the tractor.
8. The weeding mechanism will be powered manually, electrically, motorized or live aided.

3.5 Design Concepts

Several concepts were considered for the mechanisms to perform. The design requirements for choosing the weeding mechanism were:

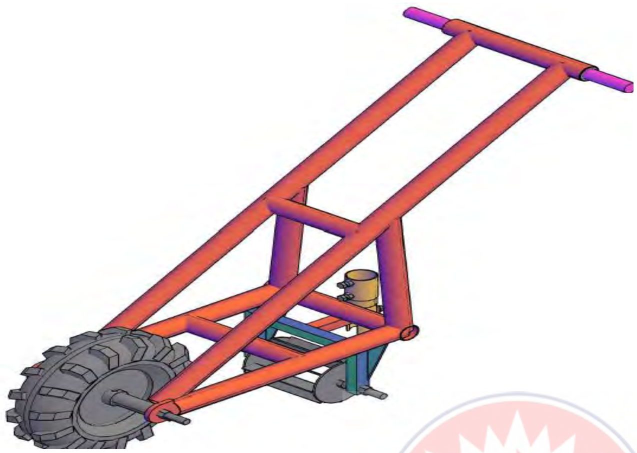
1. An effective weeding mechanism should be able to cut weeds and stir a thin layer of the top soil.
2. The working width of the weeding mechanism should be reasonable so as to possible operate within the crop row and also between crops.
3. The weeding mechanism should not exceed a depth of 50mm (2 in.),

Figure 3.2 shows design concept (A), (B) and (C), where concept (A) is a rotary cultivator used for weeding, it is operated manually by pushing and can be live aided to help in pulling to increase speed of the rotary cutter, that is expected to cut weeds during it rotating action, the design is specifically made for inter row weeding, it is freely operated in between crop rows to weed. While concept (B) is a cultivator that uses earthing disc for weeding cutting a thin layer of the top soil and turn to cover up weeds that are found in between rows, it is operated manually by pushing and can be live aided to help in pulling to increase speed of the rotary cutter, that is expected to turn weeds upside down during it operation, the design is specifically made for inter row weeding.

Concept (C) is a multi-purpose cultivator that uses four weeding attachments that function differently due to its operation, this concept is designed to be operated both manually and power aided with an electric motor, engine and live aided, the weeding attachments includes earthing disc that is proposed to function manually and power aided depending on the type nature of the soil, two rotary cutters for cutting a thin layer of the top soil and at the same time cut the weeds during its rotary action, the rotary cutter with strip blades figure 3.2 C2 rotates to cut the weed and also stirs the top soil to destroy the weed roots. The rotary cutter with worm design Figure 3.2 C3 gives a double cutting action to weed, when in operation cuts every part of its width, it also stirs the soil to destroy weed roots. The float weeder figure 3.2 C4 is an attachment designed to control weed as soon as they emerge by driving it in between the crop rows, it is designed to be operated manually and power aided. The frame of this concept was made to take any peripheral weeding device made considering its size will function with it. Both concept (A) and (B) were discarded due to due to their single action performance, human power needed and time consumption that may increase inputs to over burden the farmer.

3.6 The Proposed Conceptual Designs of the Cultivator

Figure 3.2 Concept (A) is a rotary cultivator with strip blades, (B) is a cultivator with Mould board plough and (C) is a cultivator with its four units of attachments



A

B

Figure 3.2: Shows Concept A and B with its Weeding Units

Concept (C) cultivator with its four units of attachments

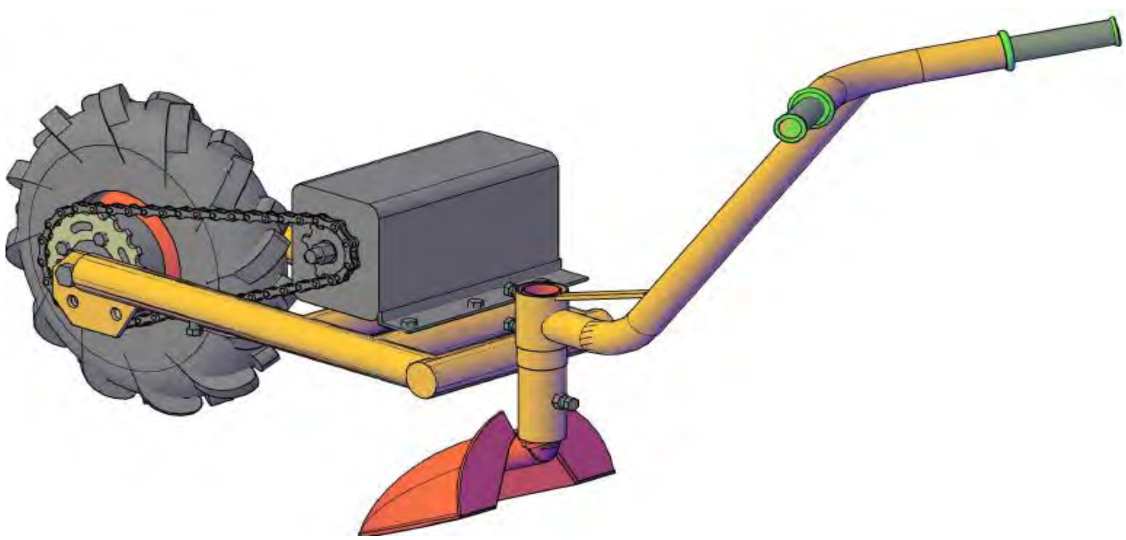
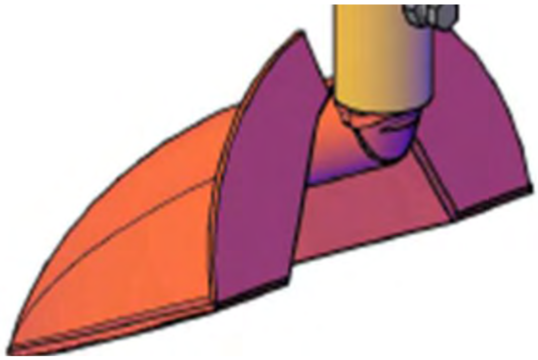
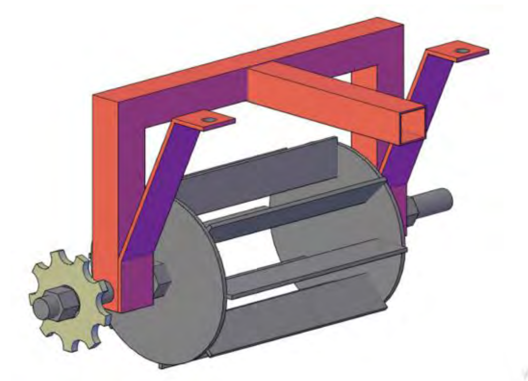


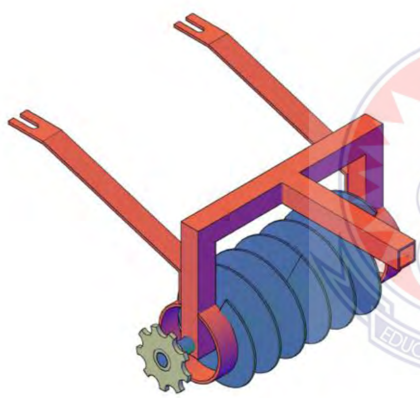
Figure 3.3: Concept (C), Cultivator with its Units of Attachments C1, C2, C3 and C4.



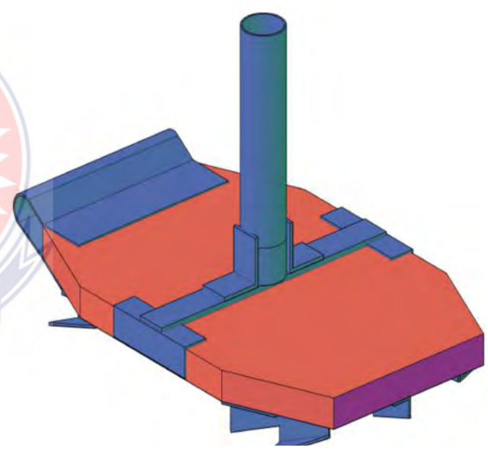
(C1) Earthing Disc



(C2) Rotary Cutter with Strip Blades



(C3) Rotary Cutter with Worm Design



(C4) Float Weeder

According to Stefanello et al. (2014), based on the global function of the system, different structures can be generated by the multiplicity of some functions and distinct flows of material and energy. As a result, three different functional structures (A, B and C) were the proposed concepts.

Table 3.1: Selection of Appropriate conceptual design Using Design matrix

Evaluation of Design Alternative – Criteria are of Equal Weight

1. Rank each design / process from poor(1) to excellent (5)
2. Number of task the design can perform(1) to (5)
3. Flexibility performance depending on soil condition (1) (5)
4. Sum of Ranking for each design/ Process ($C = \sum ri$)
5. Higher score from the concept indicates favorable design

Criteria	Design A Rating(r)	Design B Rating(r)	Design C Rating(r)
Ease in operation	2	2	3
Performing multiple task	1	1	4
Reliability	2	3	5
Shape	3	3	4
Unit cost	1	1	4
Cost of production	1	1	3
Total Score ($C = \sum \boldsymbol{ri}$)	10	11	23

Conclusion; Conceptual design C is better than conceptual design A and B, therefore concept C was chosen for the experimental research work.

In order to select the most promising concept that would be optimized at a later stage, concepts were analyzed with a decision matrix, which, pointed out the use of Concept C, as it promises multi weeding function with the same frame and not compromising the operation safety. The four weeding concepts were also selected as weeding mechanism to be incorporated in concept A for weeding task. The first technique used for the selection was the viability judgment with which the concepts were considered feasible shown in the decision matrix 2 in table 3.2 some of the concepts were discarded because of the greater energy loss which would increase energy consumption during their operation.

3.8 Design Concepts of Weeding Mechanisms Considered

Eight weeding mechanism and two seeding concepts were considered as design alternatives for which four weeding mechanisms and a seeder was considered as attachments that can be used on the frame, they are:

1. Rotary cutter with a worm design; 2. Rotary cutter with strip blades; 3. Earthing disc; 4. Float weeder; 5. Tines weeder; 6. Rake weeder; 8. Mini harrow; 9. Double rotary action

3.9 Decision Matrix for Possible Solution

A decision matrix was developed to look at the different mechanisms with specific criteria (Table 3.2). The criteria used for the selection of the most suitable mechanism were ability to cut weeds, ability to uproot weeds, the ability to bury weeds, the ability to create less dust, ability to work up to 50mm soil depth and easy maneuverability. From the decision matrix, it was shown that the flexible four out of eight weeding mechanisms were selected as best possible solution design because it met all the six criteria levels as the other four could not. The two-raw seeder was also selected on the bases that it can be conveniently attached at both sides of the machine at 270mm spacing suitable for most vegetables.

Table 3.2: Decision Matrix

No	Weeding Units	Ability to Carry out Double Action	Ability to Stir Top Soil	Ability to Stir Deep Into The Soil
1	Rotary cutter with WD	✓	✓	
2	Rotary cutter with strip blades	✓	✓	
3	Earthing disc		✓	✓
4	Float weeder		✓	
5	Tines weeder		✓	
6	Rake weeder		✓	
7	Mini harrow			✓
8	Double rotary action	✓	✓	

Decision Matrix

From the decision matrix table 1 ten design concepts was considered, out of which the Rotary cutter with a worm design (1) Rotary cutter with strip blades (2) Earthing disc (3) Surface tiller (4) were taken for feather study and are designs that will be pursued because projections indicates that they may perform better on the frame and more to the point solve the need of the researcher.

3.10 Cultivators Design and Description

The designs parameters were established after reviewing some literatures and employing the assessed engineering properties of soil on which destruction of weeds will take place. Power transfer device was sprockets and chain which the operators are familiar with in terms of use, adjustments, repairs and maintenance.

A multi-purpose-acting cultivator was designed and constructed to be operated manually, electrically or motorized and live aided. The total mass of the implement is 35 kg. The cultivator (Figure 1) consists of several components fastened together into a unit, which could be easily dismantled, if necessary. The main parts are, the frame (1) Ground wheel (2) Rotary cutter (3) Earthing discs (4) Float weeder (5). The components and the materials used were selected based on their availability and affordability. The implement was constructed with the desire to have minimum labour input for its operation. One person is needed to use the implement except in the live aided where an addition person or animal is implored to pull during manual operation of the machine.

The main factors that governed the design of various components of the weeding units of the machine were the engineering properties of materials such as; physical and mechanical properties of the materials used for the parts that are in contacts with the soil and the weed. Of these properties deep study of the mechanical properties of the materials were done for selection to suit the condition of the working environment. Among these include; hardness, compressive strength, static and sliding coefficient of friction. Similarly various physical properties of multipurpose cultivator, size and weight were also considered. The performance of the cultivator depend on: the condition of the crop, weed population, Soil characteristics, the characteristics of the interface between soil and the soil acting element of the machine and the design parameters (Sppr,1969).

Table 3.3: Part List of the Cultivator

No	Component	Quantity	Material
1	Main Frame	1	45.5mm Galvanized Steel Pipe
2	Handle	1	45.5mm Galvanized Steel Pipe
3	Front Wheel	1	Mild Steel Hub And Plastic Pneumatic Tyre
4	Sprockets	2	Stainless Steel
5	Chain	1	Stainless Steel
6	Shaft	1	Galvanized steel
7	Petrol Engine	1	-
8	Electric Motor	1	-
9	Weeding Units	4	Mild steel
Total	**-**	**12**	**-**

3.11 Factors considered in the design of the multipurpose cultivator include

1. Availability of materials for the entire design.
2. Strength of engineering materials used.
3. Operational speed of the machine both manually and power aided.
4. Weight of the machine that can easily be operated by all the target group of workers
5. Uniform depth of operation
6. Cost of machine, affordability and capacity.
7. Cost of machine, affordability and capacity.

3.12 Machine Size

Machine size was determined on the basis of operational demand, machine stability and power source. Row spacing was a major factor for designing of mechanical weeders. Stability factor and weight of the machine were considered for determining the machine length (l) and width (W) of the cultivator.

Area (A) = l × W

(3.1)

A = f (l.W)

Where:

A: area, m^2

l: length of machine,

W: width of machine,

The cultivator occupies an area of (148500mm^2) 0.1485m^2 as in appendix A.

3.13 Source of Power

Based on the literature studied, it was observed that average energy and power required in the operation of various manual operated farm equipment varied from 50 to 70W while energy expenditure was 15–22 kJ. These clearly indicate that the load exerted by human being while operating manual operated farm equipment. The energy expenditure can be reduced if major load is shared with auxiliary power source. Keeping this view, following considerations were taken to design and manufacture of this machine,

i. The auxiliary power source was petrol motor or electrical motor and synchronized with human power source, particularly speed of operation, i.e. 2-2.5 km/h (0.5 to 0.7 m/s), Singh et al. (2005).

ii. The auxiliary power source should be of light weight, high torque and rugged in its management.

iii. Stability of the developed unit should be trouble-free in its operation.

3.14 Design of the main Frame

Materials were selected based on their mechanical properties and the function of the components it would be used for to meet the need of the research. Some components of the cultivator are designed to meet the need and some are selected due to its complexity of their makeup, but they are selected to fit into the part it performs well.

Table 3.4: Parts List of the Frame

No	Component	Quantity	Material
	Main frame		
1	Arm bar	2	Galvanized Steel
2	Space Bar	2	Galvanized Steel
3	Back bar	1	Galvanized Steel
4	Hinge Plate	2	Galvanized Steel
	Handle		
6	Fix bar	1	Galvanized Steel
8	Adjustable bar	1	Galvanized Steel
9	Hand Grip	2	Plastic
Total	**-**	**11**	**-**

The frame provides support for the power transmission system, drive wheel and the cutting tools; it was constructed with 3mm galvanized steel, a hollow pipe having a diameter of 45.5mm. The frame would be mounted on the ground wheels made of a tyre with tube and a mild steel ream. Four collars of 130mm were provided to keep the ground wheel at the center of the frame with the shaft of 15.5mm. An attachment unit was kept at the back with Fly bolts arrangements for mounting cutting and the seeding system and a handle fixed at the back of the base frame as shown in figure 3.4 Frame of the Weeder.

The height and Length of the handle was based on average standing elbow height of male and female worker. The average height of male and female worker is 1027 mm and 960 mm respectively (Sharma and Mukesh, 2013) and was made adjustable to ensure proper and effective operation by every operator, the arm must be at 90˙to elbow and must not exceed angle of inclination of 45^0 (Adekoye,1999). Length of handle and angle of inclination with the horizontal surface are interdependent. The recommended handle grip diameter is 30 to 35 mm.

Length of the supporting bars = 550mm

Width = 270mm

Gap between two successive holes on individual supporting bars = 264mm

Diameter of hole wheel shaft = 15.6mm

Distance between two supporting bars = 170mm

Handle length to the base frame = 680mm with a width of 470mm

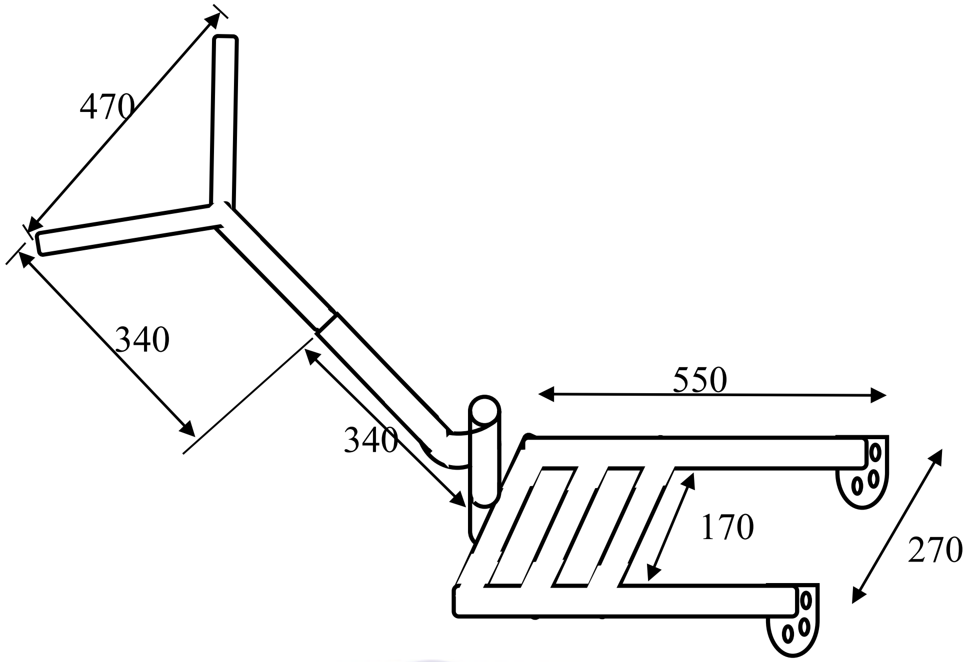
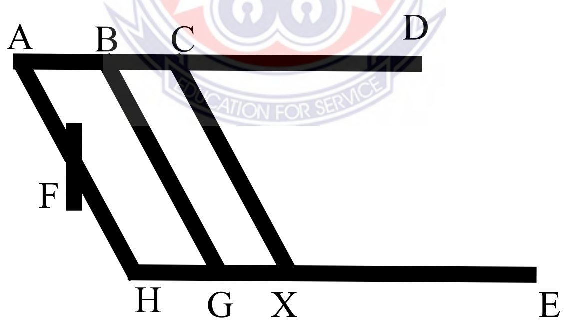
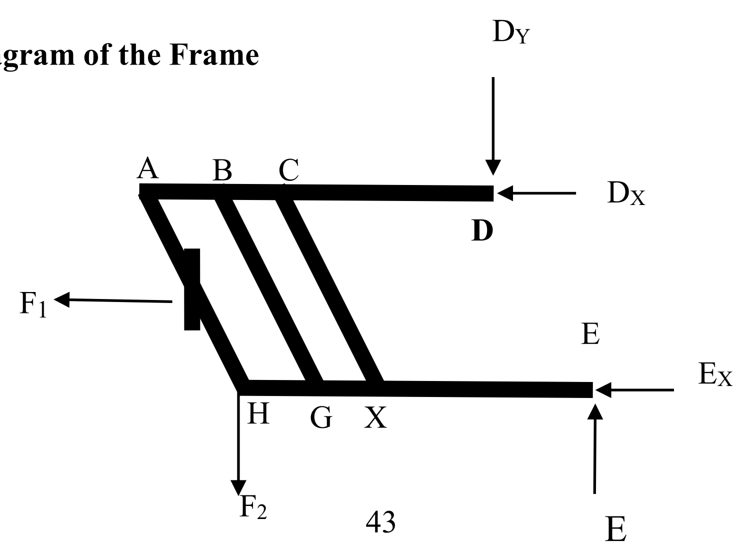


Figure 3.4: Pictorial View of the Frame Dimensioned in Millimeters

3.15 Force Analysis on each Member of the Frame

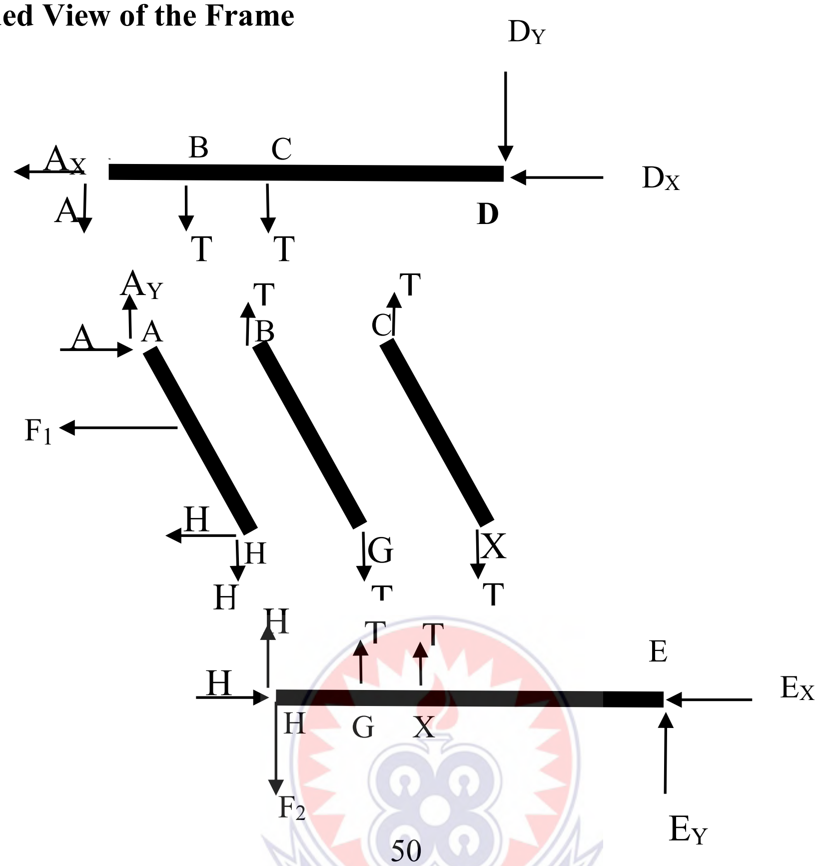


Free Body Diagram of the Frame

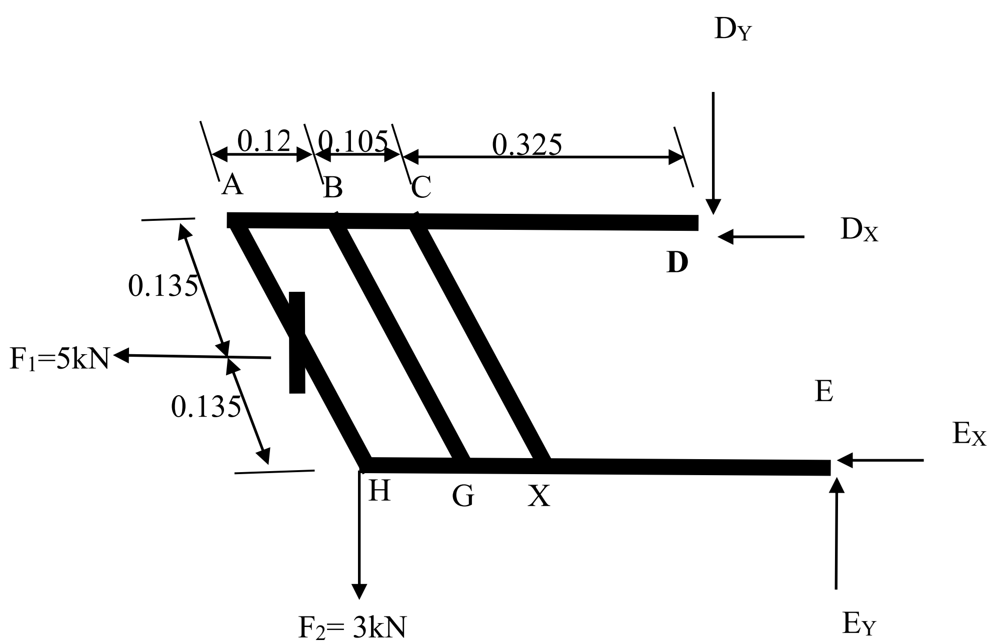


3.16 Free Body Diagram of the Frame

Exploded View of the Frame



3.17 Free Body Diagram of the F



For $\sum MD$

$5(0.135) + E_x(0.2) = 3(0.75)$

$0.675 + 0.2E_x = 3.75$

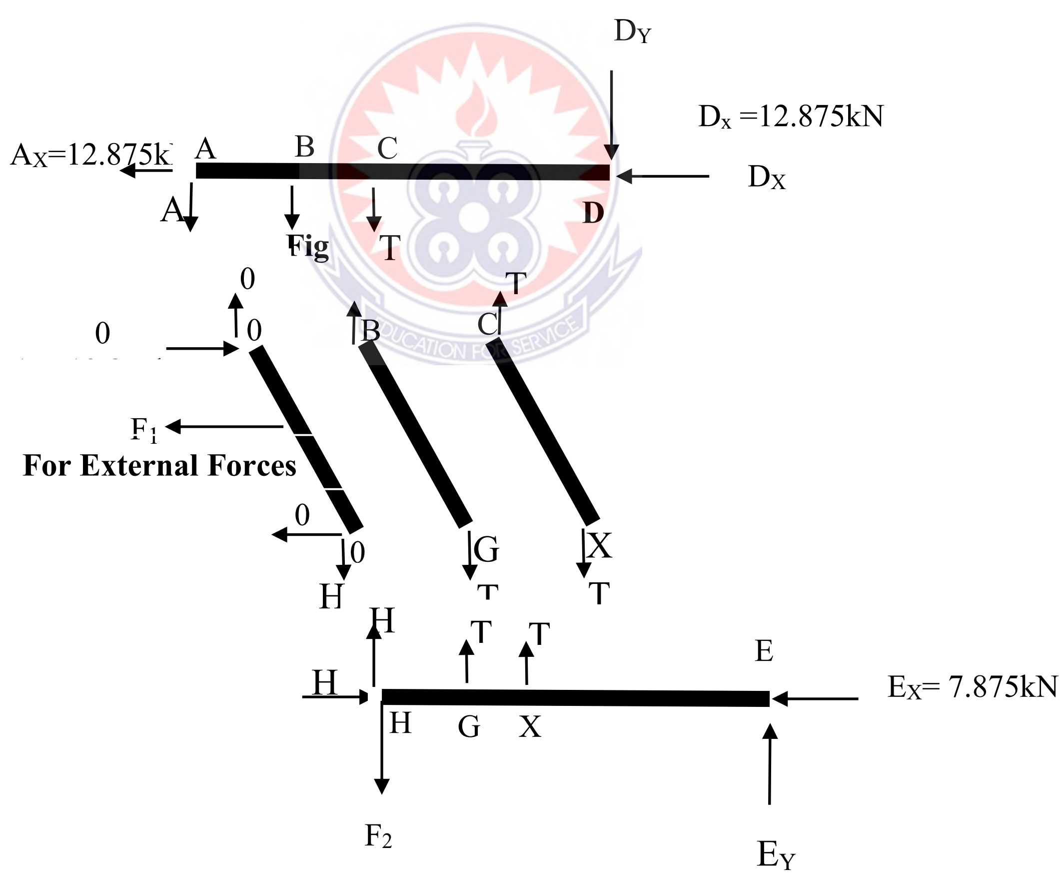
$E_x = 7.875kN$ →

For $\sum Ex$

$D_x + 7.875 + 5 = 0$

$D_x = 12.875kN$ ←

3.18 Exploded view of the frame with forces acting on each member



For Member ABCD=

$\sum Ex= 12.875kN = Dx$

For member AH

$\sum mH$

$5(0.75) = Ay(0.135)+ 12.875(0.75)$

$Ay= 2.58kN$

$\sum Ex+5+Hx=0$

$Hx =-12.88+5+ 7.88$

$Hx =0$

For $\sum Fy$

$Cy+Dy =0$

$2.58 + Dy =0$

$Dy= 2.58kN$

For $\sum mD$

$T (0.1) + 2.58(0.55) = 0$

$T = - 14.19kN$

For member EXGH

$\sum mE$

$T= -14.19$

$\sum Ey$

$Dy +14.19 - 2.58 = 0$

$Dy = -11.61kN$

$\sum Ey = Ey-14.19+ 2.58-3 = 0$

$Ey = 14.61Kn$

3.19 Handle Design and Ergonomics

Fig 3.5 Handle is a sensitive part of this machine. It is the point of application of propelling force. Engineering designs and ergonomics considerations of a handle becomes imperative for better performance. Ojo (1994) ascertained the average hip height to be 940 mm. The information was used to determine the length of the handle where the farmer/ operator can position his hands without bending down. The handle was made adjustable to suit the hight of any operator and was positioned above the hip height so as to avoid the bending posture; this was reported by Nwuba, (1982) to have contributed mostly to the high energy demand of most manually operated machines. Hence, this cultivator handle was considered good at 680 to 1200 mm height above the ground.

3.20 Design Parameters

Total length when not adjusted = 680mm

Outer diameter of pipe = 45.5mm

Inner diameter of pipe = 42.5mm

Thickness of pipe = 3mm

Length above the ground = 1500mm

Length of the handle grip = 130mm

Length of the Bend = 50mm

Pictorial View of the Handle

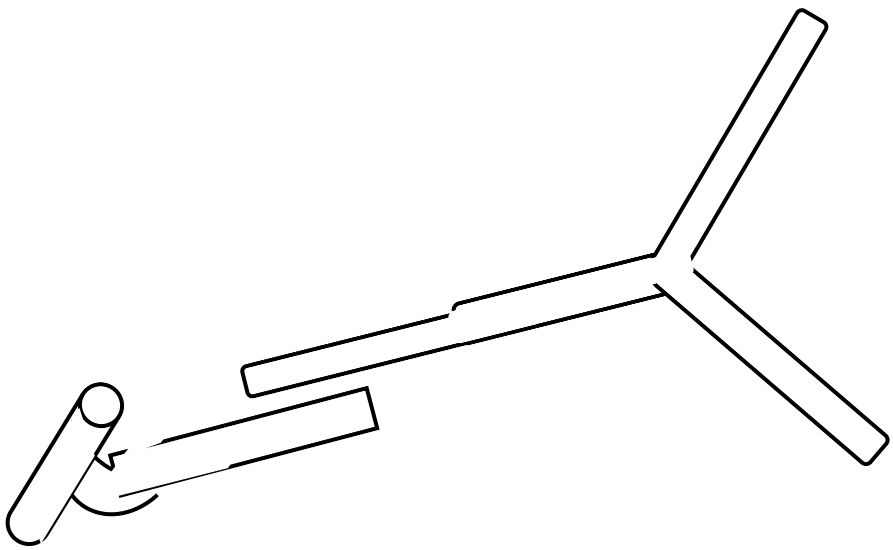


Figure 3.5: Pictorial View of the Handle

3.21 Handle height

Due to push-pull operation, the handle must be swinging to adjust the instantaneous height of operation to apply force. The instantaneous height can be defined as

$L = Y\cos\beta$

(3.2)

where,

Y is elbow length (m), and β is elbow angle to vertical plane (°).

During operation the instantaneous height varies based on the rotational angle covered by the operator. In design criteria, standard elbow height is considered as fixed height X for particular group of operators. Summation of standard elbow height (X) and instantaneous height (L) is total handle height.

$H = X + Y\cos\beta$

(3.3)

where, H is handle height (m); X: elbow height from ground (m); Y is elbow grip length (m) and β is elbow angle to vertical plane (°).

The summation of standard elbow height and instantaneous height of 95th percentile population are X = 0.98 m, Y = 0.3 m, respectively and maximum value of β is = 50^0, therefore the total height of handle can be designed as $H = 0.98 + 0.3 \sin 50$ $H = 1.20$ m

3.22 Ground Wheel

A Ground Wheel is made of a tyre and a metal hub with bearing at its both sides; two sprockets are attached to the hub at both sides, which supports the frame and help in moving the whole system. Its parameters are as follows:

Diameter of ground wheel = 400mm

Radius of ground wheel= 200mm

Circumference of ground wheel = $2\pi r$

(3.4)

$= 2\times3.14\times200$

= 1256.8mm

= 1.3m

Thickness of ground wheel spokes = 3mm

Thickness ground wheel = 10mm

Bearing hole diameter = 15.5mm

The diameter of the wheel, Dw = 400 mm The material used for the fabrication of the wheel was plasticizer and steel for the rim. The yield strength of the material, σ y = 700 N / mm2 Calculation of design safety for the wheel: Thickness of the wheel rim = 3 mm Width of the wheel rim = 70 mm

Cross sectional area of the wheel rim = 210 mm^2

Pushing force given by the worker = 1100N (approximately) Reaction force from the working surface = 500N, Factor of safety was Considered as 2

The load acting on the wheel = Pushing force + reaction force Stress induced in the wheel during the working time is, Stress = Total load / Area of cross section

σ wheel = P Total / Aw

(3.5)

= (1100 + 1000) / 210 = 10 N / mm^2

The stress developed in the wheel is less than the yield stress of the wheel material. Hence, the chosen wheel is safe to use in the cultivator and for effective performance.

3.23 The Main Shaft of the Cultivator

The Shaft design consists primarily of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operations and loading conditions. During operation process, the shaft was subjected to torsion, bending and axial loads. These were estimated by using Equations:

$\tau_{xy} = (16M_t) / (\pi d^3)$

(3.6)

$S_b = (32M_b) / (\pi d^3)$

(3.7)

$d^3 = (16/\pi)S_a[(K_bM_b)^2+(K_tM_t)^2]^{1/2}$

(3.8)

τ_{xy} = torsional shear stress, N/m^2

Mb = bending moment; Nm

Mt = torsional moment, Nm

d =diameter of shaft, m

S_a = axial stress, N/m^2

S_b = bending stress, N/m^2

K_b = combined shock and fatigue factor applied to bending moment K_t = combined shock and fatigue factor applied to torsional moment

The estimated shaft diameter of the mechanical weeder was 15mm. The main shaft of the cultivator is illustrated in figure 3.6

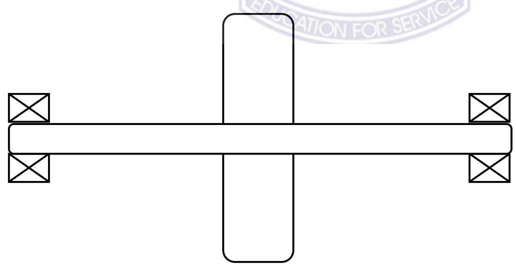


Figure 3.6: Free Sketch of the Shaft with Support at Both Ends

The shaft in this system is a machine element which transmits power from the tangential force from the chain and sprocket mechanism that results in torque (or twisting moment) setup within the shaft permitting the power to be move the machine or components linked up to the shaft.

3.23.1 Torque Transmitted by the Shaft

The torque transmitted through the shaft is worked out using the following formula (khurmi, R.S., 2012).

$T= (P \times 60 \times 10^3)/2 \times 3.14 \times N$

(3.9)

Where,

P = power, kW

T = torque transmitted by the shaft, Nm

N = revolutions per minute

Considering engine speed as 6000 rpm and engine power 0.0186

kW we get torque as $T = (0.0186 \times 60 \times 10^{3}) / 2 \times 3.14 \times 6000$

= 0.002 Nm

= 2 Nm

Thus the torque of 0.002 Nm was obtained.

3.23.2 Design and Selection of shafts

Shafts were selected on the basis of both strength and rigidity. Design based on strength was to ensure that stress at any location of the shaft does not exceed the material yield stress. Design based on rigidity was to ensure that maximum deflection (because of bending) and maximum twist (due to torsion) of the shaft is within the allowable limits. Rigidity consideration was also very important in some cases for example position of a sprockets mounted on the shaft will change if the shaft gets deflected and if this value is more than some allowable limit, it may lead to high dynamic loads, noise in the tooth and misalignment of chain may occur.

The design of the shaft was based on strength, which the following cases were considered:

(a) Shaft subjected to torque

(b) Shaft subjected to bending moment

(c) Shaft subjected to combination of torque and bending moments

(d) Shafts subjected to axial loads in addition to combination of torque and bending moments.

3.23.3 Shafts Subjected to Torque

Maximum shear stress developed in a shaft subjected to torque was given by,

$$\frac{\mathbf{q}}{\mathbf{r}} = \tau \frac{\boldsymbol{\tau}}{\mathbf{R}} = \frac{\mathbf{T}}{\mathbf{J}} = \frac{G\theta}{L}$$

(3.10)

θ = angle of twist

l = length of the shaft

T = torque

J = polar moment of inertia

$\frac{\theta}{l}$ Is also termed as twist per unit length

$$\boldsymbol{\tau} = \frac{\mathbf{Tr}}{\mathbf{j}} \leq \boldsymbol{\tau}$$

(3.11)

Where T = Twisting moment or torque acting upon the shaft,

J = Polar moment of inertia of the shaft about the axis of rotation

$\frac{\pi d^4}{32}$ for solid shafts with diameter d

(3.12)

J is the polar moment of inertia is 21 for solid circular sections of diameter D

$$\tau = \frac{0.2 \times 7.5}{21}$$

$$\tau = 0.071\text{Nmm}$$

Internal torque of the shaft

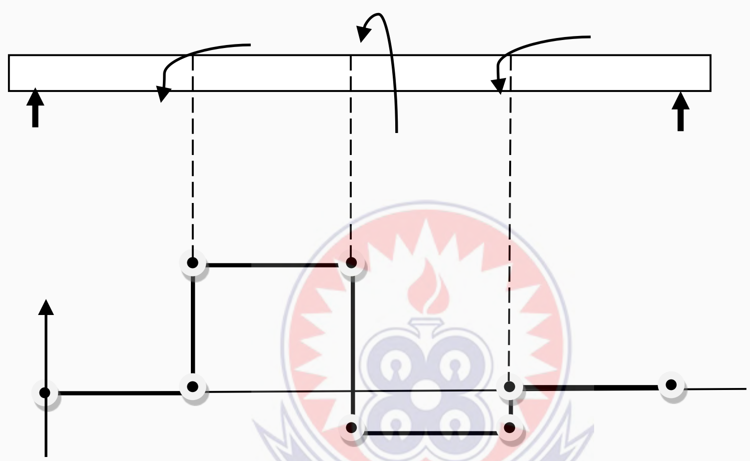


Figure 3.7: Internal torque of the shaft

Therefore the shear stresses on the shaft are negligible that makes it fit enough for the design

3.23.4 Solid Shaft

Maximum shear stress, $\tau_{max} = \frac{16T}{\pi d^3}$

(3.12)

$= 16 \text{ x } 0.2/3.142 \text{ x} 15^4$

$= 20\text{x}10^{-6}$

Angle of twist, $\boldsymbol{\theta} = \frac{\mathbf{Tl}}{\mathbf{GJ}}$

(3.13)

Where T = twisting moment

d = diameter of the shaft

3.23.5 Shaft Subjected to Bending Moments

Maximum bending stress developed in the shaft is given by,

$$\sigma_b = \frac{My}{I} \leq [\sigma_t]$$

(3.14)

Where M = Bending moment acting upon the shaft,

I = Moment of inertia of cross sectional area of the Shaft about the axis of rotation

$= \frac{\pi d^4}{64}$ For solid shafts with diameter d

Y = r that is the distance from neutral axis to the outer most fiber = $\frac{d}{2}$

So dimension of the shaft subjected to bending moment was determined from equation 3.16 relation for a known value of allowable tensile stress.

3.23.6 Shaft Subjected Combination of Torque and Bending Moment

When the shaft was subjected to combination of torque and bending moment, principal stress are calculated and then different theories of failure are used to obtain a suitable shaft for the front wheel. Bending stress and shear stress can be calculated using the equation 3.16 relation

$$\tau = \frac{Tr}{J} = \frac{T\frac{d}{2}}{\frac{\pi}{32}d^4} = \frac{16T}{\pi d^3}$$

(3.15)

$$\sigma_b = \frac{My}{I} = \frac{M\frac{d}{2}}{\frac{\pi}{64}d^4} = \frac{32T}{\pi d^3}$$

(3.16)

3.24 Design of Bolt and Nut

The material for fasteners is mild steel.

The bolt should withstand the compressive and the shear loads. Shear strength, $\tau = 0.5$ x compressive strength

= 0.5 x 280 = 140 N / mm^2 Take safety factor as 2 Then, $\tau = 70$ N / mm^2

To find the diameter of the bolt, Area = load / stress π x d2 / 4 = (1100 + 100x103) / 70

d = 42 mm

The standard diameter of the bolt available is 5mm. considering safety factors 10 mm bolt was chosen.

3.25 Design of Chain Drive Systems

Chain drives, gear drives and belt drive systems are all effective power transmission choices.

Each offers advantages and disadvantages with respect to the other. The design advantage of chain drive system was considered in the cultivators design for effective power transmissions are:

1. Chain drives systems are usually less costly to build and maintain than an equivalent.

2. Chain Drives are relatively easy to install. Assembly tolerances are not as restrictive as those for gear drives. They are better choice for less experienced builders working with a minimum of machine tools.
3. Chain drives can be readily redesigned and reconfigured in comparison to gear drive systems.
4. Chains perform better than gears under shock loading condition. They spread operation loads over many teeth whereas the operating loads acting on gear drives are concentrated on one or two teeth.
5. Chain drives do not require tension on the slack side (Belt drives do) thus bearing loading is reduced.
6. Chain drives require less space for a given loading and speed condition than pulleys and belts.

3.25.1 Chain and Sprocket Selection

Chain and sprockets used in this design was selected based on the speed required. Five sprockets and chain was used on the machine as shown in figure 2. A Chain and sprocket transmission from the drive motor to the drive the sprocket on the drive wheel with ratio 14:36 teeth. The 14teeth sprocket was attached to an electric or petrol motor (The drive sprocket is the sprocket that initiates the transfer of power) to 36 tooth sprocket is the Driven Sprocket (The Driven Sprocket receives the power from the drive sprocket) to move the front wheel which drives the hole system.

3.25.2 Drive Ratio of the System

The drive ratio between two sprockets was specified by the relationship between the number of teeth of the Driven Sprocket to the number of teeth of the Drive Sprocket, which was enough to understand that power is transferred through a drive train from one sprocket to another through the tension created on the chain.

$$\text{Ratio} = \frac{\text{Drivens procket}}{\text{Drives procket}}$$

(3.17)

$$\text{Ratio} = \frac{36}{14} = 2.5{:}1$$

The sprocket ratio in this case is given as 2.5:1. The Drive Sprocket must turn 2.5 revolutions

before the Driven Sprocket turns 1

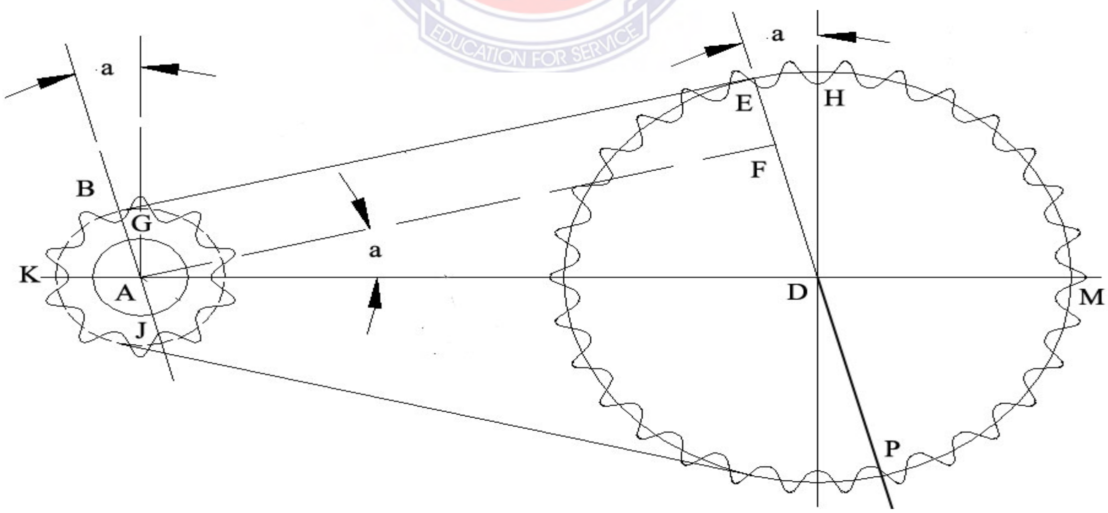


Figure 3.8: Driven Sprockets

3.25.3 Chain Length Calculation

From figure 3.8 A fix center-to-center distance of the sprockets to accommodate the existing constraints or mechanical design considerations. Chain length is a function of the number of teeth of the drive and driven sprockets as well as the center-to-center distance. Chain length is customarily expressed in (even numbers) of pitch units since chains was shortened or lengthened by multiples of their pitch units. If an odd number of pitches are required then a special link called an offset link is used. Length of chain was determined by:

Specifications:

Pitch (**P**) = ¼" = 0.250"

PR = Pitch Diameter x 0.5

Drive Sprocket (**n**) = 14 Teeth

Driven Sprocket (**N**) = 36 Teeth

Center Distance (**C**) = 6"/0.250 = 24 (expressed in pitch units

The chain length = 2 (Tangent line length BE + arc ME + arc BK)

(3.18)

The sprocket pitch diameter was determined using an imaginary circle through which the chain pin centers move on the sprocket. The pitch diameter is the fundamental design geometry that determines the size, shape and form of the sprocket teeth dimensions.

Sprocket Pitch Diameters

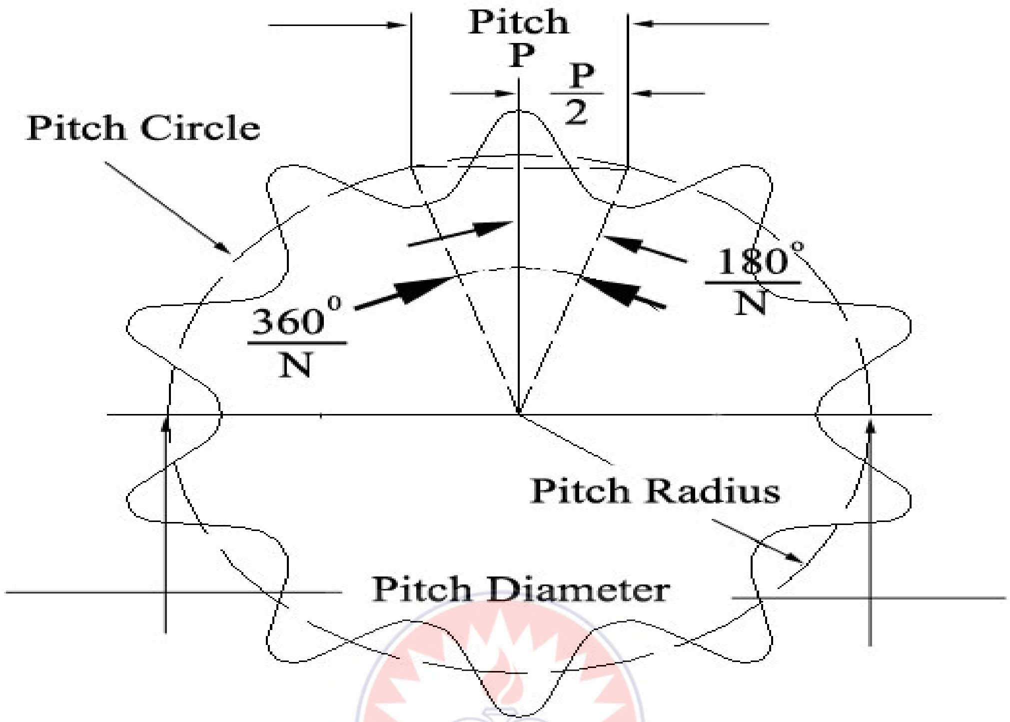


Figure 3.9: Sprocket Pitch Diameters

$$PD = \frac{P}{\sin[\frac{180}{N}]}$$

(3.19)

PD = Pitch Diameter

P = Chain Pitch in inches

N = Number of teeth on the sprocket

3.25.4 Determining Chain Length if the Center Distances are given

Chain length was measured in discreet units called links. The length of each link is the same as the pitch length. A 25 chain has a pitch length of ¼.

The chain length for drive was determined by:

1. The number of teeth in the drive sprocket

2. The number of teeth in the driven sprocket

3. The pitch diameter (PD) of the drive sprocket

4. The pitch diameter (PD) of the driven sprocket

The center-to-center distances between the sprockets.

$$L = 2[C \cos a + \frac{N+n}{4} + \frac{a}{360}(N-n)]$$

(3.20)

$$L = 2[23 \times 0.99 + \frac{36+14}{4} + \frac{7.5}{360}(36-14)]$$

L = 68.4

3.25.5 Center Distance between the Drive Sprocket and the Driven Sprocket

The desired chain length is 68 links or pitch units determined using the expression C (The required center distance).

$$C = \frac{L-n\left(\frac{90-a}{180}\right)-N\left(\frac{90-a}{180}\right)}{2 \cos a}$$

(3.21)

C = Center Distance in Pitch Units

L = Chain Length in Links or Pitch Units

N = Number of Teeth of the Large Sprocket

N = Number of Teeth of the Small Sprocket

A = pitch angle

$$C = \frac{L-14\left(\frac{90-7.5}{180}\right)-36\left(\frac{90-7.5}{180}\right)}{2\cos 7.5}$$

C = 23.81 Pitch Units or 5.9525"

3.26 Design of Cultivators Operation Units

The cultivator was designed to carry out four weeding operations and a two row seeding system, two of which was made rotary to perform different action, an earthing disc and a float weeder.

The size of each unit was determined on the based the base frame size of the cultivator. The Row spacing was a major factor for the designs. Stability factor and weight of the machine were considered. The area (A) that will be covered by the units was determined mathematically;

Area (A) = L× W

(3.22)

A = f (LW)

Where, A: area, m^2, of land space to be covered during operation.

L: length, m, of the length of tool.

W: width, m, of the tool.

3.27 Designs of the Weeding Units

Eight design ideas was developed, out of which four were considered due to their unique features for designing and manufacturing, all the units produced will be tested in an experimental field efficiency comparative performance of the weeding units. They are Rotary cutter with a worm design (1) Rotary cutter with strip blades (2) Earthing disc (3) Float weeder (4)

3.27.1 Rotary Cutter with a Worm Design

The rotary cutter was designed in the form of a single gang disc. it has four round disc with an opening from the neutral axis to its tangential point which, was then twisted at an angle of 60^0 to separate the edges such that its arrangement when motion gives a continuous worm design. Its rotary action stirs the soil to cut roots and gives double or more cuts to the stem of the weed depending on its height shown in figure 3.3C3.

Table 3.5: Components of the Rotary Cutter

No	Parts	Material	No off	Dimensions
1	Frame	Mild steel square pipe	1	Length, 270mm, Height,130mm
2	Cutting disc	Mild steel plate	5	Φ 150mm, Thickness,3mm
3	Shaft	Galvanized rod	1	Φ 15mm and length,280mm
4	Nuts	Galvanized nut	2	
5	Collars	Mild steel	2	
6	support bars	Mild steel bars	2	
7	Sprocket	Cast iron	1	

3.27.2 Rotary Cutter with Strip Blades

This design has two round plates at its ends, spaced with eight strip blades mounted on the plates at an angle 90^0 to the tangential point of the circular plates that gives a mowing action and also stir the top soil depending on the pressure applied as shown in figure 3.3C2.

Table 3.6: Components of the Rotary Cutter with Strip Blades

No	Parts	Material	No off	Dimensions
1	Frame	Mild steel square pipe	1	Length,270mm, Height,130mm
2	Cutting blades	Mild steel plate	8	Length,260mm, Thickness,3mm
3	Shaft	Galvanized rod	1	Φ 15mm and length,280mm
4	Nuts	Galvanized nut	2	
5	Collars	Mild steel	2	
6	support bars	Mild steel bars	2	
7	Sprocket	Cast iron	1	

Center hole for shaft = 20mm

3.27.3 Earthing Disc

This is the traditional mould board used on drought animal; it opens the soil and turns it upside down to bury the weed around the crops as shown in figure 3.3C1

Table 3.7: Part List of Earthing Disc

No	Parts	Material	No off	Dimensions
1	Cutting blades	Mild steel plate	8	length thickness
2	Holder	Galvanized rod	1	Φ and length

3.27.4 Float weeder

This is a newest design that can be used to stir the top soil in order not to allow the weed to show on the surface. It has special designed blade under the float board which was designed to used continuously after germination as soon as weed seedlings are spotted. It is manually operated by pushing the machine within rows and within crops but can be motor or live aided, as shown in figure 3.3C4

3.28 Manufacturing of Cultivator and its Operational Attachment

Design for manufacturing process is the integral part of Industrial Design and this research work is an example for the effective utilization of design for manufacturing process. Starting from the

Problem-statement or requirement to the development of fully functional product, every single step of the design process has played a role in the success of this work

Various machining, welding and bench fitting work processes available in the Tamale Technical University workshops were utilized to develop the cultivator for the intended purpose, which took one year. The main processes involved in, have been described in this chapter.

The fabrication of the machine mainly involved three processes, namely: developing the main frame, weeding units and other auxiliary components were planned before the start of the work. Dimensions were carefully used to arrive at the product. The materials for creating various parts were considered based on factors such as weight, strength of the material to with Sand forces that would be act on them.

Table 3.8: Part List for the Frame

No	Component	Quantity	Material
1	Side Bars (1 and 2)	2	Galvanized Steel
2	Hinge Plate (3 and 4)	2	Galvanized Steel
2	Spaced Bars (5 and 6)	2	Galvanized Steel
3	Back bar (7)	1	Galvanized Steel
4	Attachment Bar (8)	1	Galvanized Steel

Part List for the Frame

3.28.1 Manufacturing Process

The main frame was manufactured by marking and cutting out all the components of the frame with the use of fitting tools. A 45.5mm mild steel pipe was used for five members of the frame as in figure 3.10, slots was made on member one and two to take the fork plate with length 550mm. A 3mm plat was used as fork plat on which shaft holes was drilled and rimmed, all the joints were permanently fastened all pieces with arc welding after tacking and checking for right angles at all joints. All welded joints were grind and welded again to strengthen them. Welded portions were ported and smoothen by using emery cloth and were finished by spraying with oil paint. Appendix A shows the frame of the cultivator

Design of the Frame

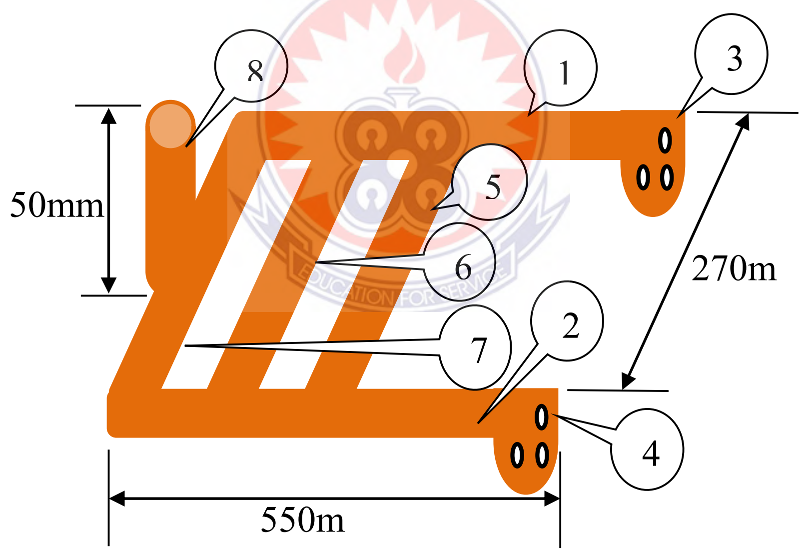


Figure 3.10: Design of the Frame

Table 3.9: Part List of Handle

No	Component	Quantity	Material
1	Hand grib	2	Mild Steel
2	Adjustable pole	2	Mild Steel
3	Attachment hole	1	Mild Steel

3.28.2 Manufacturing Process of the Handle

The handle was put to five member parts, which was marked and cut out using fitting tools, member 2 was bent using pipe bending machine, and was reduced at its ends 45.5 mm to 20mm diameter hand gripping. Member three was reduced to an external diameter of 42mm to fit into member four for adjusting the length and height of the handle. Member four was bent at one end to be joined to member five at an angle of 120^0, member five is 47mm diameter that is fixed into member of the main frame, all joints are welded permanently, grind and refilled, ported and finished with oil paint. Appendix A shows the handle of the cultivator.

The Handle

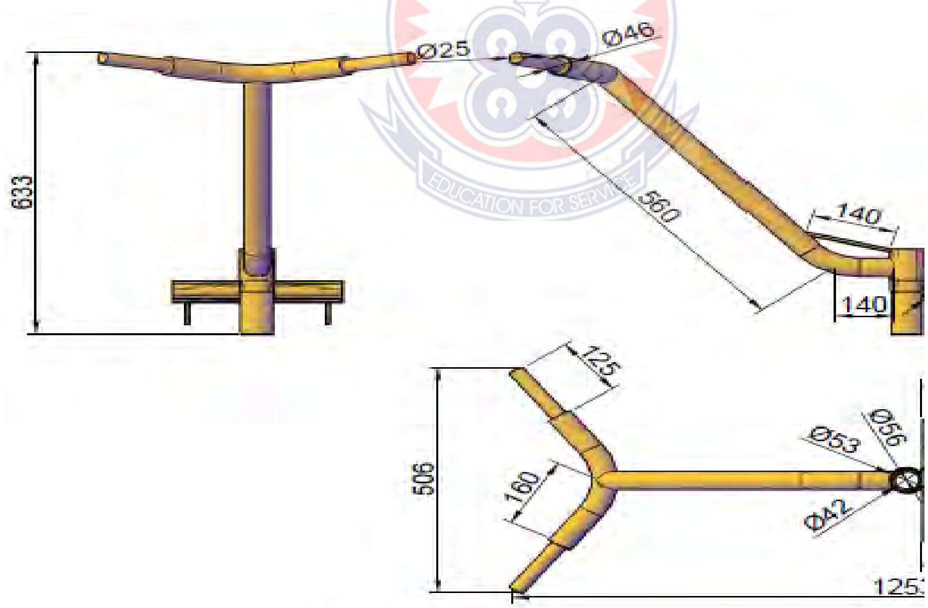


Figure 3.11: The Handle

Table 3.10: Part List of the Front Wheel

No	Component	Quantity	Material
1	Collar	2	Mild steel
2	Sprocket	2	Cast Iron
3	Wheel	1	Plasticizer
4	Rim	1	Mild steel
5	Shaft	1	Galv. Steel

Member three and seven were the wheel with bearing ream was selected for power transmission required in the system, A wheel of diameter 400mm and width 10mm with a ream diameter of 20mm was made to take member two and four were the sprockets of 36teeth at both side of the ream to be driven by a motor sprocket of 14teeth.member one and five are Collars were also machine to keep the bearing ream in position and in alignment all metallic parts were fastened with bolts and nuts. Appendix A shows the front wheel of the cultivator.

The Front Wheel

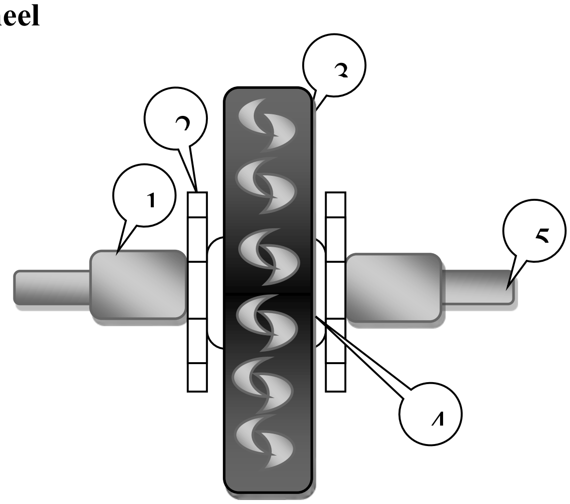


Figure 3.12: Front Wheel

3.28.3 Manufacturing Process of the Weeding Units

The weeding units were manufactured with materials that will withstand soil resistant forces for effective shearing of the soil and plant damage. Mechanical and chemical properties of the materials used were studied for selection for durability of the machine since it will be in contact with moisture and soil during its operation.

3.28.4 Manufacturing Process of the Earthing Disc

A pattern was made and traced on a three millimeter mild steel plate and was cut out to obtain a rectangular shape which was rounded at the shoulder, the shaped plat was then folded to an angle of 60^0, the shape point was supported at the base part to strengthen it. A supporting bar was marked and cut to be fitted into the disc. All parts were tacked checked for alignment and welded, grounded and refilled to strengthen joints, the surface was ported, cleaned with emery cloth and finished with oil paint. Appendix A shows the pictorial view of the earthing disc and it assemble on the cultivator.

3.28.5 Manufacturing Process of the Rotary Cutter with Strip Blades

The rotary cutter was manufactured by using the materials that was selected for the production of the unit. A three millimeter mild steel square pipe was selected for the frame, three millimeter plat was used for the rotary cuter, two round disc were put together by a strip blades to form the rotary drum, 10millimeter rod was used for the shaft and a 14 teeth sprocket, all parts were marked and cut out to size, the fabrication process was done by the tacking and checking for alignment, permanent weld was run on the joints. The sprocket was fixed on the shaft by bolting and welded. The individual members were fabricated individually and assembled to form the rotary cutter with strip blades. Appendix A shows a pictorial view of the rotary cutter with strip blades and it's assembling on the cultivator.

3.28.6 Manufacturing Process of Rotary Cutter with Worm Design

The fabrication of this cutter was carried out by first considering the selection of materials to be used for the production of the unit. A three millimeter mild steel square pipe was selected for the frame, three millimeter plat was used for the four rotary discs at a diameter of 130mms, discs was punched and drilled at the center a cut open at an angle of $60^0$from the center of the disc to its two edges and was fastened to a 10 millimeter shaft. A 14 teeth sprocket was bolted to the shaft. Assemble of the various members were carefully done by bolting and welding. Appendix A shows the pictorial view of the rotary cutter with worm design and it's assemble on the cultivator.

3.28.7 Manufacturing Process of Float Weeder

The blade was assumed to be a simply supported beam subjected to a uniformly distributed load of 150 N/m. Based on it the thickness sweep of blade, was calculated to be 3mm The float weeder was manufactured according to need of different soil properties. Parts of the blade was marked out and fabricated by bolting and welding of members together. The float board was made of mahogany in order to make the weeder light in weight, the board was cut out to obtain a hexagonal shape and eight blades were specially made and fastened to it. Appendix A shows pictorial view of the float weeder and it's assemble on the cultivator.

Autographic View of the Frame

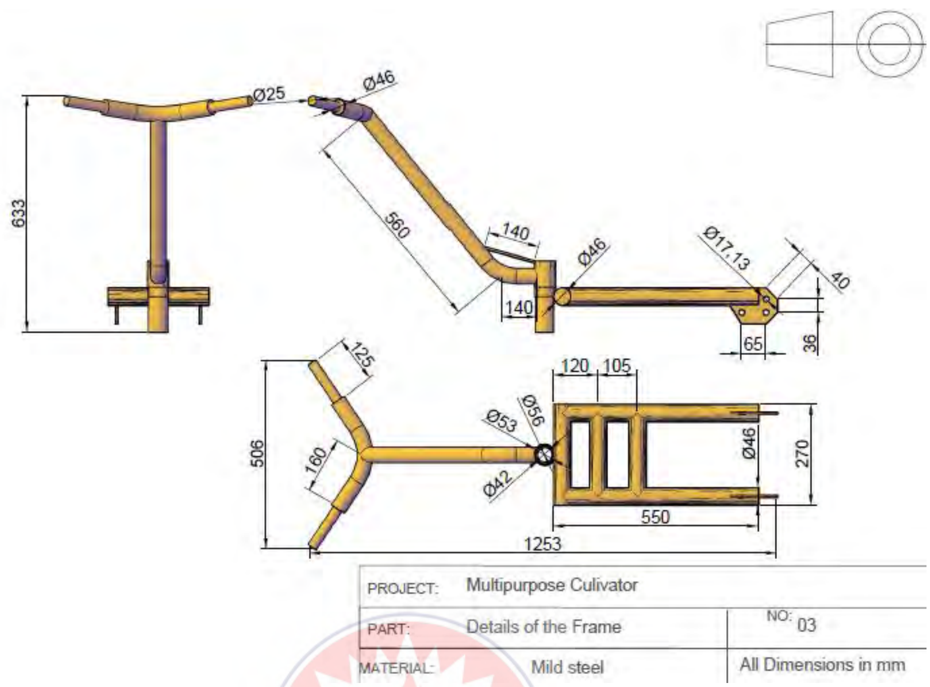


Figure 3.13: Autographic View of the Assemble of the Cultivators Frame

Exploded View of the Cultivator

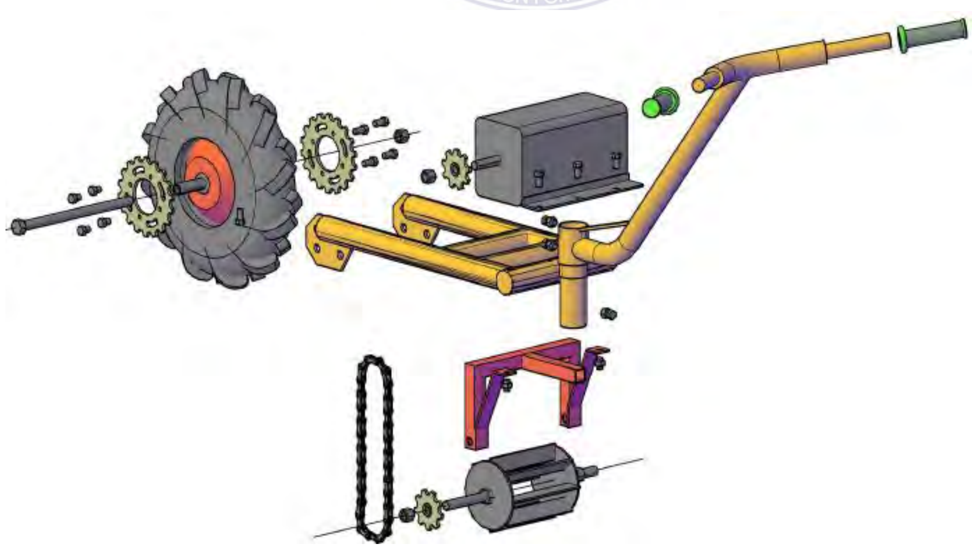


Figure 3.14: Exploded View of the Cultivator

3.29 Bill of Materials

The materials required for components fabrication of the cultivator was based on the survey from the literatures collected the materials are selected to fabricate the cultivator. The materials were chosen in such a way that they are able to withstand the working loads that act on the cultivator during the working time and also cost effective. The bills of materials used for the fabrication of the weeder are described in the Table 3.5.

Table 3.11: Cost of Design

No	Part	Material	Unit Price Gh.₵	Unit	Total Cost Gh.₵
1	Frame and Handle	Galvanized pipe	60	2	120
2	Weeding Units	3mm mild steel plate	320	1/4	80
3	Chain and sprocket	Set	30	2	60
4	Wheel	Ream and tyre	50	1	50
6	Bolts and Nuts		3	10	30
7	Miscellaneous		50		50
8	Engine		400	1	400
8	Workmanship		200	1	200
TOTAL				**17**	**990**

The total cost of materials could be lower if the implement is to be produced in a large quantity, as this was the production of one weeder, there was left over materials that that is part of the total cost.

3.30 Test for Strength and Performance of the Cultivator

Mechanical evaluation of the cultivator was done to find out the strength of material used for the main components of the machine that will subjected to various kinds loading during operation and Performance test of the cultivator was considered as a dynamic approach for doing performance analysis of the weeding units designed. In this work self-adoptive learning based approach was used the test framework, which seeks to find the efficiencies of the proposed designs under different conditions to remove the bottlenecks and scalability to ensure user friendliness.

3.31 Stress and Displacement Test was Performed on the Multipurpose Cultivator

Procedure Used for the Simulation

The multipurpose cultivator was modeled in AutoCAD and imported into COMSOL Multi-physics version 5.2 for the analysis. Stationary and Eigen frequency studies were performed to determine the stresses and displacements that the frame and the handle will be subjected to respectively. An external forces was applied to the cultivator as the frame would be subjected to various forms forces such as the engine or the motor, soil resistance internal friction resistance.

The geometry was imported from AutoCAD to COMSOL for the Finite Element Analysis (FEA) of the frame together with the handle (Figure 3.18). After the importation, structural steel was selected from the built-in material library and applied to the geometry. Under definition of physics, fixed constraint was applied to the ends of the frame where the front wheel is attached (Figure 3.19a).

Finite Element Analysis

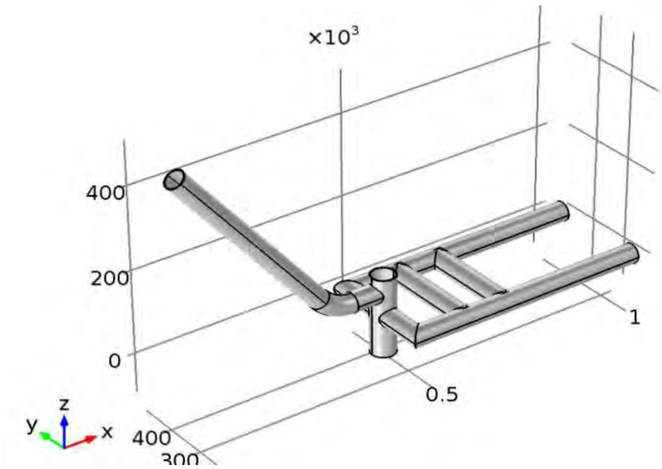
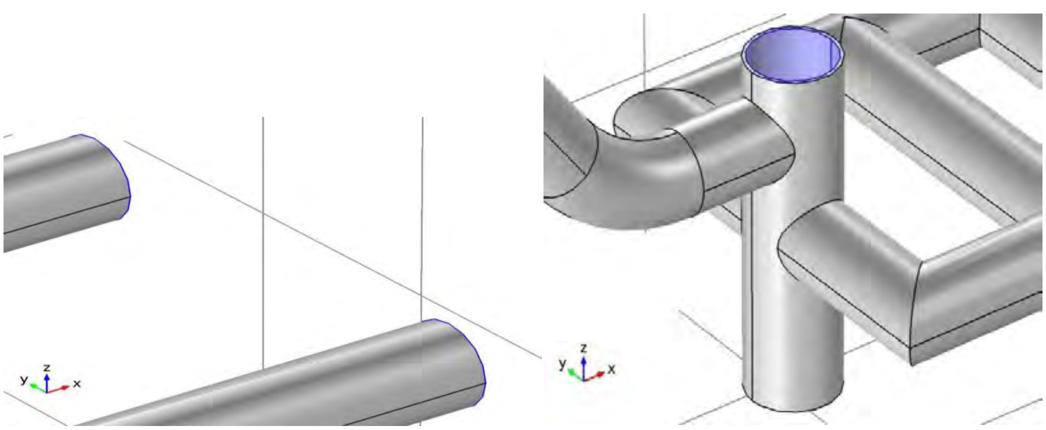


Figure 3.15: Geometry Used for the FEA Analysis

3.32 Geometry used for the FEA Analysis

Boundary loads were applied (to x - component) inside the vertical pipe between the frame and the handle where the weeding tools are fixed (Figure 3.19b).The load type used was total force (uniformly distributed load) and magnitudes used were 200N, 400N, and 600N. The 200N force was used force for both the Stationary and Eigen frequency studies.



(a) (b)

Figure 3.16: Definition of (a) Fixed Constraint (b) Boundary Load

After selecting the material and defining the physics, mesh for the geometry was built. Free Tetrahedral mesh was selected since the geometry was complex, and the study computed. Source Appendix B.

3.33 Free Tetrahedral Mesh of the Geometry

The resulted geometry after building the mesh was obtained as shown in Figure 4.1which indicates a free Tetrahedral Mesh of the geometry,

Mesh of the Geometry

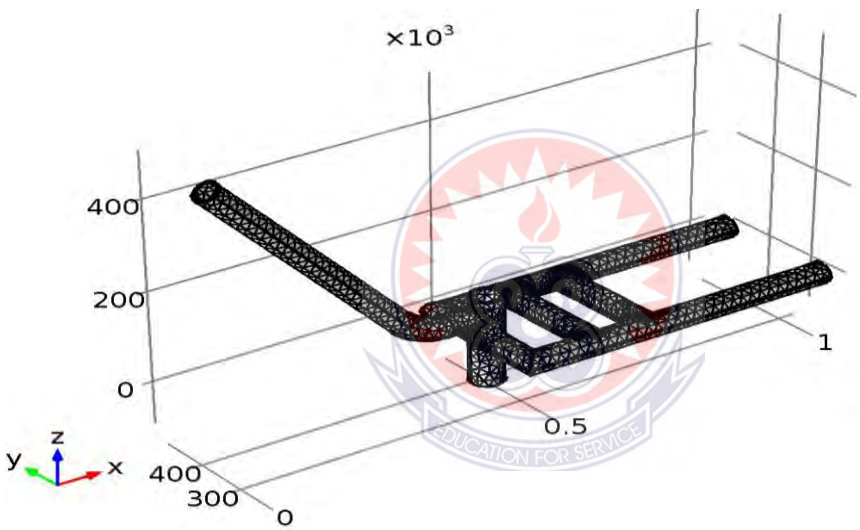


Figure 3.17: Mesh of the Geometry

3.34 Free Tetrahedral Mesh of the Geometry

The results of the Stationary study after the application of the 200N, showed minimum and maximum Von Mises stresses of 2.15 x 10^{-4}N/m^2 and3.62 x 10^6 N/m^2 respectively (Figure 3.19a). For 400N load, the minimum and maximum Von Mises stresses of 4.28 x 10^{-4}N/m^2 and7.23 x 10^6 N/m^2 respectively (Figure 4b). And for the 600N load, the minimum and maximum Von Mises stresses of 6.44 x 10^{-4}N/m^2 and1.08 x 10^7N/m^2 respectively (Figure 4). These were acting at the joint between the frame and the handle.

The units of the cultivator been the soil interacting component there are a number of forces acting on them at their point of attachment and the point that gets in contact with the soils during its operation. It was also modeled in AutoCAD and imported into COMSOL Multi-physics version 5.2 for the analysis. Stationary and Eigen frequency studies were performed to determine the stresses and displacements that the frame and the handle will be subjected to respectively. An external forces was applied to the cultivator as the frame would be subjected to various forms forces such as the engine or the motor, soil resistance internal friction resistance as in figure 3.18

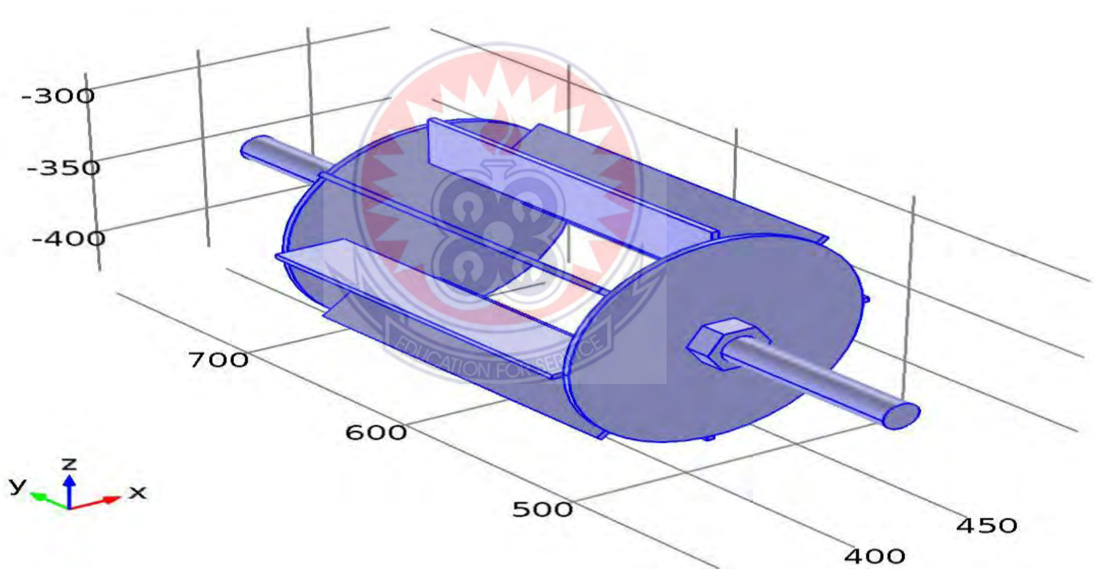


Figure 3.18: Internal Friction Resistances

Table 3.12: Boundary Conditions

Name	**Value**	**Unit**
Density	7850[kg/m^3]	kg/m^3
Young's modulus	200e9[Pa]	Pa
Poisson's ratio	0.33	1

Fixed constrain

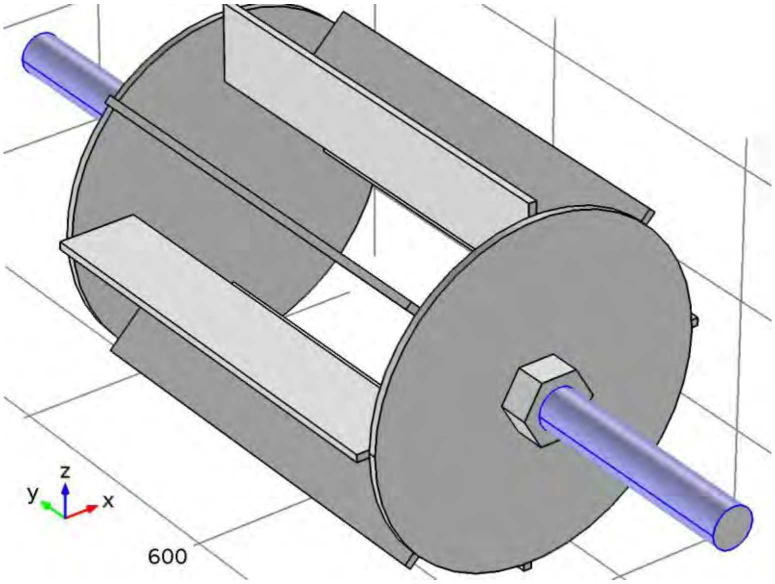


Figure 3.19: Fixed constrain

Boundary Conditions

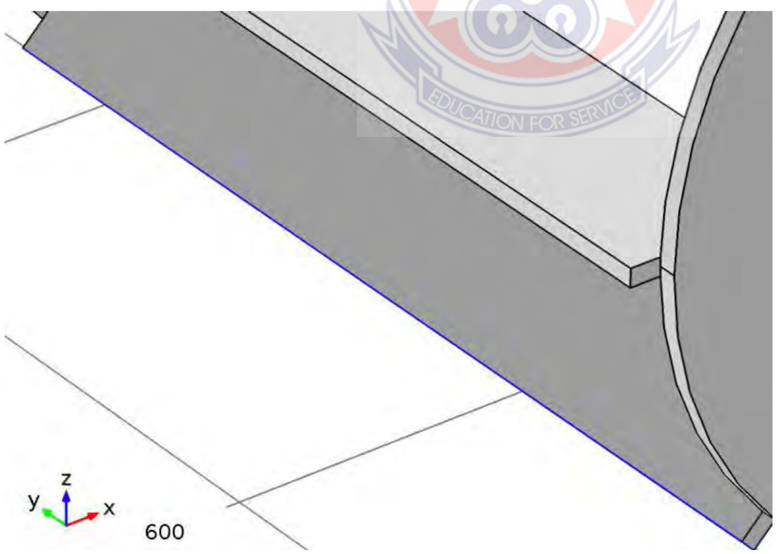


Figure 3.20: Boundary condition

3.34.1 Boundary Conditions

Boundary loads were applied (to x - component) inside the vertical pipe between the frame and the handle where the weeding tools are fixed (Figure 3.19b).The load type used was total force (uniformly distributed load) and magnitudes used were 200N.

Table 3.13: Mesh Statistics of the Rotary Cutter with Worm Design

Description	Value
Minimum element quality	0.08286
Average element quality	0.5992
Tetrahedral elements	12995
Triangular elements	9390
Edge elements	1465
Vertex elements	137

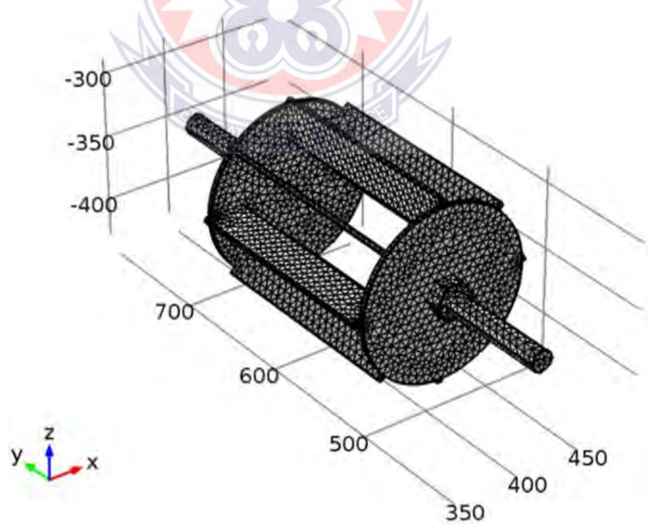


Figure 3.21: Mesh 1

Table 3.14: Size of Elements

Description	Value
Maximum element size	38.2
Minimum element size	6.88
Curvature factor	0.6
Resolution of narrow regions	0.5
Maximum element growth rate	1.5

Free Tetrahedral 1 (ftet1)

Geometric entity level	Remaining

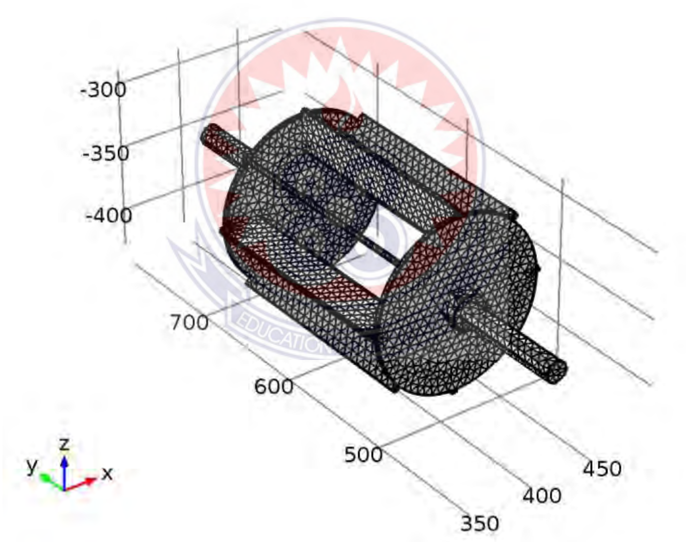


Figure 3.22: Free Tetrahedral 1

Table 3.15: Mesh statistics of the Earthing Disc

Description	Value
Minimum element quality	0.09896
Average element quality	0.6789
Tetrahedral elements	11417
Triangular elements	7528
Edge elements	359
Vertex elements	18

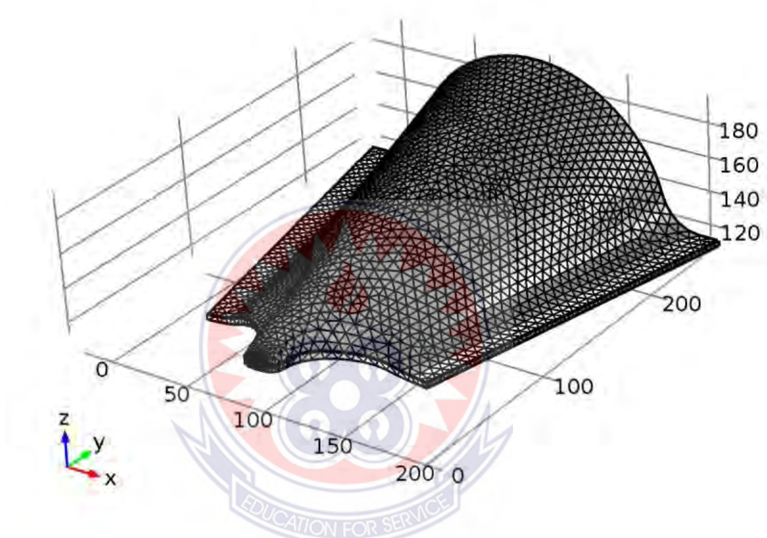


Figure 3.23: Mesh 1 for the Earthing Disc

Table 3.16: Size of Element

Description	Value
Maximum element size	25.2
Minimum element size	4.54
Curvature factor	0.6
Resolution of narrow regions	0.5
Maximum element growth rate	1.5

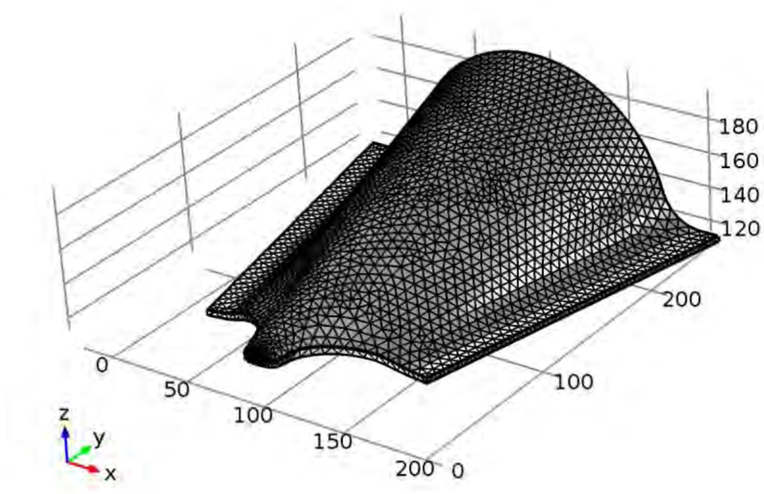


Figure 3.24: Free Tetrahedral 1

3.35 Mechanical Engineering Experimental Test to for Strength of the Material

The experiment seeks to determination of the tensile properties of the materials used for the cultivator.

Objective: To characterize the mechanical behavior of galvanized steel used for the frame and the shaft.

3.35.1 Requirements of the Experiment

1) Tensile specimen (sample material used for the frame and the shaft)
2) Universal Mechanical Tensile Testing Machine
3) Vernier caliper

Brief description of the equipment/machine: The Universal Testing Machine was used to determine the strength of the shaft and the frame as there would be a lot of forces that will be acting on it during the operation of the cultivator. The 10KN capacity testing machine and is screw driven. While the lower cross head is fixed, the upper cross head is movable and is fitted with the transducer type 'load cell'. This testing machine can also be used for compression, torsion, bend/flexural and for high temperature tensile tests.

3.35.2 Engineering Test Properties of the Sampled Materials

Strain hardening: The relationship between stress and strain is nonlinear during plastic deformation. Like E in elastic range, strength coefficient (K), strain hardening exponent **(n)** and amount of strain hardening prior to test (εo) are used to characterize material in plastic range

$\sigma = K(\varepsilon + \varepsilon o)^n, \Rightarrow \log \sigma = \log K + n \log(\varepsilon + \varepsilon o)$

Ultimate tensile strength (Su): The maximum engineering stress before rupture of specimen

Su = Pmax/Ao

Toughness: Ability to absorb energy per unit volume in the sample range UT = 0.5 (s0 + su) ×ef

3.35.3 Important Experimental Parameters

a) Original Gauge Length (Lo): Gauge length before application of force

b) Final Gauge Length (L): Gauge length after rupture

c) Engineering Stress (S) and Engineering Strain (e): S = P/Ao, e = (L – Lo)/Lo

d) True Stress (σ) and True Strain (ε): $\sigma = S(1+e), \varepsilon = \ln(1+e)$

e) Yield Stress: For most ductile metals, yield strength is usually obtained from 0.2%offset yield strength/proof stress method by drawing a parallel line with elastic region from 0.002 strains in X-axis.

f) Percentage of Total Elongation at Fracture = $(L — L_0) / L_0$

g) Percentage Reduction in Area = $(A_0 - A) / A_0$, Maximum change in cross-sectional area which has occurred during the test $(A_0\text{-}A)$ expressed as a percentage of the original cross-sectional area (A_0), where A is the final cross-sectional area.

3.35.4 Experimental Procedure

a) A sample was parallel turned to a Dogbone samples of the sample (metal) will be tested in tension.

b) Using marker, mark the gauge length reference points. The gauge length should be marked within the parallel section portion of the dogbone sample.

c) Measure original width and thickness of the sample at least four times along the reduced section (gauge length) of the specimen. Find average value of cross-sectional area.

d) Switch on the testing machine and let it get stabilized for at least 30 mins.

e) Fix the specimen into the testing machine grips.

f) Select the cross-head speed and strip chart recorder was selected

g) Start applying the load gradually and observe and record change in length.

h) As soon as sample gets fractured, note down the total extension from the chart.

3.35.5 Elastic Recovery Immediately After Fracture.

i) Carefully, measure final gauge length after fracture.

j) Measure cross sectional dimensions of the specimen after fracture.

k) Use excel to convert collected data (load in Newton and extension in mm) to engineering strain (e) and engineering stress (S), and then to true stress and true strain.

The selected material for the shaft and the frame assembly was gripped at both ends by an apparatus, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, which is plotted against the material length change, or displacement. The load is converted to a stress value and the displacement is converted to a strain value.

Also the frame was griped at one end by an apparatus and slowly force (load) was applied at the other end (handle) for compression until the frame brakes (fractures or fail), the pressing in known as load, which was plotted against the change in length or compression. The load in this case is converted to stress value and the compression is converted to deformation value.

Table 3.17: Experimental Data of the Tensile Test on the Frame and Shaft

		Shaft			Frame		
No	**Load(N)**	**Stress(MPa)**	**Strain**	**%Elongation**	**Stress(MPa)**	**Strain**	**% Elongation**
1	000	00.00	0.00	00.00	00.00	0.000	0.000
2	100	48.50	0.02	0.188	30.10	0.021	0.100
3	200	50.00	0.03	0.225	35.30	0.033	0.125
4	300	55.00	0.05	0.263	37.50	0.045	0.138
5	400	52.50	0.08	0.300	39.10	0.063	0.163
6	500	54.50	0.09	0.338	36.40	0.082	0.175
7	600	55.00	0.12	0.363	35.00	0.091	0.219
8	700	48.30	0.14	0.387	32.10	0.101	0.213

$$\% \text{ Elongation} = \frac{\text{Change in Length(L)}}{\text{Original Length(Lo)}} \times 100$$

Table 3.18: Percentage Elongation of the Shaft and Frame of the Cultivator

Change in Gauge Length(L_0= 80mm)			
Shaft		Frame	
0.00	0.00	0.00	0.00
0.15	0.19	0.08	0.11
0.18	0.23	0.10	0.13
0.21	0.26	0.11	0.14
0.24	0.03	0.13	0.16
0.27	0.34	0.14	0.18
0.29	0.36	0.16	0.20
031	0.39	0.17	0.21

These were the experimental data recorded during the tensile test experiment carried out on the machine, the experiment concentrated on the frame and the shaft, which are the main members that will be subjected to types of force reaction.

3.36 Experimental Test for Field Performance of the Cultivator

Having satisfied with the mechanical properties of the material used for the realization of the machine field performance of the machine was carried out to determine the output of the four units of attachment relation to the used of other cultural practices used for weed control.

3.37 Theoretical Framework of the Experimental Sit

The physical soil parameters pertinent to weeding have a direct bearing on the power requirement for any weeding machine operation, (Horn et al., 1994). In this experiment, Particle Soil Distribution (PSD), Texture, Moisture content, wet and dry bulk densities, Soil compaction, Penetration resistance and Shear stress were considered as it affects performance of the weeding and tilling machines and tools.

3.38 Experimental Site Description

This field experiment was conducted under irrigation conditions at Tamale in the Northern Region between June, 2020 and October, 2020. The soil at the site was sandy loam in texture in both the 0–10 cm layer and the 10–15 cm layer. Table 3.1 in appendix A, presents some physical-chemical properties of the soil at the study area prior to starting the experiment.

3.39 Experimental Design

The experiment was laid out in split-plots designed in eight beds. The weeding attachments included the Rotary cutter with a worm design, Rotary cutter with strip blades, Earthing disc and Float weeder. However the Two row seeding system was part of the units of attachment of the cultivator which was used for sowing in all the eight beds except the control bed B1 which was done with dibber and hand sowing. The weeding frequencies in B1 were done with the hand and hoe two times during the life span of the crop. The other fourth weeding frequency treatment was the test of the weeding units. Each treatment was weeded three times with the attachments.

3.40 Recommended Field Operational Pattern

Where;

A is inter-crop spacing = 20cm = 0.2m

B is row spacing = 270cm = 2.7m

C is length of row = 220cm = 2.2m

D is width of the rows = 100cm = 1.0m

BL is the length of bed = 240cm = 2.4m

Bw width of bed = 120cm = 1.2m

Area occupied by crops = 22000cm^2 = 220m^2

Area of the bed = 28800cm^2 = 288m^2

3.41 Experiment analysis of Moisture Content of the Experimental Bed.

Oven Method of testing moisture content of the soil

This test was carried out to analyze the soil samples taken during the performance test to determine the soil moisture of the test area.

Three core soil samples in three different locations of test plots were taken randomly from the test area. Each soil sample was weighed and recorded as initial weight.

The samples were dried using a convection oven maintained at 150ºC for at least eight hours.

The oven dried sample was then placed in desiccators. Each soil sample was weighed and recorded as oven-dried weight.

The soil moisture (% dry weight basis) shall be computed as follows:

Soil Moisture (% dry weight basis) = $\frac{Wi - Wf}{Wf} \times 100$

(3.23)

Where: Wi = is the initial weight of the soil, kg

Wf = is the oven-dried (final) weight of the soil, kg

WC = Water content of the soil. Shown in Table 3.15 in appendix A

Moisture content was determined mathematically as a percentage of the dry soil weight, the formula 3.23 is used.

$$MC\% = \frac{W2-W1}{W3-W1} \times 100$$

(3.24)

Where;

W1 = weight of the tin (g)

W2 = weight of moist soil + tin (g)

W3 = weight of dried soil + tin (g)

It was observed that the higher the moisture content the softer the soil while the harder the lower the MC the harder the soil which and higher the power demands, but bellow MC of 11.00 of the sandy loam the less efficient the performance of the cultivator as the soil becomes muddy and sticks to the weeding cutters.

3.42 Experimental Design and Cultural Practices

The experiment was arranged in a randomized eight beds design replication. The weeding treatments were Bed1 as the control and bed2 - Bed8. Each replication was randomly assigned to weeding units; the Rotary cutter with a worm design, Rotary cutter with strip blades, Earthing disc and the Float weeder. During sowing the size and width of the frame as well as the attachments were taken into consideration. Data collected from sowing to Three Days after Germination (TDAG) included plant spacing, row spacing and number of expected stands (ES) as compared to the stands germinated (SG), the expected crop was the first to germinate on all the eight beds (treatments).

Plant spacing, 00.20m

Row spacing, 00.27m

Number of ES, 33.00

Number of SG, 33.00

3.43 Experimental Design and Treatments

The experiment was designed to test the performance of the attachments of the cultivator under three soils conditions with constant forward speeds using motor and manually powered. These treatments were arranged in a split-split-split plot design with a unit for each treatment.

The beds as well as the inter row and inter plant spacing were designed to suit the width of all the cultivators attachments. Random selection was used to locate each treatment in a bed there was an area of five meters wide left for turning and easy maneuvering of the machine between the rows and beds.

The test was done on each bed with a specific attachment of the cultivator and time was taken on each test.

3.44 Test of Rotary Cutter with Worm Design

The weeding unit was motor and electrical powered, the motor was started and drove within the crop rows at a weeding depth of 50mm as indicated in the figure 2, operation time was noted on each row till the last row.

3.45 Test of rotary cutter with strip blades

The rotary cutter with strip blades rotates to perform the weeding action which stirs the top soil at a depth of 25mm. Weeding unit was motor and electrical powered, which was droved within the crop rows at a weeding depth of 25mm as indicated in the figure 3,operation time was noted on each row till the last row.

3.46 Test of Earthing Disc

The earth disc is used earth up a thin layer of 25mm slice to cover weeds around crops, the disc was tested manually, motor/electrical and live aided, it was drove within rows and time was recorded.

3.47 Testing of the Float Weeder

The float weeder is a weeding tool that is used to stir the top soil ten days after transplanting and germination, once the seedling of weeds are sported the device can be used to hinder the growth of weeds within crops, the unit was tested manually and motor or electrically powered. The device is driven through the bed within the crop row.

3.48 Weed Samples and Weed Dry Matter Content

Samples of types of weeds present at the experimental site were taken before ploughing for identification. Immediately after weeding with all the units on separate beds (2-8), bed one was weeded with hand hoe, a square quadrant was used on each bed and marked out. The weeds cut out or displaced were carefully pulled out from the square quadrant and the samples were placed in an envelopes and oven dried at 70 °C for 48 hours. The weed dry matter per plot was determined using an electronic balance was tabulated in table 3.4 as first weeding (1stW)

Table 3.19: Units of the Cultivator used in 14 Days after Germination (1ST W)

Weeding Units	Time Taken	Weight of WDM
-	Minutes	Kg
Hand weeding WH	30	12.0
Rotary cutter WWD	10	6.1
Rotary cutter WSB	10	5.3
Earthing disc	12	4.3
Float weeder	11	9.0
Total	**73**	**36.6**

Table 3.20: Units of the Cultivator used manually in 14 Days after Germination (1ST W)

Weeding Units	Time Taken	Weight of WDM
-	Minutes	Kg
Hand weeding WH	30	12.0
Earthing disc	16	5.0
Float weeder	14	5.7
Total	**60**	**22.7**

Table 3.21: Comparative Performance of the Cultivator's Units in 28 Days after Germination (2nd W)

Weeding Units	Time Taken	Weight of WDM
-	Minutes	Kg
Hand weeding WH	27	2.3
Rotary cutter WWD	07	1.0
Rotary cutter WSB	08	1.0
Earthing disc	10	0.7
Float weeder	08	1.0
Total	**62**	**6.0**

Table 3.22: Comparative Performance of the Cultivator Manually in 28 Days after Germination (2nd W)

Weeding Units	Time Taken	Weight of WDM
-	Minutes	Kg
Hand weeding WH	26	2.1
Earthing disc	13	0.6
Float weeder	14	0.8
Total	**53**	**3.5**

3.49 Power Requirement

Soil resistance has a considerable effect upon the power requirement of the machine. Also, width of cut and speed of operation influences power requirement. For calculating power requirement of the cultivator, maximum soil resistance was taken as 0.5kgf/cm^2. The speed of operation of the weeder was considered as 0.7 ms-1 to 1.0 ms-1. Total width of coverage of cutting blades was 270mm and the depth of operation was considered as 50 to70mm, transmission efficiency is 82%.

Pr = (SR x d x w x v) / 75 hp (3.25)

Where,

SR = soil resistance = 0.049 N/mm^2

d = depth of cut = 80 mm

w = effective width of cut = 300 mm

v = speed of operation, 1000 mm/s

Hence, power requirement is estimated as

Pr = (0.049 x 80 x300x1000)/75 hp = 0.02hp = 0.0149 KW

Therefore the power need for the cultivator to weed in any of the units was estimated at 0.02hp

3.50 Total Power Required

The total power required was estimated at 0.02 hp as:

$Pt = Pd/\eta$ (3.26)

$= 0.02/0.82$

$= 0.025$ hp

$= 0.0186$ KW

Where:

Pd = Power required digging the soil:

η = Transmission efficiency.

Thus, a prime mover of 0.0186 kW (0.02 hp) was required for this for the cultivator to work.

3.51 Assessment of Power Required

Power required to dig the soil, Pd was determined by using equation 7 and Total power required is calculated from equation 8.

$Pd = SR\times d1 \times w \times v$

(3.27)

Total power required, $Pt = Pd / \acute{\eta}$

(3.28)

Where,

d_1 = depth of cut, cm, (50mm)

w = effective width of cut, cm, (270mm)

S_R = soil resistance, kgf/mm^2, (1.5 kgf/mm^2)

P_d = power required to dig the soil

ή = efficiency of transmission, % (75 %)

The estimated power required to dig the soil, Pd was 3.5 hp and the total power required as 4.23 hp, thus, a prime mover of 5 hp was required for this cultivator to perform effectively.

3.52 Cutting Geometry

The units are the working part of the cultivator. They break and loosen the soil, uproot the plant and displace the soil particles. The plant material is uprooted as the weeding units are carried the soil along the crop rows. The velocity of the units relative to the cultivator was due to the forward speed when moved manually. The vector sum of these two components gives the velocity relative to the ground. In general, the relationship between the rake, bevel and clearance angles is presented by equation 10. In the case of the power aided the powers transmitted to any part from the power source make that move independently.

$$\phi rk + \phi bk + \phi ck = 90^0 \quad (3.29)$$

Where,

ϕ_{rk} = rake angle

ϕ_{bk} = bevel angle

ϕ_{ck} = clearance angle

3.53 Weeding force

Draft data for weeding implements are reported as the force required in the horizontal direction of travel (ASAE D230, 1990). Only functional draft (soil and crop resistance) is reported. Total implement draft was obtained by adding the rolling resistance (RR) of the transport wheels. Draft per unit effective width at typical field speeds for row cultivator was given by ASAE standards as:

$$\frac{115+230}{d} \times d = N/m$$

(3.30)

Where,

d_3= tool depth, cm

The average of the two extreme values, draft per meter at 5cm depth (by design) is

$$\frac{115 + 230}{5} \times 5 = 345N/m$$

Width of weeding tool is 270mm (by design).

Hence, draft of implement = 345 x 0.27 = 93.15N

The rolling resistance (RR) is given by ASAE (1990) as

$RR= CIbd / C_n [1.2 / C_n+0.04]$

(3.31)

Where,

C_n = dimensionless ratio which is a function of the cone index

CI for the soil b = unloaded tyre section width d = unloaded overall tyre diameter

For tilled agricultural drive wheel tyres, bd / w = 0.25 on typical soil surface,

$CI = 80$, $C_n = 20$

Where:

W = dynamic load in Newton normal to the soil surface and is given as

$$RR = CIbd / C_n \quad (3.32)$$

For the wheel on the cultivator, b = 0.0738, d = 0.0355m

Substitute these values into equation (3.32)

$RR = (80 \times 0.0738 \times 0.0355) / 20[1.2 / 20 + 0.04] = 1.048 \times 10^{-3}N$

Therefore the total draft of the machine in operation = $138 + (4.19 \times 10^{-3}\ N) = 138.004N$

3.54 Performance Evaluation

The performance evaluation of the fabricated mechanical weeder was conducted at the Tamale Technical University in Sagnarigu Municipality. About 2304m^2 plot of land was mapped out and put into crop beds. The mechanical weeder was tested on the mapped out beds to determine the weeding index, weeding efficiency and field capacity. Table 3.23 was obtained from the experimental test of the cultivator.

Table 3.23: Weight of WWM and Weight of WDM in 14 Days after Germination (1^{ST} W)

Weeding Units	Weight of WWM	Weight of WDM
-	Kg	Kg
Hand weeding WH	3.6	1.1
Rotary cutter WWD	3.4	0.9
Rotary cutter WSB	3.1	0.6
Earthing disc	2.1	0.1
Float weeder	3.4	0.9
Total	**15.6**	**3.2**

Table 3.24: Units of the Cultivator used manually in 14 Days after Germination (1^{ST} W)

Weeding Units	Weight of WWM	Weight of WDM
-	Kg	Kg
Hand weeding WH	3.5	0.9
Earthing disc	2.1	0.6
Float weeder	3.5	1.0
Total	**9 .1**	**2.5**

3.55 Weeding Index of the Cultivator with the it Attachment

Weeding index is a ratio between the number of weeds removed by a weeder and the number present in a unit area and is expressed as a percentage (Rangasamy, et al., 1993). The time taken to perform this operation was noted. Equation 14 was used to calculate weeding index.

Weeding index, $I_w = (W_1 - W_2) / W_1$

(3.33)

Where,

W_1 = Total weight of the weeds, (15.6kg)

W_2 = Weight of weeds after weeding, (3.2Kg)

W_{1m} = Total weight of the weeds manually, (9.1kg)

W_{2m} = Weight of weeds after weeding manually, (2.5Kg)

I_w = Weeding index

$I_w = \frac{15.6-3.2}{15.6} = 0.79$kg

When the machine in manual operation with earthing disc and the float weeder

$I_w = \frac{9,1 - 2.5}{9.1} = 0.73$kg

Therefore the weeding index of the cultivator both electrical aided and manual are 0.79kg and 0.73kg.

3.56 Weeding Efficiency (ε)of the Cultivator

The weeding efficiency was determined by using equation by:

$\varepsilon = [(W_1-W_2) / W_1] \text{ x } 100$

(3.34)

Where,

W_1= Total weight of the weeds

W_2 = Weight of weeds after weeding

ε = Weeding efficiency

$\varepsilon = \frac{15.6 - 3.2}{15.6} \times 100$

$= 79\%$ and

$= \frac{9.1 - 2.5}{9.1} \times 100$

$=$ 73% thus Weeding efficiency **ε** for manual operation of the machine.

The mechanical cultivator was tested on the same plots to determine the field capacity of the machine. Field capacity is the amount of area that a weeder can cover per unit time as shown in the expression (3.36). From Table 3 Units of the Cultivator used in 14 Days after Germination (1^{ST} W), the total time was recorded to be 72 minutes

Field capacity (Fc) $= \frac{2600}{t} \times \frac{A}{10000}$ (3.35)

$$Fc = \frac{2600}{72} \times \frac{2016}{10000} = 7.28$$

3.57 Wheel Slippage Measurement

The rear wheel slippage was determined as follows:

1- Fallow flat area was chosen in the field to represents normal working conditions.

2- The wheel of the cultivator was marked with a piece of chalk at a position tangent to ground surface.

3- A distance covered by six revolutions of the wheel when the cultivator was unloaded and also another distance covered by the same number of revolutions when loaded with each of the units.

4- The wheel slippage was calculated as follows:

$$\text{Wheel slippage\%} = \frac{\text{Unloaded distance(m)} - \text{Loaded distance (m)}}{\text{Unloaded distance(m)}} \times 100 \quad (3.36)$$

$$\text{Wheel slippage\%} = \frac{7.6(m) - 6.5\ (m)}{7.6(m)} \times 100$$

Wheel slippage% = 14.47% this mean in every 100 meters covered during operation of the cultivator, the wheel will slip 14.47 times.

3.58 Field Efficiency Measurement

1. On each plot distances of 25m were marked
2. The cultivator started working on the bed and then the time in seconds was recorded using stop watch. This was done for each 25m distance in the bed.
3. Time for turns at the end of each distance was recorded.
4. The theoretical or effective field capacities (TFC or EFC) and field efficiency (FE) were calculated as following:

a. $$\text{TFC (m/h)} = \frac{\text{Areacovered (m/h)}}{\text{Timetaken(h)}} \quad (3.37)$$

$$= \frac{288\text{m2}}{12}$$

$$= 24\text{m/h}$$

b. $$\text{EFC (f/hr)} = \frac{\text{Workingwidth (m)} \times \text{speed (km/hr)} \times 100\ (\text{m})}{420(\text{m2})} \quad (3.38)$$

$$= \frac{0.27\ (\text{m}) \times 2\ (\text{m/h}) \times 100\ (\text{m})}{420(\text{m2})}$$

$$= 0.129\text{m/h}$$

c. $$\text{Field efficiency (FE) \%} = \frac{\text{Effective fieldcapacity}}{\text{Theoritical Fieldcapacity}} \times 100 \quad (3.39)$$

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity and it is expressed in percent.

$$= \frac{0.129 m/h}{24 m/h} \times 100$$

$$= 0.54\%$$

3.59 Plant Damage

Plant damage was calculated by counting the number of injured plants in sample plot and total number of plants in sample plot .The plant damage was determined by following expression.

$$Pd(\%) = \frac{A}{B} \times 100 \quad (3.40)$$

Where,

Pd = plant damage (%)

A = No. of injured plants (cut or damaged) in sample bed

B = Total No. of plants in sample bed.

$$Pd(\%) = \frac{680}{756} \times 100$$

$$= 89.95$$

Table 3.25: Comparative Performance of the Weeding Mechanisms

Weeding units	Initial weed density (No.)	Final weed density (No.)	Reduction in weed density (No)	Weed control efficiency (%)
Earthing disc	72.11	05.10	67.01	92.9
Rotary WWD	74.33	18.13	56.2	75.7
Rotary WSB	70.42	19.12	51.3	72.9
Float weeder	68.42	16.12	40.2	52.6
Total	**285.28**	**58.47**	**214.71**	**294.10**

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter of the research focuses on the results and discussions of the experiments conducted on the proposed design.

Design concept C was selected, designed and realized as showed in figure 4.1, 4.2, 4.3 and 4.4 for it versatile functional characteristics. The concept functions with four weeding units which can be adjusted to take seeding system. The assembly of the cultivator was done with electrical motor and a provision for petrol engine.

Rotary Cutter with Worm Design Assembly

Figure 4.1: The Cultivator with Rotary Cutter with Worm Design Assembly

Rotary Cutter with Strip Blade Assembly

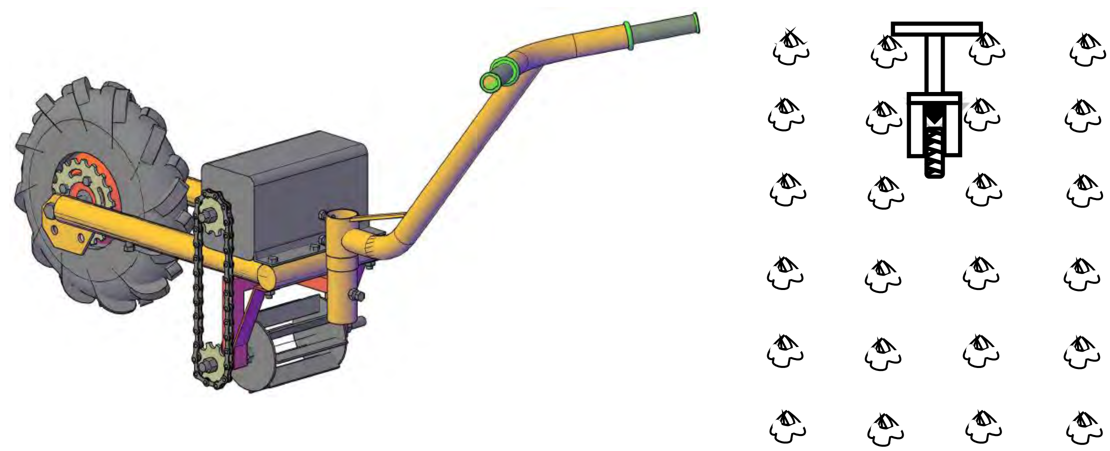


Figure 4.2: The Cultivator with Strip Blade Assembly

Earthing disc Assembly

Figure 4.3: The Cultivator with Earthing disc Assembly

Float Weeder Assembly

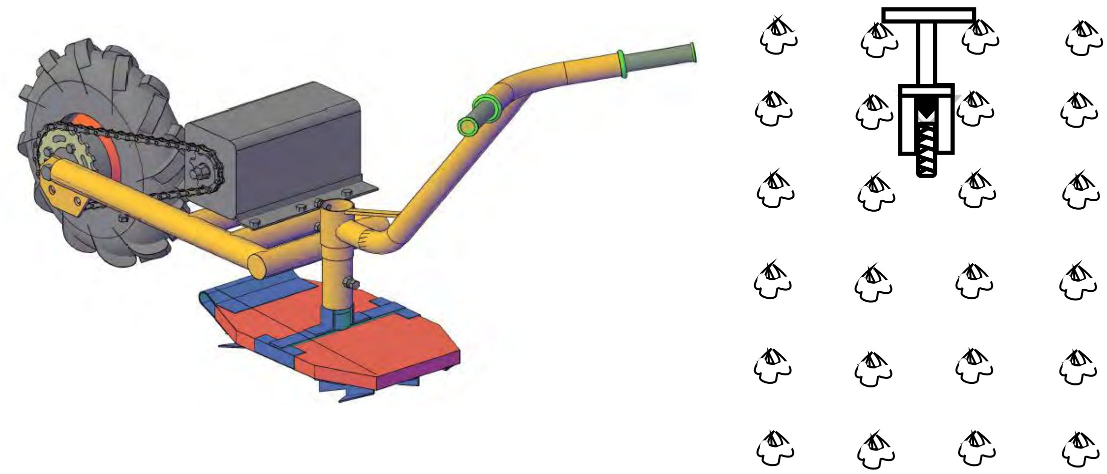


Figure 4.4: The Cultivator with float Weeder Assembly

4.2 Statistical Results

The unique and the newest designed and manufactured cultivator were achieved as a result of the study of the existing tools and equipment used, as shown in figure 3.12 , 3.13, 3.14, and 3.15 which shows the assembly of the cultivator and the proposed attachments of the machine.

The various components of the cultivator was tested for strength of material that determines the strength of the cultivator as it is made to house the motor or the petrol engine and attachment of the four weeding mechanisms that would be subjecting various forms of forces on the frame together with the handle in view of this, a geometry of the frame together with the handle was modeled and imported from AutoCAD to COMSOL for the Finite Element Analysis (FEA) as in Figure 3.18. After the importation, structural steel was selected from the built-in material library and applied to the geometry. Under definition of physics, fixed constraint was applied to the ends of the frame where the front wheel is attached (Figure 3.19a).

A boundary loads were applied the vertical pipe between the frame and the handle where the tools are fixed (Figure 3.19b).The load type used was total force (uniformly distributed load) and magnitudes used were 200N, 400N, and 600N. The 200N force was used force for both the Stationary and Eigen frequency studies.

After the material selection and definition of the physics, mesh for the geometry was built. Free Tetrahedral mesh was selected since the geometry was complex, and the study was computed to obtain the geometry statistics and material parameter in table 4.1 and 4.2.

Table 4.1: Geometry Statistics

Description	Value
Space Dimension	3
Number of Domains	27
Number of Boundaries	181
Number of Edges	308
Number of vertices	148
Total	**667**

Source: Appendix A

Table 4.2: Material Parameters

Name	Value	Units
Density	7850 [kg/m^3]	Kg/m^3
Young's Modulus	200e[Pa]	Pa
Poisson's Ratio	0.33	1
Total	**-**	**-**

Source: Appendix A

Von Miss Stress (N/m²) (A)

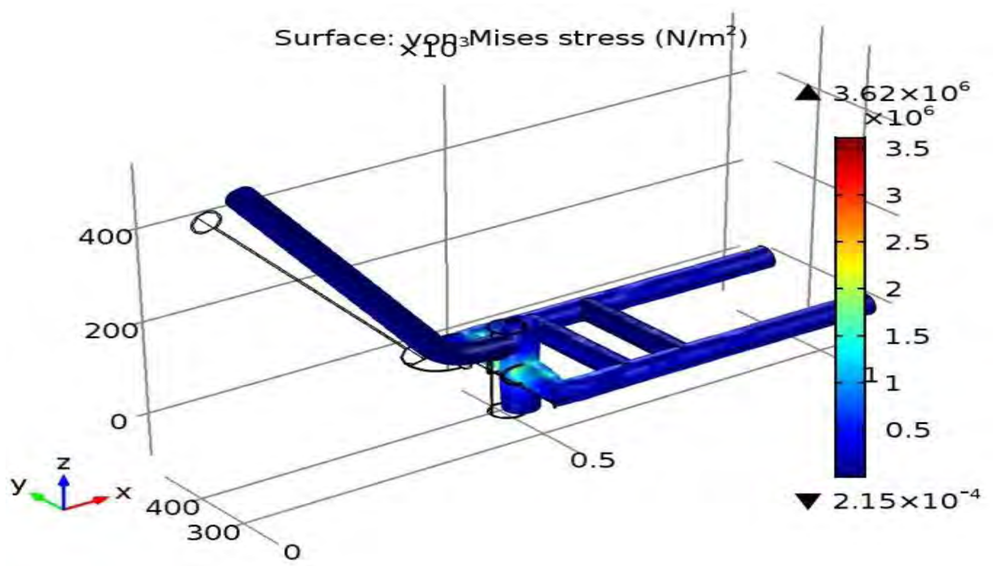


Figure 4.5: Surface Von Miss Stress (N/m²) (A, 200N)

Von Miss Stress (Nm²) (B)

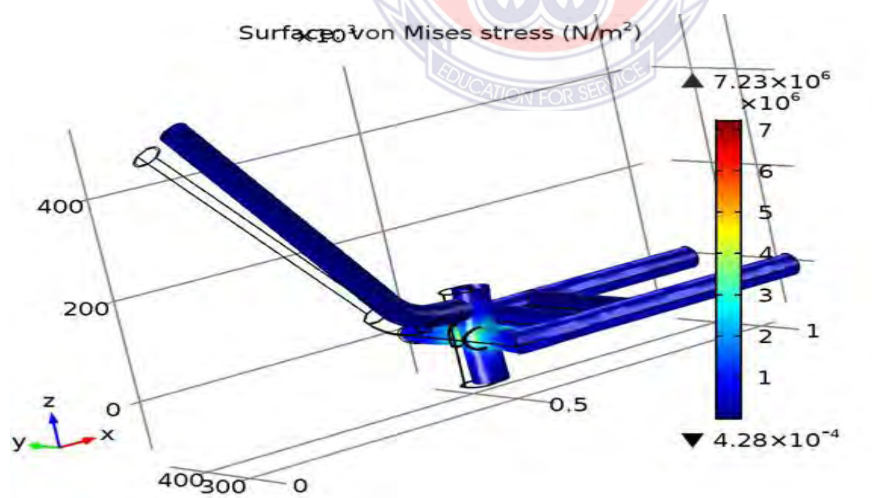


Figure 4.6: Surface Von Miss Stress (Nm²) (B, 400N)

Von Miss Stress (N/m^2) (C)

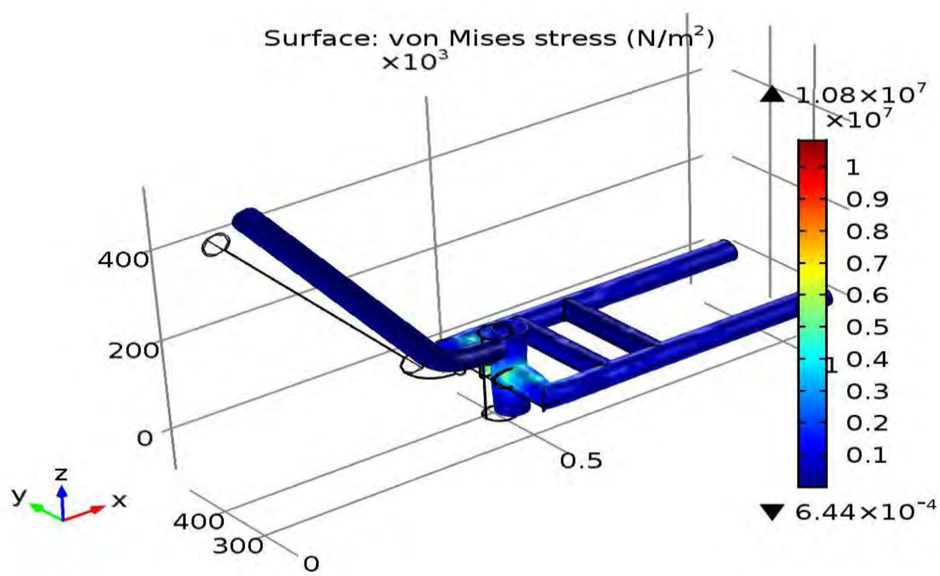


Figure 4.7: Surface Von Miss Stress (N/m^2) (C, 600N)

Stress analysis (a) 200N load (b) 400N load (c) 600N load

The results of the Eigen frequency study shows the maximum displacement 7.66 x 10^3 mm which took place at the top of the handle due to the 200N force. The location of the maximum displacement is indicated by the red colour. The gradual change of the colour from red to yellow and finally to deep blue indicates the reduction of the effect of the force up to areas where there is virtually no effect (Figure 5).

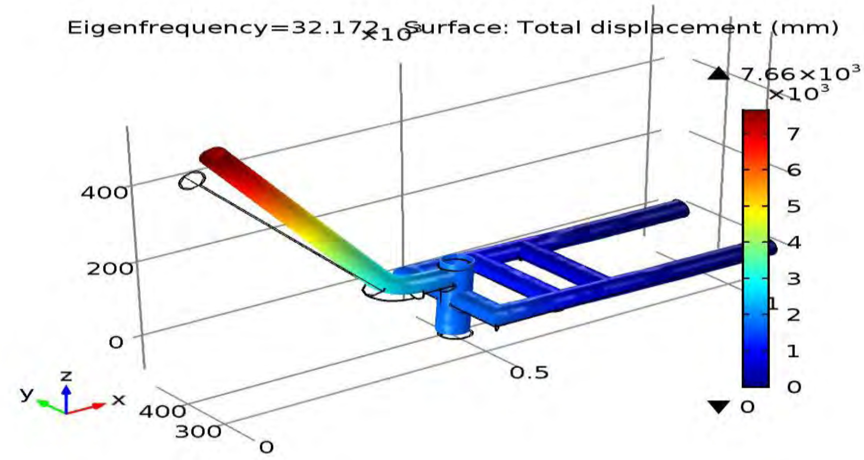


Figure 4.8: Eigen frequency (2.172) and Total displacement for 200N force applied.

Study 1/Solution

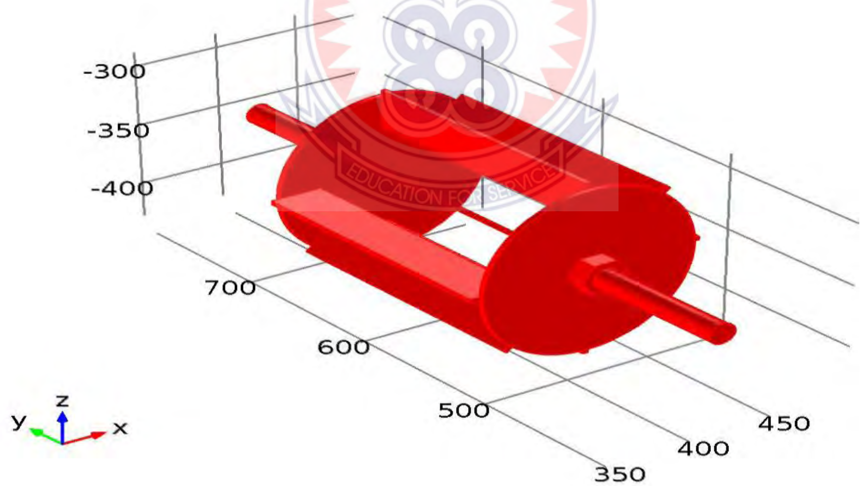


Figure 4.9: Data set: Study 1

Von Mises stress (N/m^2)

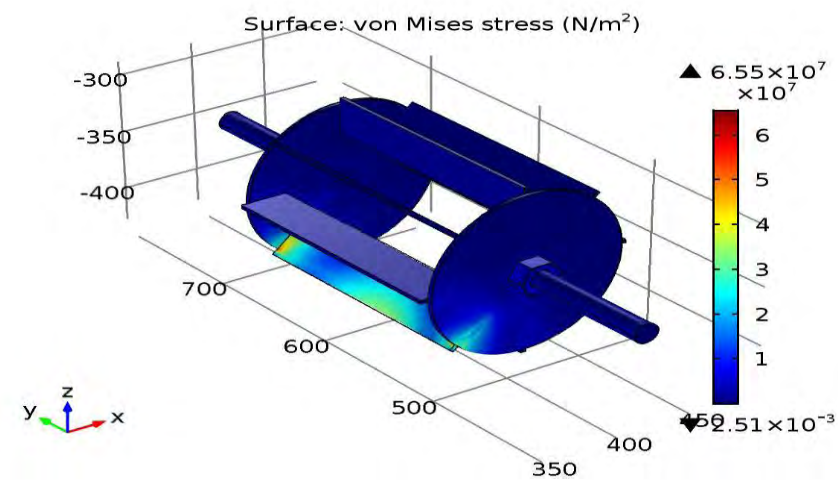


Figure 4.10: Surface: Von Mises Stress (N/m^2) Solution

Table 4.3: Geometry Description

Description	Value
Solution	Solution 1
Component	Save Point Geometry 1

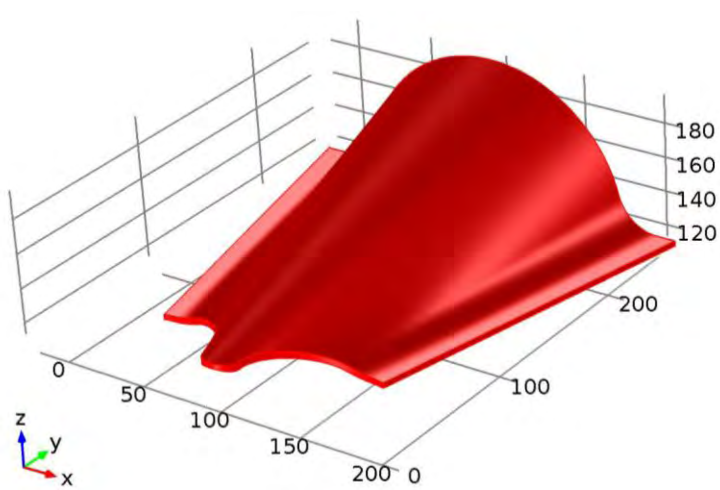


Figure 4.11: Data set: Study 1

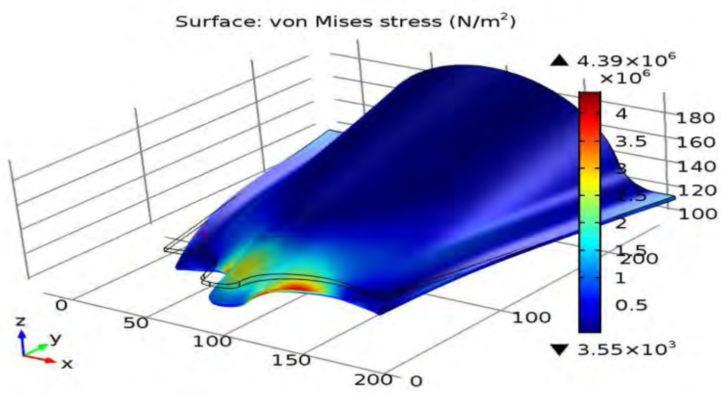


Figure 4.12: Surface Von Mises Stress

4.3 Experimental Results and analysis of Tensile Test Experiment on the Cultivator

The Universal Testing Machine was used to determine the strength of the shaft and the frame as there would be a lot of forces that will be acting on it during the operation of the cultivator. The 10KN capacity testing machine was used. While the lower cross head is fixed, the upper cross head is movable and is fitted with the transducer type 'load cell'. The data that was deduced from the tensile test experiment was analyzed as;

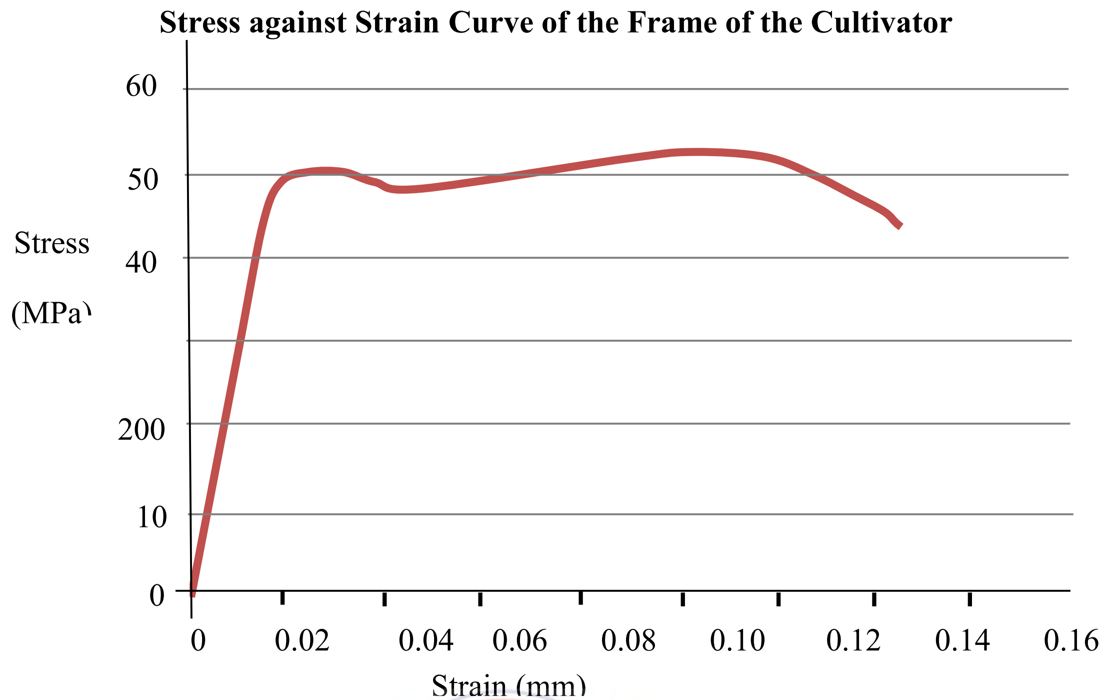


Figure 4.13: Results of Stress against Strain of the Frame of the Cultivator

Figure 4.13 shows experimental results of the stress against strain, there was a steady increases in engineering stress from zero to 450MPa linearly with a correlation increase in strain to 0.02mm indicates that its elastic region and proportional limit. At a stress of 480MPa was the elastic and yield point of the member, at 460MPa was the lower yield pint with a corresponding strain of 0.05mm. The plastic region of the member starts from the yield point to point of fracture at 450MPa with a corresponding strain of 0.15mm; therefore strain hardness was within this range. The breaking point of the curve was at a strain of 480MPa to a corresponding strain of 0.12mm. Therefore the member consists of a material with malleable and brittle property that makes it fit at tolerant range from 0 to 0.15 strains at a stress of 480MPa. Beyond which it will fail.

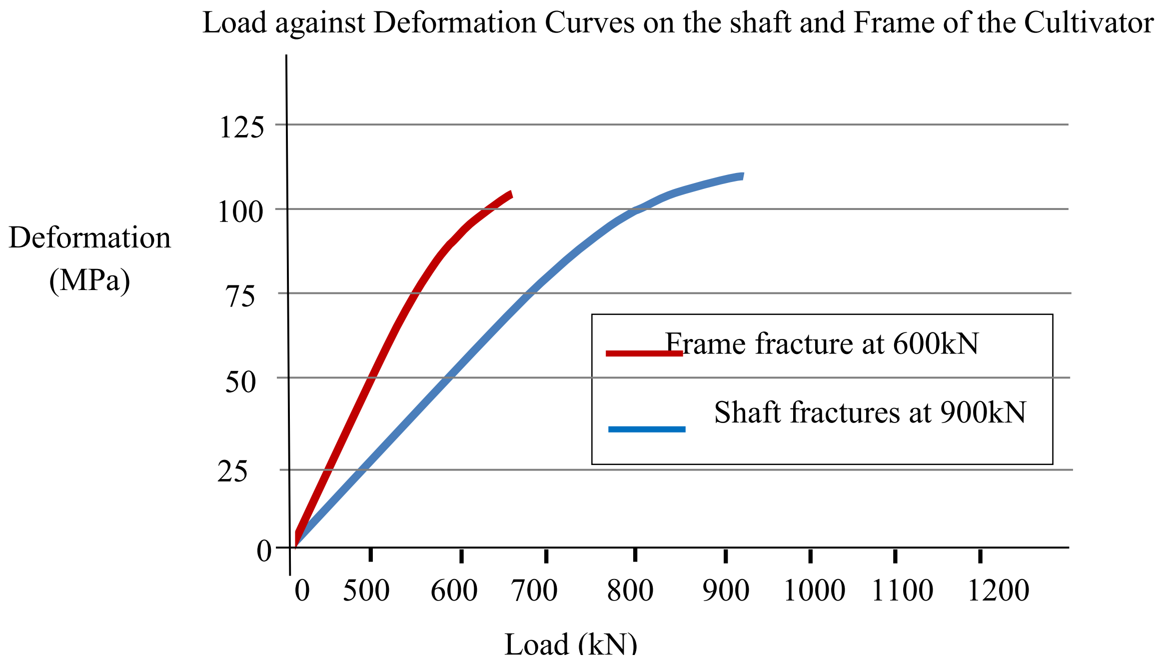


Figure 4.14: Results of Load against Deformation on the shaft and Frame of the Cultivator

Figure 4.14 shows experimental results of the Deformation against load on the shaft shown in blue curve, there was a steady increases in engineering stress from zero to about 90MPa linearly with a correlation increase in strain of load to about 700kN,indicates that its elastic region was700kN plastic region of 200kN (900-700kN) therefore strain hardness Within this range the load effect on the shaft was still in its elastic region until 700kN that the shaft reaches its maximum deformation at 120MPa which gets to its ultimate stress, the member fails (Fracture occurs) at a load of 900kN. This indicates that the shaft will be able to with stand forces up to 900kN. Therefore material is malleable and ductile which has fracture strength of 900kN with a corresponding 120MPa. The dark red curve shows deformation against load on the frame was obtained from the experimental results, loading was done from 0 up to 78MPa with a corresponding load of 650kN where the frame reached its yield stress, therefore its maximum load beyond which deformation starts to its ultimate stress at that point. The elastic region for this kind of loading was 0 to 550kN with a corresponding deformation of 78MPa and at a load of 650kN the member fails (Fracture occurred). Therefore material is ductile which will be able to withstand forces that will act on it during operation.

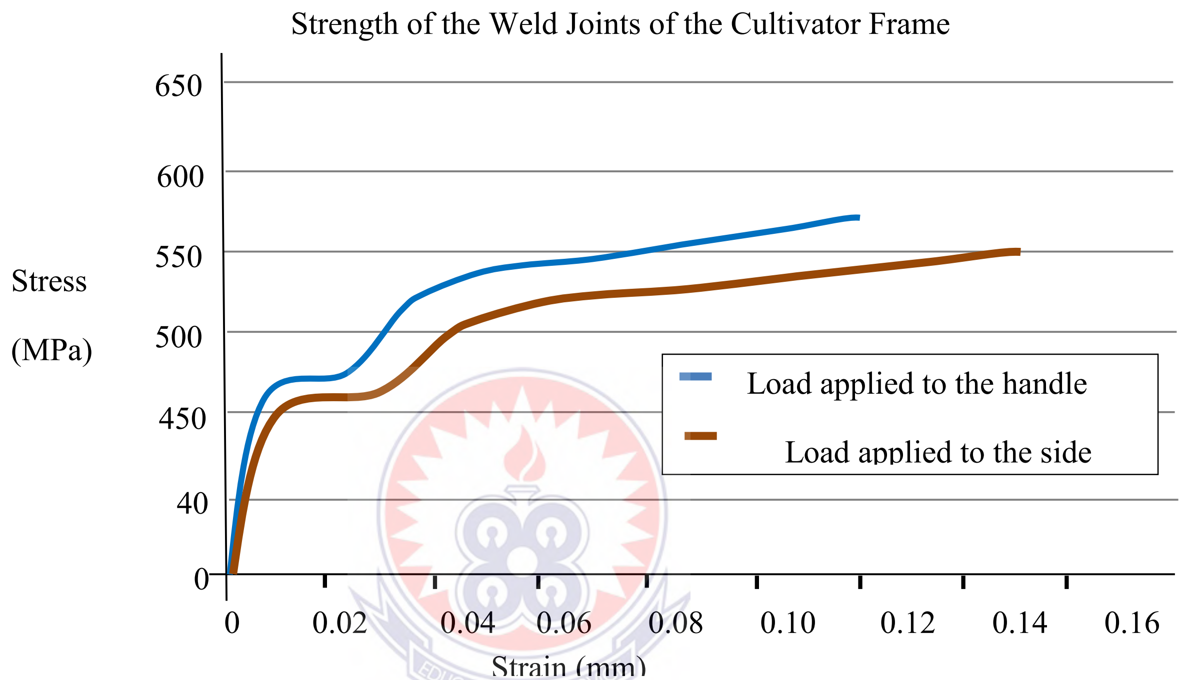


Figure 4.15: Results on the Strength of the Weld Joints of the Cultivator Frame

Figure 4.15 shows experimental results of the stress against strain of the frame. The force applied to the handle with the other end fixed produces the curve in blue, there was a steady increases in engineering stress from zero to 470MPa linearly with a correlation increase in strain to 0.01mm indicates that its elastic region and proportional limit, which offsets at that point making its maximum yield point and lower yield point at a stress of 465MPa, the curve increased and fractures at 570MPa with a corresponding strain 0.12mm stretch. The force applied to the side member of the frame with the other end fixed produces the curve in brown, there was a steady increases in engineering stress from zero to 460MPa linearly with a correlation increase in strain to 0.01mm indicates that its elastic region and proportional limit, which offsets at that point making its maximum yield point and lower yield point at a stress of 460MPa, the curve increased and fractures at 550MPa with a corresponding strain 0.15mm stretch which stretches 0.3 longer than the force applied at the handle it is as a result of the support bar.

4.4 Soil Properties on the Experimental Bed where the Cultivator would be Tested

The performance of the cultivator immensely depends on the moisture content of the experimental cite, soil physical characteristics such as bulk density, soil texture were briefly looked at, as well, the results of the field experiments conducted during the study are presented and discussed. In this chapter, the results of the field performance of the cultivator would be presented and salient features discussed.

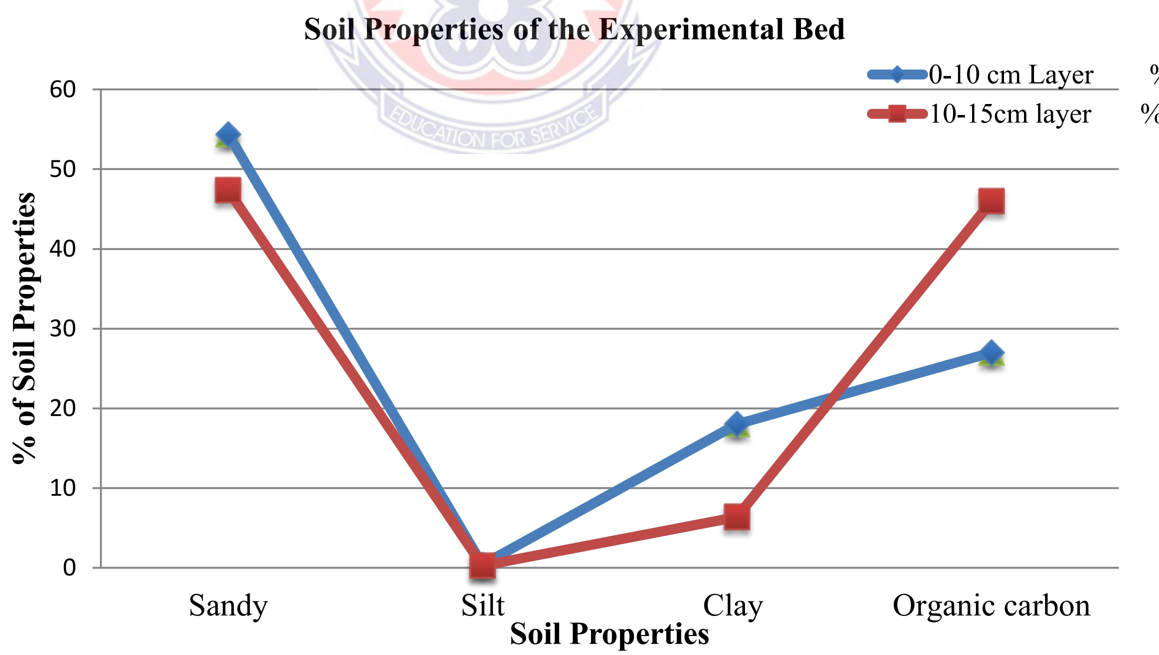


Figure 4.16: Percentage of Soil Properties on the Experimental Bed

4.4.1 Properties of the Soil

The experimental site soil composed of sandy soil 54.40%, organic matter 27.00%, clay 18% and silt 00.36% at a depth of 00-10cm on the sample and at a layer of 10-15cm sandy 47.37%, silt 46.00% clay 06.36% and organic matter content of 00.27% of the sample. Therefore the soils in the experimental site are sandy loamy soil.

4.5 Land Preparation

The plants on the field was cleared with non-selective herbicides, Glyphader 480, containing 360 g/l Glyphosate at the rate of 2,055ml ha^{-1} and was ploughed and harrowed. Mark out of the plot was done into crop beds as displayed in figure 3.2-5.3

Where;

A is inter-crop spacing = 20cm = 0.2m

B is row spacing = 270cm = 2.7m

C is length of row = 220cm = 2.2m

D is width of the rows = 100cm = 1.0m

B_L is the length of bed = 240cm = 2.4m

B_W width of bed = 120cm = 1.2m

Area occupied by crops = 22000cm^2 = 220m^2

Area of the bed = 28800cm^2 = 288m^2

4.6 Moisture Content (MC)

An Oven Method of testing moisture content of the soil was employed as the test was carried out to analyze the soil samples taken during the performance test to determine the soil moisture content of the test area.

Four soil samples were taken at random locations in each bed at a depth of 0-15 cm soil layers with a soil core sampler 15 cm long and 2 cm in diameter before ploughing. The samples were oven–dried at 105°C for 24 hours to determine the soil moisture content gravimetrically.

It was deduced that the ideal moisture content of sandy loamy soil that was suitable for the cultivator was 11.3 and 12.4kg that was water content of 0.3 and 0.4kg respectively, bellow this the soil becomes muddy and sticks to the weeding units thereby demands more power, and above that soil becomes hard and difficult to work with and equally needs more power.

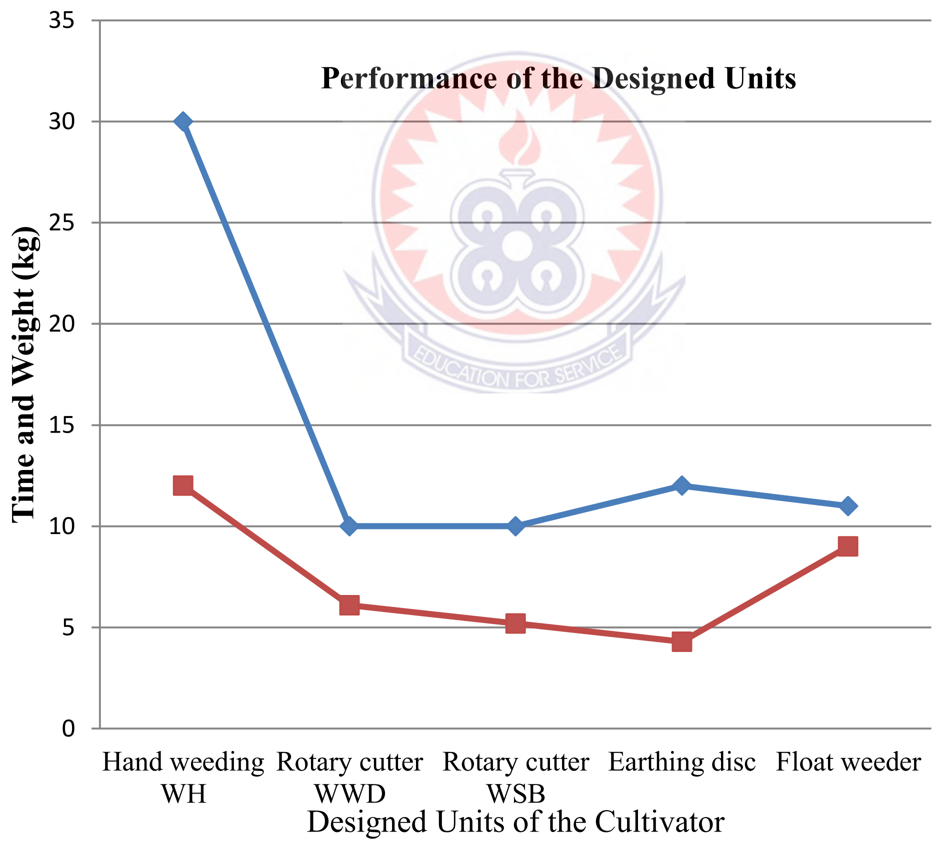


Figure 4.17: Comparative Performances of the Cultivators Units Against Time Taken and Weight of WDM.

4.7 Performance of the Designed Weeding Units against Time and Weight

The first experimental test of the cultivator, bed B1 as the control was weeded with hand hoe and B2-B5 was weeded with rotary cutter with worm design, rotary cutter with strip blades, earthing disc and float weeder respectively. The control bed B1 time taken was 30minutes as it involves a lot of human drudgery, Rotary cutter WWD took 10minutes, Rotary cutter WSB took 10minutes, Earthing disc took 11minutes and Float weeder took 10minutes. The disc took the second highest time due to the soil resistance as the disc have to cut and turn a thin layer to cover some weeds around the crop.

Figure 4.17 indicates the amount of weeds that was weeded out during the first test. The control bed B1 was weighted 12kg as it involves human intervention where the weeds and crops are carefully taken care of, the rotary cutter WWD had 6.1kg, rotary cutter WSB had 5.2kg, Earthing disc had 4.3kg and Float weeder had 11.0kg. The earthing disc was weighted the least due to working action as it throws a lamp of soil on some weeds which was not retrieved.

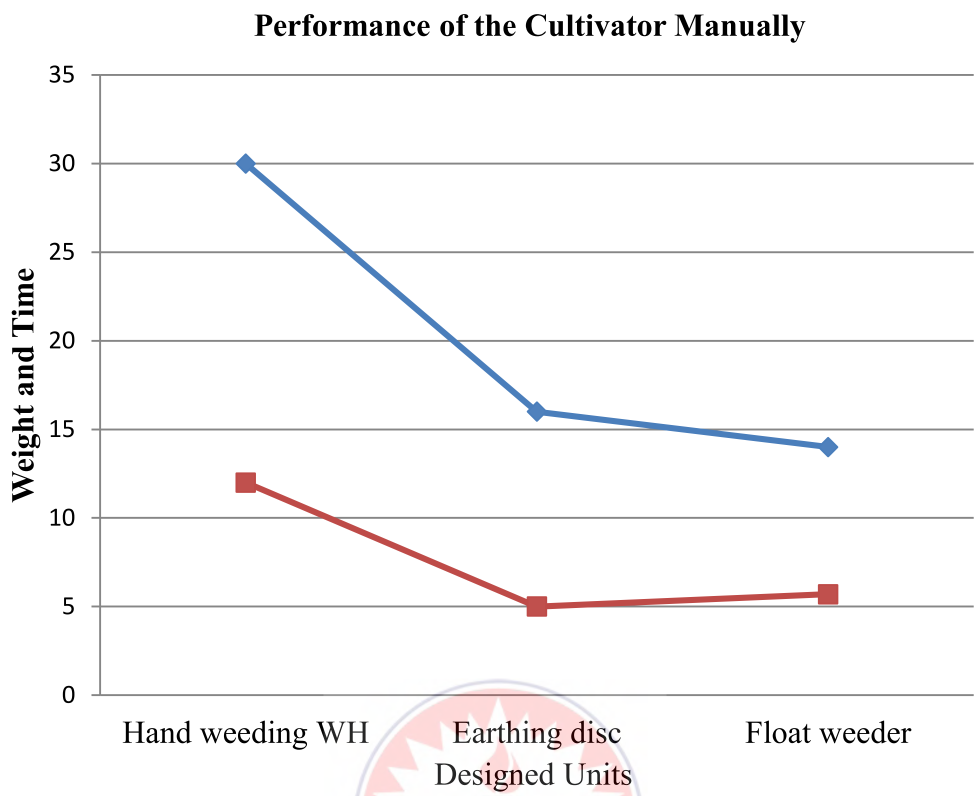


Figure 4.18: Comparative Performance of the Cultivator Manually in 14 Days After Germination (1^{ST} W)

4.8 The Weeding Units against Weight (kg) and Time in Minutes in Manual Operation

The control bed B1 time taken was 30minutes as it involves a lot of human drudgery, Earthing disc took 16 minutes and Float weeder took 14minutes. This indicates that during manual operation of the cultivator takes much time as compared to the electrical aided. The disc took the second highest time due to human drudgery as the soil resistance on the disc was greater than the float weeder as it only stirs a thin layer of the top soil.

4.9 Weeding Units against the Weight of the Dry Matter Content of Weeds

Figure 4.18 also indicates the amount of weeds that was weeded out after the manual test during the first weeding. The control bed B1 was weighted 3kg as it involves direct human intervention where the weeds and crops are carefully taken care of, Earthing disc had 1.0kg and Float weeder had 1.3kg. The earthing disc was weighted the least due to working action as it throws a lamp of soil on some weeds which was not retrieved while the float weeder scratches to uproot weed seedlings.

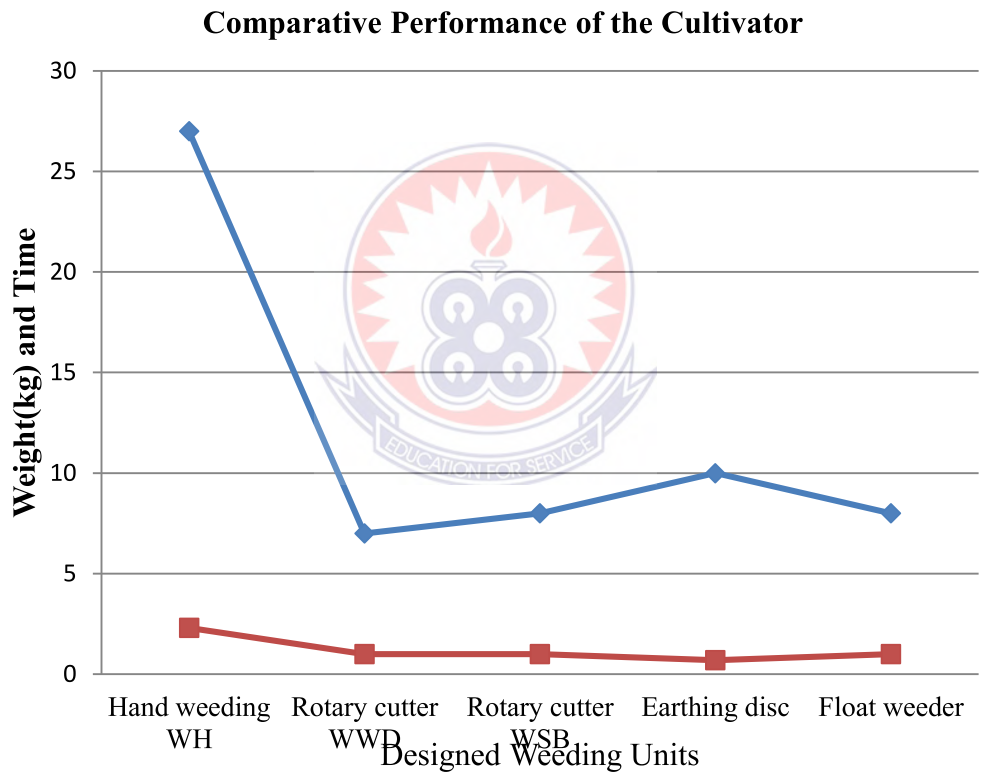


Figure 4.19: Comparative Performance of the Cultivator's Units in 28 Days after Germination (2nd W)

In Figure 4.19 indicates the performance of the Units of the Cultivator used after 28 Days of Germination (2nd W), The time taken to control weeds on B1 was 27minutes, Rotary cutter WWD took 07minutes, Rotary cutter WSB took 08minutes, Earthing disc took 10 minutes and Float weeder took 08minutes. The control took more time than all the four units of attachments. This shows that the proposed designs are faster in weed control than the traditional way of using hoes. The disc took the second highest time due to the soil resistance as the disc have to cut and turn a thin layer to cover some weeds around the crop. The Rotary cutter WWD, Rotary cutter WSB and Float weeder was apire in terms of time. It also pointed that the dry matter content of the weed obtained after the second weeding has it that the control bed B1 was weighted 2.3kg as it involves human intervention where the weeds and crops are carefully taken care of, the rotary cutter WWD had 1.0kg, rotary cutter WSB had 1.0kg, Earthing disc had 0.7kg and Float weeder had 1.0kg. The earthing disc was weighted the least due to working action as it throws a lamp of soil on some weeds which was not retrieved. Rotary cutter WWD and Float weeder were pare in terms of the amount of weeds that were removed from the experimental beds.

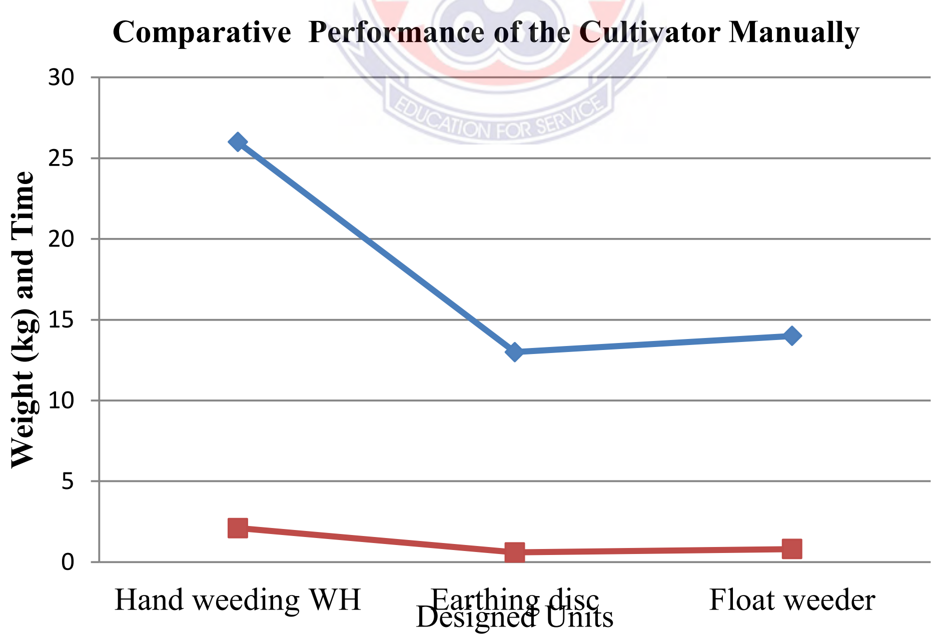


Figure 4.20: Indicates the Weight of WDM after the manual test during the third weeding

The control bed B1 was weighted 2.1kg as it involves direct human intervention where the weeds and crops are carefully taken care of, Earthing disc had 0.6kg and Float weeder had 0.8kg. The earthing disc was weighted the least due to working action as it throws a lamp of soil on some weeds which was not retrieved while the float weeder scratches to uproot weed seedlings and The time used for the control bed B1 was 26minutes as it involves a lot of human drudgery, Earthing disc took 13minutes and Float weeder took 14minutes. This indicates that during manual operation of the cultivator takes much time as compared to the electrical aided. The disc took the second highest time due to human drudgery as the soil resistance on the disc was greater than the float weeder as it only stirs a thin layer of the top soil.

4.10 Performance Evaluation

The performance evaluation of the fabricated the mechanical weeder was tested to determine the weeding index, weeding efficiency and field capacity. Figure 4.9 was obtained from the experimental test of the cultivator after the first weeding.

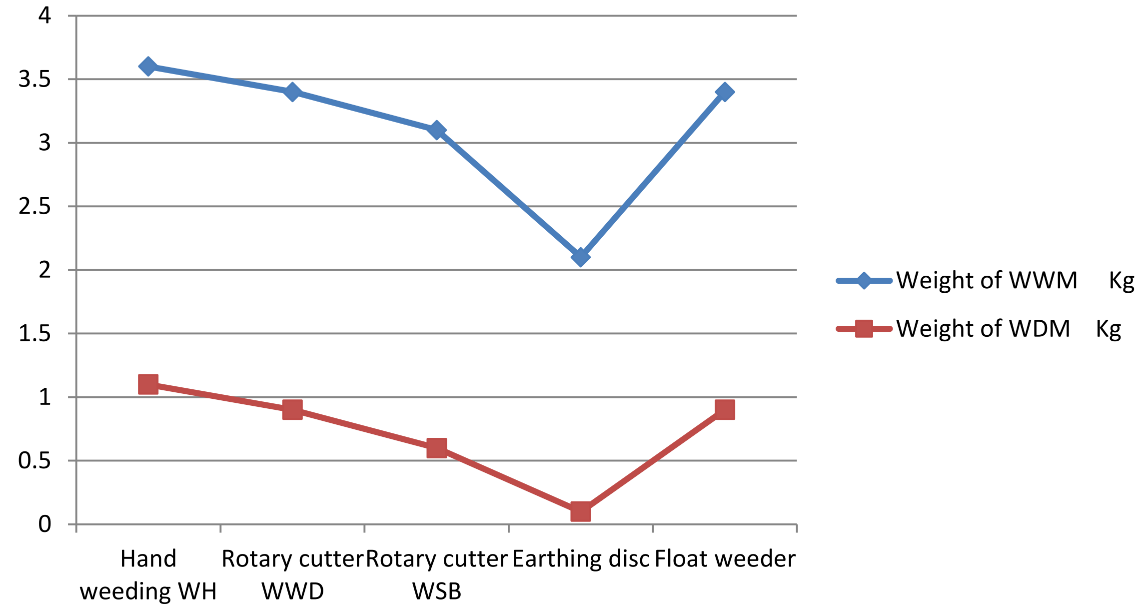


Figure 4.21: Weight of WWM and Weight of WDM in 14 Days after Germination (1^{ST} W)

Figure 4.21 indicates the Weight of WWM and Weight of WDM recorded in the first weeding 14 days after germination. The control bed B1 was weighted 3.5kg as it involves direct human intervention where the weeds and crops are carefully taken care of, Earthing disc had 2.1kg and Float weeder had 3.5kg for Weight of WWM and for Weight of WDM, the control bed B1 was weighted 0.9kg as it involves direct human intervention where the weeds and crops are carefully taken care of, Earthing disc had 0.6kg and Float weeder had 1.0kg for Weight of WDM. The earthing disc was weighted the least due to working action as it throws a lamps of soil on some weeds which was not retrieved while the float weeder scratches to uproot weed seedlings.

4.11 Weeding Index of the Cultivator with the it Attachment

Weeding index is a ratio between the number of weeds removed by a weeder and the number present in a unit area and is expressed as a percentage. The time taken to perform this operation was noted in table 3.4 and was used to calculate weeding index.

Weeding index, I_w was 0.79kg as stated in (3.35) and when the machine was in manual operation with earthing disc and the float weeder, the Weeding index, I_w was 0.73kg

4.12 Weeding Efficiency (ε)of the Cultivator

The weeding efficiency was determined by using equation (3.35) arrive at 795 and 73% efficiency when operated electrically aided and manually respectively.

Field capacity is the amount of area that a weeder can cover per unit time as shown in the expression(3.36), From Table 3 Units of the Cultivator used in 14 Days after Germination (1^{ST} W), the total time was recorded to be 72 minutes was noted to be 7.28 Field capacity.

4.13 Wheel Slippage Measurement

The rear wheel slippage was determined in the expression (3.37) where the wheel slippage was 14.47% this mean in every 100 meters covered during operation of the cultivator when loaded, the wheel will slip 14.47 times which affects performance and therefore there is the need for wheel that can perform better.

4.14 Field Efficiency Measurement

The theoretical or effective field capacity (TFC) was determined to be 24m/h using the expression (3.38) and field efficiency (FE) was 0.54% using expression, (3.40).

4.15 Plant Damage

Plant damage was calculated by counting the number of injured plants in sample plot and total number of plants in sample plot .The plant damage was determined by using expression, (3.41) to arrive at 89.95% as the percentage of weeds that will be damaged therefore the machine proves to be effective in weed management.

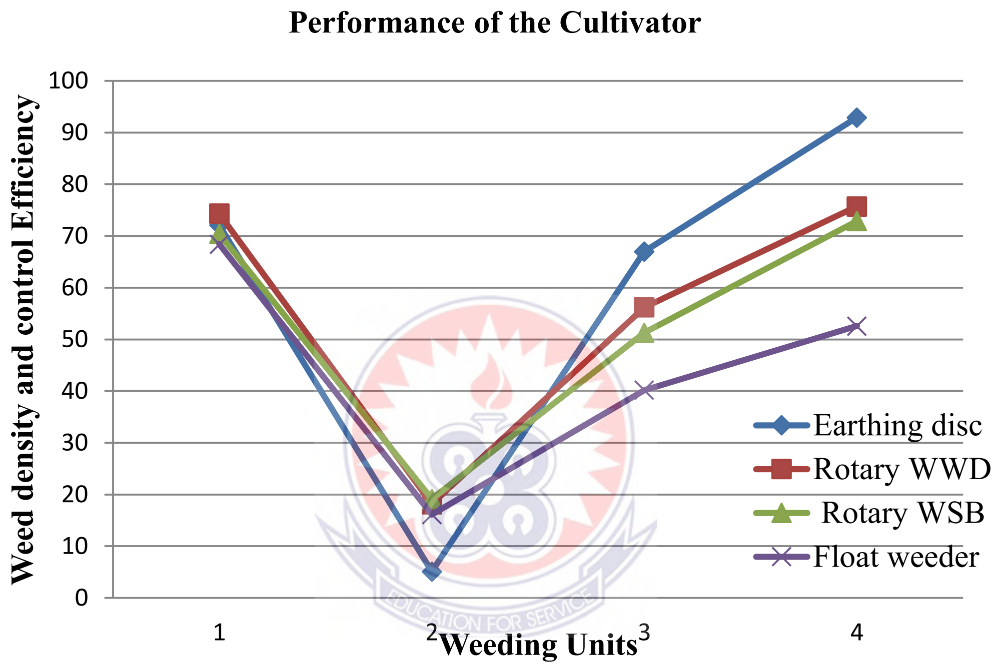


Figure 4.22: General Performances of the Cultivator Units of Attachment

The initial weed densities of the beds were 285.28 was reduced to a density of 58.47so total amount of weed density taken out was 214.71 resulting in weed control efficiency of 294.1. The involvement of man power was also examined with respect to different weeding tools used in controlling the weeds within crops and it was noted that Earthing disc consumed the maximum man hours (36.2) followed by Worm Rotary cutter (28.3), rotary cutter with Strip blades (13.56) and Floatweeder (10.67) but generally the man power needed in the operation of each unit of the cultivator in far less than the use of the hand.

The field efficiency was found maximum for Earthing disc (84.18%) followed by Worm Rotary cutter (81.02%) Strip blades rotary cutter (76.47%) and Float weeder (77.26%). The higher field efficiency of the unit was because of the minimum time loss such as turning time and other time during operation.

4.16 Field Efficiency with Different Weeding Units

The Field capacity of Strip blades rotary cutter was found to be 0.008 b/hr followed by Worm Rotary cutter (0.004b/hr), Earthing disc (0.001 b/hr) and Float weeder (0.0002 b/hr), respectively. The wide difference in field capacity of different implements is because of the width of soil cutting parts i.e. blade of the implement as well as forward speed. Float weeder facilitates the worker to provide easy push and pull action to the implement as compare to the Worm Rotary cutter. The operation of Earthing disc is usually done in quite slow, which accounts the minimum field capacity.

The human energy requirement in different weeding tools operation is also shown in Table 3. The highest human energy was consumed by Earthing disc (567.62 MJ/b) followed by Float weeder (326.62 MJ/b) when the cultivator in operated manual.

The weeding units were not only proved efficient but also useful in completing the weeding in lesser time. It was concluded that human energy can be saved by adopting energy efficient weeding tool like the cultivator.

CHAPTER FIVE

SUMMARY OF FINDING CONCLUTIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents summary of finding, conclusions and recommendations of the study. The study sought to design a multipurpose cultivator that can be operated manually and power aided. The specific objectives of the study were to:

1. To redesign a multi-purpose cultivator with new design parameters
2. To manufacture the multi-purpose cultivator
3. To perform comparative test analysis of the new design and existing design.
4. To test the cultivator's units of attachments for performance.

5.2 Summary of Findings

The following findings have been arrived at to during the research work:

1. The tensile test experiment and the stimulation results indicates that the selection of materials for the manufacture of the cultivator was appropriate except in the cases of the earthing disc and the strip blades where the thickness of plates used are to be replaced to thicker ones to prevent bending during its performance.
2. The proposed designs were realized with galvanized steel with the reason been that the machine parts are to interact with moist medium (soil) which will facilitate rusting. With the use of hollow pipes for the frame has contributed to the reduction in weight of the machine making it user friendly.
3. The hardness of the area to be weeded plays a major in the performance of the cultivator in view of this moisture content of the beds were determined experimental

using the oven dry method which indicates that the cultivator with the proposed weeding units functions efficiently at a moisture content ranging from 0.3 to 0.7, bellow or above makes the land will be too hard to work on and too watery which makes the soil sticks to the weeding tools respectively.

4. The involvement of man power was also examined with respect to different weeding tools used in controlling the weeds within crops and it was noted that Earthing disc consumed the maximum man hours (36.2) followed by Worm Rotary cutter (28.3), rotary cutter with Strip blades (13.56) and Float weeder (10.67) but generally the man power needed in the operation of each unit of the cultivator in far less than the use of the hand.
5. The field efficiency was found maximum for Earthing disc (84.18%) followed by Worm Rotary cutter (81.02%) Strip blades rotary cutter (76.47%) and Float weeder (77.26%). The higher field efficiency of the unit was because of the minimum time loss such as turning time and other time during operation. Generally the efficiency (ε) of the machine was 79% and 73% for both power aided and manual operation respectively.
6. The Field capacity of Strip blades rotary cutter was found to be 0.008 b/hr followed by Worm Rotary cutter (0.004b/hr), Earthing disc (0.001 b/hr) and Float weeder (0.0002 b/hr).

The proposed units of attachments were not only proved efficient but also useful in completing the task in lesser time. It was concluded that human energy can be saved by adopting energy efficient weeding tool like the cultivator.

5.3 Conclusion

The following are the conclusions of the research on the various experimental test carried out on the new designed machine.

The curves of the tensile stress and stress show that the material used contains high carbon and manganese, which determined strength and hardness of the steel. The experimental results of the deformation against load on the shaft indicates a steady increases in engineering stress from zero to about 90MPa linearly with a correlation increase in strain of load to approximately 700kN, indicates that its elastic region was700kN plastic region of 200kN (900-700kN) therefore strain hardness Within this range the load effect on the shaft was still in its elastic region until 700kN that the shaft reaches its maximum deformation at 120MPa which gets to its ultimate stress, the member fails (Fracture occurs) at a load of 900kN. This indicates that the shaft will be able to with stand forces up to 900kN. Therefore material is malleable and ductile which has fracture strength of 900kN with a corresponding 120MPa.

The curve shows deformation against load on the frame was obtained from the experimental results, loading was done from 0 up to 78MPa with a corresponding load of 650kN where the frame reached its yield stress, therefore its maximum load beyond which deformation starts to its ultimate stress at that point. The elastic region for this kind of loading was 0 to 550kN with a corresponding deformation of 78MPa and at a load of 650kN the member fails.

The weldment on the frame fractured at fractures at 550MPa with a corresponding strain 0.15mm stretch which stretches 0.3 longer. The fractured surfaces show ductile failure. These clearly indicate that the machine fabricated with the material it is tested with would be able to overcome soil resistance of a tilled land during it operation.

Generally, the analysis of the performance of the units reveals that the use of the new design and manufactured cultivator places each of the units tested to be technically feasible and even offer some advantages in terms of performance quality on the soil than the use of the traditional equipment and methods of weeding as a crop cultural practice. However, all the units have accomplished the aim of the research work.

The two rotary cutters was very sensitive to speed variation, but has a promising work action as it cuts the target into pieces which was not gathered during it collection and the tendency of its survival is low. The earthing disc performed better than the rotary weeder due to it weeding action but takes a little more time than the rotary due to soil resistance. The float weeder does well at the tender age of the weed but performs poorly when they are grown.

5.4 Recommendations

The experiment data gathered were on tensile test on the machine, more test such as impact test is necessary to be certain on the forces of the machine can resist. Also performance test data was limited to one soil type (Sandy loam). Additional research is necessary for different soil types and environments. The results would be more meaningful if performance on the machine at the experimental cite was compared to different places and soil samples.

Furthermore recommendations made for efficient and effective weeding mechanisms:

(1) The recommended weeding units of the cultivator should be designed to take more than one row at a time especially plantation which are not kept on ridges.

(2) Thick metal plates should be used for the blades to enable work on every farm soil which will withstand stone in the soil.

(3) Speed reduction system should be incorporated into the design to enable the entire weeding units function manual that will meet the demand of cost reduction.

This research work will help people to understand the relevance of mechanized weeding, which is not a huge time consuming and significantly improves weeding efficiency as well as the quality of weeding.

REFERENCES

Adekoye L. O. (1999). *Human factors in engineering design consciousness, knowledge and skills.* Nigeria. Conference paper presented at first national engineering conference held in Sheraton hotels and tower.

Agarwal, J.P. & Singh, O.P. (1968). *All about Weeds, Agricultural Engineering Today*. UK. Press House.

Agarwal, K.N., Tiwari, P.S., Gite, L.P. & Bhushanababu, V. (2010). Isometric push/pull strength of agricultural workers. India: *The CIGR E-journal Manuscript 1342, 12*(1).

Agarwal, K.N., Tiwari, P.S., Pharade, S., Majumdar, J. & Bhushanababu, V. (2011). Anthropometry of Agricultural Workers. Madhya Pradesh. *Journal of Agricultural Engineering, 48*(4): 1-9.

Allender, W.J. (1991). *Movement of Environmental Contamination and Toxicology*. UK. Free Press.

Anonymous, (1985). *RNAM Test Codes and Procedure for Farm Machinery*, Technical series No. New York. Quorum Pb.

Ascard, J. (1998). Comparison of flaming and infrared radiation techniques for thermal weed control. Sweden. *Weed Research 38,* 69–76.

Ascard, J. (1994). Asia, Dose–response models for flame weeding in relation to plant size and density, Publisehed by Weed Research Institute 34, 377–385.

Ascard, J. (1995a). Effects of flame weeding on weed speciesat different developmental stages. Swedish. *Weed Research 35,* 397–411.

Ascard, J. (1995b). *Thermal weed control by flaming: Biological and Technical Aspects.* PhD thesis. Department of Agricultural Engineering, Swedish University of Agricultural Sciences. Alnarp, Sweden, Report 200.

Ascard, J. (1997). Flame weeding: effects of fuel pressure and tandem burners. Sweden. *Weed Research 37,* 77–86.

Augustin, B., Fischer, E. & Seibel, H. (2001). *Possibilities of weed control in urban areas*, OT: Mo Mlichkeiten der.

Balachand, C.H. (2006). Design, development and Evaluation of Animal Drawn Weeder Suitable for non-descript bullock of C.G. region, India. Gandhi Krishi Vishwa Vidyalaya, Raipur.

Baljil, S. (2000). *Design and constructing of pedal driven slice and chipper*. Darasalam Publication, Tanzania.

Bàrberi, P. & Mazzoncini, M. 2001.Changes in weed community composition as influenced by cover crop and management system in continuous corn. *Weed Sci. 49*: 491-499.

Bernacki, H., Haman, J. & Kanafajoki, G. (1972). Agricultural Machines-Theory.

Bervldl (2000). *Non-chemical weed control in the urban landscape*. In: Proceedings California Weed Conference Vol. 41 (ed.WGraves), 15–17.California Weed Science Society, India. Fremont CA. Bhubaneswar.

Biswas, H. S., Biswas, D. S., Rajput, & Devnani, R. S. (2000). Animal- drawn weeders for weed control in India.

Biswas, H. S. (1984). Weed Control technology. Published by central institute of agriculture engineering Nabi, Bagh Barasia Road India, 17 – 33.

Biswas, H.S. (1980). *Weeding tools and implements of Asia*. Technical bulletin

Biswas, H.S. (1990). *Soil tool interaction for mechanical control of weeds in black soils.* Unpublished Ph.D. thesis, Indian Institute of Technology, Kharagpur.

Biswas, H.S., Ingale, G.S. & Ojha, T.P. (1991). Development of animal drawn weeder, Asia. Bhopal publish.

Biswas, H.S., Ingle, G.S. & Ojha, T.P. (1993). Performance evaluation and optimization of straight blades for shallow tillage and weeding in black soils Agricultural Mechanization in Asia Africa and Latin America. Ipp publication.

Bond, W. & Grundy, A.C. (2001). Non-chemical weed management in organic farming systems. UK. *Weed Research 41*, 383–405.

Brian, G.S. (2000). *Elements of design and evaluation of animal-drawn weeders*. Agricultural and Rural Cooperation (CTA), UK, Wageningen ISBN 92-9081-136-6.

Chatizwa, I., (1997). *Mechanical Weed Control:* The Case of Hand Weeders. In: Brighton Crop Protection Conference – Weeds. British. Crop Protection Council, Brighton. 203–208.

Cloutier, D.C.R.Y.V.D., Weide, A., Peruzzi, & Leblanc, M. L. (2007). Mechanical Weed Management in non- Chemical Weed Management, principles, concepts and technology. Upadhyaya M.K and R.E Blackshaw, Edition 111-134. Construction, Vol.1. Washington D.C. National Science Foundation.

Datta, S.K., Aragon, K.L. & Mlabugoe, J.A. (1974). Varietal difference in cultural practices for upland rice. Seminar Proceeding In. Rice breeding andvarietal environment. *West Africa Rice Development Association, Manorovia Bilaria*: 35-73.

Department of Agricultural Engineering, Swedish. University of Agricultural Sciences. Published by Alnarp, Sweden. Report 171.

Deshmukh, G. & Tiwari, R. K. (2011). Impact of weeders for weed management in system of rice intensification (SRI). *Indian Journal of Weed Science*. Dal publications.

Dryden, R.D. & Krishnamurthy, C.H. (1977). Year round tillage, *Indian Journal of Weed*.

Gite, L.P. & Yadav, B.G. (1985). *Ergonomic consideration in the design of mechanical weeders.* Proceedings on Design Course of Agricultural Machines. Central Institute of Agricultural Engineering, Bhopal.

Gite, L.P. & Yadav, B.G. (1989). Anthropometric survey for agricultural machinery design. *Applied Ergonomics, Asia, Publ. 20*(3), 191-196.

Gite, L.P. & Yadav, B.G. (1990). Optimum handle height for a push pull type manually operated dryland weeder, *Ergonomics, 33.*

Gite, L.P. & Yadav. B.G. (1985). *Ergonomic consideration in the design of mechanical weeders.* Proceedings on Design Course of Agricultural machines, CIAE, Bhopal.

Grandjean, E. (1988). *Fitting the Task to the man*. Taylor and Francis, London.

Gupta, C.P. (1981). *Report on weeders.* Regional Network for Agricultural Machinery, Manila.

Hansen, P.K., Kristoffersen, P. & Kristensen, K. (2004). Strategies for non-chemical weed control on public paved areas in Denmark. *Pest Management Science 60*, 600–604.

Hansson, D. & Ascard, J. (2002). Influence of developmental stage and time of assessment on hot water weed control. *Weed Research 42,* 307–316.

Hansson, D. & Mattsson, J.E. (2003). Effect of air temperature, rain and drought on hot water weed control. Weed Research 43, 245–251. in the paddy field. India. Industry News 26, 44. *International Journal of Agronomy and Plant Production, 4*(5):1060-

Jasesn & Vellema (2011). Principle of design for a small engine powered oil extractor for local manufacturer and post-harvest institute for perishables. Moscow, Published by yipog.

Javadi & Hajiahamad, (2006) Effect of a New Combined Implement for Reducing Secondary Tillage Operation. *International Journal of Agriculture & Biology. 8*(6). 724-727.

Jordan, N.R., Zhang, J. & Huerd, S. (2000). Arbuscular-mychorrhizal fungi: potential roles in weed management. *Weed Res.* 40: 397-410.

Kaul, R. N., Egbo, C.O. & Onazi (1985). *Introduction to agricultural mechanization*. London Published by Macmillan Publishers. Basingstoke pp 1

Keepner, R. A. Roy, Bainer, & Berger, E. L. (1980). Principle of Farm Machinery, (3rd ed.). Washington D.C. Published by AV Publishing Company Inc West Port, Connecticut, 117 – 121.

Khan, A.V. & Diesto, M. (1987). Push type Cono Weeder for Small Rice Farms. India. *Investigation Intelligence, 23*(3): 236-237.

Khodabakhshi, A., Kalantari, D & Mousavi, S.R. (2013). *Effects of Design Parameters of Rotary Tillers on Unevenness of the Bottom of the Furrows*. India. HuP Press.

Khurmi, R. S. & Gupta, G. K. (2005). *A text book of machine design. New Delhi. Eurasia Publication House Pvt.* Ltd. Ram Nagar.

Kumar, A.A., Haribabu, B., SrinivasRao, A. & Ch. Someswararao. (2013). Ergonomical evaluation of manually operated weeder under wetland condition. *Scientific Research and Essays, 8*(6): 249-255.

Kumar, V.J.F. & Divaker. D.R. (1992). Development and Evaluation of Weeder Simulation Testing for estimating operator fatigue. *American Journal of Agricultural Engineering, 2*(1):1-11. Machinery. ICAR Research Complex for NEH Region. Barapani, Meghalaya.

Lawson, H.M. & Topham, P.B. (1985). Competition between annual weeds and vining peas grown at a range of population densities: effects on the weeds. *Weed Res.* 25: 221-229.

Lemerle, D., Verbeek, B. & Orchard, B. (2001). Ranking the ability of wheat varieties to compete with *Loliumrigidum*. *Weed Res.* 41: 197-209.

Liebman, M. & Davis, A.S. (2000). Integration of soil, crop, and weed management in low-external-input farming systems. *Weed Res.* 40: 27-47.

Litterick, A.M., Redpath, J., Seel, W. & Leifert, C. (1999). An evaluation of weed control strategies for large-scale organic potato production in the UK.In *Proc. 1999 Brighton Conference - Weeds*, Brighton, UK. 951-956.

Mandal, K. & Singh, S. (1982). *Economics of weed control in drilled*.

Manuwa, S.I., Odubanjo, O.O., Malumi, B.O. & Olofinkua, S.G. (2009). Development and performance evaluation of row – crop mechanical weeder. *Journal of Engineering and Applied Science, 4*(4):236-239.

Mattsson, B. (1993). *Weed control by microwaves – a review.*

McCormick, E. J. & Sander, M. S. (1982). *Human factors in engineering design*. (5^{th} ed.). New York: Published by M.C Grow hill book Company.

Mohammad Reza Alizadeh., (2011). Field performance evaluation of mechanical weeders

Mohler, C.L. (1996). Ecological bases for the cultural control of annual weeds. *J. of Production Agriculture* 9: 468-474.

Murthy, G.H.K. & Gowda, M.C. (1996). *Effect of approach angle on the performance of improved blade hoe*. Departmen

Mynavathi, V.S., Prabhakaran, N.K. & Chinnusamy, C. (2009). Effect of Manually operated weeders on growth and yield of irrigated maize. *Madras Agric. J., 96* (1-6): 123-124.

Nag, P. K. & Chatterjee, S.K. (1981). Physiological reactions of female workers. USA. *Human Factors, 23,* 607–14.

Nag, P.K. & Dutta (1979). Effective of some simple agricultural weeders with reference to physiological response. *Journal of human Ergonomics.* ijus Publication, 13-21. No.CIAE/78/3, Central Institute of Agricultural Engineering publisher.

Nag, P.K., Astekar, S.P. & Pradhan, C.K. (1988). Ergonomics in sickle operation, New Delhi. *Applied Ergonomics, 19*(3): 233-239.

Parish, S. (1989). 11^{th} International Congress on Agricultural Engineering. Rotterdam Balkema edits VADodd & PM Grace), 2151–2156.

Parish, S. (1989a). Weed control – Testing the Effects of Infrared Radiation. Rotterdam. *Agricultural Engineer,* (summer), 44, 53–55.

Parish, S. (1989b). *Investigations into thermal techniques for weed control.* Rotterdam. Edits VADodd & PM.

Parish, S. (1990a). *The flame treatment of Weed Seedlings Under Controlled Conditions.* UK, In: Proceedings of a symposium organised by the British Crop Protection Council. (URoger), 45,193–196. Cambridge.

Parish, S. (1990b). A Review of Non-Chemical Weed Control Techniques. *Biological Agriculture and Horticulture 7,* 117–137.

Pawar, C. S. (2003). Design and development of a self-propelled power weeder with rotary blades and linear tool attachment for weeding in row seeded rice. Asia, pur publication.

Perron, F., Legere, A., Tremblay, G., Simard, R.R., Angers, D.A. & Hamel, C. (2001). Crop and weed response to nutrient source, tillage and weed control method in corn-soybean rotation. *Canadian Journal of Plant Science. Philippines.* Published by Manila, Philippines.

Ramamoorthy, K. & Balasubramaniam, A. (1991). Integrated weed control method for upland direct seeded rice. *Madras Agricultural Journal, 82*(3): 219-220.

Rangasamy K, Balasubramanium M and Swaminathan K.R. (1993). Evaluation of power weeder performance, Agricultural Mechanisation in Asia, *Africa and Latin America, 24* (4):16-18.

Remesan R, Roopesh M.S, Remya N. & Preman, PS. (2007). Wet Land Paddy Weeding-A Comprehensive Comparative Study from South India. *The CIGR journal. Manuscript PM 07011, 9:* 1-21. Rice. Annual Conference of Indian Society of Weed Science, B.H.U. Varanasi.

Sam, B. (2016). *International Journal of Engineering Research and Development e-ISSN:* 2278-067X, p-ISSN: 2278-800X, www.ijerd.com Volume 12, Issue 1 (January 2016), PP.68-73 Science, 9: 14-18.

Senthilkumar, I. (2003). *Effect of weed control methods on rice cultivars in Rusia rice field.* Online J Bio Sci, 3: 119-123.

Singh SP. (2012). Physiological workload of farm women while evaluating sickles for paddy harvesting. *Agric Eng Int: CIGR Journal, 14*(1): 85.

Singh, G. (1988). Development and fabrication techniques of improved grubber.

Singh, M.D. (1988). *Development and evaluation of power grass slasher*. Annual Report of All Indian Co-ordinated Research on farm Implement

Singh, R. (2001). *Studies on rotary weeder in wheat crop*. M. Tech. Thesis, Punjab Agricultural University, Ludhiana.

Singh, R.P., Reddy, B.G. & Rao, A.S. (1994). *Comparative performance of mechanical weeder alone and in combination with herbicides*.

Singh, S. P., Singh, M. K. & Solanki, R. C. (2016). Design and development of four wheel weeder for wide-row crops. *England Journal of Agricultural Sciences 86*(1): 42–9.

Singh, S., Rastogi, S.L. & Katyal, S.K. (1984). Relative efficiency of different weedicides in controlling the weeds of transplanted rice, *Pesticides, 20*(11):34-35.

Singh, S.P. (2010). Ergonomical Evaluation of Cono-Weeder with Farm Women. *Sub-centre of Directorate of Research on Women in Agriculture England, CIAE, 34*(3): 31-36.

Spandl, E., Durgan, B.R. & Forcella F. (1999). Foxtail (*Setaria* spp.) seedling dynamics in spring wheat (*Triticumaestivum*) are influenced by seeding date and tillage regime. *Weed Sci.* 47: 156-160.

Spliid, N.H., Carter, A. & Helweg, A. (2004). Non-agricultural use of pesticides - Environmental issues and alternatives. *Pest Management Science 60,* 523.

Sule, Y.W. (1983). *Selected ergonomics study of commonly used manually operated farm tools.* Unpublished M.sc (Agriculture Engineering) Theses. Ahmadu Bello University Department of agriculture engineering Zaria, Nigeria.

Sylvestre, G., Ibnou, D., Kokou, A., Jean-Martial, J., Amakoe, D.A., Atsuko, T., Sanoussi, A. & Kazuki, S. (2014). Participatory evaluation of mechanical weeders in lowland rice production systems. Benin. *Crop Protection, 61:* 32-37.

Tajuddin, A. (2006). *Design, Development and Testing of Engine Operated Weeder*. Delhi Agricultural Engineering Today Press, 30: 5-6.

Tajuddin, A. (2006). Design, development and testing of engine operated weeder. Malesia.Tw Press.

Teasdale, J.R. & Mohler, C.L. (2000).The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci.* 48: 385-392.

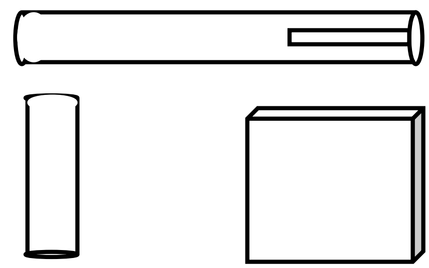
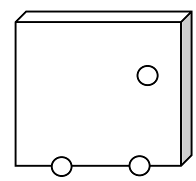
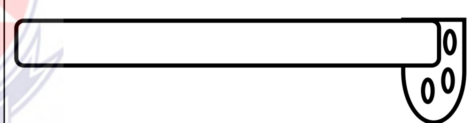
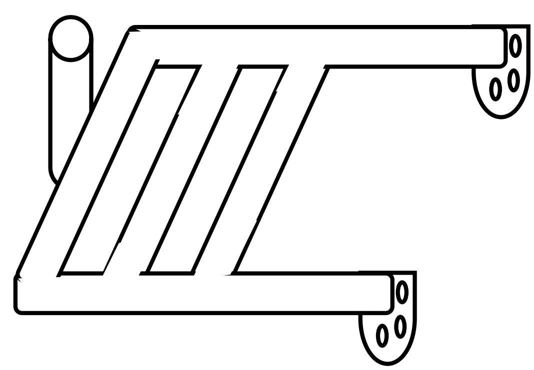
Thiyagarajan, Gupta, C.P. Reupor, N.J (2006). Network for Agricultural Machinery

Tobberup, (2014). Weed control techniques. Asia Technical bulletin No, CIAE/84/46, Central Institute of Agricultural Engineering, Publisher, Bhopal.

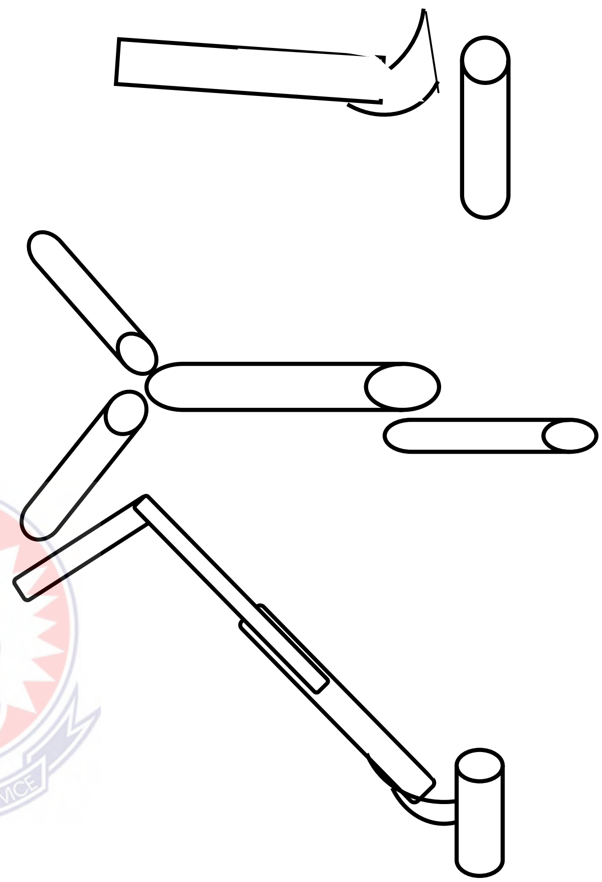
Yadav, R. & Pund, S. (2007). *Development and ergonomic evaluation of manual weeder.* Agricultural New Delhi. Chan publication.

APPENDIX A

Fabrication Design Process

No	Operational sequence	Tools and equipment	Drawing
1	Mark and cut out Cut a slot on the pipe	Tape measure, try square, hacksaw, scriber	
2	1, Drill 2, Chamfer the edges	Centre punch, Drilling machine	
3	Join the pieces and weld	Arc welding	
4	1, Join all parts and tack, 2, Check all angles and alignment of shaft slots 3,weld all joins permanently	Arc welding, hand grinding machine	

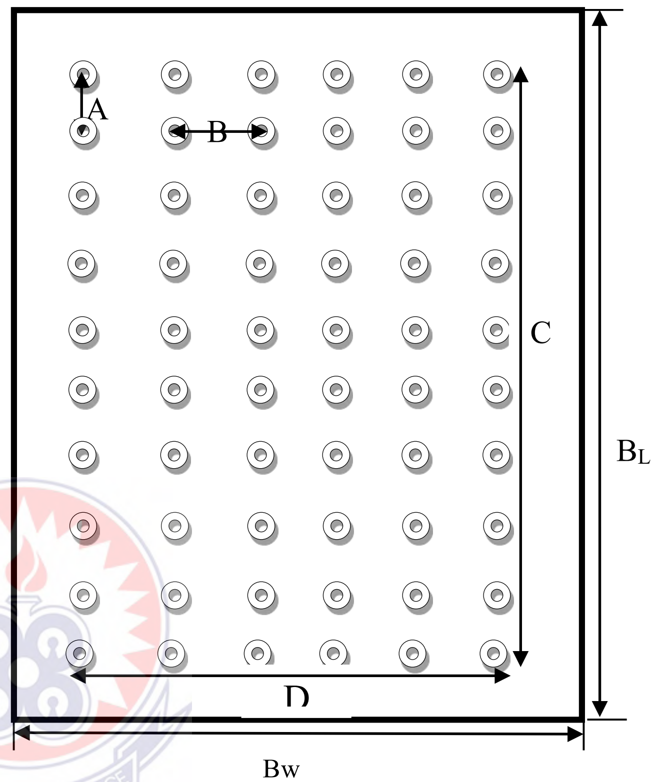
Fabrication process of the Handle

No	Operation Sequence	Tools	Drawing
1	Mark and cut all parts to size	Tape measure, try square, hacksaw, scriber	
2	1, Join all pieces by tacking, check straightness and angles 2, weld all joins permanently	Arc welding, steel rule, hand grinding machine.	

APPENDIX B

LAND PREPARATION

Recommended Field Operational Pattern



Field Operational Pattern

Where;

A is inter-crop spacing = 20cm = 0.2m

B is row spacing = 270cm = 2.7m

C is length of row = 220cm = 2.2m

D is width of the rows = 100cm = 1.0m