UNIVERSITY FOR DEVELOPMENT STUDIES

DEVELOPMENT AND PERFORMANCE EVALUATION OF A PROTOTYPE POWER TILLER INCORPORATED WITH SPRAY GUN IRRIGATION SYSTEM

BABA ZIBLIM

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BY

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

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DECLARATION

Student's Declaration

I hereby declare that this thesis is the original record of my work carried out for the award of the Doctor of Philosophy Degree in Irrigation and Drainage Engineering and that no part of it has been submitted by me or any other person for the award of any other degree. All related resources which served as source of information have been duly acknowledged.

21/08/2025

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Sign Date

Supervisors Declaration

We hereby declare that we have checked this thesis, and, in our opinion, this project is satisfactory in terms of scope and quality for the award of Doctor of Philosophy Degree in Irrigation and Drainage Engineering.

Ing. Prof. Felix K. Abagale **August, 28, 2025**
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Co-Supervisor: Sign Date

Ing. Prof. Linda Dari 29th August 2025

HOD Sign Date

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ABSTRACT

A relatively low-cost power tiller with a portable irrigation system was designed and simulated using AutoCAD and Autodesk Inventor software and manufactured with locally available materials and components. Its main components include a frame, a CG 125 motorcycle engine, a mouldboard plough, a water pump, two caged wheels, and a reel. The performance of the tilling unit and irrigation system was evaluated on a 14 m by 19 m plot of land. Microsoft Excel was used to analyse the data collected, especially in the calculation of averages and plotting graphs of the PPTISGIS performance parameters. AutoCAD2022 and Autodesk Inventor 2023 were used for modelling and simulation. The parameters measured were speed of operation, wheel revolutions, width and depth of furrow and time. The operating speeds recorded were 0.278 m/s, 0.556 m/s, and 0.833 m/s and the fuel consumption was found to be 25.75 L/ha. The percentage of wheel slip was directly proportional to speeds ranging from 5.03% at 0.278 m/s to 13.04% at 0.833 m/s, giving an average of 9.57%. The theoretical and effective field capacities were 0.889 ha/h and 0.7 ha/h respectively, resulting in a field efficiency of 78.74%. Using a sprinkler with a 6 mm diameter nozzle (circular) for the irrigation system, the pressure was 2.5 bar, pump speed was 1700 rpm, discharge rate was found to be 1.125 L/s, with an application rate of 4.42 mm/h. The coefficient of uniformity was calculated as 76.93%, which fell within the acceptable range of 60% to 90%. The cost-benefit analysis indicated that if the power tiller works for 100 days per year at a discount rate of 28.99%, the benefits to be generated over the period would be enough to offset the initial investment and related costs. Generally, the performance of the developed power tiller with an irrigation system is satisfactory and recommended for use by smallholder farmers.

Key words: pressure, performance, sprinkler, tilling, uniformity

DEDICATION

I dedicate this study to my late father, Mr. Mahama Ziblim of blessed memory and mother, Ziblim Napari for laying a strong foundation for my education.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Agriculture has been and will continue to be an economic cornerstone of many countries. In Ghana, agriculture has been the backbone of the economy. It has been the key development in the rise of settled human civilization. The study of farming is referred to as agricultural science (Habeeb, 2020). Agriculture has a history of thousands of years, and its development has been motivated and defined by very different climates, crops, and technologies. Although modern agronomy, plant improvement, agrochemicals such as pesticides and fertilizers, and technological advances have in many cases significantly increased crop yields, they have also caused extensive ecological damage (Ganguly et al., 2021). Agricultural food production and water management are increasingly emerging as global challenges. Mechanisation is a labour-saving technology, that often enables farmers to expand their farms where land is available as well as frees up labour for other agricultural functions or off-farm income generation (Diao et al., 2018).

Mechanised farming is the process of using agricultural machinery in place of manual labour. Through mechanisation, agricultural machinery, either pulled by animals such as oxen, horses and mules or powered by internal combustion engines, has replaced many jobs previously carried out by manual labour. This has led to a substantial increase in the productivity of agricultural workers in modern times (Diao et al., 2016). The history of agriculture includes numerous examples of tools, such as hoe and plough. However, the continued integration of machinery since the Industrial Revolution has made agriculture significantly less labour-intensive. Today's mechanised agriculture involves using tractors, trucks, combine harvesters, various agricultural instruments, aircraft and other vehicles. Precision farming even uses computers associated with satellite imaging and satellite navigation to increase returns (Sung, 2018).

Mechanisation has been one of the main drivers of urbanisation and industrial economies. In addition to improving production efficiency, mechanisation promotes large-scale production and sometimes improves the quality of agricultural products. it displaces unskilled farm workers and causes environmental degradation, especially if it is applied in a short-term rather than a holistic manner (Sims & Kienzle, 2017). As Africa strives to increase agricultural production, mechanisation plays an important role. There is enough evidence that increasing Agricultural Mechanisation (AM) translates into a significant increase in production. For instance, countries like China, the United States of America, South Korea and Japan are said to have the highest levels of AM (Khetigaadi, 2016), and lead in world food production. According to Statista (2019), Asia was the leading producer of fresh vegetables with 834.2 million metric tons, representing 73.23% of the global production; whereas Africa produced only 79.14 million metric tons, representing about 7.23% of the 2017 global production of 1,094.34 million metrics tons of fresh vegetables. The labour for agricultural activities is very difficult to get, and the number is constantly decreasing in Africa. This can be partly attributed to the trauma associated with it and also the impermanent nature of the job (Sutton, 1983). It is therefore expedient to increase the level of agricultural mechanisation to meet the food demand of the fast-growing population in Ghana in particular, and Africa as a whole.

In Ghana, limited access to agricultural machinery is a major hindrance to AM. Due to this, only 16% of the agricultural land is being cultivated with machines and 11% of the arable land is being irrigated (Panel, 2018). To salvage the situation, policy makers need to prioritise access to agricultural machinery and mechanisation services.

Recent experiences in both Asia and Africa suggest that machinery hiring services are required to meet the emerging demand for mechanisation among farmers who are predominantly small-scale and are unlikely to own capital-intensive machinery.

According to Taiwo and Kumi (2015), the demand for mechanisation services, particularly for land preparation for small-scale irrigation farmers, is high in Ghana due to a variety of agroecological conditions and population density. In trying to establish the main drivers for adoption and increase in mechanisation levels, Farajian et al. (2018) established a theoretical and empirical relationship between population growth in irrigation locations and the level of agriculture mechanisation. Farajian et al. (2018) contended that the use of technology and the evolution of agricultural systems under various smallholder irrigation farming systems are endogenic processes in which population is the main determining factor. It was argued that labour-saving mechanisation would be adopted where there is a growing demand for output either because of population growth or growth in the non-agricultural sector. Akolgo et al. (2022) conjectured that the demand for labour-saving technology (mechanisation) will increase with constant total population growth and limited importation of food if labour is moving from agriculture to the non-agricultural sector (Taiwo & Kumi, 2015). Partial mechanisation creates the need for more labour. That is, if there are machines for some farm activities and none for other in that same chain, the high output of the machines creates the need for more labour to complete the other activities in that chain that are to be done manually. For instance, in the northern part of Ghana, machines for ploughing and post-harvest processing are common compared to activities like sowing, fertilizer application, weeding, and harvesting. Therefore, more labour is usually required for manual planting, fertilizer application, and harvesting of fields ploughed by tractors. The level of mechanisation is not uniform across all parts of Ghana. There is a very great variation in the level of mechanisation in the Northern Region compared to that of the urban areas (Cossar, 2016).

Over the years, agriculture in Ghana and many developing countries have been dominated mostly by small-holder farmers, with farm sizes usually about 2 to 3 hectares, using human labour and traditional tools such as hoes and cutlasses etc. for activities such as sowing, weeding, harvesting, etc (Borbale et al., 2021). Smallholder farmers are not using modem agricultural techniques and equipment due to a lack of knowledge and the inability of the farmers to acquire expensive modern equipment (Thiruppathi et al., 2020). Although most farmers still utilise antiquated farming techniques, implementing scientific farming practices could result in maximum production and high-quality crops, saving a farmer from going bankrupt. The need for agricultural mechanisation in Ghana must therefore be assessed with a deeper understanding of the smallholder farmer‘s activities. Kansanga et al. (2020) demonstrated a significant disparity in the adoption and application of technology among small and marginal farmers. Implementing more resource-conserving agricultural systems is crucial to improving the livelihoods of impoverished farmers in developing nations sustainably.

One of the most important causes for the decreased rate of productivity in smallholder irrigation farmers including homesteads is the lack of suitable machinery that caters to and suits the requirements of these small-scale irrigation farms. For this reason, many small irrigation farms are regarded as unproductive and ineffective. Since the common practice is flood irrigation of the available area, the mechanisation issues in small-scale irrigation agriculture are much more complicated compared to commercial agriculture.

As conventional methods of farming depend largely on human labour are practised in small-scale irrigation farming, the requirements of mechanisation are much more diverse. Common operations in small-scale irrigation farming are land preparation, sowing, planting, intercultural operations, plant protection, and harvesting. These are considered as the oldest land-use activity which has evolved through generations (Mrema et al., 2014).

As the crop diversity and cropping pattern in small-scale irrigation farming is diverse, it requires different types of hand tools which can be manually operated or powered. Since animal power is no longer used in small-scale farming in Ghana, powered tools are required as manual operations involve hard physical labour and drudgery. Drudgery involved in farming operations is likely to decrease the efficiency of human power and that in turn affects productivity. Appropriate mechanisation is essential to sustain the interest of small-scale farmers and to increase their productivity.

Mechanisation is the most important intervention required in the system to make small-scale irrigation agriculture more attractive to the young generation. Shortages of labour and high labour wages are the factors which strongly propel mechanisation. At the same time, several factors such as the size of the farm holding, the investing capacity of a farmer and the technical know-how of the people will restrict the adoption of mechanisation. Even though it is necessary to mechanise small-scale irrigation, there are limitations as the area is limited to a few acres of land, and the farmers are not wealthy enough to purchase costly machines. Hence, it is highly relevant to evolve a technically and economically feasible mechanisation strategy for the farmers (Jayne et al., 2016).

The present scenario in small-scale irrigation warrants an affordable and versatile power-operated multipurpose tool carrier. The multipurpose tool carrier is a scientific term used to indicate a multipurpose tool frame that provides the link between the implement and the power source (Arya & Shaji , 2019). As a multipurpose unit, tool carriers are designed to be used with several implements. The unit is conceived to work in a way similar to a multipurpose tractor which facilitates quick changing of implements on the toolbar according to operational requirements. Knowledge about different operations involved and different tools used for the operations in small-scale irrigation can facilitate the design and development of different tools.

Mechanisation of the small-scale irrigation in Ghana is in its juvenile stage. Even though power tillers were expected to cater for the needs of small-scale irrigation, homestead farmers seldom owned power tillers. The reason for developing this multipurpose tool carrier powered by the engine is expected to avoid the requirement of different implements and power sources for different operations and hence offer much utility and cost saving over traditional implements. Such a machine is envisaged as farmer-friendly and women-friendly as it could easily be operated and handled. Hence the development of a multipurpose machine that could till and irrigate farms for small-scale farmers is highly relevant in the present context.

1.2 Statement of the problem

Agricultural mechanisation has not progressed well and requires better and improved machinery for land preparation and irrigation to facilitate the implementation of improved farming methods (Diao et al., 2018). However, due to the dominance of small-scale farmers in the agricultural sector in Ghana, the majority of the farmers are not able to afford tractors and other large and sophisticated equipment. An alternative is the use of low-power and multi-purpose portable equipment such as single-axle tractors also known as power tillers. An imported power tiller in the Ghanaian market as of August 2024 costs over twenty thousand Ghana Cedis (GH₵ 20,000.00). This makes them still unaffordable to a significant number of small-scale farmers who are compelled to use traditional tools and implements for land preparation and water supply. Benin (2015) indicated that almost all field operations are carried out using hand tools with human power for small-scale farming. This traditional practice is characterised by numerous challenges including drudgery since farmers using hand tools have to put in more effort, limited farm size, delayed land preparation, inefficient water supply, etc. Consequently, these small-scale farmers are not able to get maximum yield without timely land preparation and adequate water supply (Nyagumbo et al., 2017). Binswanger-Mkhize & Savastano, (2017) have shown that there is a great imbalance between the labour input and the output obtained in all small-scale irrigation agricultural production work. This has led to a chronic shortage of food in the farming population. In many cases, farmers have not been able to feed their own families and are unlikely to have a surplus product for marketing and earning cash.

Many studies have been carried out on attachments to power tillers (Nitin et al., 2017; Shabbir et al., 2018; Sharath *et al.,* 2019; Hardik et al., 2021; Pratkkumar, 2020) among others. These researchers have worked on power tiller attachments such as weeders, potato diggers, seed and fertilizer drills, slasher, planter, reaper etc., unfortunately, all these attachments did not include a gun spray system. There is therefore, the need for a locally produced power tiller that is relatively cheaper and incorporated with a spray gun for irrigation and efficient water supply to aid the activities of small-holder irrigation farming in Ghana.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of this study was to develop and evaluate the performance of a power with a spray gun for irrigation.

1.3.2 Specific Objectives

1. To design and simulate a prototype power tiller incorporated with a spray gun for irrigation.
2. To manufacture a prototype power tiller with a spry gun for irrigation.
3. To evaluate the performances of the tilling and irrigation units in terms in terms of (fuel consumption, effective field capacity, field efficiency and wheel slip, water application rate, and coefficient of uniformity).
4. To perform a cost-benefit analysis of the machine.

1.4 Research Questions

Objective 1:

1. What are the key design requirements for incorporating an irrigation system into a power tiller?

2. How can simulation tools be utilized to optimize the design of a power tiller with an integrated irrigation system?

Objective 2:

1. What manufacturing processes are most suitable for producing a power tiller with an integrated irrigation system?

2. What materials and components are required to ensure the durability and functionality of the tiller and irrigation system?

Objective 3:

1. What is the tilling unit performance in terms of speed, fuel consumption and operating width?

2. What is the irrigation system's performance in terms of water application rate, water distribution efficiency and coefficient of uniformity?

Objective 4:

1. What is the total cost of design, manufacturing, and operation for the tiller with an irrigation system?

2. What are the potential savings and benefits for farmers using this combined system compared to traditional methods?

1.5 Justification of the Study

The development and mass production of multi-utility mechanised devices to meet the needs of farmers is crucial for the growth of the Ghanaian industry. The need to speed up the mechanisation of farm operations is not only driven by the growing labour shortage and rising wage rates, but also by the need to save time, apply inputs efficiently, transport farm inputs and produce, and reduce drudgery. The study would help to improve the mechanisation drive of small-scale irrigation and land preparation in Ghana, by reducing the time and labour intensiveness of tillage, and irrigation by designing and fabricating a prototype multi-purpose power tiller at relatively affordable price. This could benefit the Government, researchers, small-scale irrigation farmers and different-scale entrepreneurs in the following ways. It will minimize the level of difficulty in tillage and irrigation by reducing the time and human energy utilised through the traditional system by farmers. They will get the opportunity to own a multi-purpose power tiller at a comparably low price. Farmers can focus on animal husbandry as a result of the reduction in time and labour and the freedom of oxen from hard work. Foreign currency expenditure for such kinds of machines will decrease and consequently improve the economy. This project can be a source of reference for researchers. Since the machine has some limitations, further research is necessary to improve its performance. Entrepreneurs (small, medium and large scale) can benefit from the fabrication and maintenance of multi-purpose power tiller and their components.

In this study, a low-cost prototype power tiller incorporated with a spray gun for irrigation was developed with an 11.0 HP single-cylinder spark ignition engine coupled with a 5.1 HP Mouvex Triplex Plunger Water Pump with a spray gun unit. This would solve major problems faced by small-scale irrigation farmers during land preparation and irrigation.

1.6 Scope of the Study

In this study, the design of the Prototype Power Tiller Incorporated with Spray Gun for Irrigation System (PPTISGIS) was done with Autodesk Inventor Professional 2023 software. Stress analysis of critical components was also done with the same software. All parts were fabricated and assembled. Preliminary testing was done and corrections were made. Finally, the developed multi-purpose prototype power tiller was tested in the field in terms of both tilling and irrigation of transplanted tomatoes till fruition.

1.7 Thesis Structure

The thesis is organised into six Chapters. Chapter 1 presents a brief background on the history of tilling and irrigation of crops. It outlines the problem statement, justification, and objectives of the study along with research questions. Chapter 2 delves into the existing body of literature within the research domain, encompassing comprehensive insights into both tillers and irrigation systems. It provides a thorough examination of the functionality of multi-purpose power tillers and sprinkler systems. Additionally, the chapter undertakes scrutiny of product literature sourced from contemporary manufacturers of multi-purpose power tillers and sprinkler systems equipment.

Chapter 3 explains the methods employed in designing and simulating the PPTISGIS. Furthermore, the chapter outlines the methodologies applied in the field for the evaluation of the machine. The details include the experimental site, experimental design, conceptual design framework and evaluation, and then data analysis tools employed. The materials used for the machine's fabrication and its field evaluation were also discussed. In Chapter 4, the manufacturing process of the PPTISGIS is discussed. The details include the materials, operational sequence, tools and equipment used in the manufacturing process. Chapter 5 presents the results of the design, simulation, manufacturing, field evaluation, and cost-benefit analysis of the PPTISGIS and discussions and Chapter 6 summarised key conclusions and recommendations for future studies and possible improvements.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tillage

Cultivation comes from the Latin term cultus, which is the past participle of colere, meaning "to till" (Turgeon & Fidanza, 2017). Tilling is a process of creating favourable conditions for the growth of plants by aerating the soil to allow moisture and air to permeate (Turgeon & Fidanza, 2017). It encourages the growth of roots and is sometimes carried out to control the growth of weeds, or to integrate fertilisers into the soil. Tilling one field multiple times before planting may sometimes be necessary to enhance crop growth. Based on the time and crop, the tillage carried out, can be put into two categories; preparatory tillage and after tillage (Papadakis, 1970).

2.1.1 Preparatory tillage

This refers to tillage operations carried out from the time of crop harvest to the time of sowing of the next crop. Preparatory tillage is sub-divided into primary tillage which involves operations carried out after the harvest of crops, to bring the filed under cultivation; and secondary tillage which involves lighter field operations such as harrowing and sowing carried out after primary tillage. Secondary tillage prepares the soil for planting after primary tillage by refining the soil structure,(Chandrasekaran, 2010).

2.1.2 After Tillage

This refers to tillage operations undertaken within crops that are still standing. After tillage operations include weeding which involves working weeders or rotary hoes within the crop rows to control weeds, inter-cultivation, drilling or side dressing of fertilizers, earthing which involves the formation of ridges at the base of crops to either provide additional support against lodging (e.g., of sugarcane) or to provide additional volume of soil for better growth of tubers (e.g., of potato) or to enhance irrigation in vegetable farms. etc. (Papadakis, 1970)

2.1.3 Modern Concepts of Tillage

Conventional tillage combines primary and secondary tillage operations to prepare seed beds by repeated ploughing using animals or machinery in most cases. However, studies have revealed that repeated use of heavy machinery is detrimental to soil structures, results in soil pans and causes soil erosion (Kumar et al., 2016). Also, these tillage operations consume a lot of fuel. The challenges enumerated above coupled with the continuous increase in fuel prices led to the development of the modern concepts of tillage. These concepts are; conservative tillage which is undertaken to conserve soil and water by reducing their losses, minimum tillage aimed at reducing tillage to the minimum, and zero or no tillage with which primary tillage is eliminated and secondary tillage is limited to seedbed preparation in the row zone only.

2.2 Tillage Implements

Tillage can either be done with tools like the hoe using human effort (manual tillage), or with implements operated by animal power or machinery. Implements used for tillage are classified either according to the purpose for which they are being used or possible hitching configuration. According to the purpose, the classes are primary tillage implements such as disc plough, mould board plough (Figure 2.1), etc.; secondary tillage implements such as cultivators (Figure 2.2), harrows, etc.; and intercultural implements such as weeders (Chandrasekaran, 2010). The categories according to hitching configuration are mounted, semi-mounted and trailed hitching configurations.

Figure 2. 1: Mould board plough (Chandrasekaran, 2010)

Figure 2. 2: Cultivator (Swapnil et al., 2015)

2.3 Sources of Farm Power

The sources of farm power for the operation of various agricultural machinery/implements are classified as; Human power, Animal power, Mechanical power which includes power tillers, tractors, self-propelled combine harvesters, etc., Electrical power (either from the national grid or electricity generators), renewable energy such as solar and wind energies, and biogas, (ICAR, 2016).

2.3.1 Mechanical Power Sources

The waterwheel is a mechanical device that taps energy from falling water using a set of paddles mounted around a wheel. It is perhaps the earliest source of mechanical power for operating machinery. Internal combustion (IC) engines convert liquid fuel (kerosene, petrol or diesel) into mechanical energy used as a mechanical source of power (ICAR, 2016). The common mechanical sources of power such as power tillers, tractors, and combine harvesters, now use either spark ignition (petrol) or compression ignition (diesel) engines.

2.3.1.1 Tractor

A tractor is a self-propelled motor vehicle with wheels or tracks that is used to pull trailers and run agricultural equipment. With the help of its power take-off (PTO), the tractor's engine not only moves the ground wheels but also serves as a prime mover for stationary farm equipment and active tools (ICAR, 2016). The first gasoline tractor was successfully introduced in 1906- by Charles W. Hart and Charles H. Parr of Charles City, Iowa where the first tractor demonstration was held in 1911at Omaha (Nebraska), (ICAR, 2016) the - Power take-off (PTO) was introduced between 1915-1919, and then extensive global manufacturing of diesel tractors started between 1950-1960 (ICAR, 2016).

Figure 2. 3: Mahindra Tractor (Source: Kiran et al., 2017)

2.3.1.2 **Classification of Tractors**

Tractors can be put into three broad classes. These are based on the type of construction, drive and purpose. The class of tractors based on construction include riding/double axle type tractors and walking/single axle type tractors. The class of tractors based on the type of drive include track/crawler type tractors and wheeled tractors. Finally, the category of tractors based on purpose include utility tractors, all-purpose tractors, orchard type, garden tractors, tillers etc (Krishi , 2012).

2.3.1.2.1 Power Tiller

A power tiller is a prime mover, meaning that the operator walks behind it to regulate its direction of motion and do field operations. Another name for it is a walking-type tractor or a hand tractor (Hensh et al., 2022). The power tiller reduces the need for human labour and is mostly used for rotating cultivation in puddle soil.

Smallholder farmers are the major group that patronises the custom hiring of power tillers. Smallholder farmers prefer to use a motorised tiller for all farm tasks, including preparatory tillage and puddling. In rural locations, the machine offers chances for self-employment. The power tiller is a multifunctional hand tractor that is mainly used on small farms for tasks like tilling. The power tillers' adaptability is limited by the lack of equipment that is compatible with various farm operations. At first, the power tillers came with a trailer, a rotavator attachment, and occasionally a plough and ridger. Power tillers were first introduced without a full complement of related equipment (Kumari et al., 2020).

In comparison to tractors, farmers use power tillers for farming tasks less frequently. According to Kumar and Kumar (2018), the concept of power tillers was discovered in 1920. Japan was the first country to implement power tillers on a significant basis. The first successful model of power tiller was designed in 1947. From 1950 to 1965, the output of power tillers expanded dramatically. It is sometimes known as a single axle walking tractor; however, some designs include a seat. Nowadays, several power tiller models include an optional riding feature. Power tillers were specifically designed and developed for usage on small or medium farms where four-wheel tractors are not readily available (Adamu et al., 2014).

A power tiller is also used as a power source for other agricultural operations such as seedbed preparation, sowing and fertilizer application. Tillers are also useful in intercultural in wide-spaced row crops (more than 1.0 m row-to-row spacing) and harvesting of cereal crops under upland conditions including transportation of farm products and power sources for stationary farm operations (Kathirvel et al., 2000). Very lately, lightweight tillers have been used. The majority of power tillers produced nowadays come with a powered rotary unit positioned on the back for both forward motion and tillage operation. Such tillers require special care to be maintained. Their low drawbar power per brake horsepower of the engine limits their application for traction duties (Cherian et al., 2016).

As African countries strive to increase agricultural production, mechanisation has been playing an increasingly important role. Mechanisation is a labour-saving technology that often enables farmers to expand their farms where land is available as well as free up labour for other agricultural functions or off-farm income generation. While early efforts to promote mechanisation in Africa failed due to minimal incentives for farmers to intensify production (Binswanger-Mkhize & Savastano, 2017), many indications suggest farming systems have evolved sufficiently for farmers to demand mechanisation (Diao et al., 2016). Ghana, with relatively large farm sizes, especially in the north (Jayne et al., 2016), and labour rapidly exiting from agriculture (Diao et al., 2019), appears to be a prime candidate for mechanization in Africa. In Ghana, increasing access to agricultural machinery could help accelerate farm expansion while also helping farmers to overcome their labour constraints, which deter the adoption of yield-enhancing technologies (Nin-Pratt & McBride, 2014). Thus, increasing access to machinery and mechanization services has become an important issue for policymakers in Ghana. Recent experiences in both Asian and African countries suggest that machinery hiring services are required to meet the emerging demand for mechanization among farmers, of which many are small-scale and are unlikely to become machinery owners. In this process, the government can play an important role in addressing key market failures by promoting private ownership of agricultural machinery and spurring the development of service-hiring markets to meet the growing demand from small-scale farmers. In line with this, the Ghana government introduced Agricultural Mechanisation Service Enterprise Center (AMSEC) concept as one of the four initiatives included in the country's agricultural development strategy in 2007 (Akolgo et al., 2022).

Figure 2.4: Power Tiller (Source: Kiran et al., 2017)

2.3.1.3 **Single Tool Carrier (STC)**

Among the many agricultural machines are soil tillers. Soil tillers are unconventional in terms of labour displacement in contrast to tractors. Since most farmers own a small amount of land, soil tillers are extremely important. Higher-priced tractors are therefore barely within their means. The soil tiller should so develop into a practical tool for farm tasks like tilling. Its main objective is to reduce the manpower as in today's scenario labourers are very hard to find as well as it reduces the working time. As it could be far better than the conventional use of labour or bull for tilling purposes (Tupkar et al., 2013).

Zakariyah et al. (2021) developed and evaluated the performance of a power tiller and compared it with the conventional method of manual weeding with a hoe and manually operated dry land weeder. The field capacity of the weeder was 0.04ha h^{-1} with a tilling efficiency of 93 % and a performance index of 453. Saving in time was 93 % while saving on cost was 65 %.

Gopan and Balu (2018) reported that Pitoyo *et al.* (2000) developed a power tiller for rice fields. The machine was driven by a two-stroke engine of 2 hp (6500 rpm) with a performance of 15 h ha^{-1} capacity at a traveling speed of 1.8 km h^{-1}. The mass of the machine was 24.5 kg. Kant et al. (2004) evaluated a self-propelled, diesel engine-operated power tiller of 3.8 hp (2600 rpm). The moisture content of the soil at the time of evaluation was 17-18 %, the depth of operation ranged from 4-7 cm and the efficiency was obtained as 88 %. Victor et al. (2020) designed, developed and fabricated a rotary power tiller for wetland paddy with the help of a 0.5 hp petrol engine. The belt and pulley as well as chain and sprocket were used for power transmission from the engine to the traction wheel and the rotary unit was equipped with four L-shaped standard blades for cutting. Two big traction wheels were used for smooth operation and a gauge wheel was provided for depth adjustment. The field capacity of the machine varied between 0.04-0.06 ha h^{-1} with a field efficiency of 71% and tilling efficiency of 90.5 %.

Muhammad and Attanda (2012) designed and fabricated a tiller and it was tested in different fields. It was found that it could be used as a tiller as well as a weeder for different fields. The tilling efficiency of 94.80 % to 97.5 % was observed at forward speeds of 0.25 to 0.5 m s^{-1}. The field capacity of 0.0504 ha/h was observed at a higher speed of 0.5m s^{-1}. Manuwa (2009) designed and developed a power tiller with a working width of 0.24 m. Effective field capacity, fuel consumption and field efficiency of the machine were 0.53 ha h^{-1}, 0.7 l h^{-1}, and 95 %, respectively. Saha *et al.* (2021) also designed and evaluated a power tiller which was fabricated with locally available materials and spare parts. An additional gearbox was fitted to get the backward and forward motion of the tiller and a dog clutch aided easy turning. From the evaluation, it was found that the power tiller saved 90 % of the tilling cost and labour requirements in comparison to traditional implements. Olaoye and Adekanye (2011) stated that the motion of the rotary tiller travels through a trochoidal or cycloidal path depending on the distance of the point from the rotor axis (radius). During operation, the motion of the rotor of a rotary tiller was generated by a combination of the machine's forward motion, the rotor's rotational motion and the distance of the rotational axis to the point of interest (rotor radius).

A power tiller with field capacity and tilling efficiency of 0.0712 ha h^{-1} and 73 % respectively, was developed and evaluated by Paman *et al.* (2012). The rotary power tiller reduces drudgery and ensures a comfortable posture of the operator with the components such as the frame, rotary hoe, power unit and transmission units. Hegazy et al. (2014) designed and fabricated a power tiller that consists of an engine, disc assembly and transmission system. Modified vertical discs were mounted on a circular rotating element which got their drive from the transmission system. Depth of operation, the effect of forward speed, moisture content of the soil, effective field capacity and field efficiency were taken into consideration for testing. The three levels of moisture contents chosen were 7.73, 12.28 and 16.18 % and the depth of operation was in the ranges of 0 to 20 mm and 20 to 40 mm. The forward speeds were 1.8, 2.1 and 2.4 km h^{-1}respectively. The minimum value of fuel consumption was 0.546 l h^{-1} and the field efficiency was 89.88 %.

Arya and Shaji (2019) came out with a manually operated ridge profile rotary tiller with two rotary hoes each tilling one-half of adjacent ridges. The inclination of the rotary hoes to the ridge profile was adjustable according to the angle of repose of the ridge. A low-cost sprocket tiller using inexpensive bicycle parts which could be operated by farmers or unskilled labourers was developed and fabricated by Aravindakshan et al. (2022). The tilling efficiency of the sprocket tiller was found to be 94.5 % which could work up to 4 cm depth and the field capacity was found to be 0.032 ha h^{-1}. Sabaji et al. (2014) developed and evaluated a power tiller. The main components of the tiller were disc blades and rotor shaft. The tilling efficiency and field capacity were 91.37 %, and 0.086 ha h^{-1}, respectively. Kumar et al. (2017) developed and evaluated a power tiller with field capacity, tilling efficiency and fuel consumption were evaluated. The field performance analysis revealed the tilling efficiency to be 76.40 %. It was also found that the power tiller had higher values of field capacity. Kankal et a*l.* (2017) developed a power tiller powered by a petrol engine of 1.33 kW with a speed reduction of 34:1. It was tested in the field with the highest of 2.3 km.

Chakravarthy et al. (2018) developed a knapsack sprayer engine operated by a tiller which consists of a 0.81 kW petrol engine and a float system. Power transmission from the engine to the tiller blades was provided through a flexible shaft. Tiller blades were rotated at 200 rpm. The cutting blades moved with a forward speed of 2.48 km h^{-1} and provided a depth of operation ranging from 4 to 6.5 cm. Tilling efficiency of the developed tiller was found to be 80.8 % with a fuel consumption of 0.55 l h^{-1}.

Pandey et al. (2018) designed a power tiller for rice. From the design point of view, the power source, cutting disc and shaft were the significant components of the power tiller. The average working speed of operation was found as 2.45 km h^{-1}. The average fuel consumption of the power tiller was found as 0.55 l h^{-1} and the maximum field capacity was found as 0.054 ha h^{-1}. The working width of the developed machine was adjustable between 140 mm to 250 mm.

Khura et al. (2018) developed a weeder and it was used as a secondary tillage tool. The maximum depth of operation was found to be 7-8 cm. The power weeder was field operated as secondary tillage implements in soil having a dry bulk density of 1.31 g cm^{-2}. Field capacity and theoretical field capacity for this operation were found to be 0.21 and 0.27 ha h^{-1} and the field performance index was calculated to be 77.78 %. The development of an electric-powered tiller for house gardening was reported by Sakamoto (2007). The tiller was composed of a driving shaft which is being powered by a 125 W DC motor. The motor drives the wheel in different rotations. The rotor of the tiller rotating at 200-400 rpm was connected to a 400W DC motor. Juan and Magaña (2020). conducted a comparative study on non-oscillating and oscillating tillage implements powered by power tiller. The oscillatory tillage implements having 25 cm tool width and non-oscillatory implement was used for tillage in dryland field conditions. A ploughing depth of 15.3 cm was achieved using a prototype oscillatory tillage implement while only a 7.4 cm depth of operation was achieved in the non-oscillatory mode of operation. The volume of soil handled per unit of time, fuel consumption and tillage performance index were higher with oscillatory tillage implement compared to non-oscillating implement.

Mandloi et al. (2011) fabricated a low-cost shrub-cutting machine with an engine of power 1.1 kW in which a rotary saw-type blade was used to cut the shrubs. The horizontal movement of the engine output shaft was translated into vertical motion by a bevel geared transmission case. Shinde et al. (2011) stated that tillage tools with different geometry designed to perform a particular tillage operation by rotary or sweep action would have more influence on the soil's physical characteristic such as soil structure, texture, moisture, resistance and cone index.

Athira et al. (2018) developed a power-operated tiller cum weeder powered by a 1.5 hp four-stroke petrol starts kerosene run engine. It was mainly composed of cutting blades made of EN-8 material, a body frame, a gear assembly and a ground wheel for guiding the direction of the machine according to operator and field conditions. Mandal et a*l*. (2014) found that the cone index of a soil-engaging tool will increase with an increase in penetration forces and soil had its own optimized moisture content at which the strength was very less. Zeng and Chen et al. (2018) reported that the power requirement for operating tillage tools was directly proportional to the depth as well as moisture content of the soil.

According to Biggs and Justice (2015), these power tillers have the potential to be utilized for inter-culture operations and seedbed preparation in widely spaced row crops such as sugarcane and cotton. At the Central Mechanical Engineering Research Institute in Durgapur, a model of a lightweight power tiller was tested in a variety of soil conditions to determine its performance. The model was widely utilised for inter-culture operations, seedbed preparation, etc. It was discovered that the field could handle 0.1 hectares each day (10 hours). One lit of fuel was used every hour.

Bhosale et al. (2017) designed a machine to uproot weeds and undesired crops from the field. A multi-purpose machine was developed for tilling and grass cutting. Testing revealed that the typical tilling procedure was time-consuming and costly.

Agalave et al. (2016) found that issues including steering difficulty, machine weight imbalance, and unpredictable pudding depth were resolved by putting a rotor assembly at the power tiller's back end and attaching a glass fiber float underneath the chassis. The outcome demonstrated that even in the most severe soil conditions, bolt-on attachments showed a lot of promise. The performance was contrasted with that of the enhanced floating tiller, imported puddles, and harrow. In wet and moist plowing circumstances, the rotor assembly effectively combined pure soil and ash more effectively than the traditional harrow.

Dhruwe (2015) conducted a study on a self-propelled locally made rotary hoe to overcome the problem of frequent transmission failure. The machine was used for mechanical weed control and hoeing. It was observed that the worm gear used in its transmission often failed due to surface wear of gear teeth. Worm gears made from three different copper alloys were tested against soil resistance in a sandy loam soil bin. The gear compositions were determined using atomic absorption. The gears under test exhibited a significant difference in surface wear among each other. As compared to gear bronze commercial gun metal and gunmetal showed surface wear of 245 % and 109 % respectively. The highest surface wear was observed in commercial gun metal whereas the lowest surface wear was observed in gear bronze. It was concluded that gear bronze may be the best material composition for use in the worm gear of the rotary hoe transmission box as compared to the other two alloys tested.

Sirisak (2008) investigated how well a rotating power tiller performed. The primary effect of the direct application to soil engagement tool revolving around a horizontal transverse axis is the primary reason why the rotary tiller is superior to the conventional implement, according to the study. This enables simultaneous harrowing and plowing in the field.

Pirowski et al. (2022) developed specifications for field and rotating plough shares with regard to the cast's composition and construction. For testing shares of casts, austempered ductile iron (ADI) was chosen as the casting material. The study recommended using Aus tempered ductile cast iron to replace the beaten and welded components of agricultural equipment used to cut through soil. These elements should have a longer lifespan thanks to such material and technical conversion, which should raise their competitiveness without raising production costs.

One of the tilling devices best suited for seedbed preparation is a rotary tiller or rotavator. Blades are essential components of a rotary tillage machine that work with soil to prepare the ground and to mix the fertilizer. Unlike standard ploughs, which are subjected to the impact that generates cyclic stresses that lead to fatigue failure of the blade, these blades interact with soil differently. A blade's service life is shortened as a result. Consequently, the design and development of an appropriate blade is required (Bhosale et al., 2017). Gopal (2020) developed a battery-powered tiller suitable for 1 acre to 3 acres of land, which was both economical and modernised with scientific methods. The study indicated that most Indian farmers are landowners of 5 acres or less. Hence it is most suitable for the Indian economy and farming techniques. Kadu et al. (2015) presented a 3.5 hp motorized tiller that specializes in weeding operations and is ideal for black soil sugarcane farming. The design includes chains and sprockets, shafts, belt drives, bearings, transmission cases, chassis, and other components that convert engine speed to power tiller speed. The machine was designed specifically for sugarcane cultivation and is suitable for black, damp, silted soil. It was also said that presently, most of the power tillers manufactured are in the range of 8-10 hp and weigh about 350 kg which is not potentially good in hilly areas due to the lack of manoeuvrability on slopes. As a result, a lightweight power tiller with engines ranging from 2 to 4 horsepower was developed. Zakariya et al. (2021) Modify a portable power tiller for small-scale weeding operations. After conducting preliminary research, it was determined that a motorized tiller might be used for weeding. As a result, the study attempted to increase its performance by modifying some key components, such as weeding and depth blades. Three sets of four, six, and eight-blade gangs were created using 3 mm mild steel sheet metal. The rebuilt equipment was evaluated for field capacity, plant damage, and fuel efficiency. There were four levels of blade types 'B' and three levels of weeding depth 'D.' At two (2) weeks, the field was laid out in a 43-randomised complete block configuration. Gavali et al. (2014) conducted a study on portable weeders and power tillers in the Indian market. According to the study, most small-scale farmers cannot afford portable tillers and weeders. Therefore, small-scale farmers do not use mechanical tilling or weed control. The two main weeding techniques used by smallholder farmers are chemical and manual. According to the literature assessment, portable tillers and weeders are less costly to run and maintain, but they are also less versatile.

Figure 2. 5: Steel cage wheel Single Tool Tiller (Source: Rasool & Raheman, 2016)

2.3.1.4 Multipurpose Tool Carrier (MPTC)

A multipurpose tool carrier (MPTC) is a multi-purpose frame that provides the link between the implement and the power source. Tool carriers were designed to provide the advantages of improved implements that could be used along with mechanical power sources in different farming systems. They were operating like tractors whose implements could be changed easily to suit the operational requirements. Timeliness, quality of operations and efficiency made wheeled tool carriers economically and technically viable in agricultural farming (Arya & Shaji, 2019). As stated by Riyaz (2021), by performing several tasks at once, such as ploughing, sowing, watering, and carrying or transporting items, the multipurpose farming machine has the potential to significantly boost crop yield. Chauhan (2006) ergonomically designed and developed a multipurpose hand tool carrier along with attachments like seed-cum fertilizer drill, cycle wheel hand hoe and rolling-type crust breaker for farmers belonging to small and marginal land holding categories. When tested for performing different operations such as sowing, hoeing and weeding, it was revealed that cycle wheel hoe had improved performance with a higher range of weeding efficiency compared to manual weeding. To increase the working efficiency a pneumatic wheeled multipurpose tool frame was developed by Tiwari et al. (2011). The tool frame consisted of a rectangular shaped frame, pneumatic wheels with screw jacks, an operator's seat, a handle and a beam. Different implements could be attached to the tool frame with the help of quick fixing type U clamps. Joshi et al. (2013) manufactured MPTC used for operations such as tillage, seeding, fertilisation and weeding in a timely and precise manner. Moreover, it could be further used as a cart to provide transportation. When the performance of the MPTC frame was compared with traditional practices, it was found that the draft requirement of MPTC was within the draft capacity of the traditional implements. It was also seen that an increase in the command area was observed in tillage and sowing operation by the MPTC frame over the traditional implement system.

Chandigarh (2009) cited by Arya and Shaji (2019) developed MPTC implement for sandy loam soil. It was indented to be used as a cultivator, seed drill, inter-culturing unit, and groundnut digger. The performance of the MPTC implement was evaluated for ploughing, sowing, bed shaping, inter-row cultivation and groundnut digging based on the draft requirement, actual field capacity, field efficiency and travel speed. From the economic analysis, it was revealed that the MPTC implementation provided an effective low-cost alternative machinery system, especially when high initial investment in machinery like tractors was a major constraint in the adoption of the improved mechanization technologies.

Jayan (2020) tested a groundnut digger developed at Marathwada Agricultural University as a matching tool to a multipurpose tool carrier. Test results were then compared with a groundnut digger developed by the Central Institute of Agricultural Engineering (CIAE) Bhopal and local designers. The performance of the developed digger was found to be better than the other two diggers.

Ramya et al. (2015) developed and evaluated an MPTC operated with a power tiller for different operations like tilling and harrowing. It was discovered that the multifunctional tool carrier completed the tasks on schedule and helped to lessen drudgery in the field. The average working speed of the tool carrier was 2.0 km/h for tilling and 2.2 km/h for harrowing, with average operating depths of 5.15 cm and 4.0 cm for tilling and harrowing, respectively. The average drafts were found to be 70.0 kg and 60.0 kg with filed efficiencies of 66.66 % and 69.88 % for tilling and harrowing respectively.

The performance of an MPTC was evaluated by Patel (2020) for tillage and weeding operations. Ploughing and other intercultural operations were done with the developed MPTC in wet soil conditions as well as in sandy loam soil. The field test for finding its power utilization, speed of operation and field capacity while doing both ploughing and weeding operations revealed that the average field capacity found in the primary tillage operation and weeding operation was 0.0985 and 0.112 ha h^{-1}.

Gautam et al. (2013) developed an MPTC to prepare seedbeds in dry as well as wet soil conditions and to perform various other agricultural operations. The machine consisted of a tool frame, furrow openers, a hitching system and a depth control system. Provision for adjusting row-to-row distance according to crop requirements in different operations was provided. The performance of the MPTC was evaluated for secondary tillage, sowing, and weeding operation. Observation of operating time and turning time in each bed were recorded for all operations. The field performance of the multipurpose tool carrier was evaluated using the draft requirement, real field capacity, field efficiency, and travel speed of the MPTC. MPTC was found to be significantly more cost effective than traditional tools. Three different concepts of MPTC were developed by Achuta et al. (2016). Out of which the first concept included a cubic-shaped frame in which a sowing tool and an inter-cultivator were assembled in a bulky manner. The second concept dealt with a single frame to which all the implements could attach. As the third concept, he proposed that means of a single frame and single attachment to a bicycle results in a reduction in space, and cost and also helps in local transportation. By comparing all the concepts, it revealed that the third concept was economically feasible to undertake different operations. Ginoya et al. (2019) developed a low-cost MPTC fabricated and tested in the field. The developed carrier along with its attachments was evaluated for field efficiency, unit draft, power requirement, energy requirement, performance index, fuel consumption, field capacity, soil pulverization and cone index at different moisture content. The speed of operation was kept uniform and additional weights were added according to the desired depth of operation. From the field evaluation, it was found that the plough was suitable as a primary tillage tool while the shovel was found to be an effective soil-cutting tool for secondary tillage operation. The horizontal blade could be used effectively for levelling. It was reported that the tool carrier was found to be suitable for year-round use as different tools could be attached with only a slight effort.

The energy expenditure of MPTC was determined by Ramya et al. (2015). They compared two models of multipurpose tool carriers developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad and Maharana Pratap University of Agriculture (MPUAT) Udaipur. It was shown that the ICRISAT model had the highest performance and least energy expenditure.

Annasaheb et al. (2017) concluded that the developed MPTC could be used as a planter, sprayer and inter-cultivator. The result showed that the implement performed better in the field, especially for sowing with a seed covering device and spraying with a theoretical field capacity of 0.189 ha hr^{-1} and field efficiency of 88% respectively. Veerangouda et al. (2012) Fabricated an MPTC multipurpose equipment to utilise it for different operations such as tilling, sowing and weed removal operations. It was revealed that according to operational requirements, different tools could be easily rearranged since they were attached to the equipment with the help of fasteners.

MPTC machine developed by Singh (2017) for different attachments needed in sugarcane cultivation included furrow opening, herbicide spraying, earthing up and intercultural operations were mainly focused. From the performance evaluation, the use of a multipurpose tool frame in intercultural operation and fertilizer spraying was found to be more economical compared to manual weeding and spraying. Mandloi et al. (2017) developed a multipurpose toolbar which was drawn by a mini tractor of 15 hp. It was tested in the field with different tool combinations of the iron plough and clod crusher as well as clod crusher and planter. From the performance evaluation, it was found that the developed multi toolbar with clod crusher for breaking clods was suitable for seedbed preparation in a single pass with a saving of about 20% in the cost of operation as compared to the cultivator. Nisha and Shridar (2018) reported that basic concepts of the selection of different attachments as well as their adjustments such as depth, width and spacing adjustments were easily possible when they were mounted on a basic frame. Tools could be separated from the system to make transportation easy.

Udhayakumar (2016) developed MPTC agricultural vehicle, for performing major agricultural operations like ploughing, seeding, and harvesting. The modification includes fabricating a vehicle which is small, and compact and makes cultivation much simpler with the help of a scotch yoke mechanism. The design of the chassis of the vehicle was made in such a way that it is suitable and can withstand static and dynamic loads during operation.

Saxena (2023) developed an electric induction MPTC. this uses an Electric Induction motor for driving the shaft instead of a Diesel Engine which greatly reduces the cost and avoids the use of fossil fuels. The farming events occurred sequentially like tilling the blades followed by the sowing of seeds from the hopper and finally hilling of sand by shovel. Prashant Rahat et al. (2021) designed “a portable electric power tiller machine. To provide maximum soil grip, the machine uses a wheel with welded angles. The wheel design was created to offer a strong grip on the soil that would allow the cultivator prongs to drag during the tilling process.

Figure 2. 6: Multi-Purpose Tiller (Source: Swapnil *et al.,* 2015)

According to Schmitz and Moss (2015), tractors have become one of the major sources of power which are generally used for most agricultural operations like irrigation, land development, tillage, sowing, harvesting, threshing, and transportation. Tractors help in reducing the time required for these operations. It is also used as a power source in farms for harvesting, threshing, pumping of water, etc. Hence, it has become an integral part of mechanised agriculture. Most of the tractor-operated pumps are driven by PTO. It was concluded that tractor power is advantageous to operate the centrifugal pump.

2.4 Sprinkler irrigation technology

Sprinkler irrigation is a method of applying water to crops or land by spraying it into the air, mimicking rainfall. Irrigation water is used to supplement the water available from rainfall, soil moisture, and the capillary rise of spring water. Many parts of the world do not receive enough rainfall to meet crop moisture requirements. As a result, enough irrigation is required for effective crop production (Patel & Prajapati, 2020), which is consistent with Shah's (2004) findings. Irrigation systems are frequently classified as providing both direct and indirect advantages. The cultivation of cash crops, increased crop production output through a greater yield to attain food self-sufficiency, and land value appreciation that makes the domestic water system and landholders more accessible to towns and villages are all examples of the direct benefits.

Irrigation systems are frequently designed to improve efficiency and minimise labour and capital needs while also maintaining a favourable crop growth environment. Some management inputs depend on the type of irrigation system and its design. Managerial decisions can be influenced by factors such as automation level, system type, soil type, topographic variance, and management tools. The frequency of irrigation, the depth of water to be supplied, and steps to improve uniformity of application are management choices that are shared by all sprinkler systems, regardless of type. (Jabbary et al. 2018), Furthermore, it is possible to significantly improve application efficiencies by adjusting specific sprinkler systems. The farm manager has benefited from irrigation scheduling services in recent years when deciding how much and how often to apply. The benefits of spray irrigation systems are advised and applied to almost every crop kind, soil type, and topographic situation. Because of its adaptability and effective water management, more area may now be designated as irrigable and a greater variety of soils using surface water application techniques can now be irrigated. Sprinklers are advised for improved leaching and crop germination on some salty soils. In areas with high permeability and/or low water-holding capacity, sprinklers are particularly preferred. Sprinklers can provide clear benefits over conventional irrigation techniques in low-permeability, thick soils. Sprinklers may be the most cost-effective method of applying water in locations with high labour and water expenses. Sprinklers have frequently been demonstrated to boost productivity, especially in fresh fruits and vegetables where quality and colour are crucial. The ability to achieve greater uniformity in salt leaching even with light irrigation is one benefit of sprinkler irrigation (Pathan et al., 2020). Leaching is accomplished by sprinkling in Israel and occasionally the US. Sprinkler irrigation has an advantage over floods because it allows water to be supplied at a rate lower than the rate at which soil infiltration occurs, preventing ponding. According to Bel-Lahbib et al. (2023), 260 mm of water delivered sporadically by sprinkling decreased the salt contents of the upper 0.6 m of the profile to the same extent as 750 mm applied by continuous flooding in a field experiment on silt-clay soil that was categorised as moderately alkali and rich in salts. This demonstrates that using sprinkler irrigation reduced the amount of water required for reclamation by one-third when compared to surface irrigation. Sprinklers frequently have numerous applications. Irrigation, crop cooling, frost control, pesticide, herbicide, and fertilizer application can all be done with the same equipment. Furthermore, contemporary farming procedures, which necessitate massive machinery and large fields for cost-effective farming operations, are simply irrigated using sprinklers, with little loss of efficiency.

2.4.2 Irrigation System Performance Evaluation

An indispensable tool in an irrigation project management is evaluation. This entails the measurement and analysis of key aspects of irrigation system performance and management. Evaluation will enable irrigation managers to measure and determine actual performance; identify which factors are responsible for the less-than-ideal performance and determine the relative impact of these factors and how they may be addressed.

Nasab et al. (2007) in their evaluation of sprinkler systems in Iran, concluded that the main problems of sprinkler irrigation systems are deficient design and implementation, low distribution uniformity, low water pressure, deficient distribution of pressure, insufficient lengths of lateral pipelines in addition to poor quality equipment and deficient management and maintenance processes. According to Jabbary et al. (2018), the uniformity of sprinkler irrigation is a central design goal. Uniformity relates to how evenly water is applied over a given area. Since no irrigation system can apply water precisely to all areas of the field, it becomes necessary to estimate the uniformity of water application in order to assess the performance of the system. The uniformity of water application is also sought to minimise the variability of crop yield or plant quality (Dukes et al., 2006). The two most common methods of expressing uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU). CU calculates the average deviation of the catch compared to the depth of the catch, while DU compares the driest quarter of the field to the rest. For a typical overhead system with a statistically normal distribution, CU > 70 %; CU and DU are approximately related (Nasab et al., 2007). Li and Rao (2004) studied the spatial variation of water in the soil and the response of crop growth and yield to non-uniform water application. The results showed that the coefficients of uniformity for water storage in the soil were always greater than those of the sprinkler uniformities. It was, therefore, concluded that reduced sprinkler uniformity may not necessarily result in a lower yield. Ahaneku (2010) found that the coefficient of variation (CV) of infiltrated water was one-third of the applied water measured by catch cans under sprinkler irrigation. This indicates that variability in the catch can data does not adequately represent soil moisture variability. Several works have been reported on the evaluation of sprinkler systems with an emphasis on irrigation uniformity.

Jadhav et al. (2017) indicated that sprinklers are suitable in areas where surface irrigation is not possible. Rain gun is most popular because of their ease of operation and less costly as compared to conventional sprinkler irrigation systems. It can be used for all types of crops under varying topographic conditions and different types of soils. Rain gun sprinklers have been adapted for various agricultural and non-agricultural uses. It can also be used for frost and fire protection. The sprinkler irrigation ensures adequate seed germination with only one irrigation of water after germination. Gun spray system results in overall higher irrigation efficiency as compared to conventional irrigation system by minimising the losses such as conveyance, percolation, evaporation etc. Rain gun sprinkler improves the yield and water use efficiency (Ashoka, 2015).

Sanden (2011) said it is impossible to irrigate efficiently with bad uniformity; parts of the field will be either over-irrigated or under-rigated which affects the agronomy of plants under and over-watering. Irrigation uniformity is related to crop productivity and the efficient use of water resources, making it a key element to consider when selecting, designing, and managing irrigation systems. Daccache et al. (2010) stressed that the sprinkler water distribution pattern is determined by system design factors such as sprinkler spacing, operating pressure, nozzle diameter, and environmental variables including wind speed and direction. Alsayim et al. (2015) concluded that increasing water efficiency is the most effective approach to save irrigation water and conserve water resources. It was also reported that the use of large numbers of sprinklers on irrigation laterals has been the main reason for the low CU and DU of sprinkler irrigation systems. Ortíz et al. (2010) found that the uniformity is increased when the two coefficients (CU and DU) are closer. The uniformity coefficient of a sprinkler irrigation system has a direct effect on the system's application efficiency as well as the crop yield.

2.4.1 Mobile Sprinkler Rain Gun Irrigation System and Water Use Efficiency

Although various advanced and cost-effective techniques, including surface and subsurface drip irrigation systems, have been developed in recent decades (Kalfountzos et al., 2007), traditional mobile sprinkler irrigation systems continue to play an important role in vegetable and crop production. A moving rain gun, for example, could be a viable alternative option for farmers looking to implement pressurised irrigation system. Most irrigation systems are designed for rectangular or square irrigation surfaces. The system's adaptability is determined by the type of irrigation movement, structural flexibility, and quantity of sprinklers. When compared to the centre pivot irrigation mechanism, the moving rain gun is far more adaptable. The irrigation surface is utilised at 60 % with these methods (Spencer, 2019), however this can be reduced if the irrigated area is not square. According to Anwar et al. (2004), the employment of a travelling rain gun is frequently accompanied by a number of issues such as the optimal choice of the rain gun model and type, proper adjustment of operational parameters and maintenance, effective control, continuous monitoring, and among others. In general, an irrigation system should offer homogeneous water deposition in both the longitudinal and lateral directions, consistent with the irrigation standard established for each specific season of the year.

Sprinklers can be a worthwhile investment if properly designed, installed, maintained, and monitored. Sprinklers administer water more effectively and consistently thstandard surface irrigation systems, resulting in higher yields per unit area (Hill & Heaton, 2001).

2.4.3 Comparative Water Use Efficiency of Sprinklers and Drip Irrigation Systems

According to Deng et al. (2006) and Hassanli *et al.* (2009), drip and sprinkler irrigation systems can maximise water use efficiency and yield per unit of water applied to crops. When combined with good farming practices, these two irrigation systems can reward farmers with high or optimum crop yield. Furthermore, Quiros et al. (2022) believe that the two-irrigation method can lessen artificial environmental consequences involving water waste, such as land reclamation with sewage and water waste from cities and factories, by transforming them into agricultural crop productivity. Much published research has examined the feasibility of deficit irrigation (drip and sprinkler) and whether significant irrigation water savings are possible without significant yield effects, with yield and production efficiency differences observed on various field crops and vegetables (Pascale et al., 2011).

According to Quiros et al. (2022), both sprinkler and drip irrigation are water-use efficient, which means they utilise less water and provide adequate moisture control, resulting in high and quality crop output. Phogat (FAO, 2002) reported that sub-surface drip irrigation increases water use efficiency (WUE) by more than 95 %. It was determined that, as compared to sprinklers, drip irrigation covers less surface water application area, maintains moisture, and directs water to crops while lowering farming costs.

2.4.4 A choice Between Low and High pressurised Sprinkler Irrigation Systems

A fundamental challenge in sprinkler irrigation is improving application efficiency in low-pressure situations, especially for high-pressure sprinklers like impact sprinklers. Low-pressure sprinkler irrigation is increasing popularity, putting pressurised irrigation's long-term viability at risk. Dispersion devices can be tuned and fitted on impact sprinklers to improve jet breakup and provide a favorable microclimate for optimal crop yield (Issaka et al., 2018).

Zou (2013) identified the primary challenges in sprinkler irrigation methods for crop productivity. It was also said that the fixed dispersion mechanism for impact sprinklers must be optimised, as well as how water savings estimates gained from field experiments can be applied to other places with drastically different conditions.

High-pressure sprinklers, such as impact and fluidic sprinklers, produce moving streams of water across long distances. Impact sprinklers offer a complete or half-circle application pattern with a head-to-head distance of 12 m (Shaughnessy, 2013). Sprinklers meant to operate under high-pressure circumstances should not be used in low-pressure environments. Sprinklers are intended to meet certain flow and pressure requirements. For example, operating impact sprinklers at 70 KPa-100 KPa will cause distortion in the application pattern and lower efficiency (Siebert, 2010). When operated at low pressure, impact sprinklers provide insufficient jet break-up, resulting in inadequate water distribution. Operating impact sprinklers under low-pressure conditions results in unequal water distribution and wastage of irrigation water. For these reasons, mechanically breaking up the jet with a permanent water dispersion device is critical to improving water distribution under low-pressure conditions (Nordey et al., 2017).

Fordjour et al. (2020) created a fluidic sprinkler using the "Coanda effect" principle, in which water flows from the nozzle into a tube put in the fluidic component, forming a low-pressure area. Although this application improves water distribution, the fluidic sprinkler's rotational homogeneity remains an issue. According to Li et al. (2019), both impact and fluidic sprinklers are employed in a solid set configuration, with enough nozzles installed to spray water throughout the irrigated area. It was also claimed that they are employed in lateral move designs and require 12-24 hours of irrigation time. Interest in low-pressure sprinkler applications to save irrigation water is growing. Low-pressure sprinklers, such as the R3000 and R33, save money and time while providing better performance than brass impact sprinklers. R33 sprinklers are modern, high-performance sprinklers that provide a longer sprinkler range, wind resistance, and equal water distribution. Low-cost sprinklers retain the benefits of traditional sprinklers while eliminating the barriers to their adoption by smallholders. Factors include pressure and cost needs, as well as the complexities of its use and maintenance. Improvements in the design and management of such systems reduce water loss from runoff and soil erosion (Yisheng, 2014).

According to Colaizzi et al. (2017), pivot sprinklers have the ability to optimise water distribution in a crop field by managing crop evapotranspiration, which is influenced by factors such as crop type, irrigation method, climate, and soil condition. There is an inbuilt sensor to monitor soil and plant health, which is connected to a wireless communication system and provides inputs for algorithms that control and manage irrigation. According to Li et al. (2019), while the use of site-specific irrigation systems is increasing, there is a lack of knowledge about how these systems should be maintained and optimszed to save resources. The report also indicated that, while there is considerable interest in low-pressure sprinkler systems with applications within or near the crop canopy to potentially maximise energy and reduce evaporative losses, their performance can be significantly hampered by increased runoff potential. King (2016) created a soil-independent, quantitative runoff-potential indicator to help with the selection of moving spray-plate sprinklers for center-pivoted and lateral-move sprinkler irrigation systems. The methodology was tested with numerous commercially available sprinkler packages. The findings revealed significant variances, with numerous packages having similar runoff potential. Mobile sprinkler irrigation system allows for the movement of sprinklers and sometimes the entire system to water different areas. These systems are versatile and can be moved around a property to provide irrigation to various locations, making them suitable for pastures, gardens, orchards, and other areas.

Figure 2. 7: Canvas pipe Hose reel Equipped with Mobile Sprinkler Rain Gun (Source: Muhammad et al., 2017)

2.4.5 Deficit Irrigation (DI) Systems

A major factor in the increase in agricultural output over the past 50 years has been the nearly twofold increase in irrigated areas in recent decades (Mateos et al., 2002). Furthermore, according to FAO (2014), which Agnew (2018) referenced, irrigated agriculture uses over 70 % of the water extracted from the world's rivers, with the percentage rising to over 80 % in developing nations. Although water is still a limited resource, its use in agricultural food production is becoming increasingly competitive due to present and upcoming factors like the world's population growth, which is predicted to reach 9 billion people by 2050 (FAO, 2014), climate change, and activities in the agricultural and industrial sectors. Due to unsustainable agricultural techniques that use excessive amounts of water and other production inputs, which result in inefficient output and water scarcity, this poses a danger to both sustainable agricultural production and global food security (Chaves, 2007). The majority of people, particularly in developing nations, continue to suffer from malnutrition and live below the poverty line. Therefore, it is crucial to take into account the following: how much agricultural practices can be controlled, and how much cropland water requirements can be reduced at high output through improved management techniques to satisfy the current crop production demand, and how much food can be produced continuously to feed the world's expanding population and future generations without endangering the environment (Oweis, 2017). Water-efficient farming methods and yield-enhancing irrigation techniques should be used to lessen these impacts (Jackson et al., 2011). Furthermore, a number of studies have shown that, at the small-scale level, the use of irrigation techniques like deficit irrigation (DI) systems—which are especially advised for arid and semi-arid regions—can be one way to address water issues and low crop yields (FAO, 2002). DI techniques like drip irrigation and sprinklers can increase crop quality and output in arid regions, according to Shock and Feibert (2002). Drip and sprinkler irrigation systems can optimise water use efficiency for a high yield per unit of water supplied to crops, according to studies (Kirda, 2002). When paired with effective farming techniques including management of pests, fertilizer, soil, mechanisation, and improved seeds, the two irrigation systems (sprinkler and drip) can provide farmers with high or optimal crop yields. According to Jackson et al. (2011), the two-irrigation method can reduce water-wasting man-made environmental consequences, such as sewage-filled land reclamation and water waste from industry and towns, and turn them into agricultural crop productivity. The technology of drip and sprinkler irrigation has demonstrated success in terms of water use efficiency (WUE), high agricultural yield or productivity, and crop adaptability to nearly all crops. In a large semi-arid region of China, it has also been effective in raising grain productivity (Kang et al., 2000) and producing vegetable crops such as potatoes, tomatoes, and spicy peppers (De Rouphael et al., 2018). Numerous published studies assessed the viability of deficit irrigation (drip and sprinkler) and whether large irrigation water savings are achievable without causing appreciable yield effects. Variations in yield and production efficiency between the two irrigation systems have been noted for various vegetables and field crops (Rouphael et al., 2018). The two irrigation systems have been the subject of additional research, and the majority of these studies have shown success in terms of irrigation output efficiency. A study by Imtiyaz et al. (2000) found that vegetables such spinach, rapeseeds, tomatoes, onions, and cabbage had a high economic return and were successful in terms of production efficiency; nevertheless, the findings were positively connected with the amount of irrigation water. Additionally, it is claimed that additional factors including irrigation schedule, input costs, and agricultural methods are among those that affect efficiency (Lanfranchi et al., 2014). The two irrigation methods' respective efficiency results were reported by several scientists. According to Martins et al. (2013), drip irrigation and sprinkler irrigation are both water-efficient, meaning they consume little water resources and effectively regulate moisture levels to produce high-quality crop yields. According to Phogat (2017), cited in FAO (2002), subsurface drip irrigation increases water use efficiency (WUE) for a variety of crops and vegetables by more than 95 %

when compared to sprinklers. This is because drip irrigation uses less surface water application area, retains moisture, and directs water to crops while also lowering farming costs. In contrast to the study (Stegman, 1982) that found no statistically significant yield differences in maize between drip and sprinkler irrigation techniques, albeit they differ in WUE, Kuscu & Demir (2013) found that drip irrigation reduced the yield of Zea mays production. Other research, focusing on vegetable crops, found no statistically significant differences in yield between drip and spray watering.

2.4.7 Crop Water Requirement and Irrigation Water Use Efficiency

Optimising irrigation systems and tailoring water application to crop water requirements is critical for sustaining agricultural production in the next years. This will help to protect the quantitative and qualitative components of water conservation (Delirhasannia et al., 2010). Although irrigation boosts output, it may also incur large costs (Tanasescu, 2004). Miodragović (2012) suggests that minimising losses in water distribution networks is crucial for reducing crop production costs and ensuring agricultural sustainability. Crop water consumption efficiency has been demonstrated to be dependent on irrigation quantity and frequency. Tillage methods can also affect water use efficiency for a particular irrigation frequency (Adekalu, 2006). Irrigation scheduling efficiency is primarily determined by the quantity, amount, and consistency of water applications.

Excessive doses of infrequently delivered water will result in significant percolation losses. One conceivable technique, among many others, is to create irrigation systems with as equally distributed water deposits as possible. Furthermore, based on the water yield connection established by Kiziloglu et al. (2009), an optimal irrigation water amount plan must be developed utilising various optimisation criteria and techniques. Miodragovic et al. (2012) observed that the uniformity of water distribution given by moving rain guns varied greatly, ranging from 1% to 88% of nominal value, with an average value of 62%. In addition, only two of the Smith et al. (2008) created customised modelling software that provides useful information on the water deposition uniformity of a rain cannon based on wind velocity and direction. It was said that simulation allows for the evaluation of raining track distance, and that water deposition between two tracks ranges from 0 to 39.5 mm. The investigation collected data from many stationary rain meters spaced every 5m along the rain-gun width. The data were gathered at various wind speeds ranging from 0.68 to 3.66 m/s. Different types of irrigation systems have been created and implemented to fulfil the specific needs of various crops, climates, soil conditions, and growth technologies (Skataric & Dragovic, 2018).

2.5 Cost-benefit analysis

Acharya et a*l.* (2020) carried out a cost-benefit analysis (CBA) of small farm equipment (trans planter and power tiller) utilised for rice cultivation in Nepal's Bardiya districts. The power tiller's benefit-cost ratio (2.89) was larger than the transplanter's (1.61), according to the analysis. Because of the power tiller's lower payback period and better internal rate of return, the investment seemed to be lucrative. Sensitivity analysis results indicated that even a 20 % drop in benefit or cost rise would still be profitable.

Additionally, it was mentioned that low-income farmers would find it difficult to purchase power tillers; therefore, the government ought to assist farmers by offering subsidies or setting up specially designed service centres to promote the use of this equipment for rice cultivation. It was recommended that varied amounts of subsidies and technical capacity building be used to encourage farmers to use small farm equipment in rice farming. This demonstrated that even a 20 % drop in benefit or cost increase would result in a profit.

Mottalib et al. (2019) evaluated the cost-benefit ratios of conservation agricultural equipment for the growth of custom hire entrepreneurship in Bangladesh's southern area. Determining the economic parameters for the development of conservation agriculture (CA) was one of the study's main goals. The machine's benefit-cost ratio was determined to be 1.10, making it a successful business endeavour for an entrepreneur. 3.12 hectares of machine operation were calculated to be the CA machines break-even.

The economic assessment of a robotic tiller-planter as a remedy for small-scale farmers' issues is the main topic of Rathod et al. (2024). The results demonstrate the robotic system's affordability and environmental advantages. This tiller-planter turns out to be a profitable investment. Spot tilling and planting, drastically saved prices by 54.72 % and time requirements by 61.58% when compared to traditional approaches. Additionally, the tiller-planter reduces the requirement for physical labour by performing two tasks.

According to Akudugu et al. (2019), primary and secondary data from irrigation facilities in northern Ghana was used to investigate irrigation investments and the financial and economic repercussions for the generation of wealth and jobs. Climate change, which makes it harder to get water for cultivation in the drier regions of the continent, was cited as one of the main obstacles to achieving the Vision 2020 agenda for agricultural development in Africa. To overcome this problem, investments in technologies and infrastructure for water harvesting were essential for the development of irrigable crops. They examined the costs and advantages of three technologies in particular: groups of farmers using electricity-powered water pumps, and individual farmers using gasoline and diesel-powered pumps. The findings showed that there is a good chance that irrigation technology investments will yield returns that outweigh the expenses.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presents the methods employed in designing and simulating the PPTISGIS. It further outlines the methodologies applied in the field evaluation of the PPTISGIS. The details include the experimental site, experimental design, conceptual design framework, evaluation, and data analysis tools employed to generate the results. The materials used for fabrication and field evaluation of the PPTISGIS are discussed in this chapter.

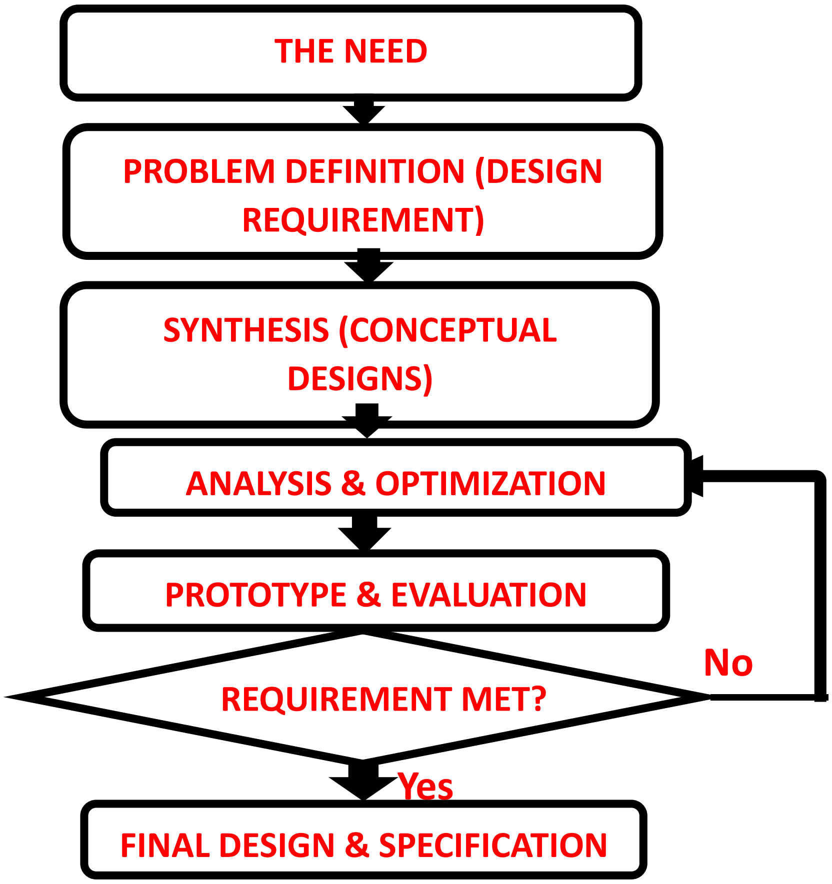


Figure 3. 1: Framework for the Design Process

3.1 Design Process

3.1.1 The Need

This is the starting point of the design process. It involves recognizing and clearly stating that a problem exists or an opportunity for improvement has been identified.

3.1.2 Problem Definition (Design Requirements)

Here, the general need is turned into a specific, well-defined problem. Design requirements are outlined, which guide the rest of the process. These requirements include: Functional needs (what it must do), Constraints (budget, size, materials), Performance criteria and Regulatory or safety standards

3.1.3 Synthesis (Conceptual Designs)

This is the **creative phase** where multiple **concepts or possible solutions** are developed. It's about generating ideas based on the problem definition: Sketches, diagrams, or CAD models might be made, Designers consider different ways the solution could be approached.

3.1.4 Analysis & Optimization

Each concept is **evaluated and tested** through simulations, calculations and compare to the criteria set in the design requirements. Weak ideas are discarded. Promising ideas are refined or **optimized** for performance, cost, durability, etc.

3.1.5 Prototype & Evaluation

A working prototype of the best design was built. It was tested in real conditions to evaluate: cost of production, ease of maintenance, ease of operation, Functionality, reliability and Torque Production capacity.

3.1.6 Final Design & Specification

After successful prototyping and testing, the design is finalized. Detailed documentation prepared, including: Engineering drawings, Manufacturing instructions, Materials specifications and Assembly guides

3.2 Materials used

The design and manufacturing of a prototype power tiller incorporated with spray gun for irrigation. The machine is to be powered by a four-stroke engine and therefore requires a careful selection of materials to ensure durability, efficiency, and safety. The key components and their materials in this design are:

3.3.1 The Frame

Mild (low carbon) steel was used for the frame due to its strength, durability, and relatively low weight. Mild steel is also readily available at a relatively low cost in the local market.

3.3.2 Prime Mover

The engine is made of aluminium alloy because it balances strength and weight well. A petrol engine (single cylinder) of CG 125 was used as a prime mover for running the tiller and the sprinkler system. To transmit power from the engine to the wheels and the pump, a chain and a set of V-pulleys were provided. A V-pulley of 152 mm diameter was attached to the engine's output shaft while another pulley of diameter 203 mm was provided at the pump shaft. The details of the engine are shown in Table 3.1.

Table 3. 1: Engine Specifications

S/No	Specifications	
1	Model	Apsonic C G 125
2	Model year	2022
3	Displacement	125.0 cc (7.63 cubic inches)
4	Engine type	Single-cylinder, four-stroke
5	Top speed	85.0 km/h (52.8 mph)
6	Compression	9 :1
7	Fuel system	Carburettor
8	Ignition	CDI (Capacitor discharge ignition)
9	Cooling system	Air
10	Gearbox	5-speed
11	Transmission type	Chain (final drive)
12	Clutch	Wet multi-plate

3.3.3 Tiller Components

Medium carbon steel was used for the blade due to its durability and resistance to wear. It was heat-treated to increase ductility and hardness, and also boost yield strength and resistance to impact loads (Gorni, 2011).

3.3.4 Spray Gun Components

The pump housing is made of cast iron due to its strength whereas the inlet and outlet pipes are made of brass due to its corrosion-resistance. Polyvinyl chloride (PVC) hoses were used to connect the pump inlet to the water source, and outlet to the sprinkler.

3.3.5 Transmission System

The belt is made of synthetic rubber and reinforced with fibres for greater strength. Regarding the chain, the rollers are high carbon steel, the pins are hardened steel, and the side plates are mild steel. This combination gives optimum strength at a competitive cost.

3.3.6 Wheels

High-quality sturdy rim, made of steel alloy.

3.3.7 Controls and Handles

Round galvanized steel pipe was used for the handle-bars due to its strength, stability and lightweight. The gear lever was made of mild steel whereas the clutch and brake levers were made of aluminium alloy.

3.3 The Design Process

In the design of a Prototype power tiller incorporated with spray gun for irrigation (PPTISGI) powered by a motorbike engine, several key steps were involved. The design process typically included defining the requirements, conducting research, conceptualising the design, detailing the design, prototyping, testing, and refining the final product.

3.3.1 Design considerations

Designing and manufacturing a PPTISGIS using a motorbike engine required careful consideration of various factors to ensure efficiency, functionality and ease of use. Key requirements were set regarding power, size, versatility in attachments, spray gun integration, operator ergonomics, engine efficiency, adjustability of depth, safety features, and cost-effectiveness in manufacturing. With these design considerations, the resulting power tiller incorporated with a spray gun can offer a practical and efficient solution for farmers with limited resources.

3.3.2 Power Requirements

The tiller and spray gun power needs must match the motorbike engine's capacity. It is essential to optimise power distribution to efficiently support both the tiller and irrigation components, ensuring it stays within the limits of the engine's capacity.

3.3.3 Size of the Design

The design should be compact and lightweight structure to facilitate easy manoeuvrability, considering the limitations of a motorbike engine. Space requirements for storage and transportation should also be kept to the barest minimum.

3.3.4 Versatility in Attachments

The design should be flexible enough to allow for easy attachment and detachment of implements for different agricultural tasks and irrigation needs. That is, compatibility with a variety of implements suitable for different soil types and crops must be ensured.

3.3.5 Spray gun Integration

To integrate an efficient spray gun into the design, factors such as water pump capacity, distribution mechanisms, and irrigation area coverage must be considered. The system should be easily connected to water sources and adapt to various irrigation methods, such as drip or sprinkler systems.

3.3.6 Operator Ergonomics

The comfort and safety of the operator must be prioritised by designing intuitive, easy-to-access, and easy-to-use handles and controls for both the tiller and spray gun components. Consider adjustable features to accommodate operators of varying sizes. Also, provide clear labelling and instructions for operation and maintenance.

3.3.7 Engine Efficiency

The motorbike engine for fuel efficiency and reliable performance was optimised. A cooling system was incorporated to prevent overheating during prolonged use.

3.3.8 Adjustable Depth

A mechanism for adjusting the tiller's depth to accommodate different soil conditions and crop types was provided.

3.3.9 Safety Features

Safety features such as emergency shut-off switches, protective guards, and clear warning labels should be provided. That is, proper shielding of all moving parts was provided to prevent accidents during operation.

3.3.10 Cost-Effective Manufacturing

Cost-effective manufacturing processes was employed without compromising quality. Also, local sourcing options for materials and components were explored to reduce production costs. The overall cost of the power tiller and the spray gun are within the budget constraints of small-scale farmers to ensure affordability.

3.3.11 Conceptual designs

Designing a prototype power tiller with an integrated irrigation system powered by a motorbike engine involves combining elements of agricultural machinery and irrigation technology. These include a frame, power source (Motorbike Engine), fuel tank, power transmission system, wheels, belt, chain, tilling unit, spray gun irrigation system (water pump, hoses and nozzles, water filter, Sprinkler Stand), and safety features. In line with standard design practice, three conceptual designs were generated for the PPTISGIS and evaluated. The conceptual designs were a petrol prime mover engine with a lagged tyre (Concept A), a petrol AP 125 prime mover engine with a caged wheel (concept B), and a motorcycle engine with two cage wheels and two caster wheels (concept C). The best concept was selected and analysed further.

3.3.12 Concept A (a petrol engine prime mover with lagged tyre)

In addition to the mouldboard plough and the water pump, this concept consists of a 5.5 hp petrol engine, a lagged tyre located at the front, and a depth control wheel at the back (Figure 3.2). The lagged tyre is suitable for providing efficient traction. It has a reel mounted on a vertical support, for carrying the water hose. The main challenge with this design is that the petrol engine is used as the prime mover and does not have an inbuilt gearbox, making it impossible to increase torque without an increase in speed.

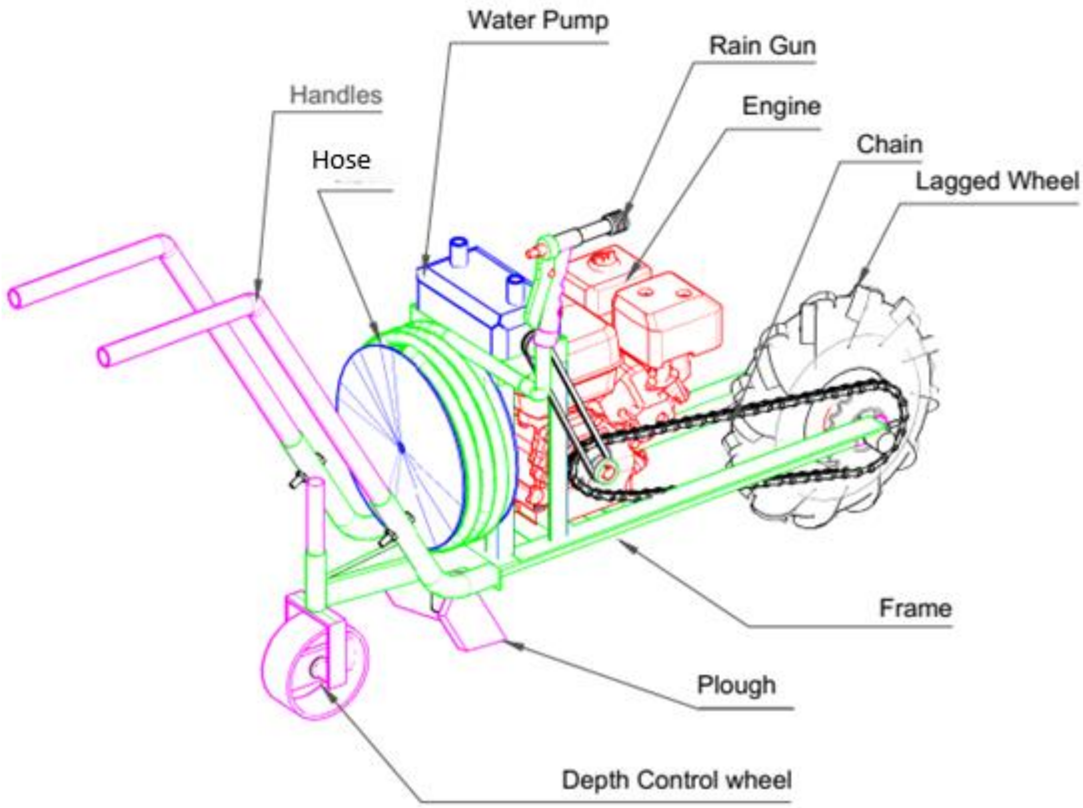


Figure 3. 2: Concept A

3.3.12.1 *Concept B (motorbike engine with caged wheel)*

In addition to the water pump and the mouldboard plough, this concept comprises of AP 125 motorbike engine with 11 hp @ 8500 rpm. It has a cage wheel at the back which drives the machine, and two plain wheels at the front to keep the machine in a balanced position. It also has a reel mounted on a horizontal support with the water pump. The cage wheel can provide the required traction, reducing slip to the barest minimum. What are the limitations or otherwise with this design?

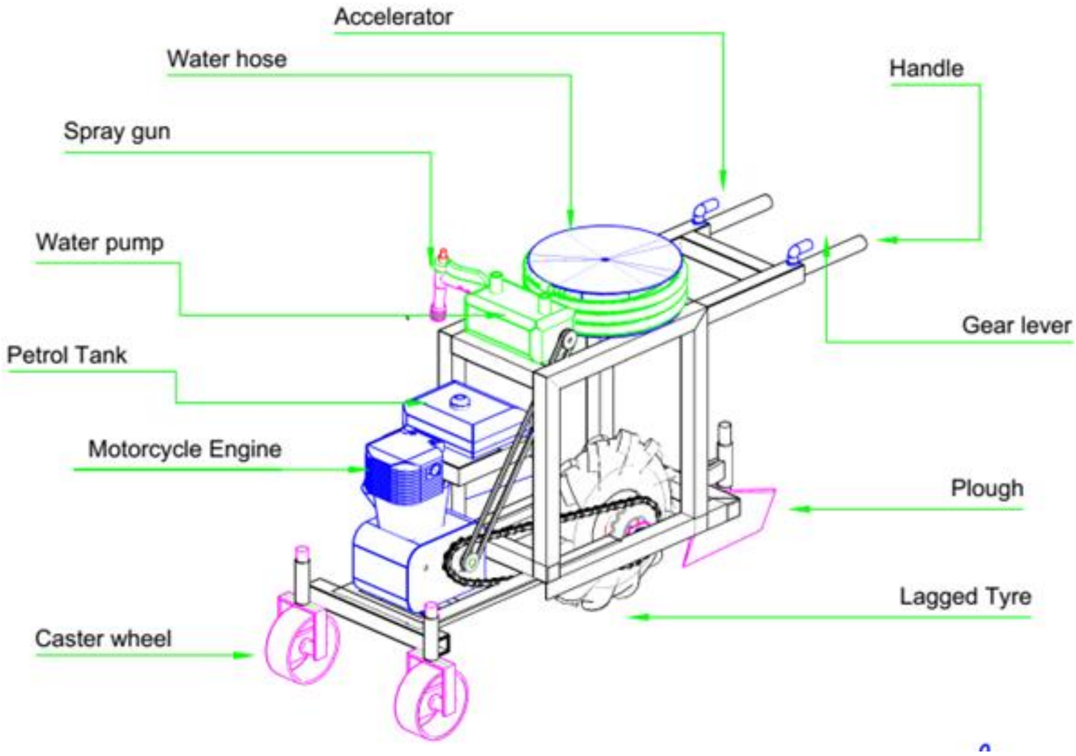


Figure 3.3: Concept B

3.3.12.2 ***Concept C (motorbike engine with two cage wheels)***

In addition to the mouldboard plough and the water pump, this concept also has a CG 125 motorbike engine with 11hp @ 8500 rpm. This gives the concept the same advantage of the possibility of increasing torque without necessarily increasing speed. The reel for carrying the water hose in this concept is also mounted on a vertical support as in concept A. While power tillers are versatile, they may not be ideal for large-scale irrigation or in areas with very hard or uneven terrain.

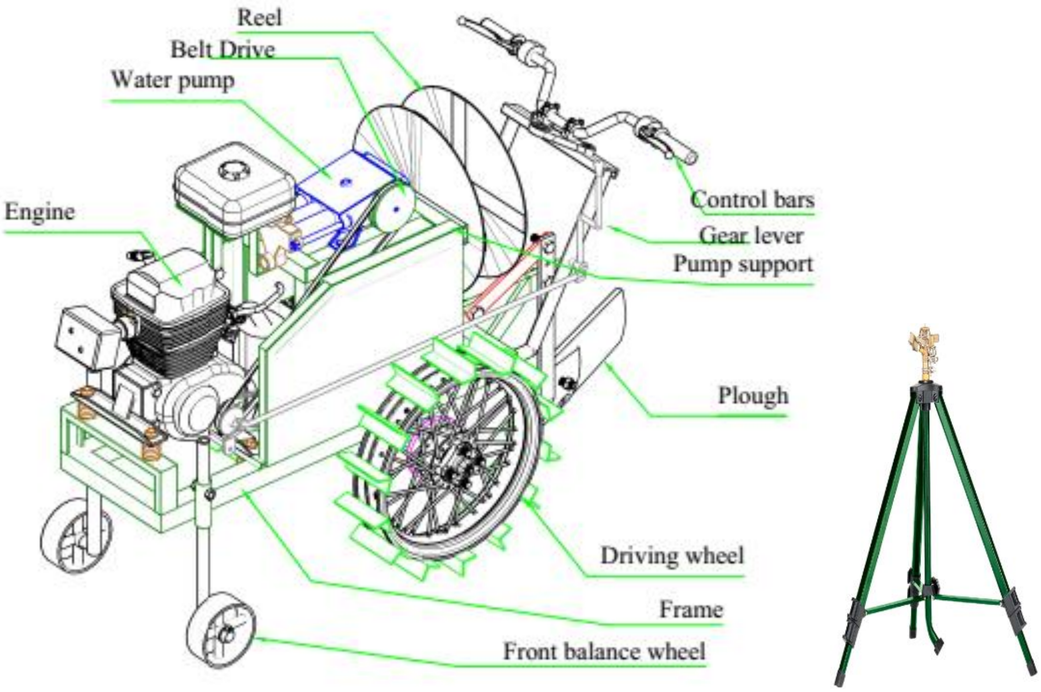


Figure 3. 4: Concept C

3.3.13 Concept evaluation parameters

The conceptual designs were evaluated using generic design factors (cost of manufacture, ease of maintenance, ease of operation, and dependability). In addition, a parameter peculiar to power tillers (torque production capacity) was also used.

3.3.14 Cost of production

This parameter took into account the expected overall production cost for each conceptual design. This included the cost of materials, the method/equipment to be utilised, the necessary abilities, and the amount of energy and labour required.

3.3.15 Ease of maintenance

This measure assessed how easily the power tiller could be maintained in each potential design. It assessed the accessibility of all parts that required regular cleaning, the availability of replacement parts, and the simplicity with which parts could be replaced.

3.3.16 Ease of operation

This measure compared the operational processes of each conceptual design to determine which was the least complex and tiresome. It precisely examined the level of training that an operator would require before using the equipment in each situation.

3.3.17 Reliability

This parameter examined the elements of conceptual designs that protect the Power tiller against failure. It precisely examined the Power tiller's capacity to till at the specified pace without failure and to function successfully during the expected lifespan.

3.3.18 Torque Production Capacity

This parameter accessed the potentials of the various concepts concerning the production of torque. It specifically considered the number of mechanical advantages each concept can generate using the same inputs.

3.3.19 Concept evaluation criteria

The criteria used to evaluate the conceptual designs are presented in Table 3.1

Table 3. 2: Design Concept evaluation criteria

Parameters					
Cost of production	**Magnitude (GH₵)**	≤5,000	5,100-6,000	6,100-7,000	7,100-8,000
	score	4	3	2	1
Ease of maintenance	**Magnitude**	Very easy	easy	normal	difficult
	score	4	3	2	1
Ease of operation	**Magnitude**	Very easy	easy	normal	complicated
	score	4	3	2	1
Reliability	**Magnitude**	Most reliable	Very reliable	reliable	unreliable
	score	4	3	2	1
Torque Production Capacity	**Magnitude**	Most Capable	Very Capable	Capable	Less Capable
	score	4	3	2	1

Table 3.3: Decision matrix

Parameters		Concept A	Concept B	Concept C
Cost of production	Magnitude (GH₵)	5,800.00	6, 500.00	7,285.20
	Score	4	3	3
Ease of Maintenance	Magnitude	Easy	Easy	Easy
	Score	3	3	3
Ease of operation	Magnitude	Easy	Easy	Very easy
	Score	3	3	4
Reliability	Magnitude	Reliable	Most reliable	Most reliable
	Score	2	4	4
Torque Production Capacity	Magnitude	Capable	Most Capable	Most Capable
	Score	2	4	4
Total		**14/20 =70%**	**17/20 = 85%**	**18/20 = 90%**

3.4 Kinematic analysis

In the design of a moving machine, the mechanism of speed reduction and the kinematic parameters of each power transmitting element should be determined before starting the stress analysis. Mechanisms through which the power passes until it reaches the ground must be known and all possible kinematic values should be well-defined. However, without some basic design analysis, and kinematic analysis could be impossible. Therefore, some parameters were predetermined using force analysis and some dimensions by geometrical measurements as shown in Table 3.4.

Table 3.4: Basic input parameters of the kinematic analysis (see Appendix B1)

Parameter	Units	Quantity
Engine output power	hp	11
Engine maximum revolution	rpm	8500
Engine output shaft diameter	mm	18
Engine output shaft keyway (length × width × height)	mm× mm × mm	365.4 × 263.2 × 512.7

3.4.1 Mechanisms of power transmission

The engine generates the power and provides the rotation to the output shaft. The rotation is then transferred to the driving wheel through sprocket and chain drive. Also from the output shaft, the rotation is transferred to the water pump through pulley and belt drive system. This transmission arrangement is illustrated in Figure 3.5.

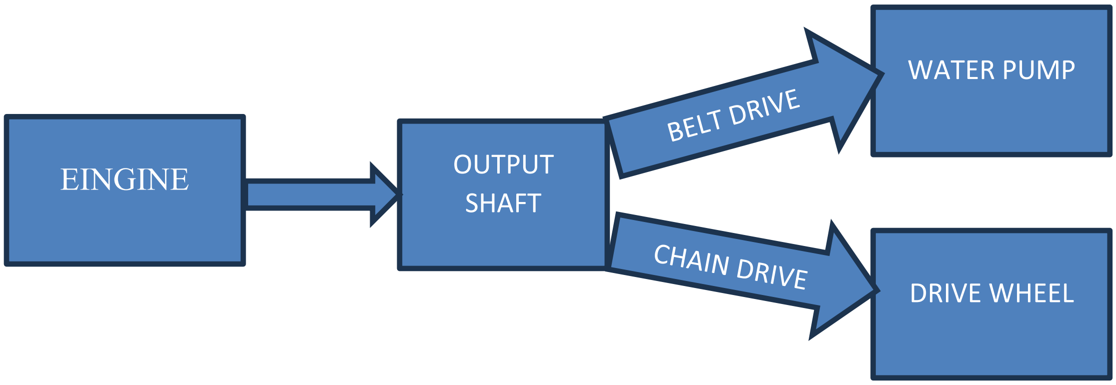


Figure 3.5: Power Transmission Arrangement

3.5 Determination of Speed reduction ratio

3.5.1 Design of the belt drive system

In the kinematic analysis of the belt, all possible kinematic parameters of the drive have been determined. The durability of the belt depends on various factors. The load carrying capacity, the life span of the belt and the number of belts needed for the transmission need to be analysed taking into account the power, forces and working conditions of the drive are essential inputs for this analysis.

The length of the belt was calculated using Equation 3.1 (Kalmar-Nagy, 2002)

$L = 2C + 1.57(D + d) + (D - d)^2/4C$ ………………………….. (3.1)

Where:

C = centre distance = 580 mm

D = diameter of large pulley = 123 mm

d = diameter of small pulley =70 mm

Reduction Ratio of belt Drive System = 123mm / 70mm = 1:2

3.5.2 Design of the Chain Drive System

Chain drives are selected to fit a certain power transmission system rather than being designed and manufactured. The reason is, that the manufacturing process of chains needs highly precise operations. In this study, the chain drive components have been selected to fit the kinematic relations and conditions of work listed in Table 3.6

Table 3.5: Input parameters for the selection of chain drive

Chain Drive Input parameters	
Reduction ratio	2.8:1
Drive sprocket	15 teeth
Driven sprocket	42 teeth
Center-to-center distance	510 mm
Working conditions	Moderate shock

3.5.3 Design of the Spray gun Sprinkler system

In this study, a medium-pressure plunger type of positive displacement pump was used to draw water from the source to shower the field under pressure through a sprinkler. The pump operates at a maximum of 4,285 rpm and delivers 31 m^3/h with 25 mm suction and 19 mm delivery diameter pipes. The pump is capable of delivering water to a head of 70.3 m with a 6 mm diameter nozzle and 11m throw length. The pump is driven by the Spark Ignition Engine (SIE) through a belt drive system. The Model Number of the sprinkler is K-350 1.3, Country of Origin: Chaina

3.5.4 Selecting the Pump

The essential component of the irrigation system that creates the desired water sprinkling is a pump and the type and size of the nozzles used. varied irrigation situations call for varied delivery rates and pressures, and utilizing the right pump is crucial to getting the intended effects. A pump's capacity must be adequate to deliver the required amount of water to the nozzles. The power needed to pump the water is known as water horsepower. Stated differently, it is the amount of electricity that pumps would need if they were completely efficient. Knowing the flow rate of water and the force needed to generate it (total head) will help calculate the water horsepower.

When friction losses in the pipe are taken into account, the total head is the total height at which a fluid is to be pumped. The total head is the sum of the friction loss, suction lift, and discharge head.

Table 3.6: Pump Specifications

S/No.	Specification	
1	Brand	Mouvex Triplex plunger Water Pump
2	Maximum flow Rate	5 GPM
3	Pressure Range	100-1500psi
4	Inlet	1/2in MPT
5	Outlet	3/8in FPT
6	RPM	4,285
7	Shaft	20 mm
8	Drive Type	Belt
9	Horsepower	5.1

3.6 Finite Element Analysis (FEA)

Analysis is the part in which a test is done to ascertain whether the component will work in the specific conditions or not with desired improvements and modifications. In the real world, no analysis is typical, as there are usually facts that cause it to differ from others. However, the following procedure was used for the analysis.

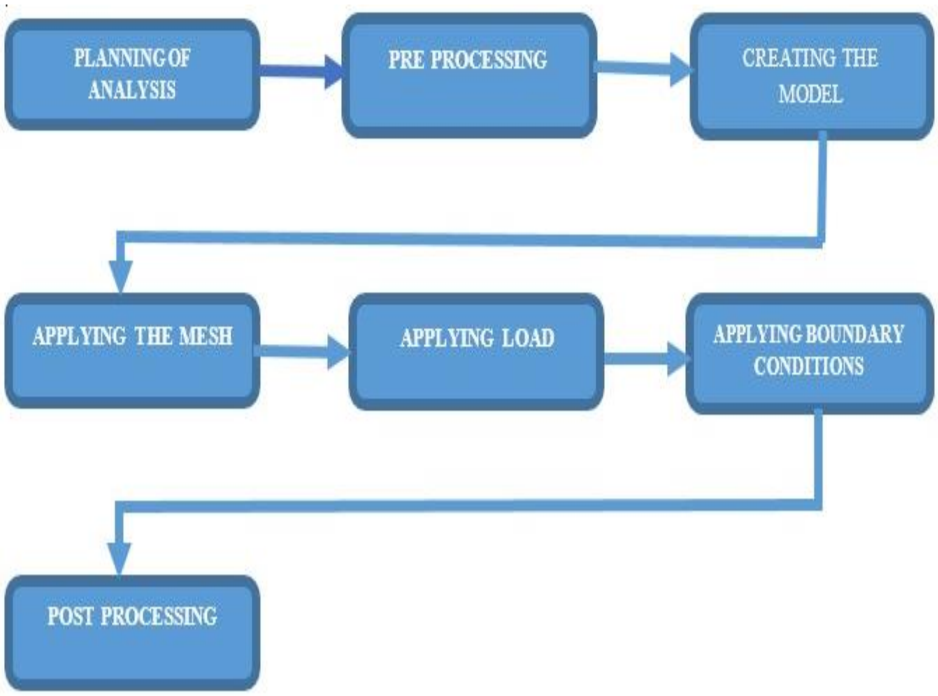


Figure 3.6: Analysis Procedure and the Steps Involved in the Process Planning the Analysis

Modeling a structure's behavior under a load arrangement is the primary goal of a finite element analysis. The degree of planning required for the analysis determines how accurate the results will be.

3.6.1 Pre-Processor

At this point, the problem and the file name were given. Although it is optional, giving a file a name is particularly helpful when working on many analyses for the same project. It also helps to distinguish between different iterations of the processes that are used on the same basic model.

3.6.2 Creating the Model

Initially, the models were created in AutoCAD's 2D sketch space using the proper units (mm). The neutral file formats were then used to turn the models into 3D space and upload them into Autodesk Inventor, another CAD design program, if a model is made in the program with, say, a unit of millimeters, the units of the model in the software stay the same when the model is imported; otherwise, the results can be off-scale and fall short of final expectations.

3.6.3 Applying a Mesh

Structured meshing is distinguished by its regular arrays of connected elements; it was chosen for the investigation. The storage structure establishes neighborhood ties, and the regularity of the connectivity permits space conservation. Finding the stress produced after load or calculating various other outcomes is a very time-consuming operation because the power tiller has multiple components with geometries that have variable shapes and sizes. Meshing breaks up such geometry into smaller components, for which there are specific formulas and functions to compute these outcomes, making all of these computations simpler. The overall solution for the geometry is then obtained by integrating all of these findings.

3.6.4 Apply Loads

Appropriate loads were applied to the models during the simulation which is equal to the maximum force exerted on the components during the operation of the machine.

3.6.5 Applying Boundary Conditions

A model is likely to accelerate when a load is applied. To prevent it from rushing endlessly through the virtual ether of the computer, at least one limitation or boundary condition needs to be in place. All of the machine's parts were restrained in this investigation to avoid acceleration. This made it clear that the boundary condition would only act in the (y-y) direction. For the design problem to be accurately solved, the right boundary conditions must be applied.

3.6.6 Post-Processor

The Finite Analysis (FEA) solver was divided into three main components: the pre-processor, the mathematical engine, and the post-processor. The pre-processor examines the model and determines its scientific representation. All parameters defined in the pre-processing stage are used to accomplish this, so if something is neglected, the pre-processor will complain and reject the call to the mathematical engine. If the model is changed, the solver continues to shape the component solidness network for the problem and invokes the mathematical engine, which computes the results. The results are returned to the solver, and the post-solver is used to calculate stresses, hassles, heat fluxes, speeds, and so on for each hub within the part or continuum. Each of these results is saved in an outcome record, which is then reviewed by the post-processor.

3.6.7 FEA of Frame

The frame was modelled in AutoCAD 2022 version and imported into Autodesk inventor 2023 software. The static analysis was selected, and mild steel applied from the built-in material library. The total weight acting on the frame (450 N), which comprises the weight of the engine, the water pump, and the pump support, was applied as a distributed load. Fixed constrain was applied to the ends and Tetrahedral mesh applied to the frame. The study was then computed.

3.6.8 FEA of the Engine Seats

In this analysis, the engine seat sub-assemblies (both front and rear seats) were modelled in AutoCAD 2022 version and imported into Autodesk Inventor 2023 software. The weight of the engine (305 N) was applied on the seats as a distributed load. Fixed constrain was then applied to the ends of the seat after which the study was computed.

3.6.9 FEA of the Mouldboard Plough

Like the engine seat, the geometry of the mouldboard was modelled in AutoCAD 2022 and imported into Autodesk Inventor 2023. The force applied at the end was 2525 N (the soil penetration resistance) which induces a tensile stress. Fixed constraints were applied to the ends of the holder after which the study was computed.

3.6.10 FEA of the Handle

The handle, just like the other parts, was modelled in AutoCAD 2022 and imported into Autodesk Inventor 2023. It was considered a cantilever beam, and loads were applied on the two ends of the handle. On both ends, a 157.5 N which is half of the force an average human being can apply (Giambattista and Betty, 2023) was applied downwards to each end. Fixed constraint was applied to the middle of the handle. The default mesh was used, and the study was computed.

3.6.11 FEA of the Driving wheel Shaft

The shaft was modelled in AutoCAD 2022 version and imported into Autodesk Inventor 2023 software. The static analysis was selected, and mild steel was applied from the built-in material library. The total vertical load acting on the shaft (550 N), which comprises the weight of the engine, the water pump, and the pump support, was applied, and a torsional load of 8090 Nmm due to the driving from the engine, was also applied. Fixed constrain were applied to the ends and Tetrahedral mesh was applied to the shaft.

3.7 Performance Evaluation of the Tilling Unit

3.7.1 Equipment used

The equipment used during the evaluation of the PPTISGIS Tilling Unit includes a stopwatch, measuring tape, and measuring can.

(a) Stopwatch (b) Measuring tape (c) Measuring can

Figure 3. 7: Equipment for Evaluation of the Tilling Unit

3.7.2 Experimental design for the tilling unit

The experimental design used to evaluate the tilling unit is a Randomized Complete Block Design (RCBD). There were two factors namely, operation speed and ploughing depth. Each of the factors had three levels.

The experiment followed a factorial arrangement, where each level of one factor is tested in combination with each level of the other factor. This results in 3 speeds x 3 depths = 9 treatment combinations.

Three replicate blocks were used, meaning each treatment combination was tested three times, resulting in 9 treatments by 3 replicates giving 27 experimental. Each plot was 1m by 19m.

3.7.2.1 *Randomization and Layout of the Experimental Field*

The speeds used are A (1 km/h), B (2 km/h), and C (3 km/h).

Table 3. 7: Randomization of the Treatments

	Block
	Plot 1: A
	Plot 2: B
	Plot 3: C
PLOTS	Plot 4: B
	Plot 5: C
	Plot 6: A
	Plot 7: C
	Plot 8: A
	Plot 9: B

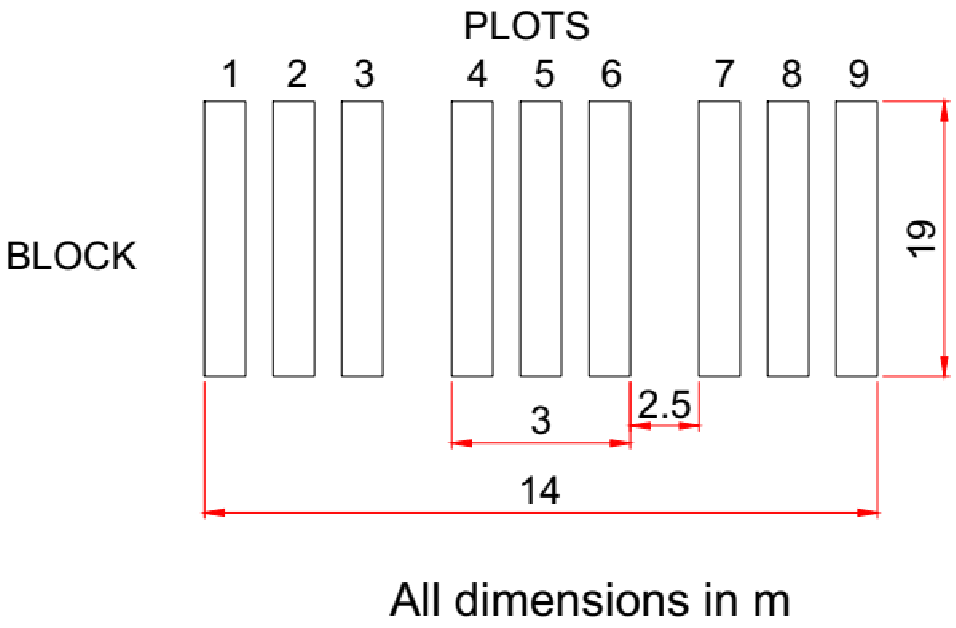


Figure 3. 8: Layout of the Experimental Field

3.7.2.2 ***Soil Analysis***

3.7.2.2.1 Materials/Tools

The equipment used in the soil analysis was a weighing can, electronic Scale, marker/Pen, electric oven and desiccator, Soil core rings with lids, a Mallet, and a Knife or Cutlass. The field experiment was conducted in loamy-sand soil at the University for Development Studies (Nynkpala Campus) at the Agricultural Mechanization Workshop site with a total land size of 14m by 19m.

The depth of sampling is critical because tillage and nutrient mobility in the soil can influence nutrient levels in different soil zones. Sampling depth depends on the crop, cultural practices, tillage depth, and the nutrients to be analyzed. Plant roots, biological activity, and nutrient levels occur mainly in the surface layers (0-25 cm); hence, most of the soil samples from the study site were collected within this layer.

3.7.2.2.2 Method

A double diagonal method (pattern) was used during field sampling. This was started by scraping away surface litter and crop residues and sampling the whole core from the true soil surface to 25 cm depth with a soil auger. Considering this, 9 cores were taken from the study site. All the core sampling was placed in a bucket, mixed thoroughly, and then composited. A half-full Soil sample bag (1000g) of this mixed representative sample was labelled and taken to the lab for air drying. After air drying in the lab, it was Sieved with a 2mm Laboratory Test Sieve (British Standard) and ready for use. Tools for soil sampling were Soil core rings with lids, a Mallet and a Knife or Cutlass. The core rings were drilled into the sampling points with the help of the Mallet without disturbing the soil structure. Dig around the core rings and then use the knife to shape the bottom carefully cover both sides and label.

The first step during the soil analysis was cleaning and drying the container and weighing (g) (W_1). The next step was placing the soil sample in the container and weighing (g) (W_2) this was followed by placing the container in an oven and drying it between 105 °C and 110 °C for 24 -hours to a constant weight. After drying, the soil samples plus the containers were removed from the oven and allowed to cool. The last step was to weigh (g) the container with soil (W_3).

3.7.2.2.3 ***Calculations***

Calculating the moisture content of the soil as a percentage of the dry soil weight.

$$MC\% = \frac{w_2 - w_3}{w_3 - w_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

Where:

w_1 = Weight of tin (g)

w_2 = Weight of moist soil + tin (g)

w_3 = Weight of dried soil + tin (g)

3.7.2.2.4 Determination of bulk density of soil

3.7.2.2.5 Materials Needed

The materials used in the determination of bulk density of soil were balance, sampling cans (Core Sampler), permanent marker, hammer or mallet, a knife, pencil or pen, sealable plastic bags, jars, or other containers to store samples and extra soil, and drying oven.

3.7.2.2.6 Sampling Procedure

The sampling procedure adopted involved inserting a 5 cm metal ring or core sampler by hammering to make sure the soil structure is not disturbed, carefully cutting the edge of the core sampler using the knife, covering both sides with the lid of the core sampler to avoid loss of soil and label the sample with the marker. Each core sampler plus moist soil (if wet Bulk Density is required) was weighed in the laboratory. The lids of all the core samplers were removed and each was placed in a 105° C oven for 48 hours. After this step, the weight of dry soil in the sample was determined using the balance. This was followed by measuring the length and diameter of the metal cylinders (Core sampler). Finally, the information was used to calculate bulk density, porosity, and water-filled pore volume.

V = volume of sample (cm^3) [$V=\pi 4d^2h$]

W_d = Weight of oven-dried sample at 105° C until the weight becomes constant

W_i = initial weight of the sample taken at the time of sample (g)

BD = bulk density. (g/cm3)

3.7.2.2.7 Permanent wilting point (pwp) using membrane apparatus

Materials/Apparatus:

The complete set consists of a pressure membrane extractor suitable for a maximum of 15 samples, a 20-bar compressor including a reducing valve and manometer, an air filter, cellophane membrane, filter cloth, synthetic soil sample retaining rings and various accessories including a balance, a drying oven and aluminium soil sample boxes with lids.

3.7.2.2.8 Procedure:

The permanent wilting point is the amount of water in soil held by force stronger than 15 bar, 4.2 pF or 225 psi, it represents the minimum point of plant available water. This was determined using a membrane apparatus for pF determination (pF 3.0 - 4.2 or 1.0 - 15.5 bar). In this setup, the semi-disturbed sample was saturated before measurement in the laboratory and placed in a synthetic ring.

After saturation of the sample for 6 to 24 hours, part of this sample is placed in a synthetic retaining ring and prepared further.

After closing the pressure membrane extractor, an overpressure is realised in the pressure membrane extractor using the compressor at 15 bars.

On reaching the equilibrium the samples are removed, weighed (W_1), oven-dried at 105^o C and weighed (W_2) again.

3.7.2.2.9 Mechanical Analysis (Texture)

Reagent.

The reagents used were Sodium Hexametaphosphate (5%), Hydrogen Peroxide and Ethanol.

3.7.2.2.10 Procedure

Particle size distribution (Clay, Silt, Sand) by hydrometer method.

Apparatus with components such as mixer (with baffled cups) (Soil test Inc.), Sedimentation cylinder, Hydrometer (ASTM 152H), Beaker (250 ml), Top loading balance, dispenser (50 ml, 100 ml), measuring cylinder (50 ml, 100 ml), stopwatch, timer, and thermometer.

3.7.2.2.11 Reagents

The reagents included Sodium hexametaphosphate, Na $(PO_3)_6$ (611.78) 99%, Deionized water, Ethanol, Hydrogen Peroxide.

3.7.2.2.12 Preparation of calgon Solution

In 1 litre flask, dissolve 35.7 g of sodium hexametaphosphate in 750 ml of deionized water. Then, vigorous shaking is required to dissolve the hexametaphosphate.

3.7.2.2.13 Procedure

The procedure used in the preparation of calgon solution included weight 51 g of air-dried soil (< 2 mm) and transfer into a 250 ml beaker, dispense 50 ml of the calgon solution prepared above and 100 ml of deionized water to the soil, shake on a mechanical shaker overnight to soak and disperse the soil particles. After mixing, the suspension was transferred into a sedimentation cylinder and made up to 1 litre with deionized water.

3.7.2.2.14 Measurement

This was done by placing the cylinder on a flat surface and the time taken. Followed immediately with placing the soil hydrometer into the suspension. The hydrometer slowly slides into the suspension until it is floating. The first reading on the hydrometer was taken at 40 seconds after the cylinder is set down (H_1). The hydrometer removed and the temperature of the suspension measured with a thermometer (T_1 in ^{o}C). Finally, after the first hydrometer readings (H_1), the suspension was allowed for 5 hours and a second reading (H_2) taken. Also, the temperature of the suspension (T_2 in ^{o} C) was taken.

3.7.2.2.15 Calculation (1)

% Sand = 100 – [H1 + 0.2 (T1 - 20) – 2] × 2

% Clay = [H2 + 0. 2 (T2 – 20) – 2] × 2

% Silt = 100 – (% Sand + % clay)

Where

WT= Total Weight of air-dried soil

H1 = 1st Hydrometer reading at 40 seconds

T1 = 1st Temperature reading at 40 seconds

H2 = 2nd Hydrometer reading at 3 hours

T2 = 2nd Temperature reading at 3 hours

– 2 = Salt correction to be added to hydrometer reading

0.2 (T – 20) = Temperature correction to be added to hydrometer reading, and T = degrees Celsius.

SOIL TEXTURAL TRIANGLE

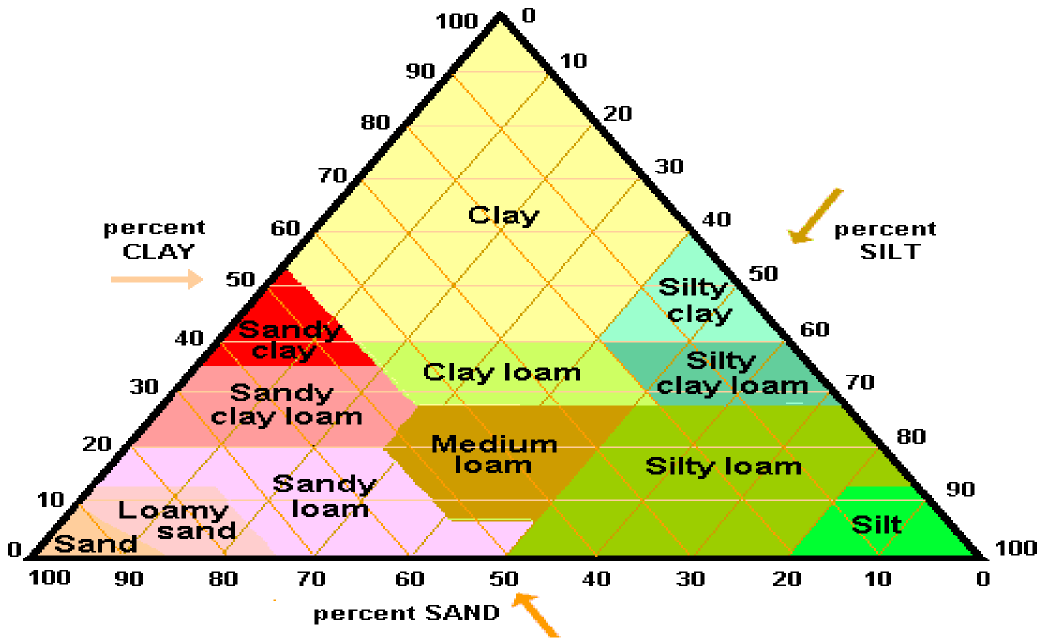


Figure 3. 9: Soil Texture Triangle

Based on the soil texture triangle above, the soil may be categorized into a texture class after the distribution of sand, silt, and clay has been measured. Different soil textures that rely on the relative quantities of soil particles are found within the textural triangle. Users only need to use the particle size distribution to determine the right texture.

The provided data indicates that the soil type is Loamy Sand. This is determined by analyzing the percentages of sand, silt, and clay in the soil sample, and comparing them to the textural triangle.

3.7.3 Data collected

The data collected during the test are fuel consumed, width and depth of penetration, Number of revolutions under loading condition, Number of revolutions under unloaded condition, Operating/forward speed, Operated width, Area covered (ha), and Total time taken (h) for tilling.

3.7.4 Parameters determined during the tilling unit evaluation

The parameters measured during the performance evaluation include: fuel consumption, width, and depth of plough penetration, theoretical and effective field capacities, and then field efficiency.

3.7.4.1 *Fuel consumption*

The fuel consumed during the test was measured using a volumetric cylinder with graduations at 5 ml intervals. The top-fill method was employed. With this method, the fuel tank was filled to the top at the levelled surface. At the end of the test, the quantity of fuel required to refill the tank again is equivalent to the fuel consumed.

3.7.4.2 *Width and Depth of Plough Penetration*

A tape measure was used to measure the width and depth of penetration after the plough.

3.7.4.3 *Wheel slip*

During the test, the number of revolutions of the driving wheel for a fixed distance (10 m) under no load and then under varying loads (different depths) were recorded and the percentage slip calculated using Equation (3.6).

$$S = \frac{N_l - N_u}{N_u} X\ 100\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

where N_l = Number of revolutions under loading condition; N_u = Number of revolution under unloaded condition (Hoque and Miah, 2015)

3.7.4.4 *Theoretical field capacity (C_{th})*

Theoretical field capacity (C_{th}) represents the field performance recorded for a given time if 100 % of the time and its operating width were used in performing its function at its rated operating speed. This was determined using equation (3.7).

$$C_{th} = \frac{v.w}{10} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.7}$$

Where:

v = Operating/forward speed, and w = Operated width.

3.7.4.5 *Effective Field Capacity*

Effective field capacity is the actual average rate of coverage by the machine, based on the total field time. It is a function of the rated width of the machine, the percentage of rated width utilized, the speed of the travel, and the amount of field time lost during the operation. It was calculated using equation 3.8.

$$Effective\ field\ capacity\ = \frac{(A)}{(T)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.8}$$

Where: A = $rea\ covered, ha$

T = $Total\ time\ taken, h$

3.7.4.6 *Field efficiency*

Field efficiency is the ratio of the effective field capacity to the theoretical field capacity and is expressed as a percentage.

3.8 Performance Evaluation of the Irrigation System

3.8.1 Equipment used

The equipment used in the evaluation of the irrigation system of the PPTISGIS is an anemometer, pressure gauge (0-100 psi) with pitot attachment, a stopwatch, a calibrated container (1-gallon capacity), a flexible hose of length 4 feet, and a diameter 1 inch (diameter appreciably larger than the outside diameter of nozzles), and a soil probe or soil auger (Merriam and Keller, 1978).

(a) anemometer (b) Pressure gauge (c) stopwatch (d)soil auger) (e)Tachometer

Figure 3. 10: Tools for the Evaluation of the Irrigation System

3.8.2 Experimental Design for the Irrigation System Evaluation

The experimental design used in the evaluation of the irrigation unit was Completely Randomized Design (CRD) with one factor (pump speed) at three levels (1300 rpm, 1500 rpm, and 1700 rpm). Sprinkled water was collected in 16 catch cans with surface diameters of 125 mm, placed in a circular order around the sprinkler, and equally spaced at 3m, 7m and 11m respectively. The experiment was replicated three times.

The experimental design of the spray gun system was developed in alignment with standard testing protocols outlined by the **American Society of Agricultural and Biological Engineers (ASABE)**. Specifically, the standards **ASABE S327.1** ("Test Procedure for Agricultural Nozzles") and **ASABE S330.1** ("Procedure for Sprinkler Distribution Testing for Research") were followed to ensure consistency, reliability, and repeatability in data collection. The height of the sprinkler or spray gun should reflect the typical operational height used in the field or be adjusted to ensure full development of the spray pattern. In this experiment, the spray gun was mounted at a height of **1.0 meter** above the ground. This height was selected to ensure adequate spray pattern formation and to avoid ground interference, while simulating realistic field conditions for overhead or broadcast applications.

Manual control valves were installed upstream of the spray gun to manage the initiation and termination of water flow. The spray gun was tested at a pressure of 2.5bar. The experimental setup was systematically developed using ASABE standards to ensure the results are valid and suitable for engineering evaluation of spray performance. The controlled height, use of flow valves, and varied pressure inputs all contribute to a robust and standardised testing methodology.

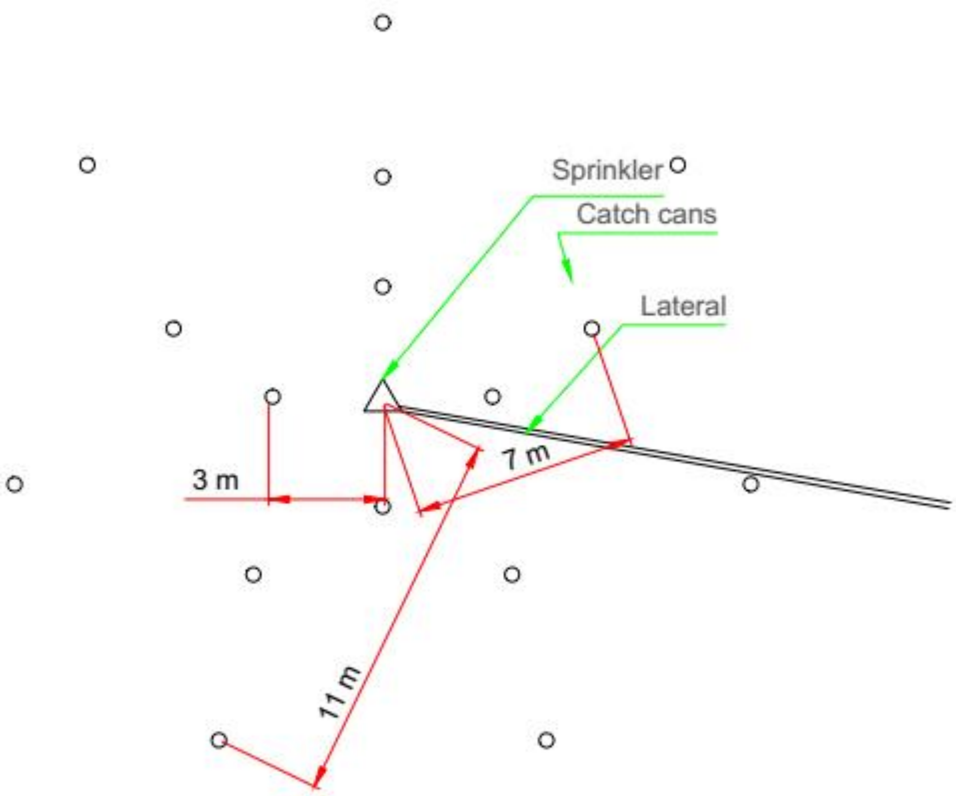


Figure 3. 11: Layout of catch cans for uniformity

3.8.3 Data collected

The data collected during the test were the Diameter of the sprinkler nozzle (mm), Throw length of the sprinkler (m), Operating pressure (N/m^2), Time (s) for discharge, sprinkler wetted radius (m), angle of the wetted sector (^{0}), and wind speed (km/h).

3.8.3.1 *Length of Throw (m)*

The length of the sprinkler throw was measured with tape. The throw distance was measured from the nozzle tip to the last place where water reached. It specifies the beginning point for sprinkling and the height of the sprinkler nozzle in the field.

3.8.4 Parameters determined during the irrigation system evaluation

The performance of the irrigation system was evaluated in terms of sprinkler discharge rate, average sprinkler application rate, and coefficient of uniformity.

3.8.4.1 *Sprinkler Discharge Rate*

This study utilised sprinklers to shower water on the crops. A sprinkler with a 6 mm diameter nozzle and 15 mm inlet pipe was used. The sprinkler set was mounted on a tripod stand and the inlet was attached. Wind is a factor that can cause uneven distribution of water. The sprinkler discharge was measured using equation 3.8.

$$Q_{rg} = \frac{d_{nozzle} * L_{throw} * P}{K * t} \quad \text{……………………. (3.9)}$$

Q_{rg} = $Discharge\ /\ flow\ \ rate\ of$ sprinkler (L/s)

d_{nozzle} = Diameter of sprinkler nozzle (mm)

L_{throw} = Throw length of sprinkler (m)

P = Operating pressure (N/m^2)

K = Constant factor (9800)

t = Time (s)

3.8.4.2 *Average Sprinkler Application Rate*

According to Cemagref (1992) and Tarjuelo (2005), it is essential to confirm that the average sprinkler application rate (mm/h) remains lesser than the infiltration rate (mm/h) of soil. The average sprinkler application rate was calculated using Equation 3.9.

$$l_t = 1000 \frac{Q\ 360}{\pi\ (0.9R)^2\ \alpha_{sr}} \quad \text{………………………… (3.10)}$$

l_t = Sprinkler average application rate (mm/hr)

R = Sprinkler wetted radius (m)

α_{sr} = Angle of wetted sector (°)

3.8.4.3 *Coefficient of Uniformity*

How uniformly the amount of water was distributed along the length of the throw in the field was determined. This parameter, known as the coefficient of uniformity, was computed using Christiansen's equation (Eqn. 3.10).

$$CU = \left[1 - \left(\frac{\sum f \; lxi - X_{axl}}{\sum f \; X_{av}}\right)\right] \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.10)}$$

$$X_{av} = \frac{\sum f xi}{\sum f}$$

Where: Z is the amount discharged in each catch can during the test, m is the Average discharge in cans ($m = \frac{\sum f \times z}{\sum f}$), and f is the frequency of cans.

3.9 Cost-Benefits Analysis

In order to determine whether to proceed with a project, the cost-benefit analysis compares the project's costs and benefits. A true picture of the project's costs and benefits is provided by quantifying them in monetary terms after accounting for time value for money.

3.9.1 Cost analysis

The cost of using the PPTISGIS was analysed by considering its ownership and operating costs.

3.9.1.1 *Ownership cost*

The total ownership cost (TOC) of the PPTISGIS was estimated by adding depreciation, interest, taxes, insurance and housing costs using the assumptions made in Table 3.8. The manufacturing cost was obtained from the bill of quantities presented in Appendix B1. Depreciation was calculated using Equation 3.11 as indicated in the ASABE Standard (2005).

$$Depreciation = \frac{Purchase\ price - Salvage\ Value}{Economic\ life} \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.11}$$

Insurance and Tax charges were estimated using the prevailing rates and government policies regarding agricultural machinery in Ghana.

Table 3.8: Assumptions for Ownership Cost Calculation

Item	Assumption
The purchase price	120% of the manufacturing cost
The economic life of the PPTISGIS	10 years
Salvage value of the PPTISGIS	40% of the purchase price (Lazarus, 2009)
The Bank of Ghana Interest rate	16%
Taxes on agricultural machinery in Ghana	Tax-free
Insurance cost	0.25% of the purchase price (Srivastava *et al.,* 1993)
Cost of housing	0.75 % of its purchase price (Srivastava *et al.,* 1993)
Annual usage	100 days per year, and 6 hours per day

3.9.1.2 *Operating cost*

The operating (variable) cost was calculated by adding the repair and maintenance, gasoline, lubricant, and labour costs. The cost of repairing and maintaining a single machine varies by geographical location according to soil and atmospheric conditions. Repair and maintenance expenses might vary even within the same geographical location due to changes in operator skill and management tactics. Aside from these aspects, the cost of repairs and maintenance varies with the machine's size and complexity. As a result, the operator's logbook provides the most accurate data for determining repair costs. Because there were no records of the newly designed Vegetable PPTISGIS, repair costs were anticipated at 15 % of the purchase price

(Aikins, 2018). The assumptions made for the operating cost analysis are presented in Table 3.8

Table 3.9: Assumptions for operating cost calculation

Item	Assumption
The repair and maintenance cost	15 % of the purchase price
Fuel price per litre	Prevailing price (GH₵ 13.25)
The cost of lubrication	15 % of the fuel cost (Ajit *et al.,* 2013)
The operator's labour cost	GH₵17.00 and GH₵10.00 per hour for tilling and irrigating respectively

3.9.1.3 ***Benefit Cost Ratio***

The benefit-cost ratio (B/C ratio) is the ratio of benefits to costs (expressed in present or annual value). It is a simple benefit-cost ratio for investment. In the current study, the cost ratio of farm machinery was estimated using the following formula:

$$\frac{B}{C} ratio = \sum_{t=1}^{t} \frac{B_t}{(1+r)^t} \Big/ \sum_{t=1}^{t} C_t / (1+r)^t \ldots\ldots\ldots\ldots\ldots (3.12)$$

Where:

Bt = Discounted benefit from the machine (NRs)

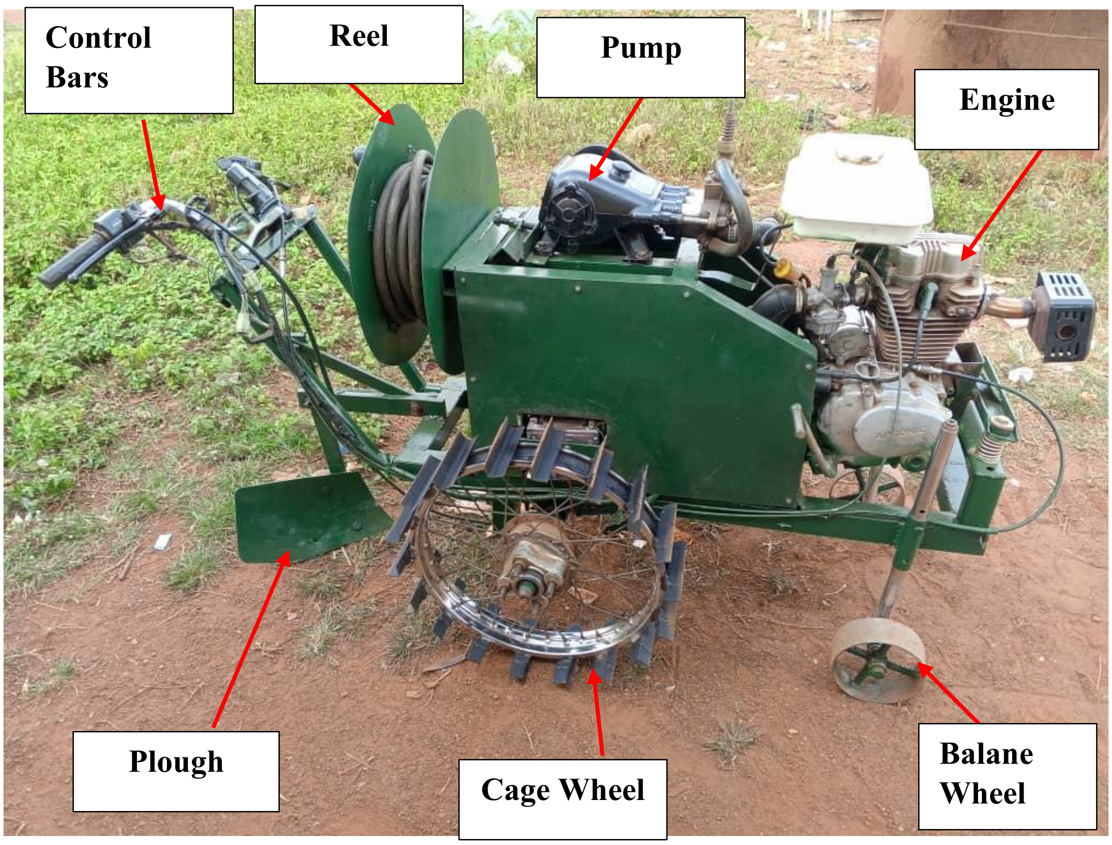
Ct = Discounted cost incurred (NRs)

t = time (years)

r = discount rate (28.84 % 06 Sept. 2024). If, B/C ratio > 1, Accept investment, B/C ratio < 1, Reject investment, B/C ratio = 1, Indifferent

3.9.2 Statistical Analysis

Microsoft Excel is a widely used tool in agricultural and engineering experiments for data analysis, statistical calculations, and graphical representation**.** In the context of analyzing power tiller performance parameters, Excel provides a simple yet effective platform to process the raw data collected during the experiment. Raw data collected during the experiment (e.g., fuel consumption, speed, tillage depth, area covered, power output) is first entered into an Excel spreadsheet and analysed.



3.11: The Manufactured PPTISGIS

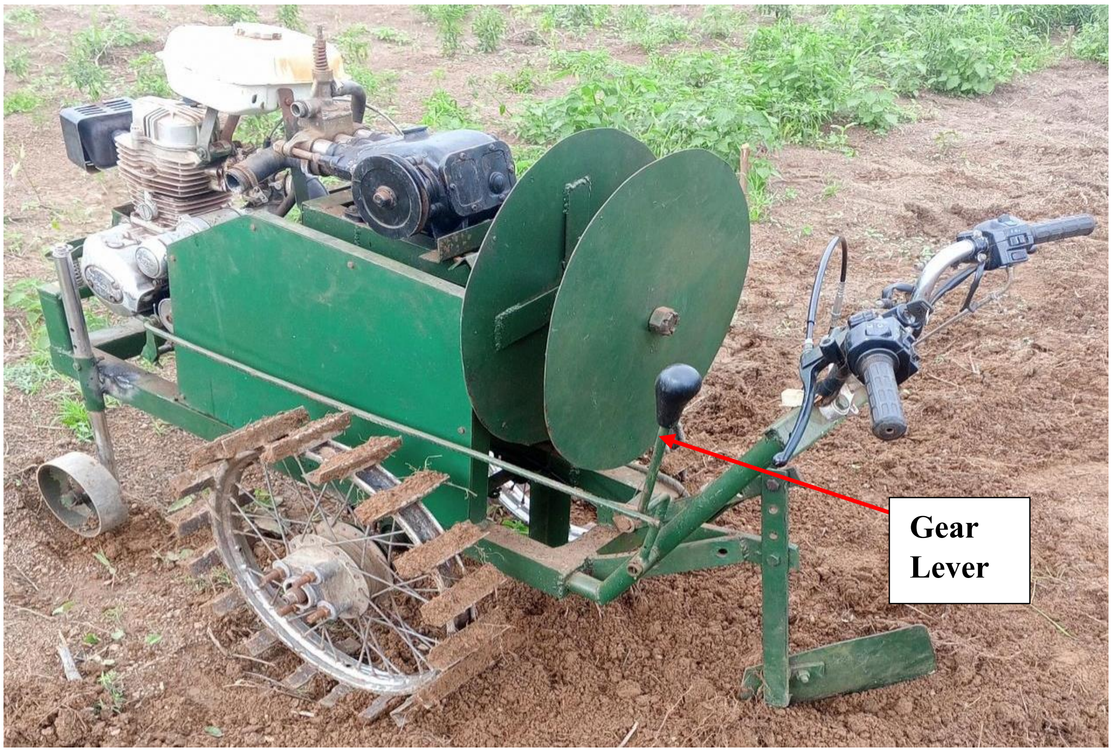


Figure 3.12: The Manufactured PPTISGIS

Table 3.9: Report on the FEA Simulation

S/N	Component	Material	Yield Strength	Element Size	Mesh type,	Young's Modulus	Poisson's Ratio	Shear Modulus	Tensile Strength,
1	Frame	Steel, Mild	207 MPa	1/10th	Structured mesh	220 GPa	0.275 ul	86.2745 GPa	345 MPa
2	Front Engine Seat	Steel, Mild	207 MPa	1/10th	Structured mesh	220 GPa	0.275 ul	86.2745 GPa	345 MPa
3	Back Engine Back seat	Steel, Mild	207 MPa	1/10th	Structured mesh	220 GPa	0.275 ul	86.2745 GPa	
4	Mouldboard Plough	High Strength, Low Alloy Steel	275.8 MPa	1/10th	Structured mesh	200 GPa	0.287 ul	77.7001 GPa	448 MPa
5	Control Bars	Steel, Mild	207 MPa	1/10th	Structured mesh	220 GPa	0.275 ul	86.2745 GPa	345 MPa
6	Driving Wheel Shaft	Steel, Mild	207 MPa	1/10th	Structured mesh	220 GPa	0.275 ul	86.2745 GPa	345 MPa

.

3.10 Shaft Design

3.10.1 Geometric Properties

Diameter (d) =30 mm = 0.03 m

Radius (r) = 0.015 m

Length (L) = 750 mm = 0.75 m

3.10.2 Cross-sectional Area (A):

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.03)^2}{4\downarrow} = 7.07\times10^{-4}m^2$$

3.10.3 Cross- section Area (A):

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.03)^2}{4} = 7.07\times10^{-4}m^2$$

3.10.4 Moment of inertial (for bending) I:

$$I = \frac{\pi d^4}{64} = \frac{\pi(0.03)^4}{64} = 3.98 \times 10^{-9} m^4$$

3.10.5 Polar Moment of inertia (for torsion), J:

$$J = \frac{\pi d^4}{32} = \frac{\pi(0.03)^4}{32} = 7.96 \times 10^{-9} m^4$$

3.10.6 Torsional strength (torque capacity)

Using:

$$\mathrm{T} = \frac{T \cdot r}{J} \rightarrow \mathbf{T} = \frac{\mathbf{T} \cdot \mathbf{J}}{\mathbf{r}}$$

3.10.7 Material: Mild steel

Allowable shear stress $Tallow$ =50 $MPa = 50 \times 10^6 Pa$

Then

$$T = \frac{50 \times 10^6 \cdot 7.96 \times 10^{-9}}{0.015} = 26.53\ Nm$$

Maximum Torque Capacity = 26.5 Nm

3.10.8 Bending deflection (stiffness check)

Using:

$$\delta = \frac{\mathrm{M \cdot C}}{\mathrm{I}} \Rightarrow \mathrm{M} = \frac{\delta \cdot \mathrm{I}}{\mathrm{C}}$$

Allowable bending stress δ_{allow} =100 MPa

C = $^{d}/_{2}$ =0.015m

Then :

$$\mathrm{M} = \frac{100 \times 10^6 \cdot 3.98 \times 10^{-9}}{0.015} = 26.53\ Nm$$

Maximum Bending Momem ≈ 26.5Nm

3.10.9 Bending Deflection (stiffness Check)

$$\delta_{max} = \frac{FL^3}{48EI}$$

Where:

$$\mathrm{E} = 200\ \mathrm{GPa} = 2 \times 10^{11}\ \mathrm{Pa}$$

Maximum Allowable Load For 1 Mm Deflection:

$$0.001 = \frac{F(0.75)^3}{48.2 \times 10^{11} \cdot 3.98 \times 10^{-9}}$$

$$\mathrm{F} = \frac{0.001 \cdot 48.2 \times 10^{11} \cdot 3.98 \times 10^{-9}}{(0.75)^3}$$

$$\mathrm{F} \approx 113.1\mathrm{N}$$

Max central load for ≤ 1 mm deflection ≈ 113N

3.10.10 Buckling Check (Axial Compression)

Use Eulers formula (pinned ends):

$$P_{cr}\frac{\pi^2 EI}{(KL)^2} \Rightarrow K = 1(pinned - pinned)$$

$$P_{cr}\frac{\pi^2 \cdot 2\times 10^{11} \cdot 3.98\times 10^{-9}}{(0.95)^2} \approx 13.95\ KN$$

Critical Buckling load ≈ $\mathbf{13.95\ KN}$

3.10.11 Summary of Shaft Design Capacity ($\mathbf{\emptyset 30\ mm, L = 750\ mm}$):

Load Type	**Capacity**
Torsion (shear)	~26.5 Nm
Bending moment	~26.5 Nm
Poit load at center (for 1 mm deflection)	~113 N
Axial load (buckling)	~13.95 KN

CHAPTER FOUR

MANUFACTURING AND ASSEMBLING PROCESSES

4.1 Introduction

The main objective of this study was to design, manufacture and evaluate a prototype power tiller incorporated with a spray gun sprinkler irrigation system (PPTISGIS). This explains the processes adopted in the manufacturing and assembly of the PPTISGSIS. Specifically, it presents the manufacturing processes of the main components of the machine. It also explains the assembly methods used after manufacturing the individual components, the working principles of the machine, and the maintenance methods recommended for the PPTISGIS.

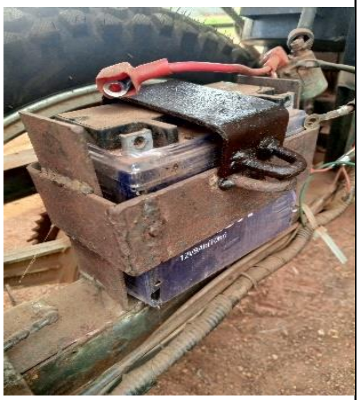
4.2 Manufacturing

4.2.1 Manufacturing the Components

Table 4. 1: Components and their materials and manufacturing processes

Parts	Qty	Material	Operation	Final shape
Frame	1	Mild steel angle iron (50 x 50 x 5 mm)	1. cutting of 1,100 mm and 365 mm lengths 2. framing of angle irons into square pipes 3. framing of pipes into rectangular shape or 1,100 x 365 mm	
Pump support	1	Mild steel angle iron (40 x 40 x 3 mm)	1. Cutting of the angle iron to the required lengths 2. Welding them together to form a 400 x268 x 425 mm shape	

Water pump	1	Aluminium alloy housing and brass inlet and outlet	Ordered	
Engine	1	Aluminium alloy	Ordered	
Exhaust	1	Mild steel plate (1.5 mm) and Ø¾ inch pipe	Silencer ordered	
4L Fuel tank	1	Mild steel pale (1.5 mm)	Ordered	

Front balance wheels	2	Ø25 mm shaft, Ø18 mm iron rod, Ø 30 and Ø 165 mm mild steel pipes (4mm thick)	The Ø165 mm pipe was cut to a length of 60 mm, and iron rod cut into four pieces and used to support the hub at the middle of the pipe. The Ø30 mm pipe was cut to a length of 515 mm and welded to one end of the shaft.	
Control handle	1	Chrome plated steel and grips made from silicone foam and rubber	Ordered	
Battery, AGM 12V 5Ah and Housing	1	50 x 3 mm flat bar	Battery ordered and housing cut and welded from a 50 x 3 mm flat bar to form the rectangular shape of 165 x90 x 140 mm. A lock bar was also formed from the flat bar and hinged at the top of the housing with U-hooks.	

Mould board plough	1	Medium carbon steel plate Mild steel plate and flat bar	The blade, made of medium carbon steel was ordered. Diameter 18 mm holes drilled at end.	
Reel	1	1.5 mm mild steel plate and 50 x 3 mm flat bar, Ø4 inches pipe.	Two pieces of circular shape with diameters of 480 mm were cut from the mild steel plate. A length of 127 mm was cut from the pipe, and the circular plates welded at its ends. The flat bar was used to strengthen the plate at 90º to each other.	
Drive wheel	2	17" steel rim 40 x 40 mm mild steel angle iron	18 pieces of 150 mm length were cut from the 40 x 40 mm angle iron. These were welded around the rim, evenly spaced.	

Driving wheel shaft sub-assembly	1	Ø30 x 750 mm mild wheel shaft 10 mm thick galv. Plate (300 x 300 mm)	A length of 100 mm from each end of the shaft was turned to Ø15 mm. M14 x 2 mm thread was machined over a length of 25 mm at each end. The galv. plate was machined into 3 circular pieces of (Ø155 each). Two of the Circular plates were welded at the steps on the shaft ends, and the third one placed 360 mm from the left end.	
Water Hose	2	Vinyl/PVC ½ in.	Ordered	
Sprinkler Stand	1	Aluminium	Ordered	

Drive Belt	1	Synthetic rubber & Nylon (DIN 7753)	Ordered	
Drive Chain	1	High carbon Steel (size 428)	Ordered	

4.3 Assembling Methods

4.3.1 Assembling the frame

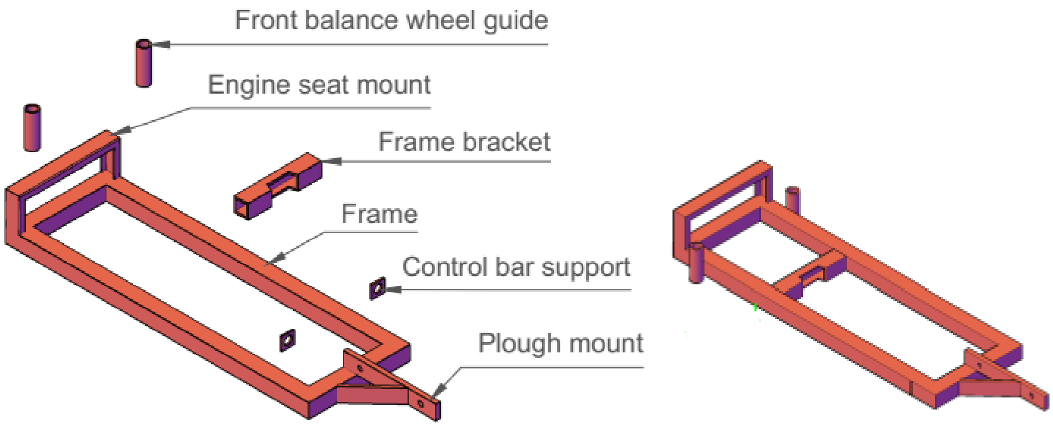


Figure 4. 1: The Frame Assembly

All the frame parts were made independently as shown in Figure 4.1 and finally assembled together. The assembling started by welding the engine seat mount followed by the front balance wheel guide. The frame bracket was also inserted and joined to the frame by welding. The plough mount and its bracket were carefully positioned and welded.

4.3.2 Assembling the Mouldboard Plough

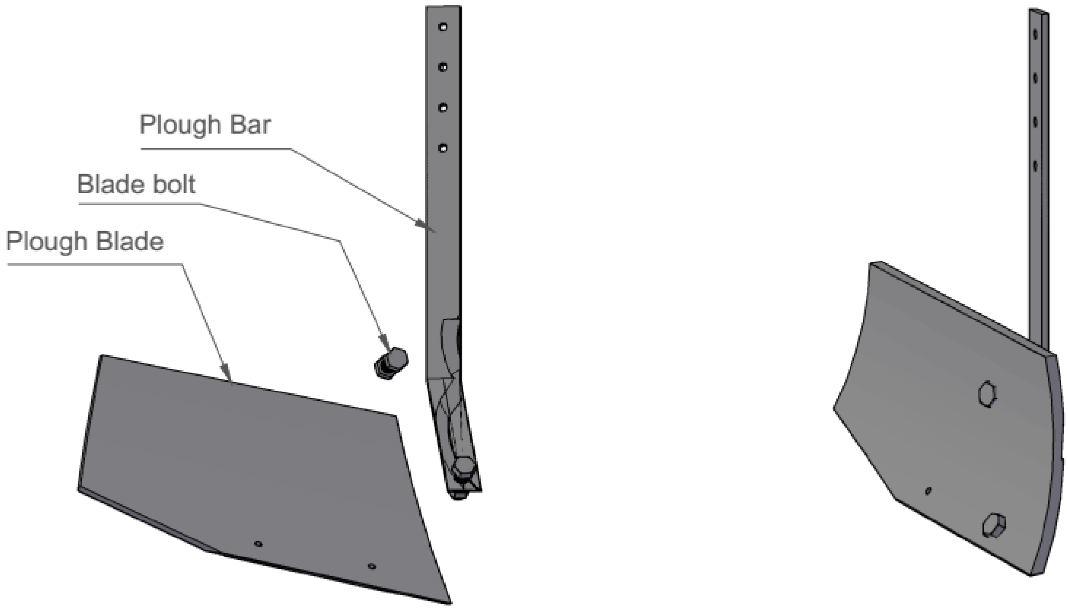


Figure 4. 2: The Plough Assembly

The mouldboard plough comprises two major components, the blade and the plough adjusting bar. The blade is attached to the adjustment bar by two M12 × 50 mm. This is shown in Figure 4.2.

4.3.3 Assembling the Control Bars and its Attachments

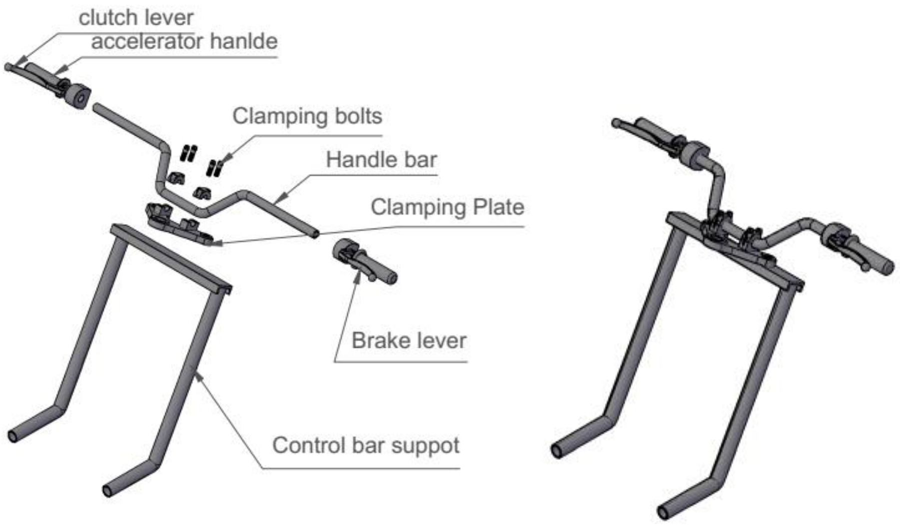


Figure 4. 3: The control bars Assembly

Unlike other sub-assemblies, this sub-assembly is not assembled once and for all. Rather it is re-assembled based on the desire of the operator until they are comfortable and the desired position of handle is achieved. This can be done by tilting the handle and its height from the ground.

The assembling procedures are as follows. First, the handle was inserted into the handle clamp and tightened together using four M10 x 25 mm bolts. Secondly, the gear lever was inserted into the pivot on the handlebar and an M10×100 pin through a hole and locked it. The brake and clutch handles were also fixed and the cables connected to the hub and clutch housing on the engine. Finally, the link bar was connected between the gear lever and the gearbox output shaft of the engine and an M10×100 pin through the holes and locked it Now, the lever with its clamp is free to rotate around the pivot and freely move the link bar.

4.3.4 Assembling the Pump Support

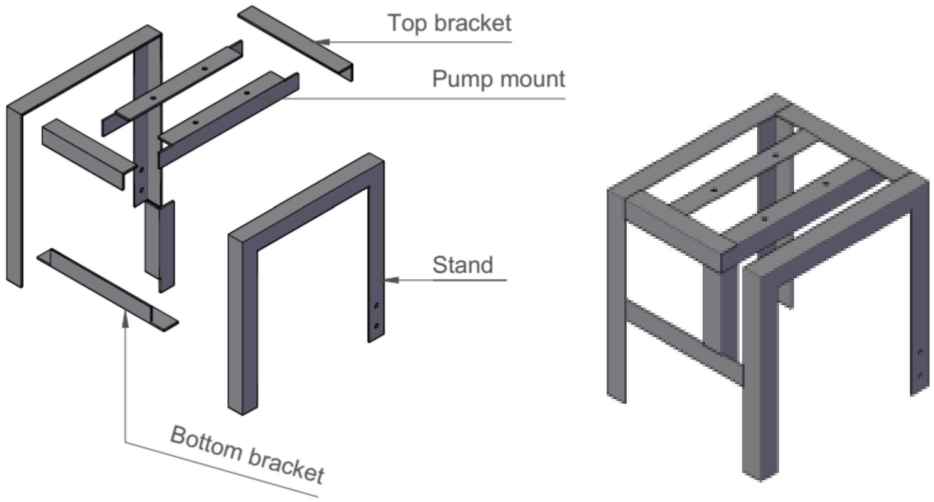


Figure 4. 4: The Pump Support Assembly

Similarly, like the frame, most of the pump support parts were joined together by welding. The stand is the base component from which all other parts are positioned. The assembling process includes placing the top bracket angle irons parallel to each other to join the top part of the stand and then, tack weld at the joints. The pump mounts were placed to join the top bracket and check if all the edges of the plate were aligned with the edges of the stand, and it was then tack welded at the joints.

All the positions and orientations were to see if they were correct, after this, it was permanently welded, tack welded all joints by a continuous fillet and edge welds. Finally, the assembly was drilled to create slots for the adjustment of the pump.

4.3.5 Assembling the belt and pulleys

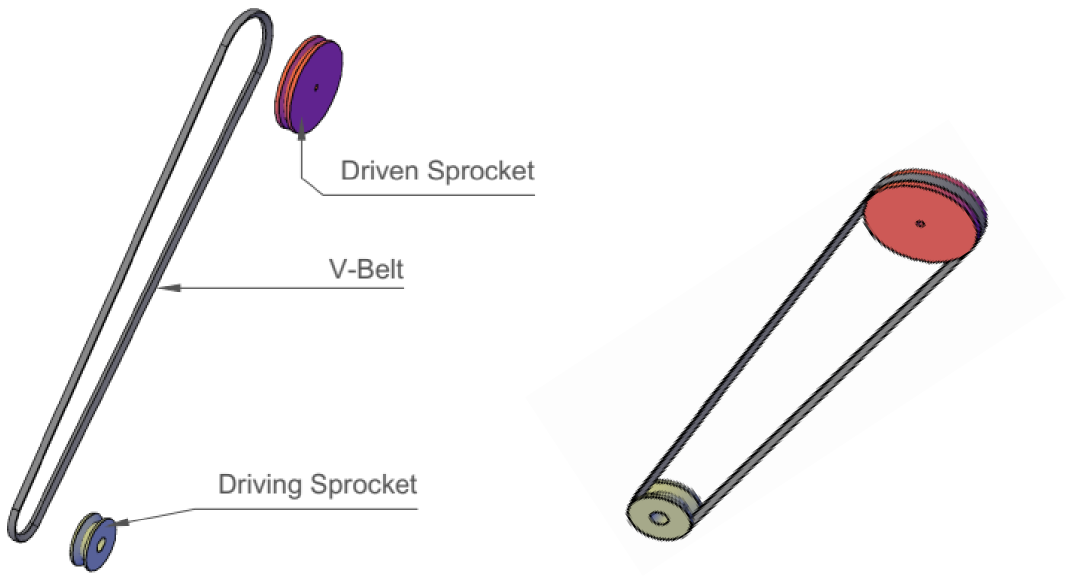


Figure 4. 5: The Belt Drive Assembly

First, the large pulley was fixed to the pump shaft and the key was inserted between the pump shaft and the pulley. This was followed by fixing the small pulley to the gearbox output shaft, ensuring the pulley bore and the shaft surface were clean and free from dirt and lubricant residue. The lock nut was then tightened down enough to keep it in the desired position on the shaft. The bolts holding down the pump were then slacked to enable the pump to be shifted towards the small pulley to allow the belt to be mounted. The pump was adjusted backwards with the adjusting bolt to tension the belt. This was followed by tightening down the lock nut to hold the pump securely in place during operation. Pulley alignment was then checked. Misaligned pulleys will accelerate the wear of belt side walls, which will shorten both belt and sheave life.

Misalignment can also cause belts to roll over in the pulley or throw all the load to one side of the belt breaking or stretching the tensile cord.

4.3.6 Assembling the Front Engine Seat

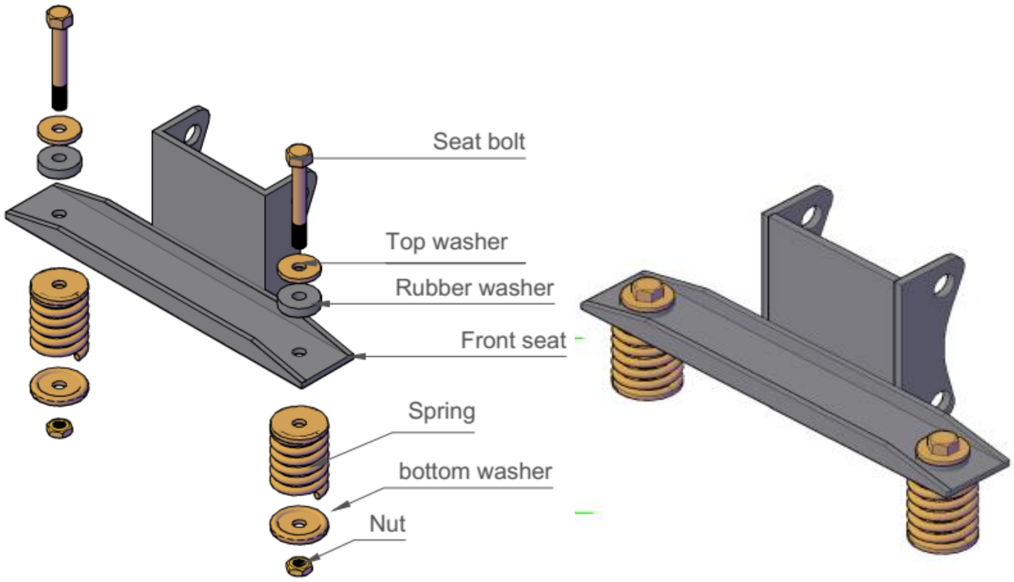


Figure 4. 6: The Front Engine Seat Assembly

The engine seat frame was selected as the base component and the metal washer was inserted into the seat bolt (M14 x 40mm) on the same side as the head of the bolt and the rubber washer onto the bolt after the metal washer, The rubber washer helps absorb vibrations and provides a cushion between metal parts. The front engine seat bolt was inserted into the frame with the compression spring between the front engine seat and the frame to isolate the frame from vibration emanating from the engine due to the combustion process in the engine. The bottom washer was also fixed to the seat bolt and nut used to hold it down ensuring that all the two bolts were tight enough to prevent play during operation.

4.3.6.1 *Final Adjustment*

Wrenches were used to tighten the support nut and bolt. Ensuring that the assembly is secure but not so tight that it restricts the movement of the spring. All components were double-checked to make sure they were in the correct order and properly aligned.

4.3.7 Assembling the Engine Back Seat

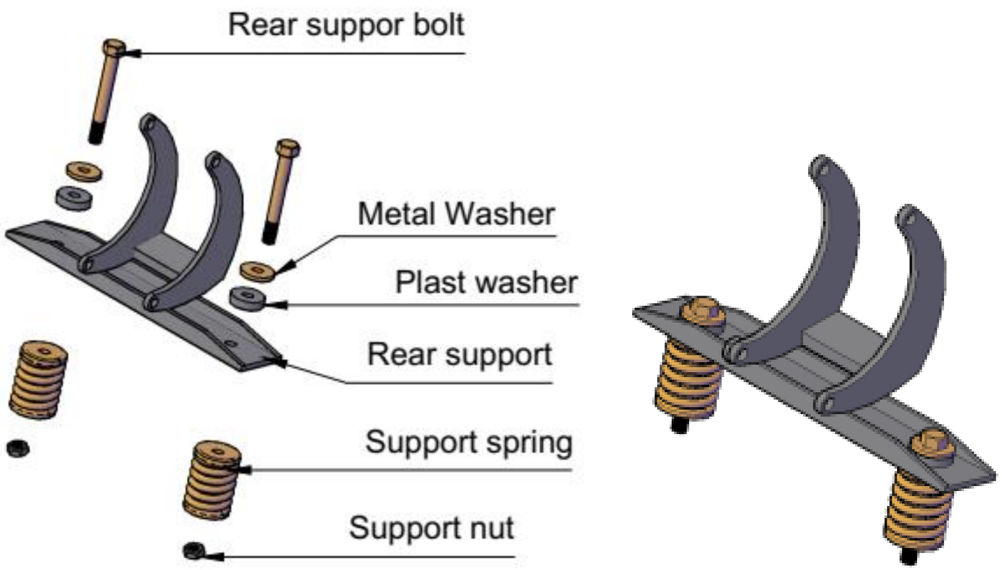


Figure 4. 7: The Engine Back Seat

Similarly, the rear engine seat frame was selected as the base component and the metal washer was placed onto the rear support bolt on the same side as the head of the bolt and then slide the plastic washer onto the bolt after the metal washer. The plastic washer helps provide a smooth surface and can reduce friction between metal parts. Rear support bolt (M14 x 40 mm) was also inserted to fasten the seat to the frame. A compression spring was inserted between the rear engine seat and the frame to mitigate the transmission of vibration from the engine to the chassis frame. The spring also allows for flexibility and movement. Finally, the support nut was threaded onto the end of the rear support bolt and hand-tighten it at first.

4.3.7.1 *Final Adjustment*

Wrenches were used to tighten the support nut and bolt to ensure that the assembly was secured but not so tight that it restricted the movement of the spring. All components were double-checked to make sure they were in the correct order and properly aligned.

4.3.8 Assembling the Chain Drive System

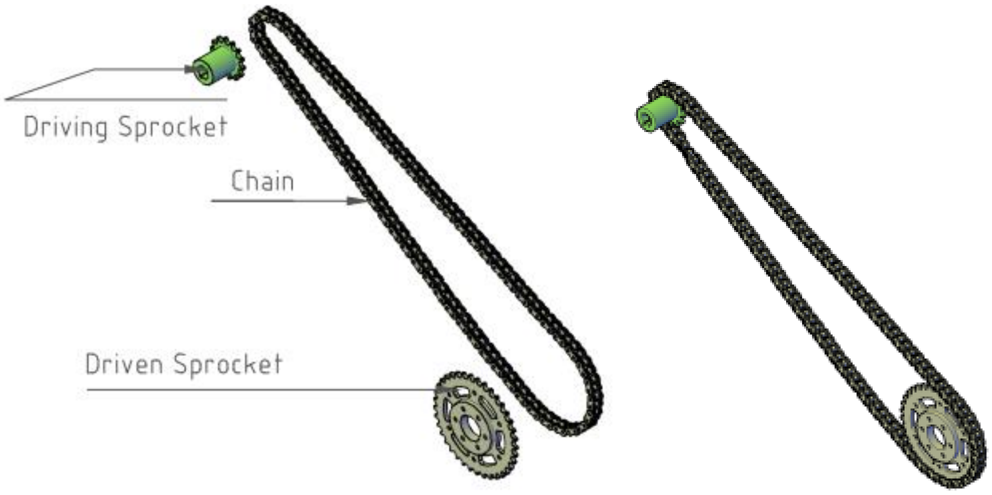


Figure 4. 8: The Chain Drive Assembly

The assembly was done by considering first the gearbox output shaft and the driving wheel hub as base components onto which other parts were connected. The small sprocket was fixed to the gearbox output shaft and locked with a lock nut. This was followed by the larger sprocket which is attached to the driving wheel hub with four M10 x 50 bolts. The larger sprocket was then connected to the preceding smaller sprocket with the chain. After that, the gearbox output shaft and lock nut were tightened to the required torque loading. Ensuring that both the driving and driven sprockets were aligned correctly. Misalignment can cause uneven wear on the sprockets and chain, and may lead to chain derailment. A spirit level was used to check the alignment. Finally, the whole gear train was checked to ensure all the components were working appropriately.

4.3.8.1 *Adjustment of Chain Tension*

The tension of the chain was adjusted by moving the driven component using a chain tensioner. The chain was allowed some small amount of slack, about 1/2 inch to 1 inch of movement when pressed midway between the sprockets. Over-tightening the chain can cause excessive wear, while under-tightening the chain can also cause derailment.

4.3.8.2 *Lubrication of the Chain*

Oil was applied to the chain to reduce friction, wear, and noise, and prolong the life of the chain and sprockets. After this, the driving sprocket is rotated manually to ensure the chain moves smoothly and is properly seated on both sprockets. The chain was checked for unusual noise or resistance.

4.3.9 Assembling the Front Balance Wheels

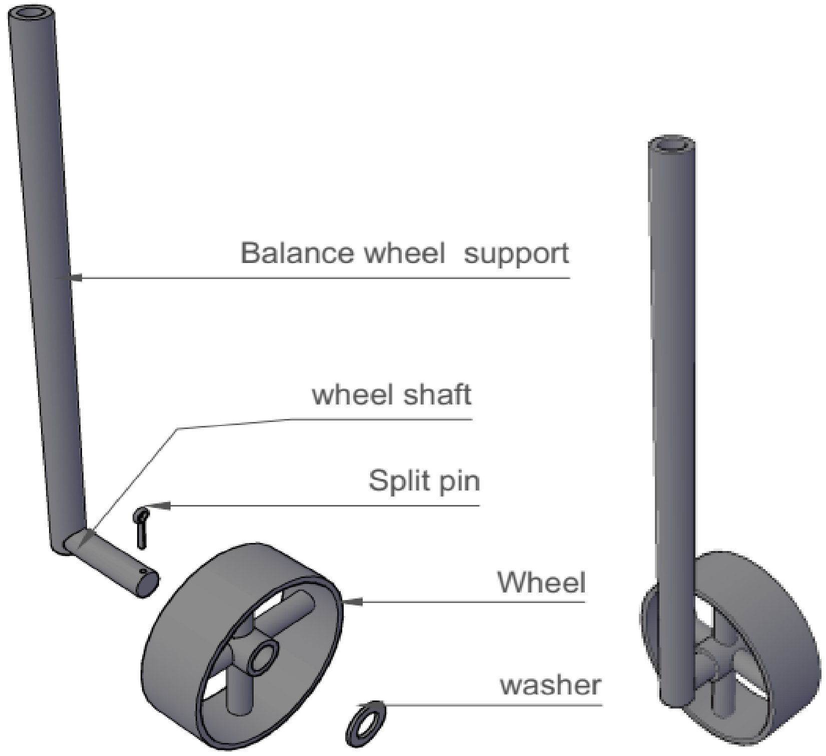


Figure 4. 9: The Front Balance Wheel Assembly

The front balance wheel shaft was inserted into the balance wheel through the hole, ensuring it fit snugly and the wheel washer slid onto the wheel shaft. The washer typically goes between the balance wheel and the split pin making sure the washer is properly seated on the shaft. Once the wheel washer was in place, the split pin was inserted at the end of the wheel shaft. The split pin locks the assembly in place and prevents the wheel shaft from sliding out. Mallet was gently used to tap the split pin into place, ensuring it went through the hole completely. A plier was used to bend the ends of the split pin outward to secure the pin and prevent it from falling out. All components were properly aligned and securely fastened. The wheel shaft was checked to make sure it rotates freely within the balance wheel without excessive play.

4.3.10 Assembling the side covers

The side covers were put into position and bolted to the frame.

4.3.11 Assembling the Gear Selector Sub Assembly

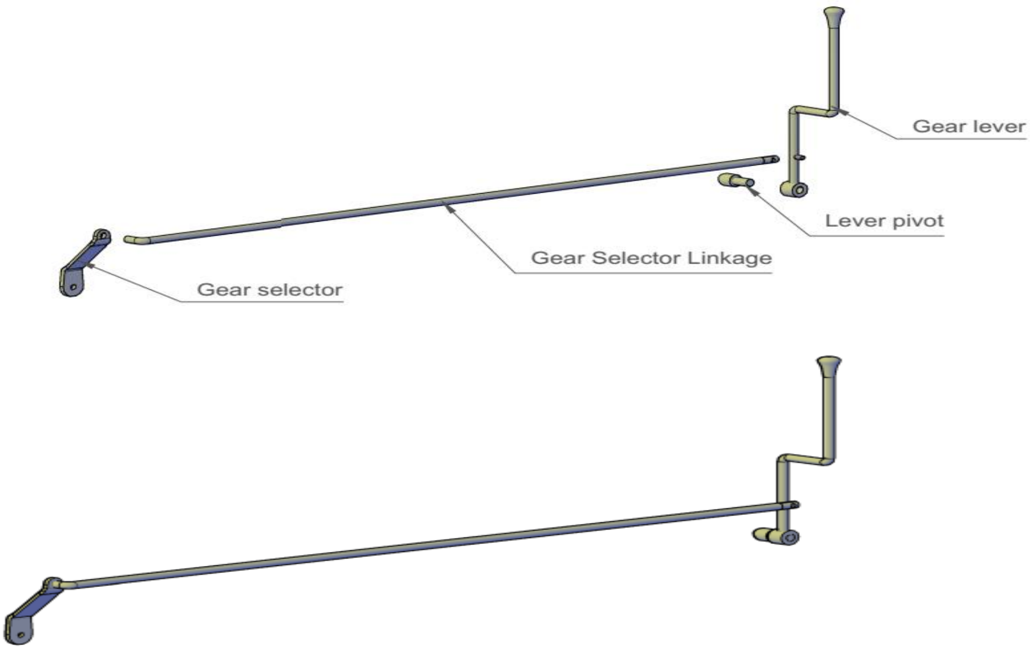


Figure 4. 10: The Gear Selector Sub-Assembly

The lever pivot was attached to the mounting point on the handle using the appropriate bolts and nuts (Figure 4.10). Hand-tightening was done initially, followed by a wrench to securely fasten it to ensure the pivot moves freely and firmly attached. The gear lever was slid onto the lever pivot. This involved sliding the lever through a hole in the pivot and securing the gear lever to the lever pivot by a split pin. This was followed by aligning the gear selector with the mounting point on the gear lever. The gear selector was attached to the gear lever using the M5 x 20 mm bolts, nuts, and washers. Hand-tightening was done by the bolts first and then secured by a wrench.

4.3.11.1 *Attach the Gear Selector Linkage*

One end of the gear selector linkage was connected to the gear selector. This involved inserting a pin through the linkage and selector and the connection secured with a split pin. Ensuring the connection is tightened, but allows for smooth movement. The other end was aligned to the gear selector linkage with the connection point on the gearbox output shaft. Gear linkage to the transmission was done using the appropriate split pin. This was to ensure that the linkage was securely fastened and allowed for smooth movement.

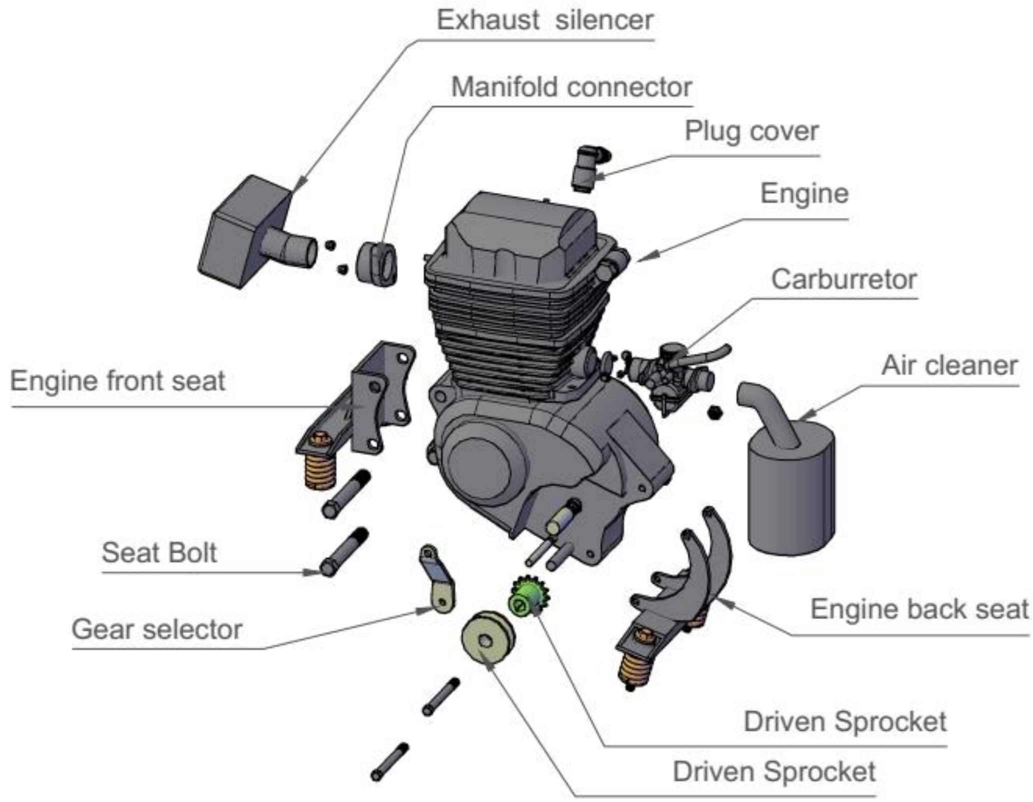
4.3.11.2 *Lubrication of Moving Parts*

Grease was applied to the moving parts such as the lever pivot and linkage connections to ensure smooth operation and reduce wear.

4.3.11.3 *Final Adjustments and Checks*

Alignment of all components was checked and ensured that the gear lever moved smoothly and engaged each gear properly. The gear selector mechanism was tested by moving the gear lever through its range of motion to ensure it operates smoothly and reliably.

4.3.12 Assembling the Engine Attachments



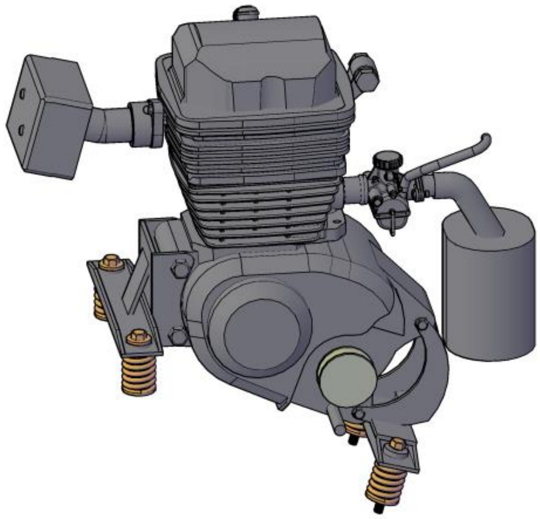


Figure 4. 11: The Engine and its Attachments (a) Exploded View (b) Assembly view

The engine was mounted on both front and rear seats as shown in Figure 4.11. The seats are made up of rubber bushings and coil compression springs to isolate the engine from vibration emanating from the chassis frame due to the undulating ground surface. The silencer and exhaust manifold are connected to the engine's exhaust port to minimise the sound of the engine. The carburettor was connected to the inlet port of the engine to meter and atomise the air-fuel mixture into the combustion chamber. The air cleaner, which is connected to the carburettor, filters the air before it enters the carburettor.

4.3.13 Mounting the water pump on its Support

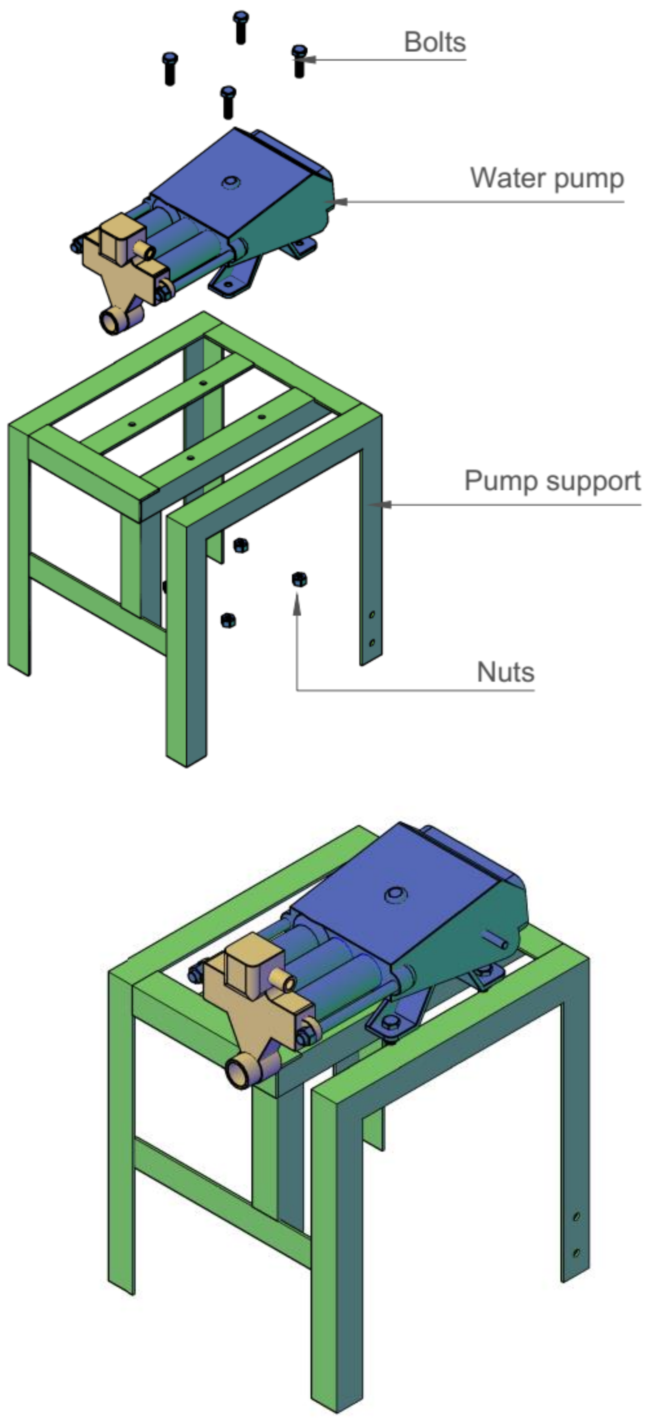
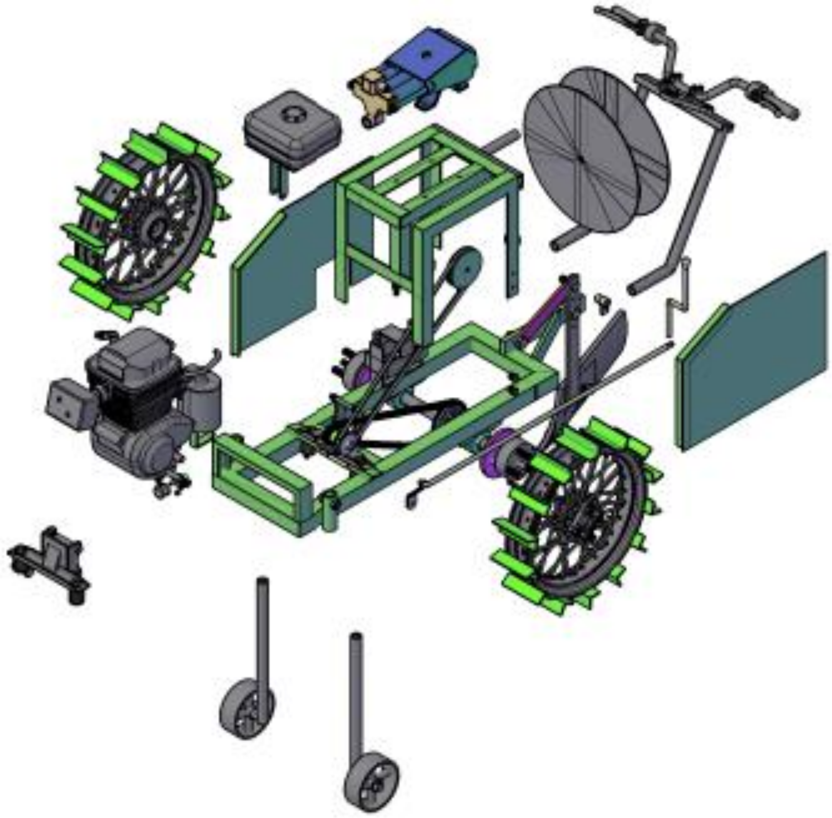


Figure 4. 12: The Water Pump and its Support

The water pump was mounted on its support using 4 pieces of M10 x 50 mm mild steel bolts and nuts. The pump seat was slotted to enable adjustment of the belt tension.

4.3.14 The Final Assembling



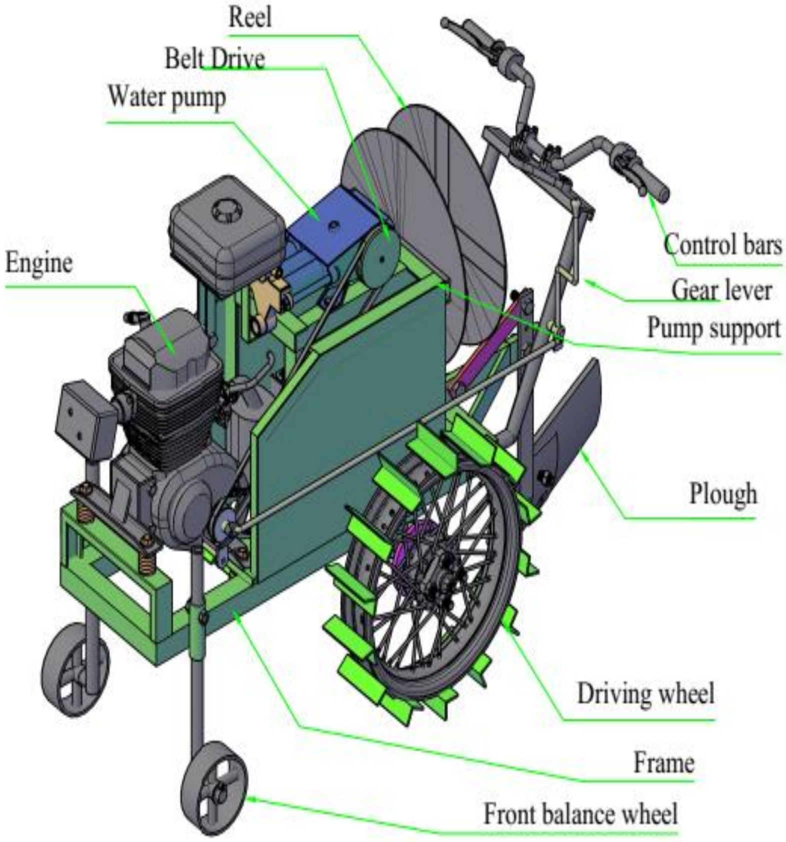


Figure 4. 13: The Main Assembly of the PPTISGIS

Finally, all the sub-assemblies were joined together to give the complete PPTISGIS (Figure 4.13). The engine with the seats, was mounted on the frame. The sprocket and pulley were mounted on the output shaft of the engine's gearbox to drive the wheel and water pump respectively. The pump and its support sub-assembly were also mounted on the frame, with the reel attached. The driven pulley was mounted on the pump shaft, and a V-belt was used to connect it to the driving pulley on the engine. The plough sub-assembly was then attached to the plough mount at the back of the frame.

The control bars sub-assembly was fixed through Ø30 mm holes at the back edges of the frame into its support. The cage wheels were attached to the frame through a shaft and bearings with the sprocket using an M16 x 300 mm bolt and nut. The driving sprocket was then linked to the sprocket on the wheel with a chain size of 428. Finally, the front balance wheels were attached to the frame through 130 mm circular guides, which permitted the upward and downward adjustment of the wheel.

4.3.15 Assembling the electrical system

The Tools and materials used in assembling the electrical system include Screwdrivers, wrenches, wire cutters, and strippers, soldering iron and solder, electrical tape and heat shrink tubing. Others are multi-meter, wiring harnesses, electrical connectors and terminals.

4.3.15.1 *Installing the battery*

In installing the battery, it was placed in its designated compartment (battery housing). The next step was connecting the positive (+) terminal first, followed by the negative (-) terminal. Finally, the battery was secured in place using the provided bracket or strap.

4.3.15.2 *Main Wiring Harness*

The main wiring harness was routed along the machine frame as the first step. This was followed by securing the harness with zip ties or clips, ensuring it was away from hot engine parts and moving components.

4.3.15.3 *Ignition System*

Wiring of the ignition system starts with connecting the ignition switch to the main wiring harness. Wires from the ignition switch were then attached to the respective terminals on the ignition coil and starter relay, ensuring the switch was properly connected to the ignition circuit. The handlebar control switches were then attached. Finally, the control switches were connected to the wiring harness.

4.3.15.4 *Charging System*

The stator and rectifier/regulator were connected to the wiring harness, ensuring the stator wires were connected to the rectifier/regulator and the output from the rectifier/regulator was also connected to the battery.

4.3.15.5 *Ground Connections*

It is important to ensure all components have proper ground connections. The ground wires were attached to the machine frame or designated grounding points. To ensure Connections were secured and insulated, solder and electrical tape were used for all wire connections.

4.3.15.6 *Testing*

Upon completing the wiring, the battery was connected, and the ignition switch turned on. A multi-meter was used to check the voltage at different points in the system. All electrical components were tested including the ignition and starter, to ensure was working correctly.

4.3.16 Assembling the brake system

The tools and materials used in the assembling of the brake system include wrenches and screwdrivers, pliers, brake drum and brake shoes, brake cable, lubricant, torque wrench, and safety cloths (gloves, goggles). First, the brake drum was positioned onto the wheel hub and secured.

4.3.16.1 *Installing the Brake Shoes*

Light coat of high-temperature brake grease was applied to the pivot points and the cam surfaces inside the brake drum. The brake shoes were then positioned inside the brake drum ensuring it was fitted securely against the backing plate. In addition, the brake springs was also attached to the brake shoes, ensuring they were correctly seated and provided proper tension to retract the shoes when the brake was not engaged.

4.3.16.2 *Mounting the Wheel*

The wheel was installed onto the motorcycle, ensuring the brake drum aligned correctly with the wheel hub and axle. This was secured with M16 x 300 mm axle bolt and nut.

4.3.17 Connecting the Irrigation System

The inlet of the pump was connected to a 10 mm diameter pipe which leads to the source of water and the outlet connected to the sprinkler.

4.4 Working principles

Two power tillers are also known as walk-behind tractors because the operator of the machine walks behind it by controlling the overall operations of the tiller. Starting the tiller begins by switching on the ignition with a key cracking the engine to start working by the second turn of the key and pulling the clutch handle to operate the clutch. The tiller does not immediately start going forward; it waits until the operator engages a gear through a remote-acting gear lever. When the operator starts releasing the clutch handle the wheel starts to move. At that moment power starts to be transferred into the rear wheel through the chain. Though the engine speed is very high, the mechanisms in the power train reduce the speed to the comfortable walking speed of the operator, thereby multiplying the low torque output of the engine into very high amount. This torque is then directly applied to the ground via the rear wheels. The rear wheel is the traction devices that pull the mouldboard against the soil. The mouldboard has a sharp edge which enables it to break the soil apart. When the operator needs to stop the operation, just by pushing the gear lever to a neutral position the tiller can be stopped. The principle of controlling the mechanism of the pump is that ‘to operate the pump tighten the belts by pulling the pump back by adjusting bolt and nut. By manipulating the clutch and the gear lever mechanism, the engine can keep on working. This enables the operator to clean up debris sticking over the mouldboard without turning the engine off.

4.5 Maintenance methods

To prevent the tiller from high damaged, periodic inspection and preventive maintenance actions are needed. Because the tiller running parts and static parts are subjected to high loads, there may be unexpected failures. For this reason, preventive maintenance and continuous inspections are required. Below are the recommended inspection periods.

4.5.1 Preventive maintenances

4.5.1.1 *Before starting to work*

Every time before starting the engine, the level of the engine oil must be checked. Using a deep stick, the amount of engine oil inside the oil pan and its viscosity has to be checked. If the oil level is below the expected, engine oil must be added. Similarly, if the engine oil service time has ended (by checking the viscosity and the darkness of the oil), it should be replaced by a new oil. If these are not done properly, the crankshaft, cylinder liner, piston and piston rings will be highly damaged. In addition to these, the carburettor and petrol fuel level also have to be inspected.

The whole power train also has to be inspected both visually and by trial. Lubricate the sprocket and chain assembly. Tighten if there are loose parts, in the handle adjustment and in the hub pins. The belt also has to be checked if there is any loose or lost bolt and nut. Check if it is tight enough to transfer power to the pump. Clean the mouldboard penetrating edge from debris after every operation.

4.5.1.2 *During operation.*

The operator has to apply only the necessary force to adjust the depth of penetration and steer the machine. Overloading the machine can result in damage to parts. The operator has to manage the depth of the penetration based on the strength of the soil, the response of the machine and ease of operation. Follow the machine carefully to observe if there is a failure or probability of failure. If debris sticks over the mouldboard, disengage the gear, stop the machine and remove it.

4.5.1.3 *After finishing the work*

Clean all the debris, mud or anything else from the machine, as they can cause rust which shortens the life span of the parts. Check every component if there is a loosened or lost part during work time.

4.5.1.4 *Corrective maintenances*

The power tiller was designed in a way that it can give access to the operator or the maintainer access all the parts easily. The power transmission system can be reached by hand without any difficulty. The lubrication of the chain linkage assembly can be done easily. The parts of the tiller that are prone to permanent damage are the shafts and the sprockets. The hub shafts are subjected to high torque as they join the sprocket and the output shaft from the engine which are the final drive elements. During steering, since there is no steering clutch, the weight goes to the front balance wheel that is inside the turning radius. At this time, the pins could break. In those situations, replace the pins with new pins. In case of permanent damages to the power transmission elements conduct the respective corrective maintenance.

4.5.1.5 *Operation and Maintenance of Spray Gun Sprinkler Irrigation Systems*

A sprinkler system's success is not guaranteed by its proper design alone. The alignment of the prime mover and the pump should be checked. For these, the driving shaft and the pump shaft should be almost at the same height to avoid an excessive angle. The pump belt should also be adjusted to the proper tension to prevent slippage. Always start at the pump while installing the main and lateral pipes. This ensures that all quick coupling pipes are connected correctly. It is appropriate to ensure that the couplings and the rubber seal rings are clean before attaching them. The engine or motor is started with the valves closed when the sprinkler system is turned on. The pump needs to reach the type-plate pressure; if it does not, there is a suction line problem. The delivery valve is gradually opened once the pump has reached the regulatory pressure. Likewise, when the power unit is stopped, the delivery valve is closed. After stopping, the sprinkler lines and pipes are moved as needed. The installation is disassembled in the opposite order as the assembly mentioned above.

4.5.1.6 *Pipes and fittings*

Although the pipes and fittings need very little upkeep, they do occasionally need to have any sand or debris removed from the coupler's groove where the rubber sealing ring fits. The effectiveness of the rubber sealing ring will be impacted by any buildup of sand or debris. Nuts and bolts must all be tight, and they shouldn't be installed on freshly built, wet concrete or on fertilizer mounds. Additionally, it is not advisable to place fertilizer sacks on the pipe.

4.5.1.7 *Sprinkler heads*

Be careful not to damage or force the sprinklers into the ground when relocating the sprinkler lines. The sprinklers should not be lubricated with any kind of oil, grease, or other substance. Since they are water lubricated, applying oil, grease, or any other type of lubrication could cause them to malfunction. Sprinklers often have a sealed bearing with washers at the bottom of the bearing. Usually, the washers—rather than the more costly metal components—wear. Every six months or once a season, the washers are inspected for wear, which is crucial in areas with sandy water. If the washers are worn, replace them. The swing arm spring may require adjusting after a few seasons of use. The spring end is pulled out at the top and bent to do this. The spring tension will rise as a result. To ensure that the equipment is in top shape to begin the following season, generally inspect all equipment at the conclusion of the season, make any necessary repairs and modifications, and order replacement components right away.

4.5.1.8 *Storage*

During the off-season, sprinklers must be removed and stored in a cool, dry place. Additionally, the couplers and fittings' rubber sealing rings are kept in a dark, cool location. The pipes should be arranged in racks with one end higher than the other if they are to be stored outside. Fertilizer should not be stored next to pipes. Disconnect the suction and delivery pipework from the pump and add a small amount of medium-grade oil. Rotate the pump for several minutes. Blank the suction and delivery branches. This will protect the pump from corrosion. Grease the shaft. Protect the pump from dust, humidity, and rodents.

4.5.1.9 *Trouble Shooting*

The following are general suggestions for identifying and removing typical problems with spray gun sprinkler irrigation systems.

4.5.1.10 *Pump does not prime or develop pressure*

If the pump does not prime or create pressure, the following areas need to be examined: the suction lift is within the acceptable range. If not, move the pump closer to the water, check the suction pipeline and all connections for air leaks, make sure all flanges and connections are airtight, make sure the foot valve's strainer is not obstructed, and make sure the flap can open all the way. Check for air leaks in the pump gland or glands. Gently tighten the gland or glands if air leaks are suspected. If required, repack the gland or glands with a thick oil to ensure a satisfactory seal. Ensure that the gate valve on the delivery line is completely closed during priming and fully open when the pump is working.

4.5.1.11 *Sprinkler do not turn*

Low pressure and a blocked nozzle can cause the sprinkler not to turn. To remove the obstruction, preferably unscrew the nozzle or use a small soft piece of wood. A piece of metal or wire should never be used since it could harm the nozzle. Examine the bearing's bottom washers for wear and damage, and replace them if necessary. By comparing it to a sprinkler that is functioning properly, you can make sure the swing arm swings smoothly and that the spoon that enters the water stream is not bent. Adjust the spring tension on the swing arm. Generally speaking, the spring ought not to be pulled up more than 6 mm.

4.5.1.12 *Leakage from coupler or fittings*

The sealing rings of couplers and fittings are typically designed to drain water from pipes when the pressure is turned off. This guarantees that the pipes are automatically drained and ready for movement. With the system at maximum pressure, the couplers and fittings will not leak. If, however, there is a leakage, the following must be checked: Ensure that no dirt or sand has accumulated in the coupler's groove where the sealing ring inserts. Remove any dirt or sand and reattach the sealing ring. The end of the pipe that goes inside the coupler is smooth, clean, and free of distortion. In the case of bends, tees, and reducers, make sure they are properly linked to the coupler.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Results of the Design Process

An Isometric view of the final design of the PPTISGIS is shown in Figure 5.1. It comprises two caged wheels, a driving wheel shaft, a frame, a pump and its support, an engine, a reel, and control bars. Two orthographic views of the design are shown in Figure 6.2. This gives the overall dimensions of the machine.

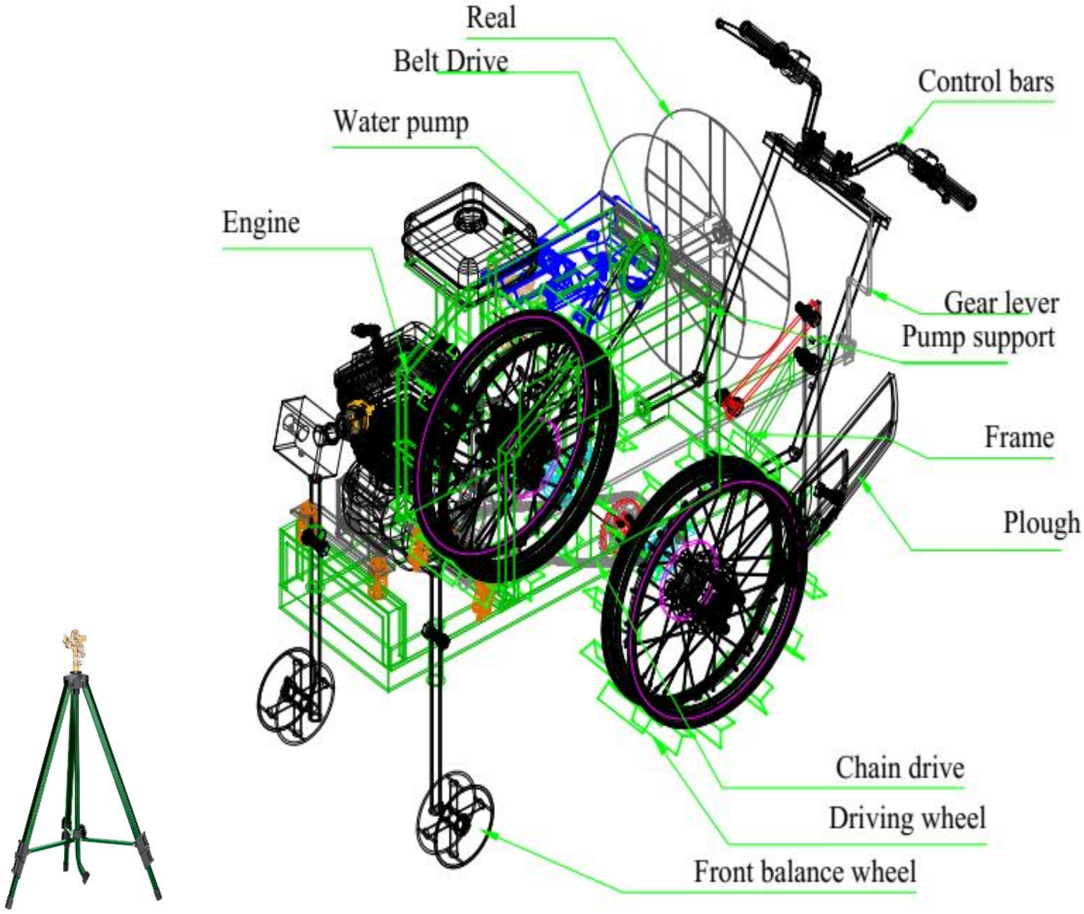


Figure 5.1: Isometric view of the PPTISGIS Final Design

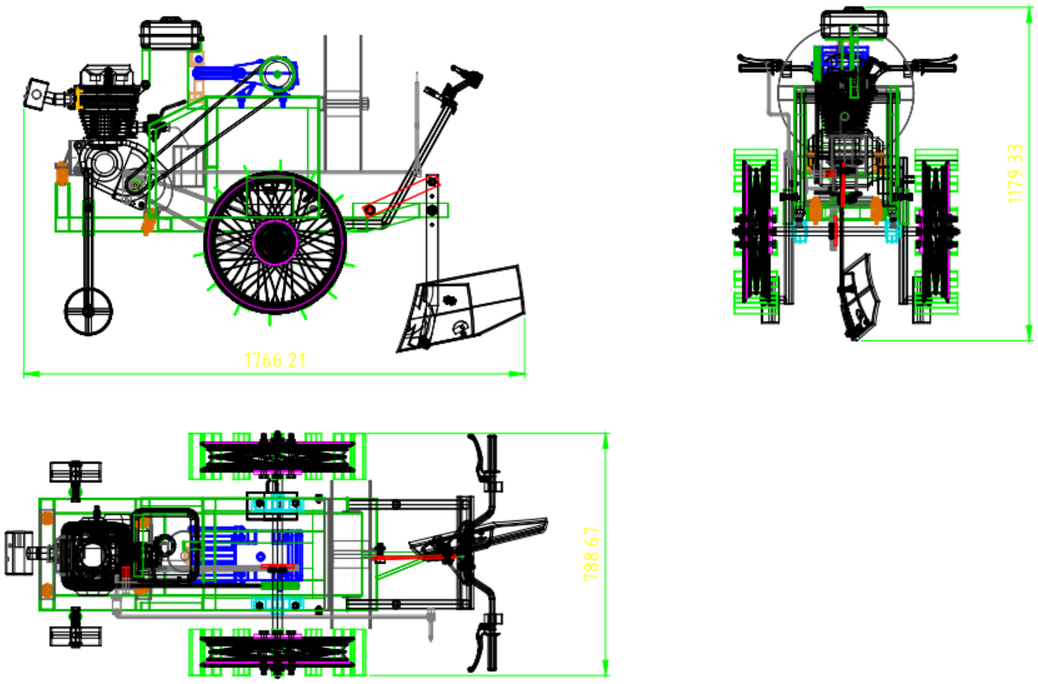


Figure 5.2: Orthographic Views of the PPTISGIS Final Design

5.2 Results of the Finite Element Analysis

The results of the Finite Element Analysis of the frame, the engine seats, the plough, the control bars, and the shaft are systematically presented here.

5.2.1 Finite Element Analysis of Frame

The results showed a maximum Von Mises stress of 17.3815 MPa (Figure 5.3) which is less than the yield strength of the material used (207 MPa), indicating that the frame can safely carry the 450 N. The colours in the legend show red for the most stressed portion concentrated in the middle of the frame. The blue colour indicates the less stressed portions of the frame. The maximum and minimum values of the 1st principal stress were 15.6227 MPa and -1.34991 MPa respectively (Figure 5.4), which represent the maximum and minimum tensile stresses induced in the frame. This is usually less than the Von Mises stress and occurs at the bottom side of the middle portion of the frame.

The minimum and maximum values for the 3rd principal stress were -19.7014 MPa and 1.38881 MPa (Figure 5.5), representing the compressive stresses induced in the frame. The top side of the middle portion of the frame suffered the maximum compressive stress. The maximum displacement occurred in the middle portion of the frame (Figure 5.6). This is expected since the middle of the frame is far from the wheels supporting it. The maximum displacement was 0.0112926 mm, which is negligible and will not have any impact on the machine. Unlike the other parameters, designers usually work with the minimum safety factor value from the analysis results instead of the maximum value. The minimum safety factor achieved in this design is 3 as shown in Figure 5.7. This is acceptable since the recommended safety factor for most engineering designs is between 1 and 5 (Tooley, 2009). A design having a safety factor of less than 1 is not recommended.

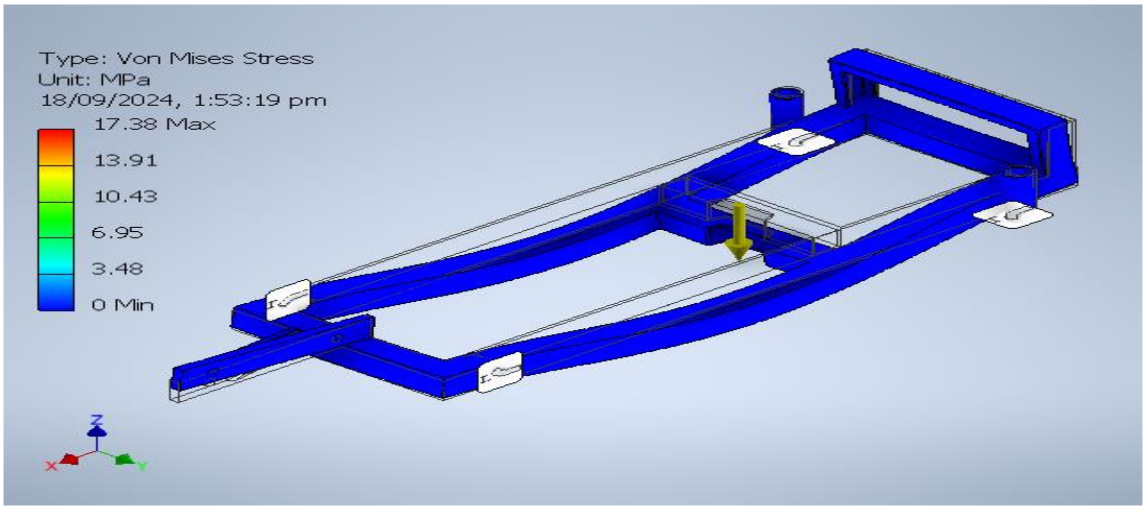


Figure 5. 3: Von Mises stress of the Frame

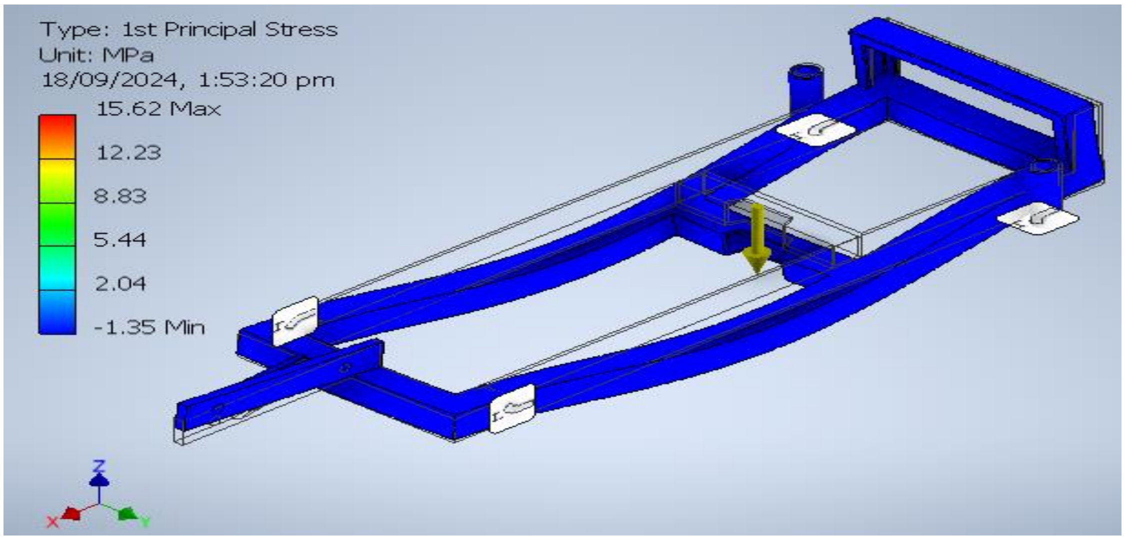


Figure 5. 4: 1st Principal Stress of the Frame

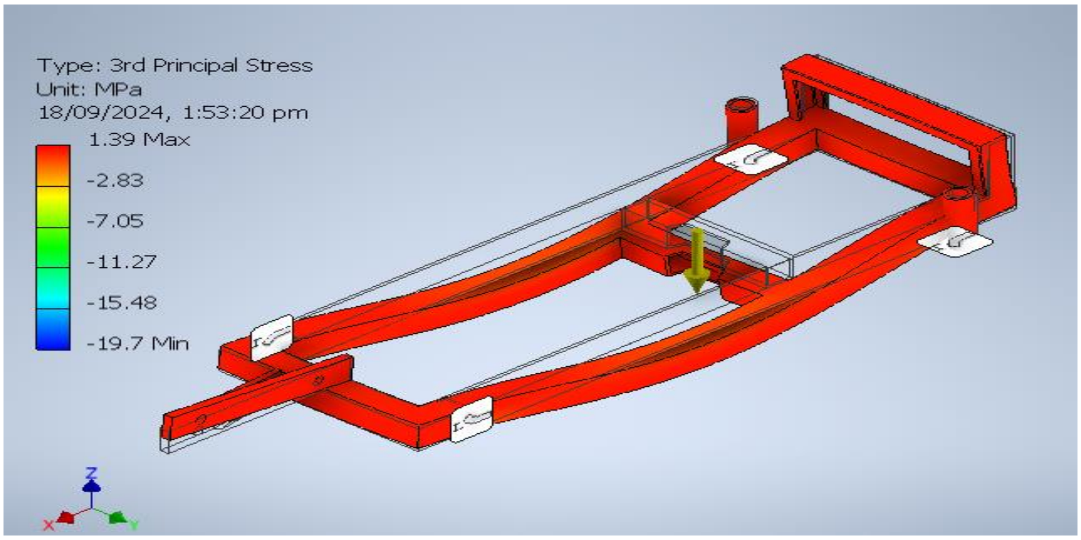


Figure 5. 5: 3rd Principal Stress of the Frame

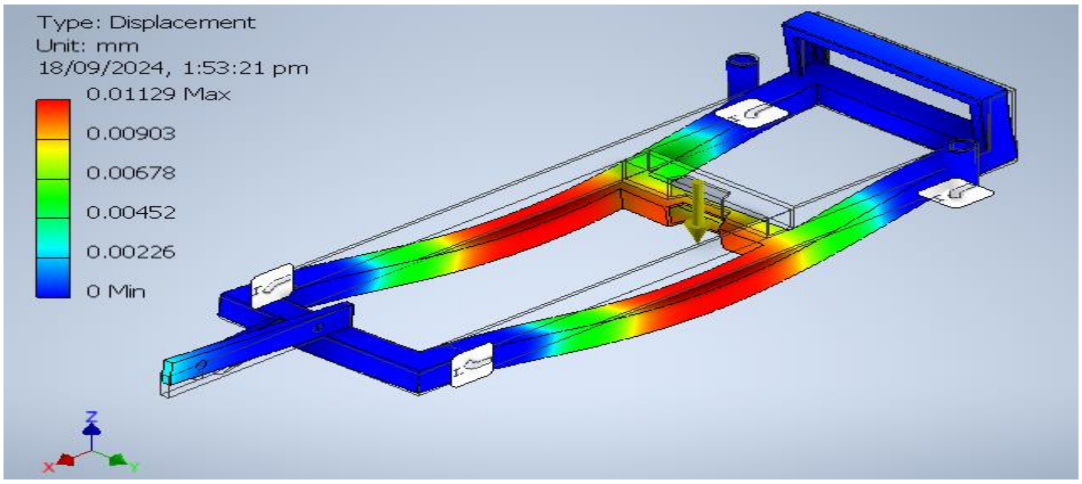


Figure 5. 6: Displacement of the Frame

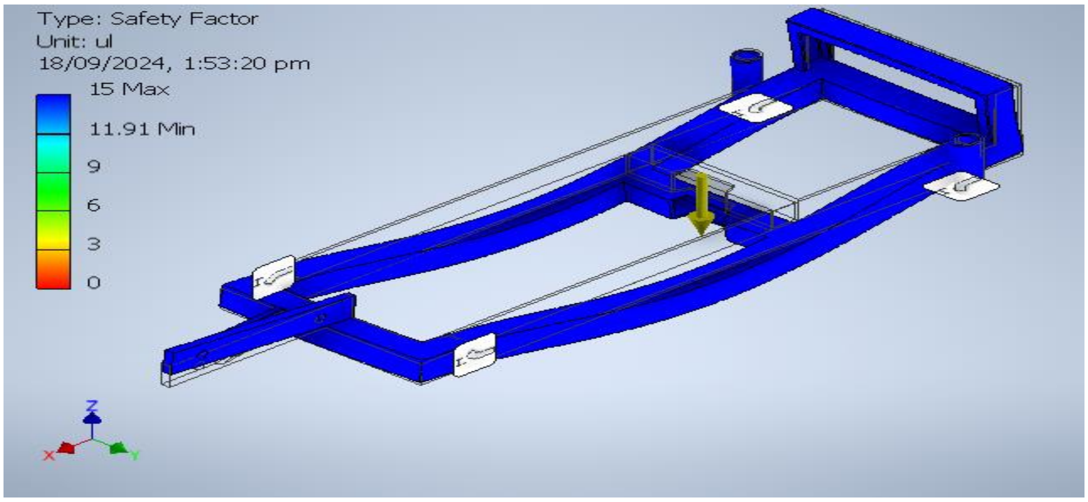


Figure 5.7: Factor of Safety

5.2.2 Finite Element Analysis for Front Engine Seat

The results showed a maximum Von Mises stress of 1.67239 MPa (Figure 5.8) which is less than the yield strength of the material used (207 MPa), indicating that the engine seat can safely carry the 305N. The colours in the legend show red for the most stressed portion concentrated in the holes of the engine seat. The blue colour indicates the less stress portions of the seat. The minimum and maximum values of the 1st principal stress were -0.125177 MPa and 0.517791 MPa respectively (Figure 5.9), which represent the minimum and maximum tensile stresses induced in the seat. This is usually less than the Von Mises stress and occurs at the holes of the engine seat. The minimum and maximum values for the 3rd principal stress were -1.52659 MPa and 0.0369072 MPa (Figure 5.10), representing the compressive stresses induced in the engine seat. The entire seat, apart from the holes suffered the maximum compressive stress.

The maximum displacement occurred near the holes of the seat (Figure 5.11). This is expected since the seat support is far from the holes where the load is applied. The maximum displacement was 0.0000680383 mm, which is negligible and will not have any impact on the machine. The minimum safety factor achieved in this design is 15 as shown in Figure 5.12. This is acceptable since the recommended safety factor for most engineering designs is between 1 and 5 (Tooley, 2009).

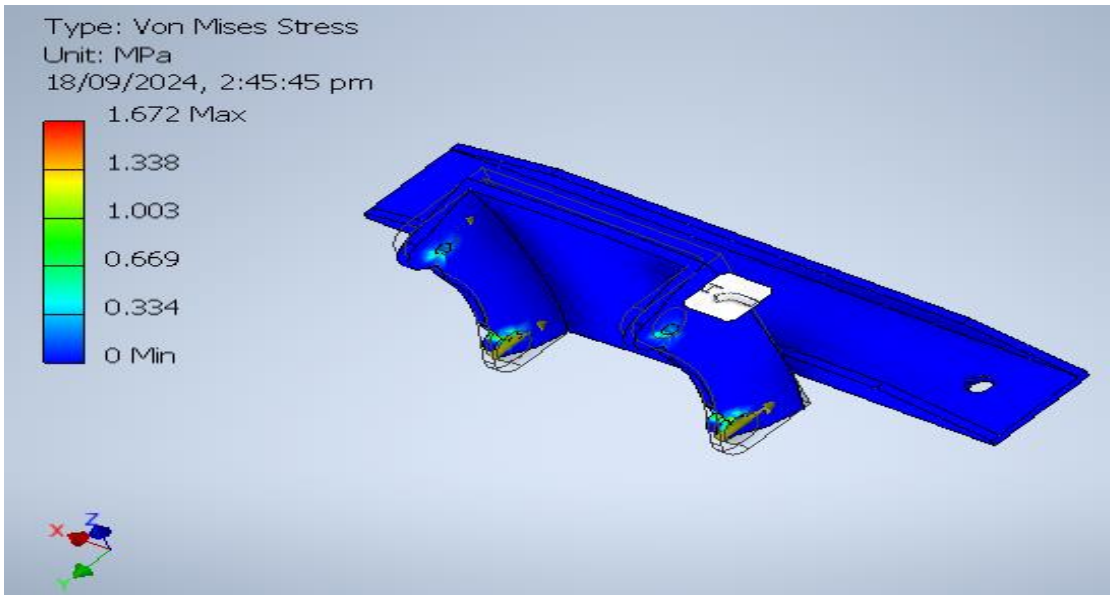


Figure 5. 8: Von Mises Stress of the Front Engine Seat

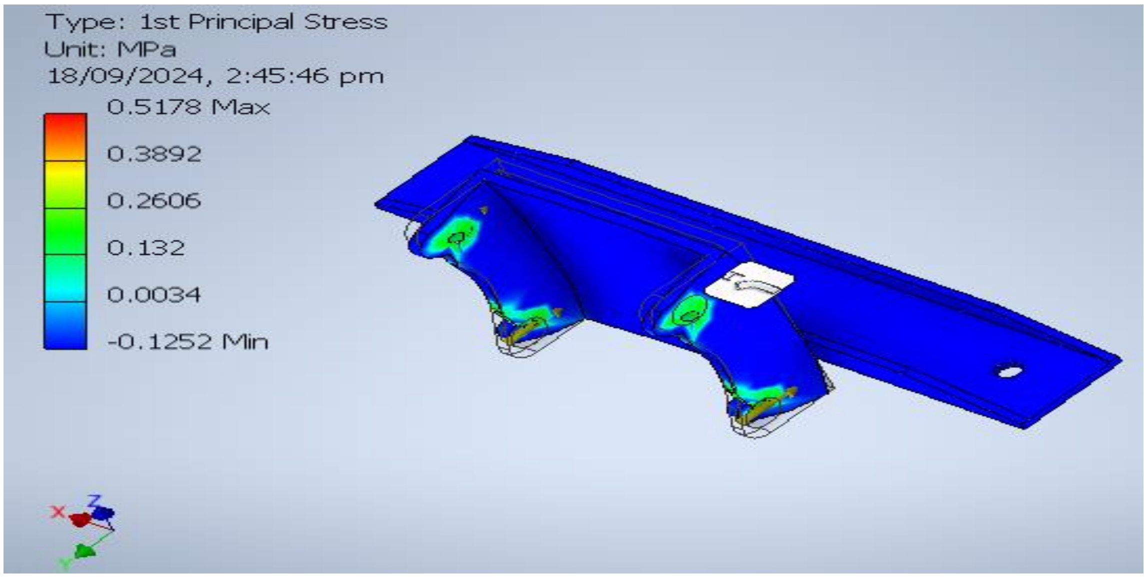


Figure 5. 9: 1st Principal Stress of the Front Engine Seat

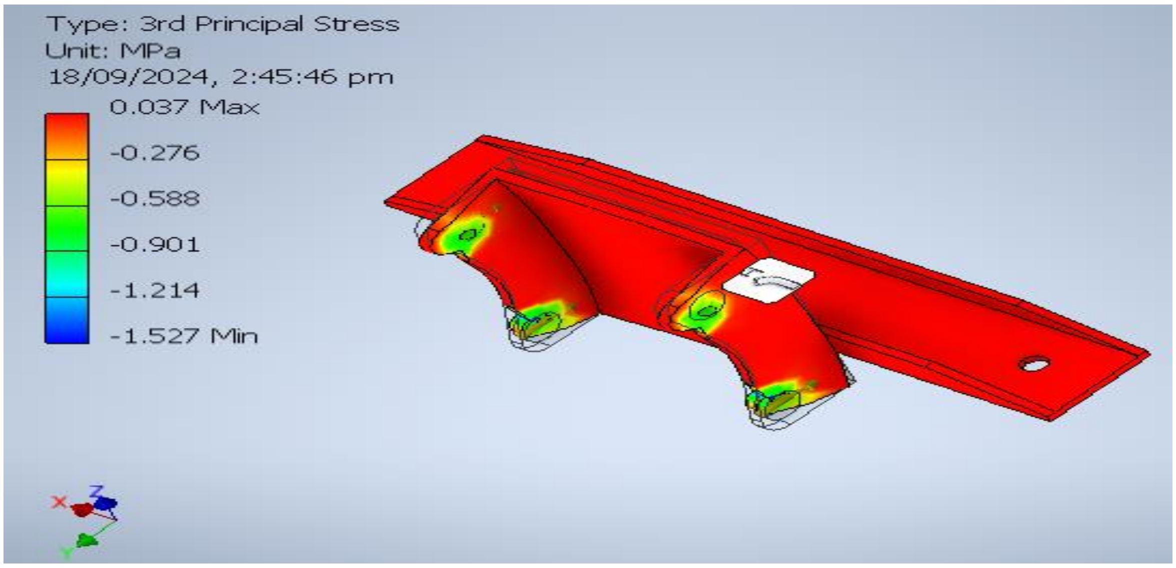


Figure 5. 10: 3rd Principal Stress of the Front Engine Seat

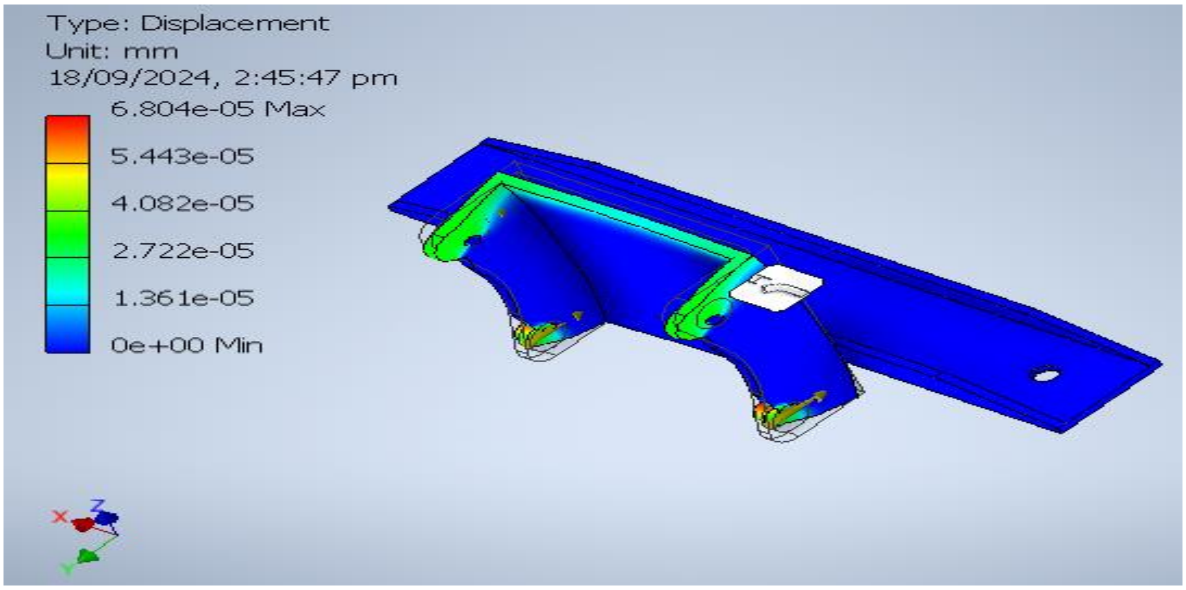


Figure 5. 11: Displacement of the Front Engine Seat

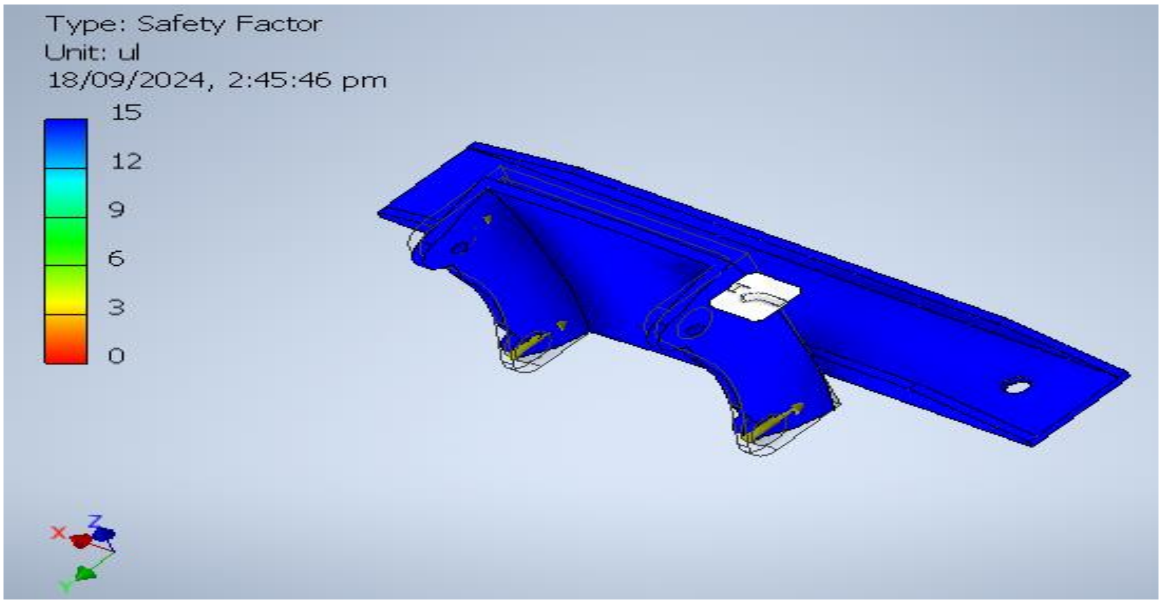


Figure 5.12: Safety Factor of the Front Engine Seat

5.2.3 Finite Element Analysis Engine Backseat

The results showed a maximum Von Mises stress of 13.656 MPa (Figure 6.13) which is less than the yield strength of the material used (207 MPa), indicating that the engine back seat can safely carry the 305N. The minimum and maximum values of the **1st** principal stress were -2.52687 MPa and 12.7728 MPa respectively (Figure 5.14), which represents the minimum and maximum tensile stresses induced in the engine back seat. This is usually less than the Von Mises stress and occurs at the holes of the engine seat. The minimum and maximum values for the 3rd principal stress were -10.598 MPa and 2.19186 MPa (Figure 5.15), representing the compressive stresses induced in the engine's back seat.

The maximum displacement occurred near the holes of the seat (Figure 5.16). This is expected since the seat support is far from the holes where the load is applied. The maximum displacement was 6.08 x 10^{-5} mm, which is negligible and will not have any impact on the machine. The minimum safety factor achieved in this design is 15 as shown in Figure 5.17.

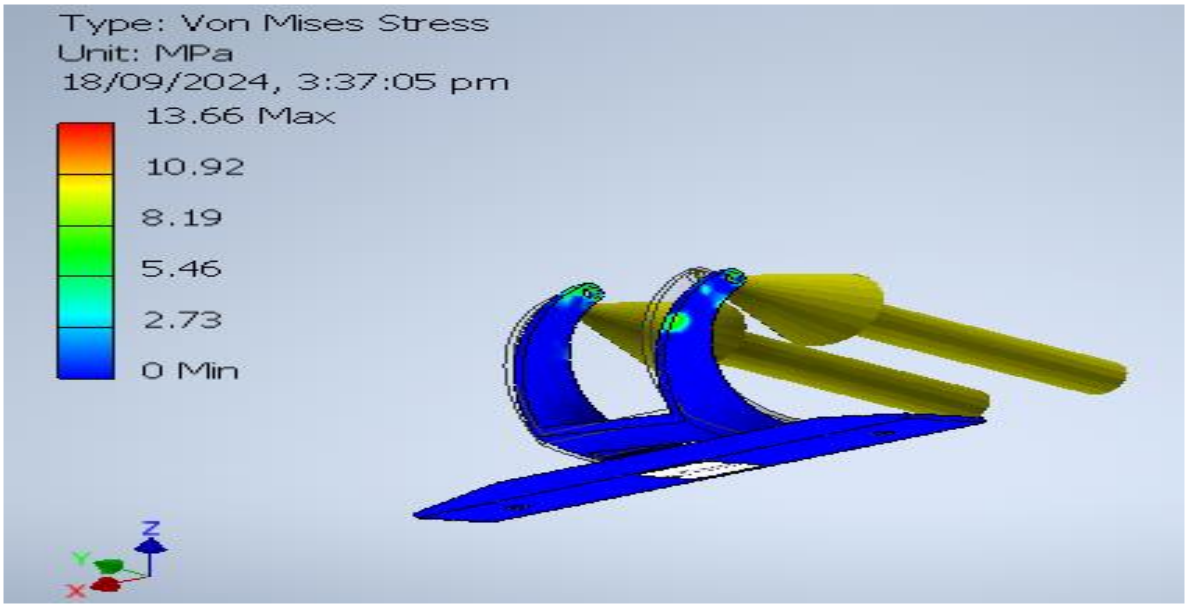


Figure 5.13: Von Mises Stress of the Engine Back seat

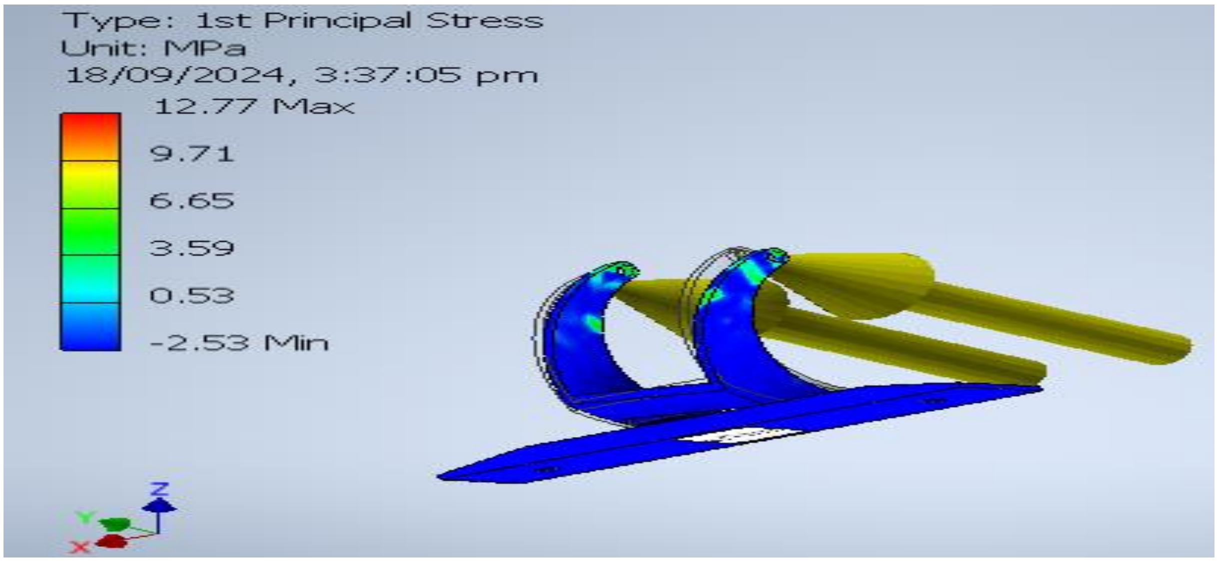


Figure 5.14: 1st Principal Stress of the Engine Back seat

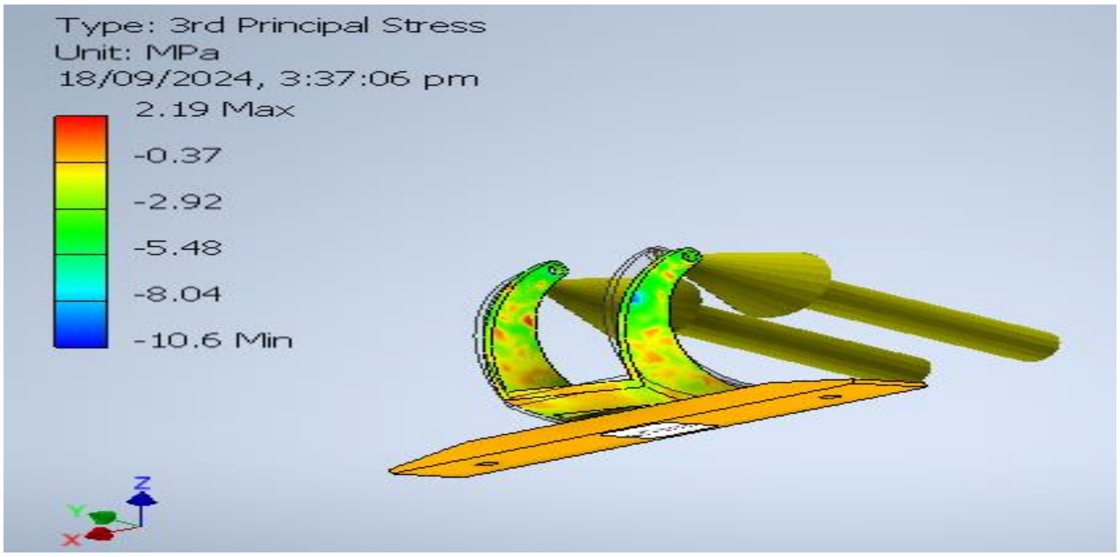


Figure 5. 15: 3rd Principal Stress of the Engine Back seat

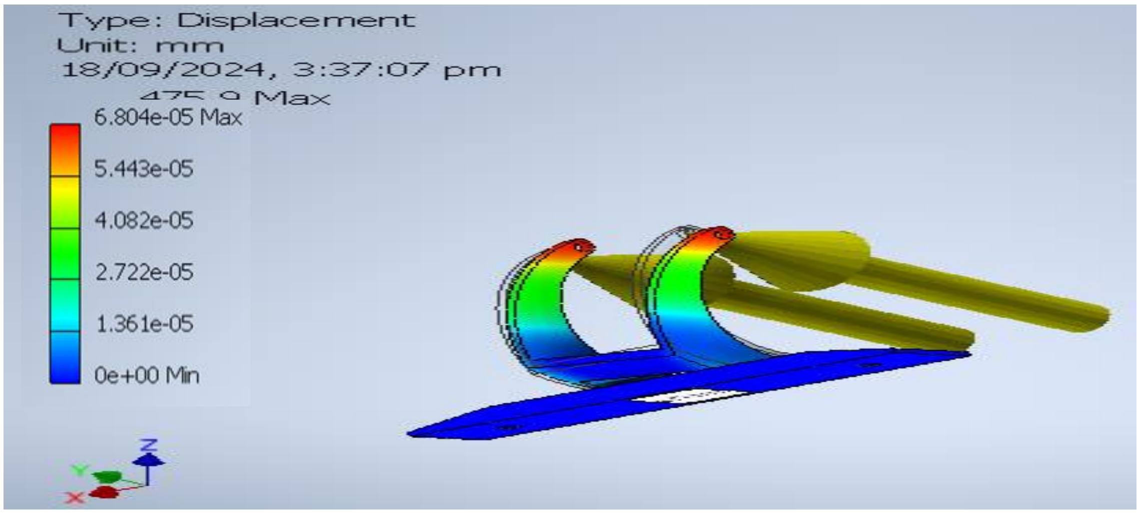


Figure 5. 16: Displacement of the Engine Back seat

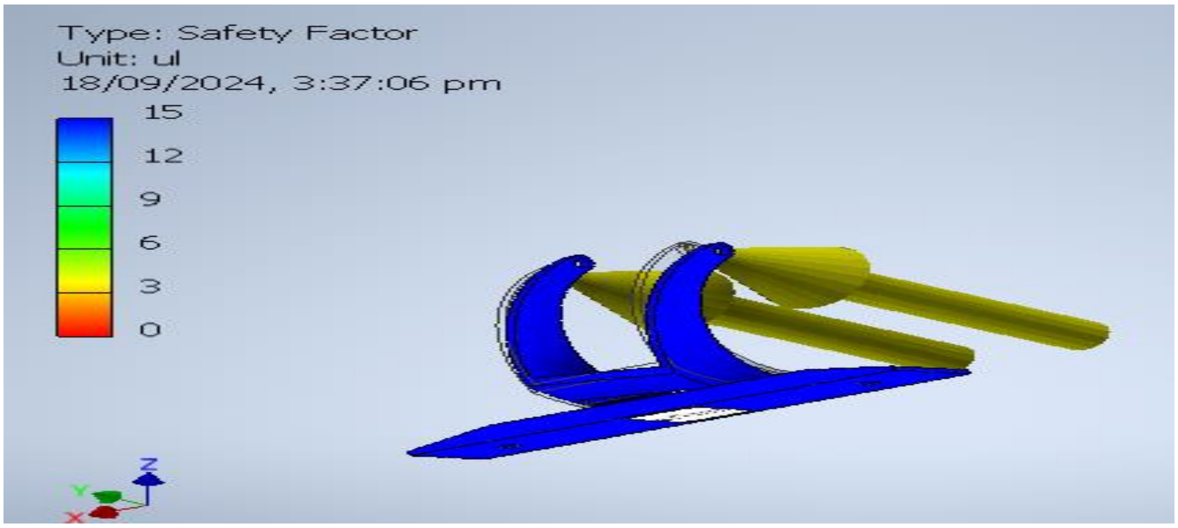


Figure 5. 17: Safety Factor of the Engine Back Seat

5.2.4 Finite Element Analysis of the Mouldboard Plough

The results showed a maximum Von Mises stress of 220.727 MPa (Figure 5.18) which is less than the yield strength of the material used (275.8 MPa), indicating that the plough can safely carry the 707.107 N load. The minimum and maximum values of the **1st principal stress were -23.8222 MPa and 178.719 MPa respectively** (Figure 5.19), which represents the minimum and maximum tensile stresses induced in the plough.

The minimum and maximum values for the 3rd principal stress were -145.972 MPa and 15.3181 MPa (Figure 5.20), representing the compressive stresses induced in the plough.

The maximum displacement occurred at the tip of the plough (Figure 5.21). This is expected since the tip is far from the holes where the plough is hinged to the frame. The maximum displacement was 0.284135 mm. The minimum safety factor achieved for the plough in this design is 1.24951 ul as shown in Figure 5.22. This is acceptable since the recommended safety factor for most engineering designs is between 1 and 5 (Tooley, 2009).

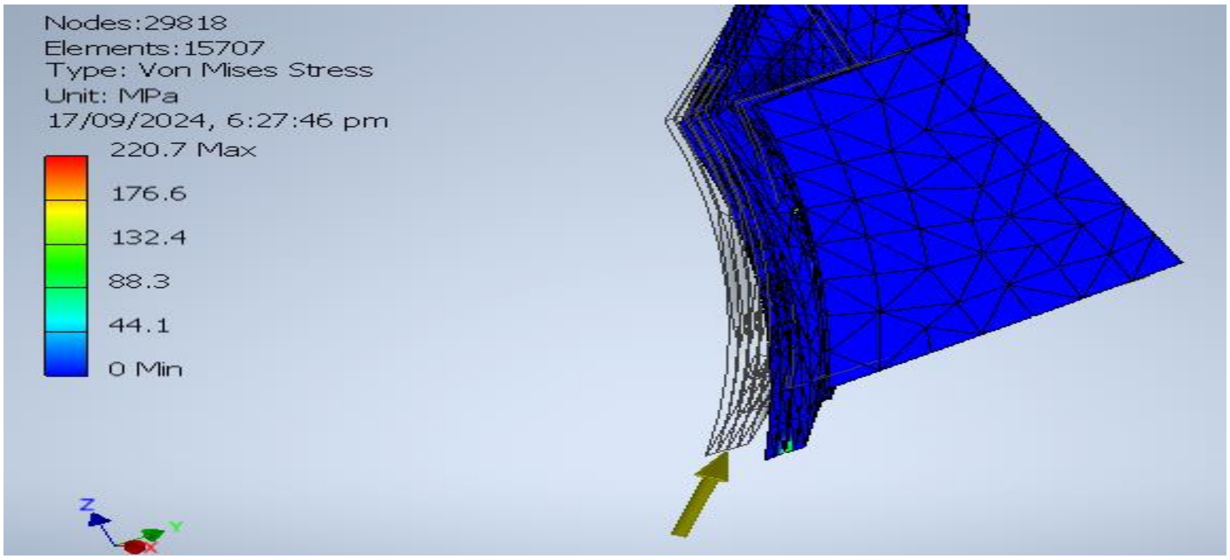


Figure 5.18: Von Mises Stress

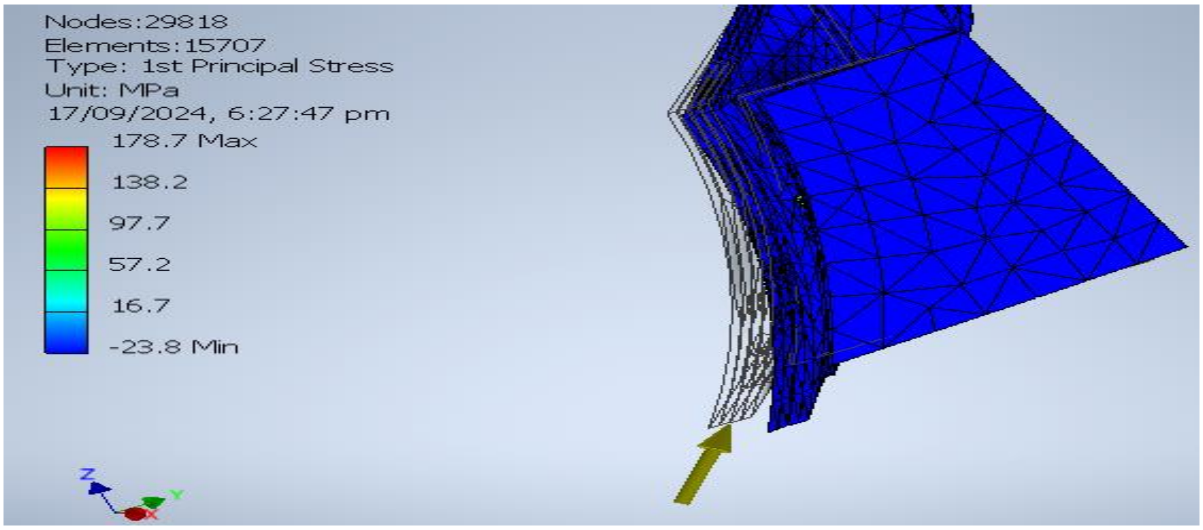


Figure 5.19: 1st Principal Stress of the Plough

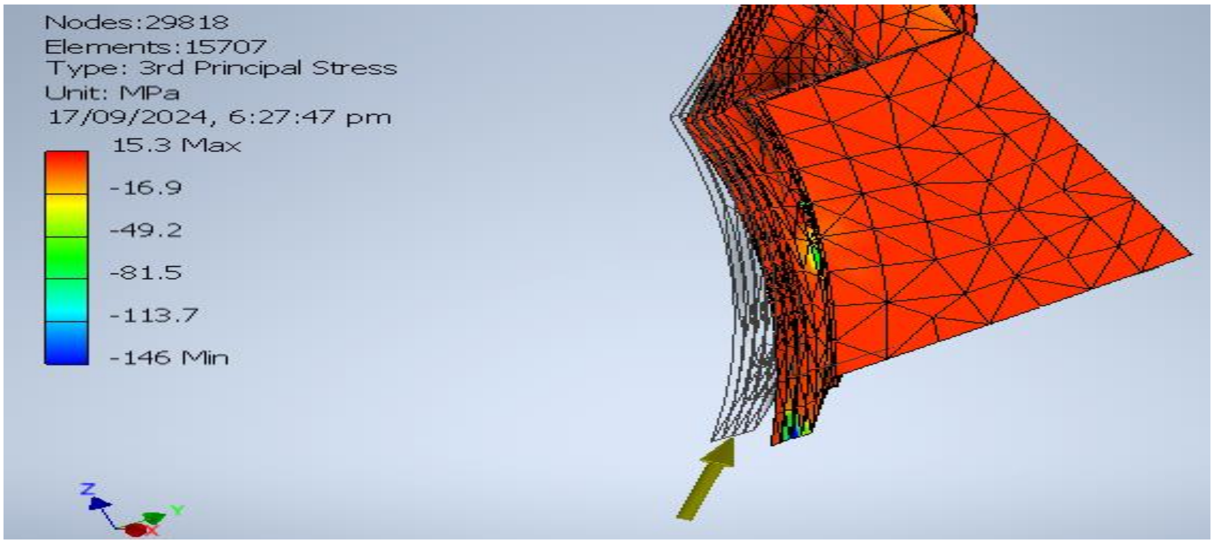


Figure 5.20: 3rd Principal Stress of the Plough

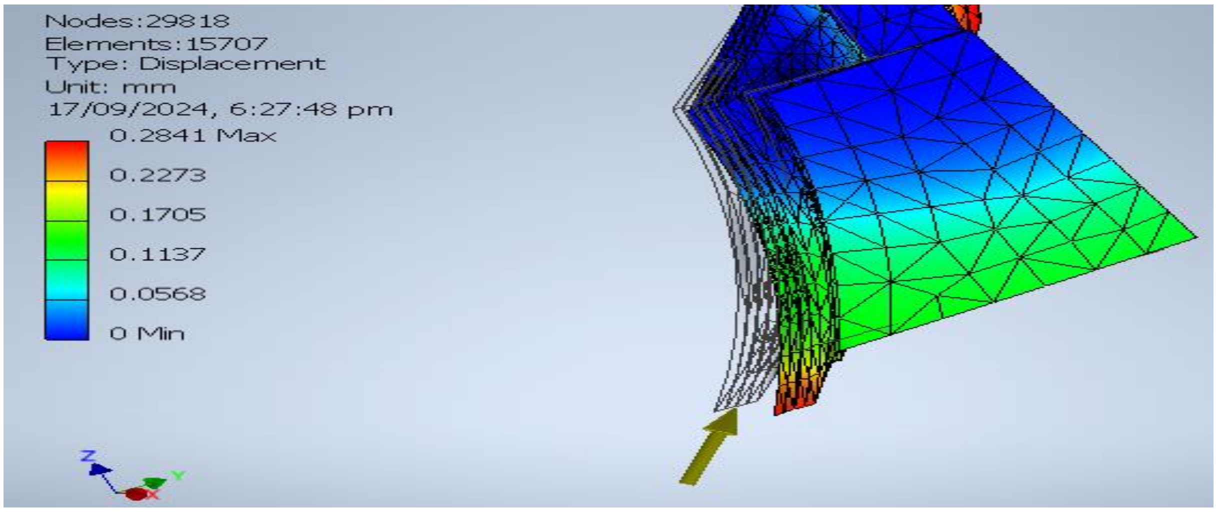


Figure 5.21: Displacement of the Plough

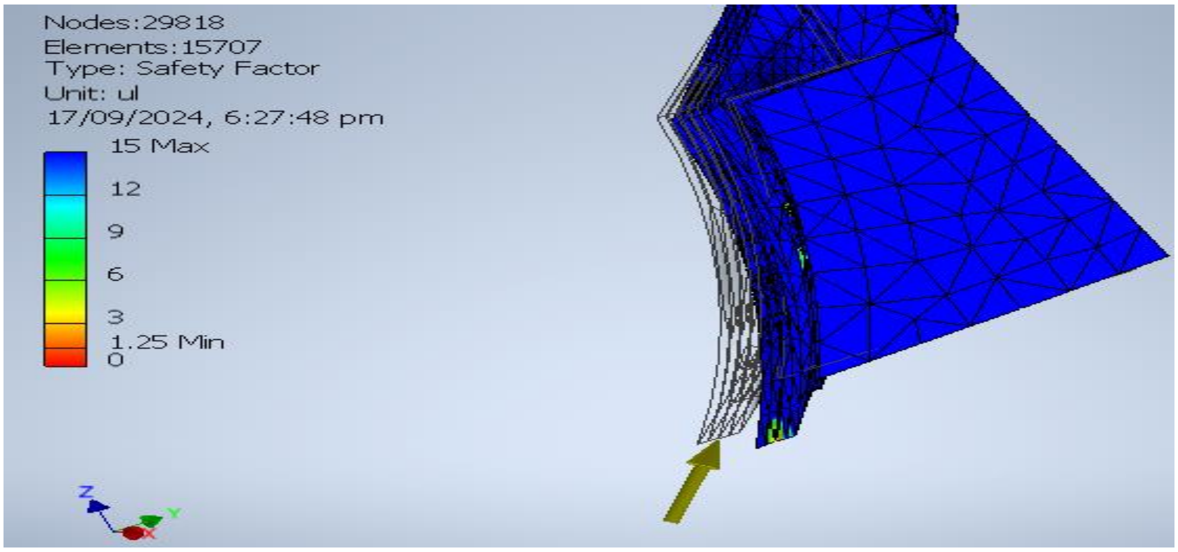


Figure 5. 22: Factor of Safety of the Plough

5.2.5 Finite Element Analysis of the Control Handle

The results showed a maximum Von Mises stress **of** 0.0909601 MPa (Figure 5.23) which is less than the yield strength of the material used (207 MPa), indicating that the control bars can safely carry the 157.500 N load. The minimum and maximum values of the 1st principal stress were -0.0551032 MPa and 0.138225 MPa respectively (Figure 5.24), which represents the minimum and maximum tensile stresses induced in the control bars. The minimum and maximum values for the 3rd principal stress were -0.139721 MPa and 0.0469922 MPa (Figure 6525), representing the compressive stresses induced in the control bars. The maximum displacement occurred at the handles of the control bars (Figure 5.26). This is expected since the handles are far from the points where the control bars are welded to the frame. The maximum displacement was 0.151546 mm. The minimum safety factor achieved for the control bars is 15 ul as shown in Figure 5.27.

Figure 5.23: Von Mises Stress of the Control Bars

Figure 5.24: 1st Principal Stress of the Control Bars

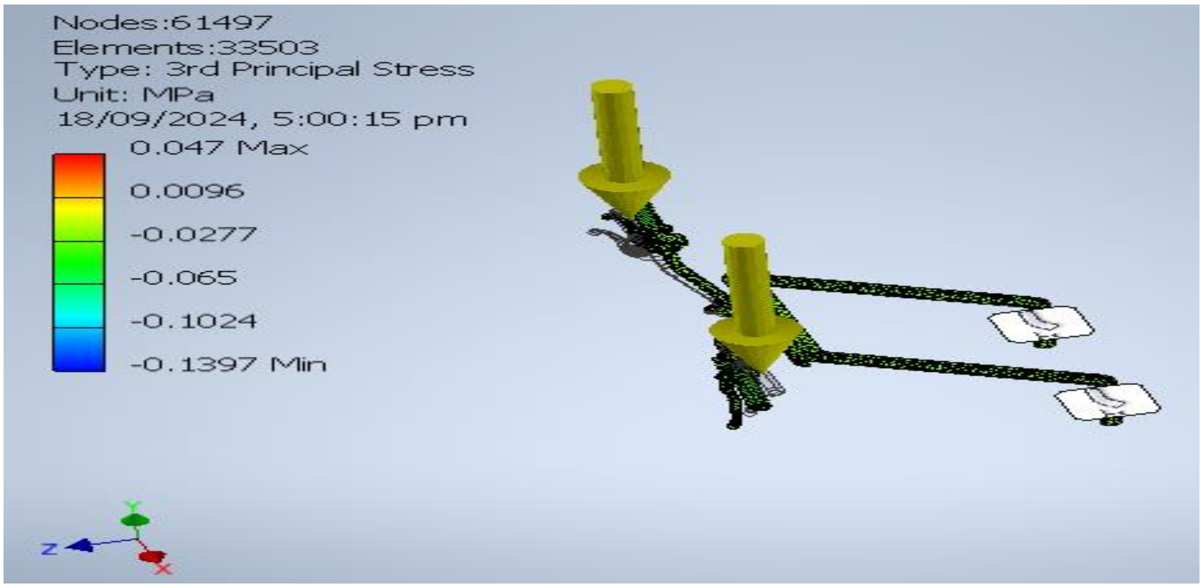


Figure 5.25: 3rd Principal Stress of the Control Bars

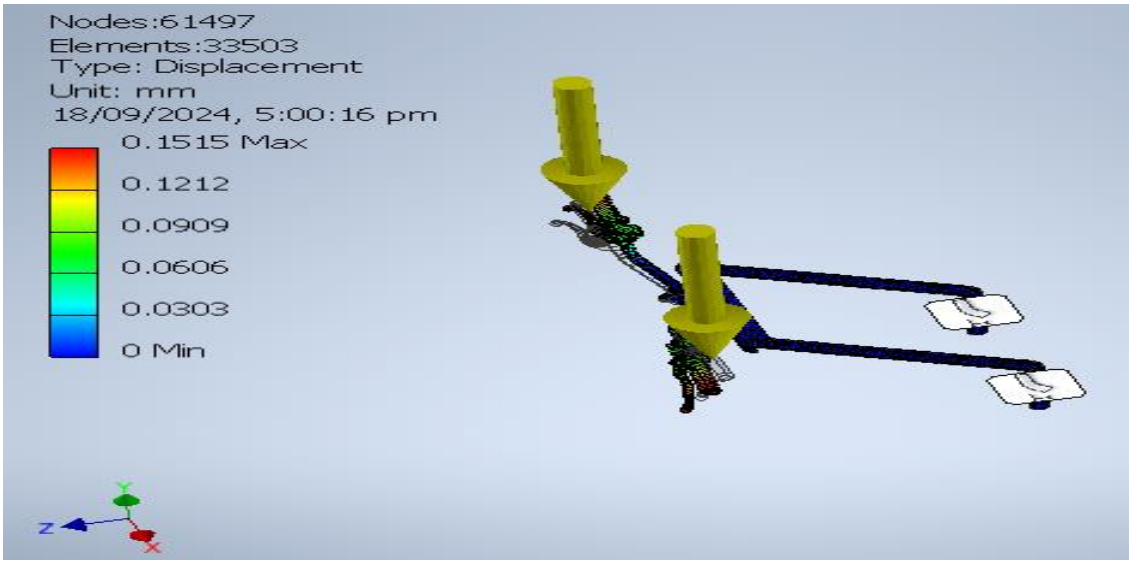


Figure 5.26: Displacement of the Control Bars

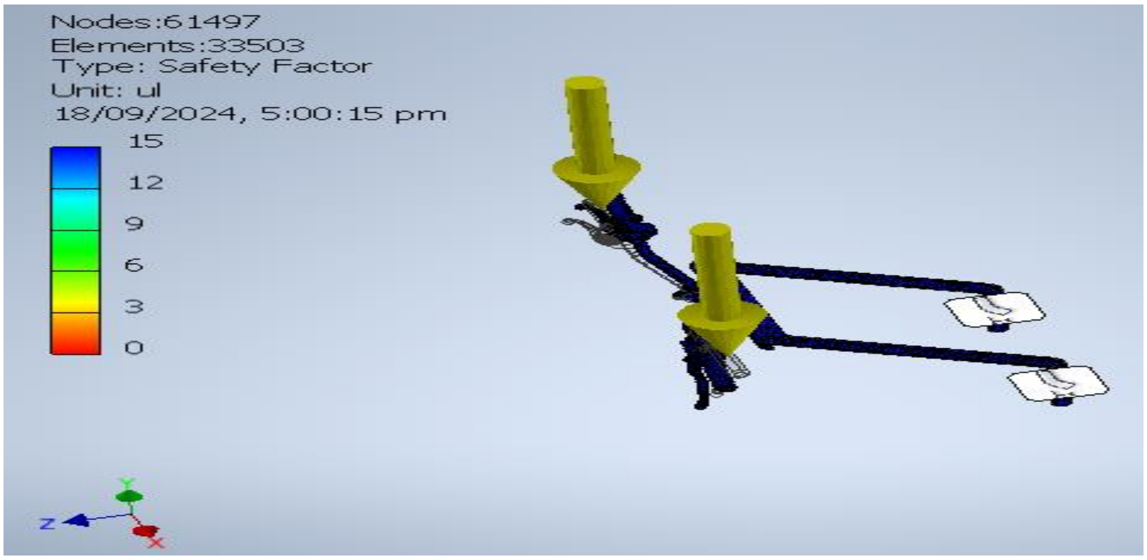


Figure 5.27: Safety Factor of the Control Bars

5.2.6 Finite Element Analysis of the Driving wheel shaft

The results showed a maximum Von Mises stress of 74.8531 MPa (Figure 5.28) which is less than the yield strength of the material used (207 MPa), indicating that the driving wheel shaft can safely carry the 550.00 N load applied. The minimum and maximum values of the 1st principal stress were -5.86302 MPa and 78.489 MPa respectively (Figure 5.29), which represents the minimum and maximum tensile stresses induced in the control bars. The minimum and maximum values for the 3rd principal stress were -83.2412 MPa and 5.98696 MPa (Figure 5.30), representing the compressive stresses induced in the control bars. The maximum displacement occurred at the middle of the shaft (Figure 5.31). This is expected since the supports which are the wheels, are far from the middle of the shaft. The maximum displacement was 0.089977 mm. The minimum safety factor achieved for the driving wheel shaft is 2.7 as shown in Figure 5.32.

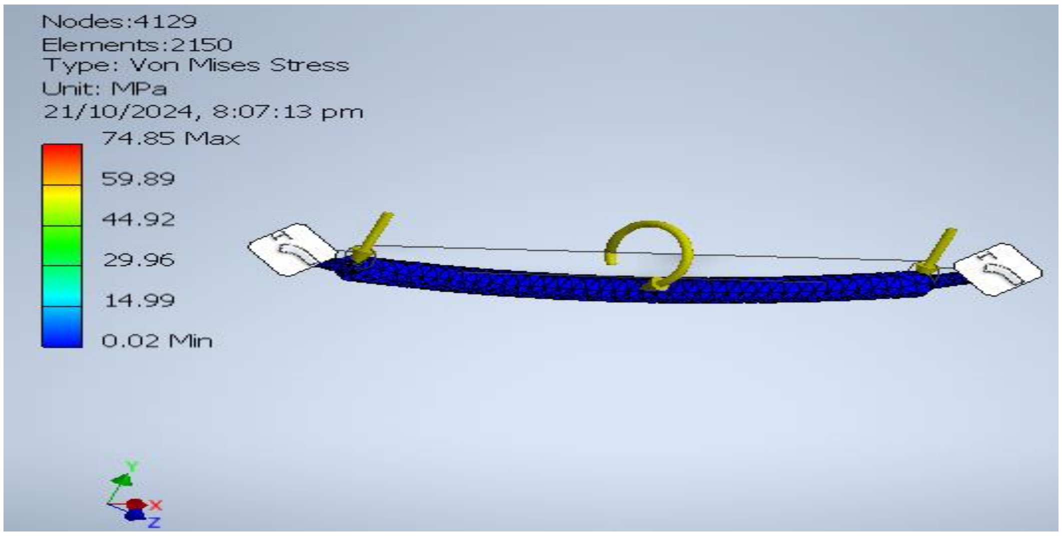


Figure 5.28: Von Mises Stress of the Driving Wheel Shaft

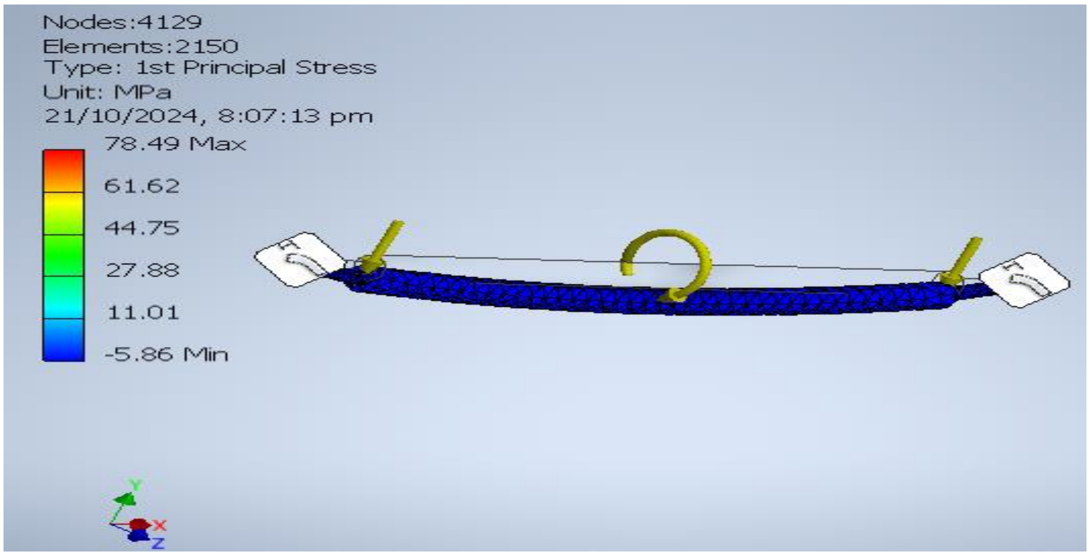


Figure 5.29: 1st Principal Stress of the Driving Wheel Shaft

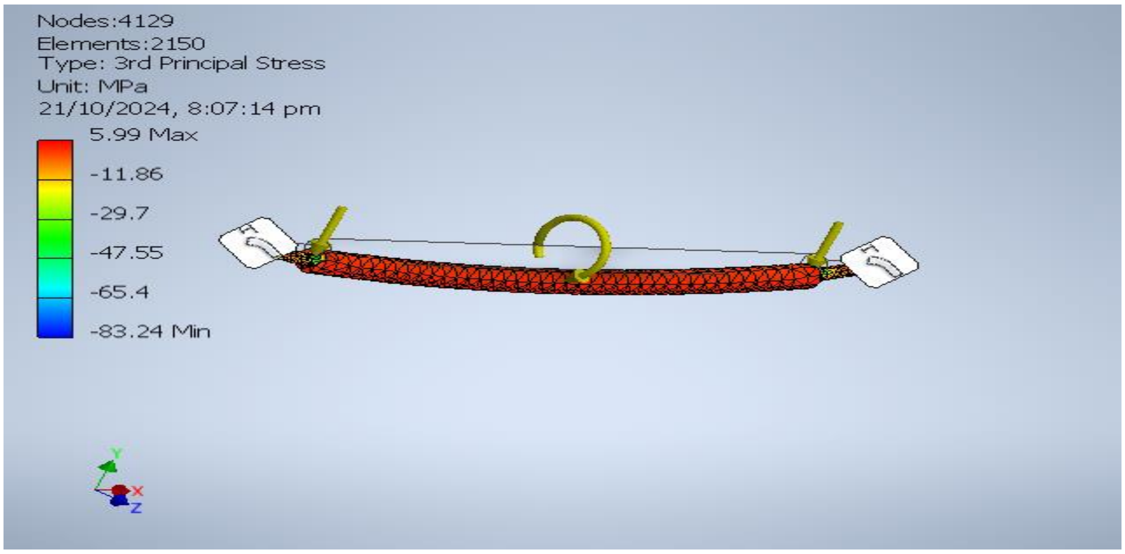


Figure 5. 30: 3rd Principal Stress of the Driving Wheel Shaft

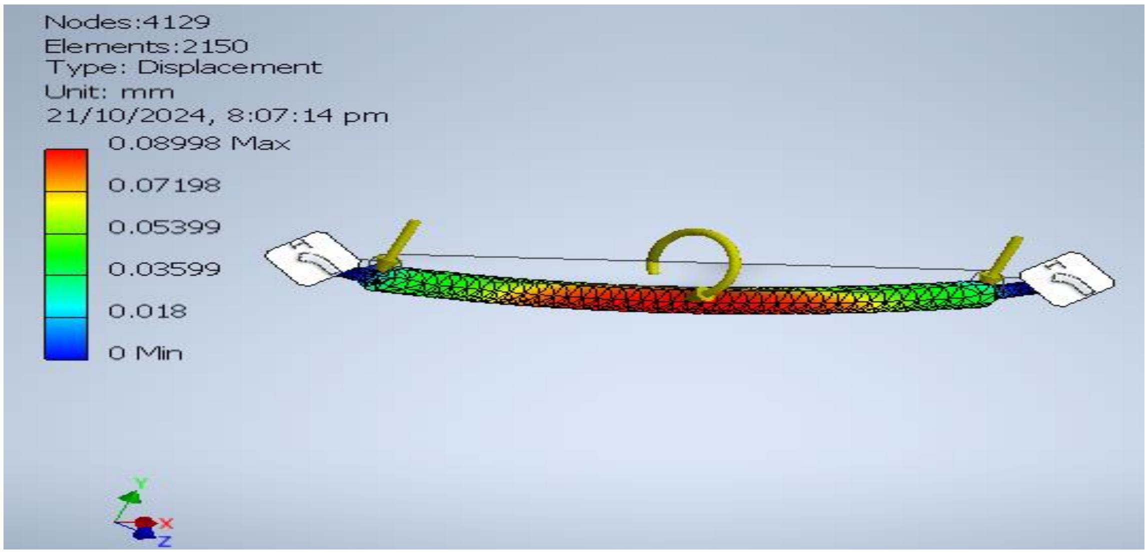


Figure 5.31: Displacement of the Driving Wheel Shaft

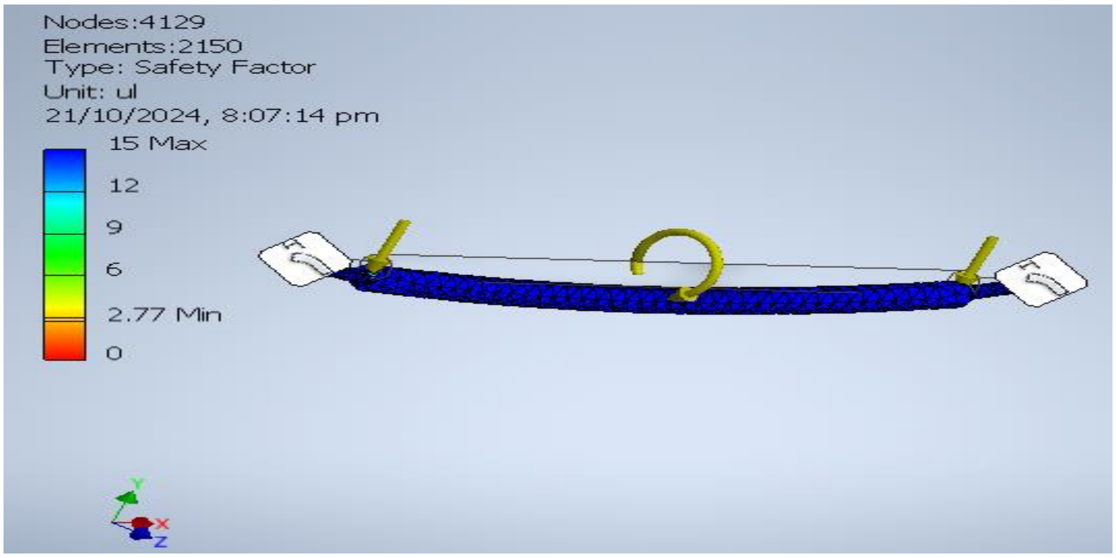


Figure 5.32: Safety Factor of the Driving Wheel Shaft

5.3 Results of the Manufacturing

The PPTISGSIS was successfully manufactured using mild steel plates and angle irons for the structure since mild steel is readily available on the market and strong enough to bear the anticipated loads. The motorcycle engine and the water pump were ordered together with some parts of the control bars. A picture of the manufactured PPTISGIS is shown in Figures 5.33 and 5.34.

5.4 Performance Evaluation of the Tilling Unit

5.4.1 Soil Analysis Results

Table 5.1: Soil Properties

Lab ID	Sample ID	% MC	%Vol PWP	%Vol FC	g/cm3 Bulk Density	% Sand	% Silt	% Clay	Soil Texture
004	**UDS Merch**	15.76	6.30	13.30	1.45	79.00	13.84	7.16	Loamy Sand

5.4.2 Data collected

General parameters for the evaluation are presented in Table 5.8 and the averages of data for the different speeds are presented in Table 5.8. The parameters involved are: length of throw, number of tests, quantity of fuel filled in the tank before commencement of evaluation and fuel left after the experiment.

Table 5. 2: General Parameters for the Evaluation

parameters	Values
Length of furrow	19 m
Number of tests	3
Fuel filler	800 ml
Fuel left after the tests	115 ml

Table 5.3: Averages of Field Data

Speed (m/s)	Furrow depth (cm)	Wheel Revolutions (rpm)(Under load)	Wheel Revolutions (rpm) (No load)	Operating width (cm)	Time (s)
0.278	6.5	12.08	11.5	14.67	56
0.556	6.67	12.75	11.5	15	47.36
0.833	7	13	11.5	18	43.36

5.4.3 Parameters determined after the tilling unit evaluation

5.4.3.1 *Fuel consumption*

Using the data presented in Table 5.1, the fuel consumed at the end of the test was determined to be 685 ml. The size of the plot ploughed was 19 x 14 m. The estimated fuel consumption of the machine in tilling one hectare is 25.75. This value is acceptable since it is not significantly different from what GETACHEW (2020) got (24 l/h) when he developed and tested a two-wheel tractor.

5.4.3.2 *Wheel slip*

The percentage wheel slip was calculated for the three different speeds. The value for the first speed (0.278 m/s) was 5.03 %. The second and third speeds (0.556 and 0.833 m/s) were 10.64% and 13.04 % respectively. These results indicate that wheel sleep increases as the speed increases (Figure 5.35). The average percentage of wheel slip was therefore 9.57 %. This figure is commendable since it falls within the acceptable range which is up to 15 % (Popoff, 1967)

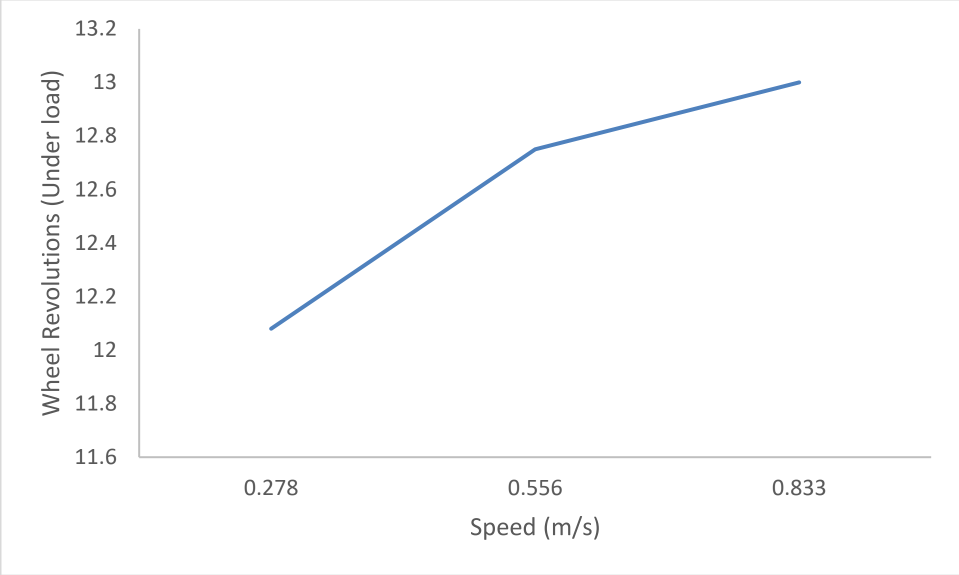


Figure 5.33: Relationship between speed and wheel slip

The influence of speed on the operating width was also studied. As seen in Figure 5.36, the speed is directly proportional to the operating width. When the speed increased from 0.278 to 0.833 m/s, the operating width also increased from 14.67 cm to cm.

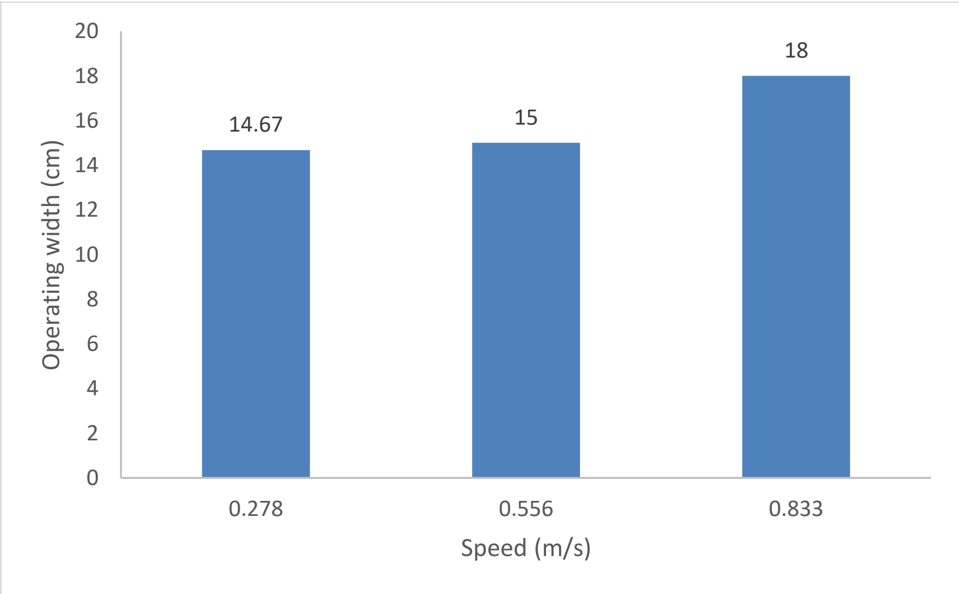


Figure 5.34: Relationship between Speed and Operating Width

5.4.3.3 *Theoretical field capacity (C_{th}) for tilling*

The operating width was 15.89 cm on average, while the operating speed was 0.56 m/s. The United Nations Economic and Social Commission for Asia and the

Pacific (ESCAP 2024) states that, depending on the tiller parameters, a power tiller's theoretical field capacity might vary from 0.2 to 1.5 ha/h: The power tiller's field capacity can be affected by its gear ratio, engine power, and tiller width. A power tiller's theoretical field capacity of 0.889 ha/h falls within an acceptable range.

5.4.3.4 *Effective Field Capacity for Tilling*

The Effective field capacity was found to be 0.7 ha/h. The effective field capacity for a power tiller range from 0.3 to 1.2 ha/h. Typical Effective Field Capacities: Small-scale power tillers: 0.2-0.5 ha/h, Medium-scale power tillers: 0.5-1.0 ha/h, Large-scale power tillers: 1.0-2.0 ha/h or more (ESCAP, 2024) The effective field capacity of 0.7 ha/h is within the acceptable range for a medium-scale power tiller. This suggests that the power tiller is suitable for small to medium-sized farms, and can efficiently cover a moderate area in a given time.

5.4.3.5 *Field efficiency for tilling*

The field efficiency was calculated to be 0.7874 or 78.74 %. According to Calcante & Oberti (2019), the field efficiency of a power tiller can range from 60% to 90%, depending on the tiller design, operating conditions, and soil type. The field efficiency of 78.74% looks to be relatively good for a power tiller. This suggests that the power tiller can effectively utilize its power and time to cover the field with minimal losses due to factors such as turning, overlap, and idle time.

5.4.3.6 *Effective Field Capacity for Irrigation*

The effective field capacity of a power tiller refers to the actual area that can be tilled (or cultivated) per unit time, typically expressed in hectares per hour (ha/h). It takes into account real-world conditions, such as turning, overlapping, operator efficiency, and downtime, so it's always **less** than the theoretical field capacity. The application rate was found to be 1.125 L/s or 0.00112 m³/s, and the water requirement for chilli pepper is 7,396 m³/ha (Tuyển *et al.,* 2016). The effective field capacity was therefore found to be 0.143 ha/h.

Figure 5.35: Field Test

5.5 Performance Evaluation of the Irrigation System

5.5.1 Data collected

The data collected during the evaluation of the irrigation system's performance is shown in Table 5.10. The parameters include the diameter of the sprinkler nozzle (mm), the Throw, the length of the sprinkler (wetted radius), the average time for discharge, the angle of the wetted sector, wind speed, and discharge pressure. The values of all these parameters are shown in Table 5. There will be no obstruction to the operator's location. There are connectors for the pump's inlet and exit. A water hose connects the input to the water supply, and the sprinkler spray cannon, which is located distant from the power tiller, is attached to the outlet. The operator can work without coming into contact with the sprinkler.

Table 5. 4: Data on the irrigation system performance

No	Parameter	Value
1	Diameter of the sprinkler nozzle (mm)	6 mm
2	Throw the length of the sprinkler of sprinkler (wetted radius)	11m
3	Average Time for Discharge	80 s
4	the angle of the wetted sector	360 °
5	wind speed	18 Km/h
6	Pressure	2.5 bar

5.5.2 Parameters determined during the irrigation system evaluation

5.5.2.1 *Discharge Rate*

The discharge rate using a spray gun with a 6 mm diameter nozzle to discharge 90 liters in an average time of 80 s, was found to be 1.125 L/s. According to Makin, (2020), the discharge rate for a sprinkler nozzle can range from 0.5 to 10.0 L/s, depending on the nozzle diameter, pressure, and application. Given the nozzle diameter of 6 mm and discharge rate of 1.125 L/s, it appears to be within the acceptable range for a small to medium-scale irrigation system. This suggests that the spray gun nozzle is suitable for irrigating small to medium-sized areas, such as gardens, lawns, or small crops.

5.5.2.2 *Average Application Rate*

The average spray gun application rate for a discharge rate of 1.125 L/s was found to be 4.42 mm/h. Given the nozzle diameter of 6 mm and application rate of 4.42 mm/h, it appears to be within the acceptable range for a medium-application-rate sprinkler irrigation system (Kirui & Braun, 2018). This suggests that the sprinkler is suitable for irrigating most crops, such as grasses, cereals, and legumes, and can provide a moderate to high level of water application.

5.5.2.3 Coefficient of Uniformity

The coefficient of uniformity was computed to be 76.93 %. This value is close to the 80.2 % achieved by Yaseen *et al.* (2019) when they Developed and tested a mobile sprinkler rain gun for smart irrigation in arid zone-based crops in India. Furthermore, 76.93 % is within the acceptable range of 60 % to 90 % (VanderGulik and Branch, 1989). The trend of the volume of water collected along the throw length was also studied. The results pointed out that the amount of water collected reduced as you moved away from the sprinkler. It can be seen from Figure 5.38 that at a distance of 3 m from the spray gun, an average volume of 103.8 ml of water was collected while at 11 m from the spray gun, the average volume of water collected was reduced to 60.3 ml.

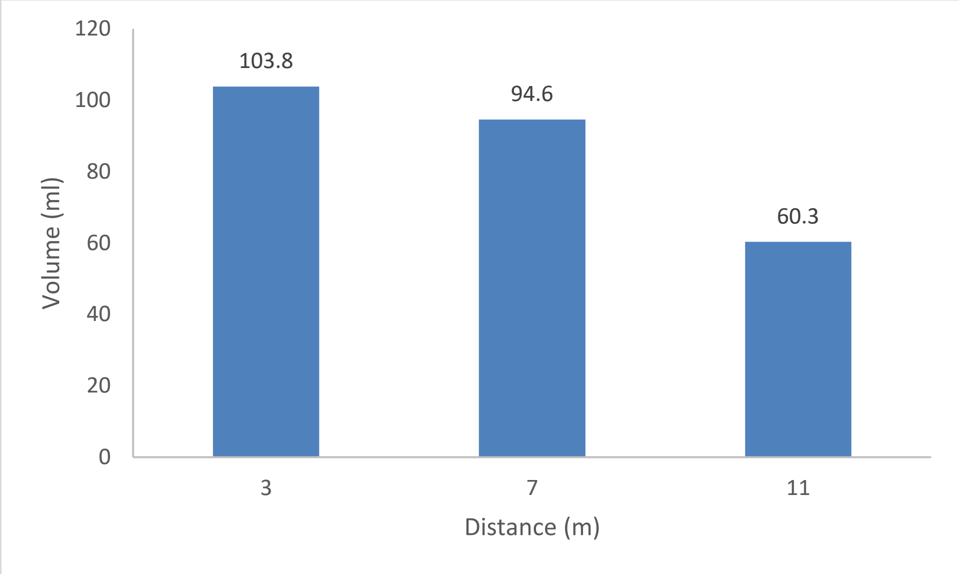


Figure 5.36: Effect of Distance from the Sprinkler on Water Collected.

Figure 5.37: Collection of Water to Measure the Coefficient of Uniformity

5.5.2.3 *Distribution Uniformity*

According to ESCAP, U. (2024), the distribution uniformity of a spray gun irrigation system should be at least 75% for most crops. The International Commission on Irrigation and Drainage (Vlotman, 2020). also recommends a minimum distribution uniformity of 75% for spray gun irrigation systems.

Given the distribution uniformity of 76.96%, it appears to be slightly above the minimum recommended value. This suggests that the spray gun irrigation system is capable of providing a relatively uniform water distribution, which is suitable for most crops. However, there may be some room for improvement to achieve higher uniformity and more efficient water use.

5.5.3 Cost-Benefits Analysis

The PPGISGIS cost was analysed by considering its ownership and operating costs. The total ownership cost (TOC) of the PPGISGIS was estimated by adding depreciation, interest, taxes, insurance and housing costs using the assumptions made in Tables 5.6 to 5.7 (Appendix D). Depreciation was calculated to be GH¢ 437.112/year. Insurance was estimated to be GH¢18.21 while Tax charges were exempted due to government policies regarding agricultural machinery in Ghana.

Benefits and cost ratios were computed to determine the worthiness of the investment in the PTIS. The results indicate that if the PTIS works for 100 days per year at a discount rate of 28.99% per annum, based on the Bank of Ghana rates as of September 18, 2024, the benefits to be generated over the period would be enough to generate returns to offset the initial investment and related costs. Thus, a GH¢1 investment would yield about GH¢2.13 returns (Appendix C).

CHAPTER SIX

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

6.1 Conclusion on Tillage

The prototype multifunctional agricultural equipment was successfully built to its 3D design and tested in the field. The machine is less bulky than previous multifunctional machines since all of the pieces are connected, allowing for easy rearrangement or quick assembly using fasteners. The forward speeds used were 0.278 m/s, 0.556 m/s, and 0.833 m/s under tillage. The field efficiency was calculated to be 78.74% and the fuel consumed was 25.75 liters of petrol per hectare. The developed prototype power tiller is faster than the traditional one because of its varying gear ratios, reducing the farmers' effort on tillage. As a result, it increases the capacity of the farmers to cover more fields in time, when planting time gets limited. The power tiller's lightweight makes it ideal for use under both wet and dry land conditions.

The forward speed of the developed prototype power tiller is similar to the imported power tiller, as the imported power tiller performs in its first and second gears. However, the developed power tiller has five speeds which can perform up to the third gear. Generally, the developed power tiller can perform faster with less drudgery than the imported power tiller.

6.2 Conclusion on Irrigation

According to the findings, employing a power tiller with an irrigation system greatly enhanced uniformity (76.93%) in field conditions. This means that 76.93 % of the area received equal water and the rest was under uneven distribution. If the uniformity is closer to 100% then the application efficiency will be higher. The values of throw length of sprinkler (m), Discharge rate (L/s), Area covered (m^2), and Application rate (mm/hr) were 11m, 1.125 L/s, 380.2 m² and 4.42 mm/h respectively. The machine costs only GH¢8,742.24 while those imported into the country cost between GH¢20,000 and GH¢25,000.00 as at August 2024. This confirms that the overall performance parameters of a power tiller with an irrigation system were at the recommended level. It implies that a power tiller with an irrigation system is technically feasible.

6.3 Recommendations

The following are some recommendations:

1. The government should allow duty-free import of engines and pumps. The reason is that about half of the cost of the tiller is due to the engine and pump.
2. There should be sensitisation to increase the awareness on the use of the machine. Since the machine is designed for five forward speeds, installing engines with gear ratios higher than the specified engine will result in high travel speeds and failure of the components of the machine. Thus, engines having speeds more than the design speed range should not be used.
3. Government should provide subsidies to encourage farmers to use power tillers and irrigation systems for more extensive crop farming.
4. Instruction on how to use power tillers with irrigation systems, as well as credit facilities for purchasing adequate water pumps can help increase the adoption of this technology.

6.4 Future Work

To provide smoother take up of drive synchronizing unit or constant mesh gearbox should be included in the design of the next researchers. In addition, the handle's design should be rigid enough to reduce the vibrations at their ends. As it has been found from the FEA analysis, the control bars have a maximum deformation reaching up to 0.151546 mm. When the engine is started, some vibrations are also induced into the handle, which amplifies the amplitude of the vibrations. Furthermore, if some devices like vibration measurement devices are included, better results can be achieved.

Further focus can be made on providing comfortable operator seating. A trolley can also be provided as an attachment so that goods can be transported. Total weight needs to be reduced by using aluminium alloys for the chassis.

6.5 Journal / Conference Papers

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Design and analysis of a multipurpose power tiller with C G 125 prime mover (*Accepted by Journal of Science & Technology JST/1001/07*)

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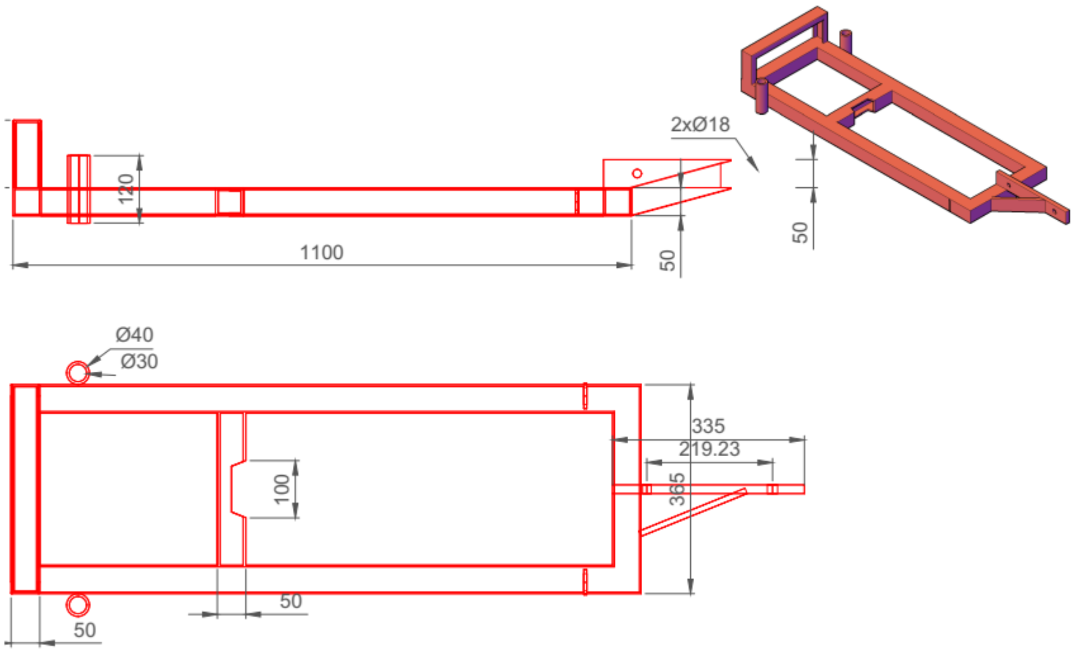
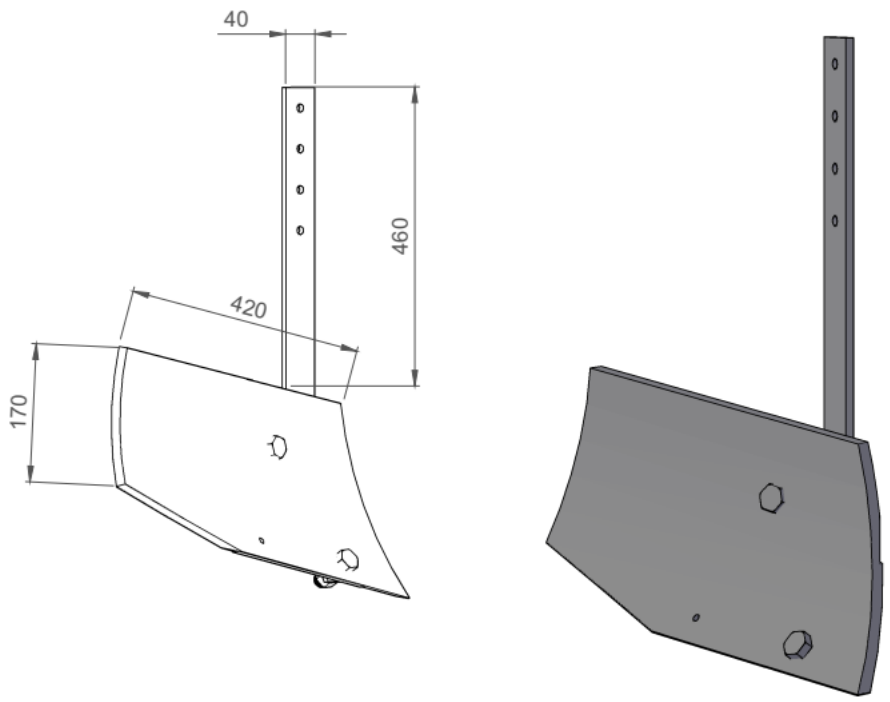
APPENDICES

APPENDIX A: Detail Drawings of the PPISGIS

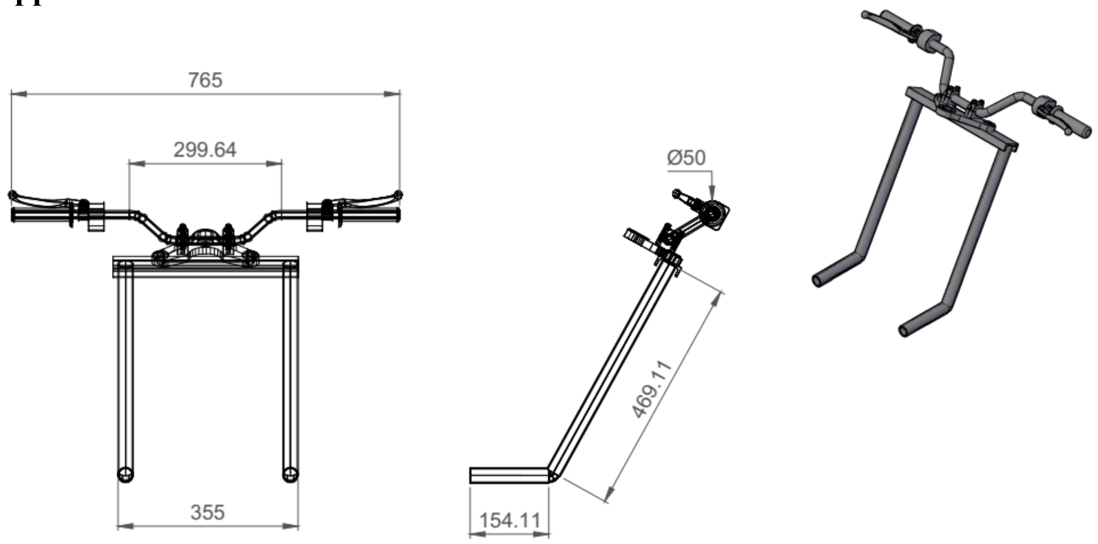
Appendix A1: The Frame



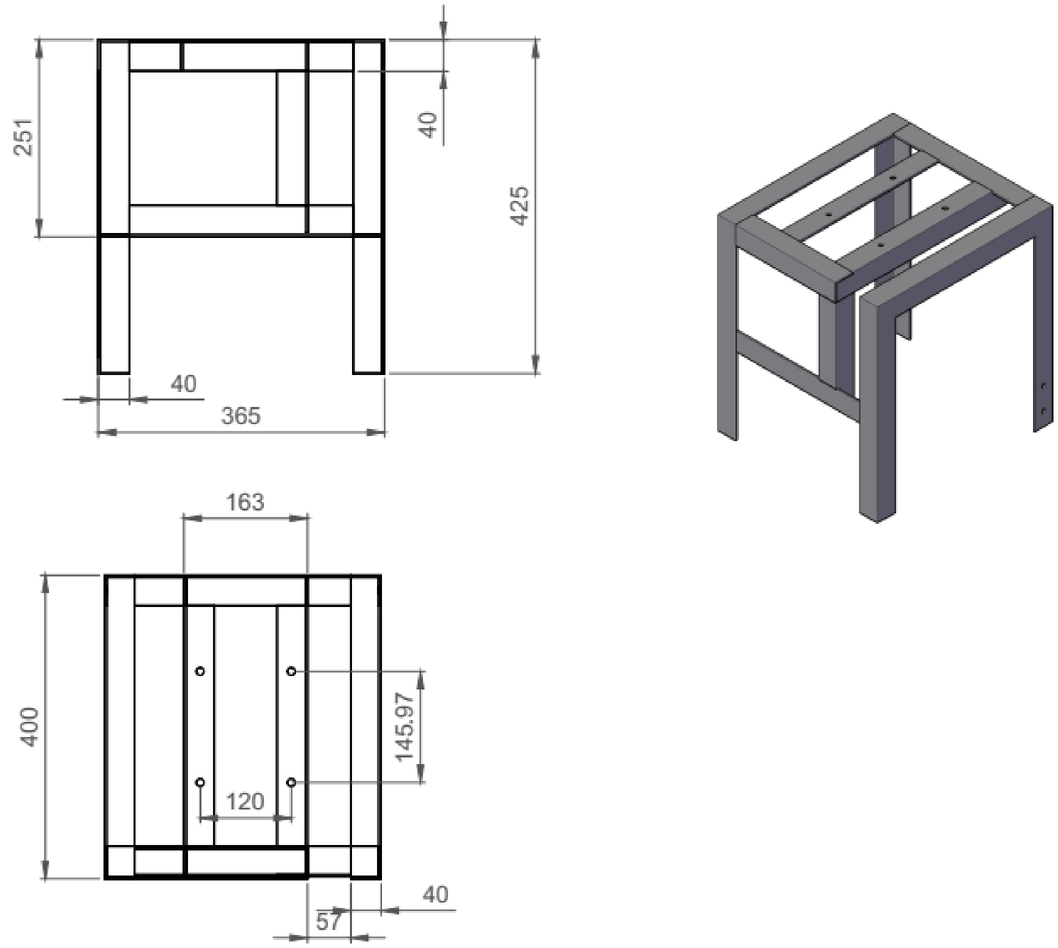
Appendix A2: The Mouldboard Plough



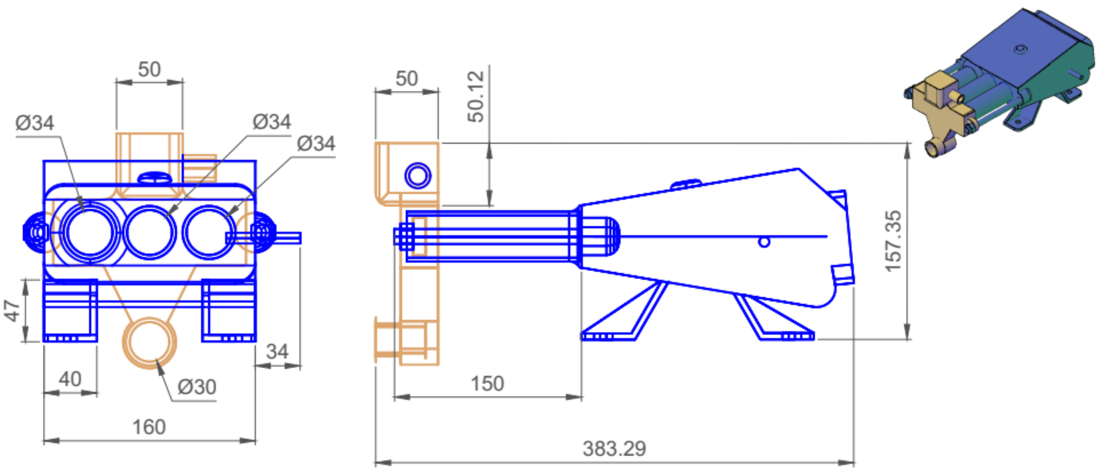
Appendix A3: The Control Bars



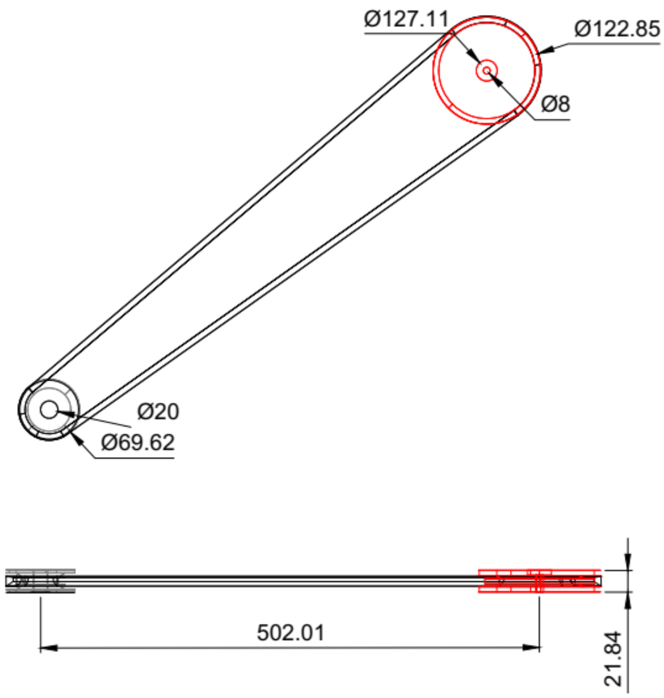
Appendix A4: The Pump Support



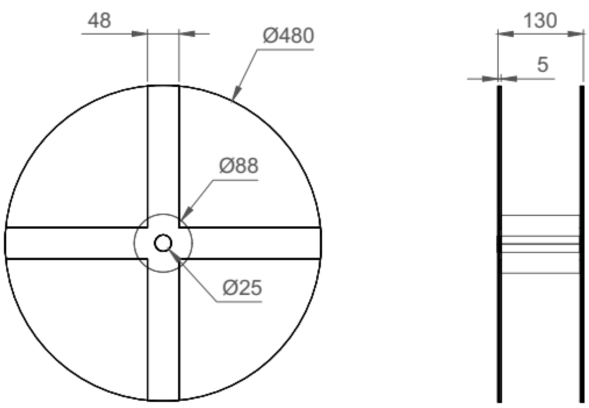
Appendix A5: The Water Pump

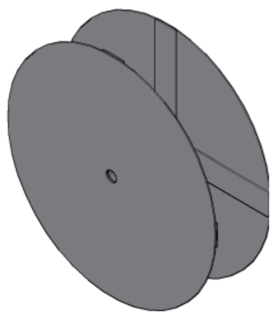


Appendix A6: The Belt Drive System

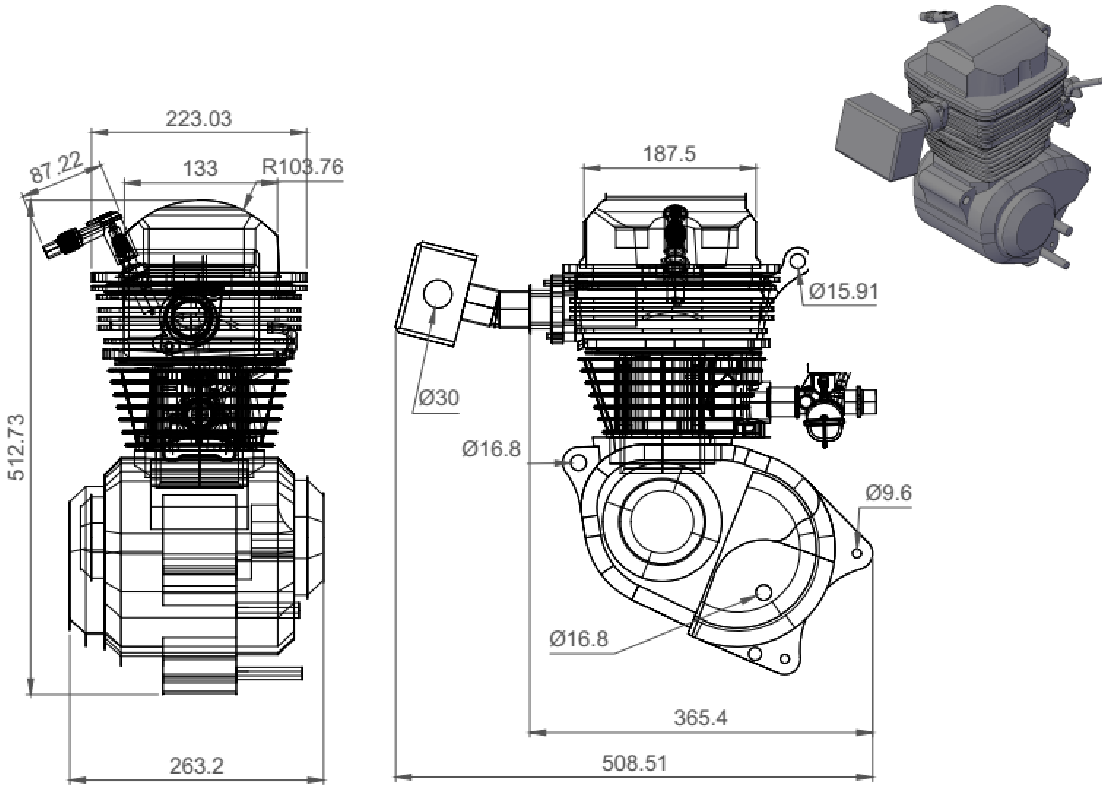


Appendix A7: The Reel

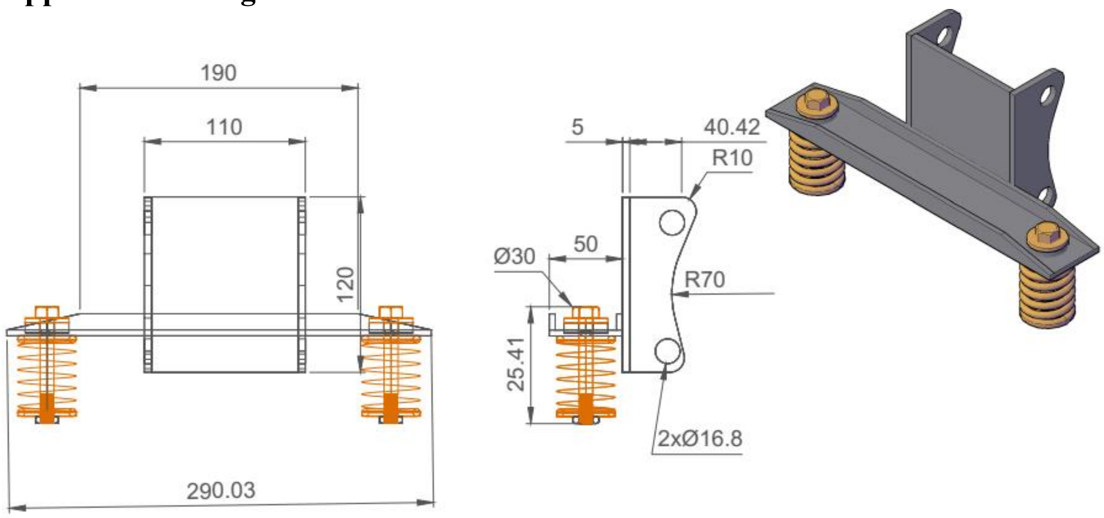




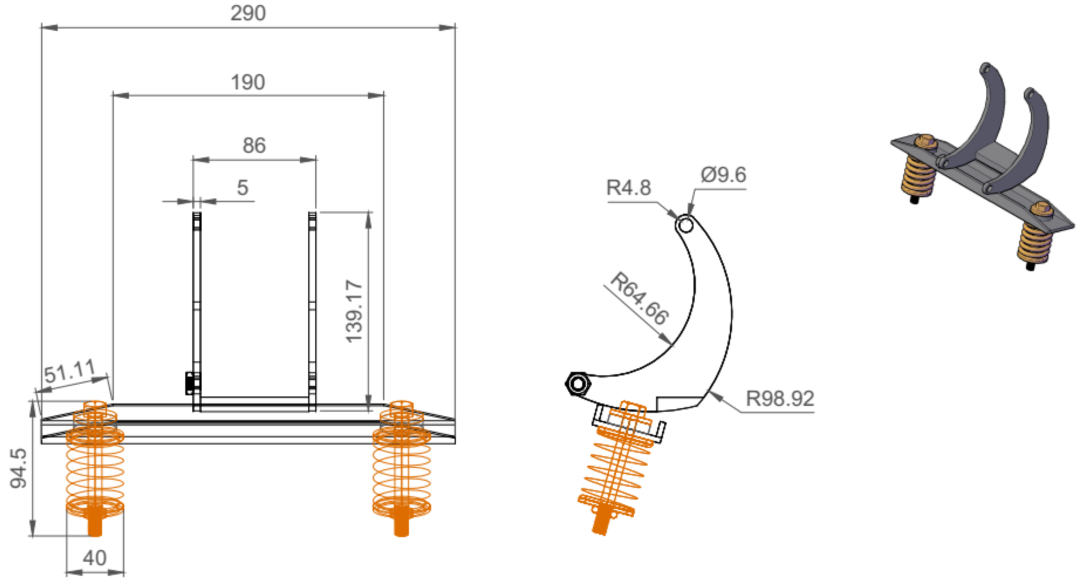
Appendix A8: The Engine



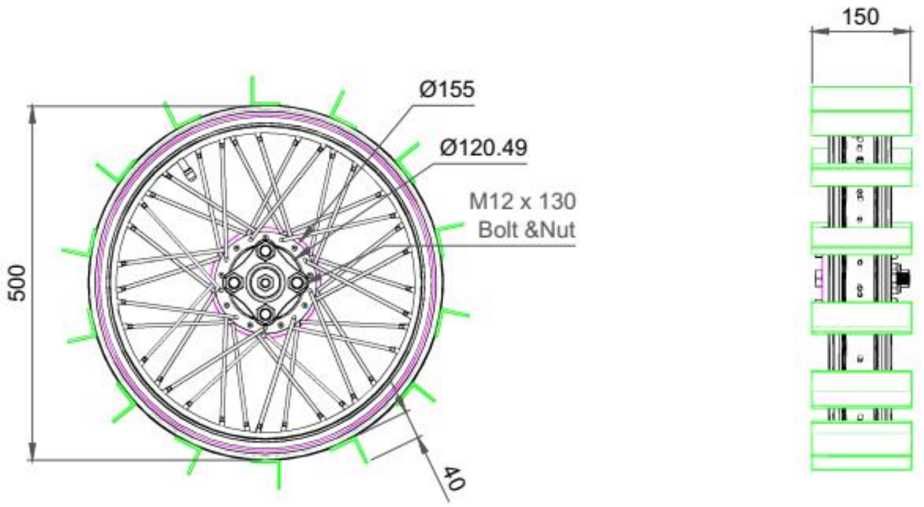
Appendix A9: Engine Front seat

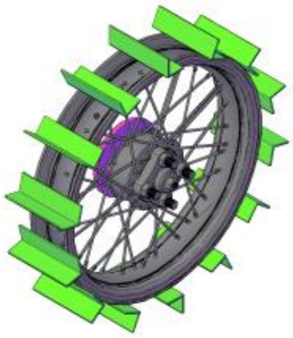


Appendix A10: Engine Back Seat

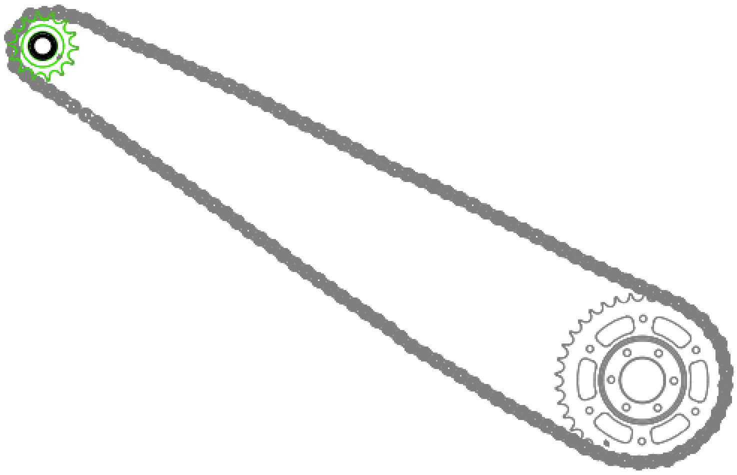


Appendix A11: The Driving Wheel

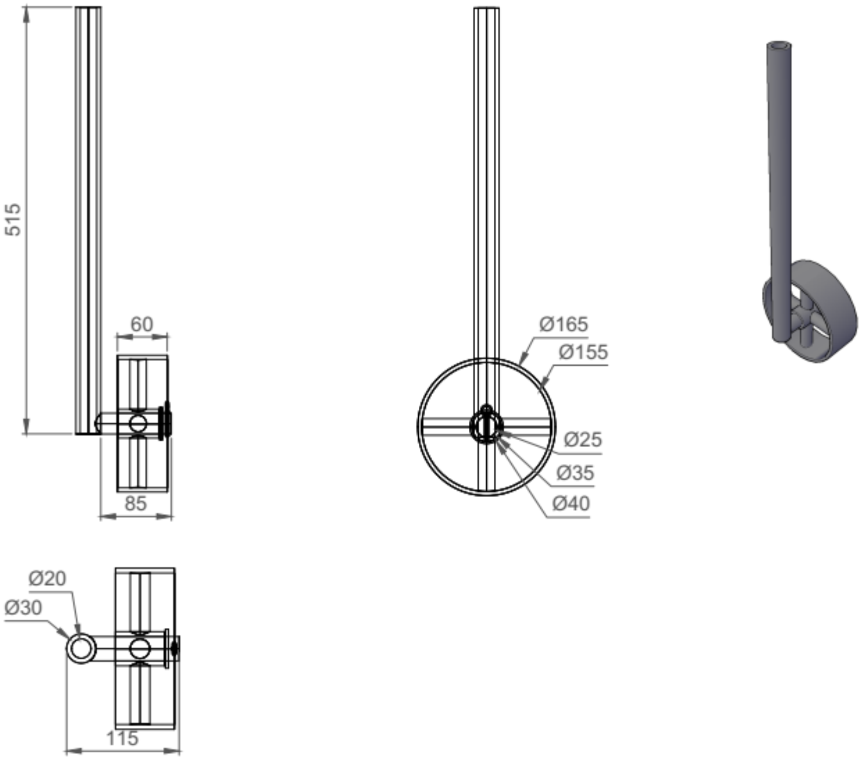




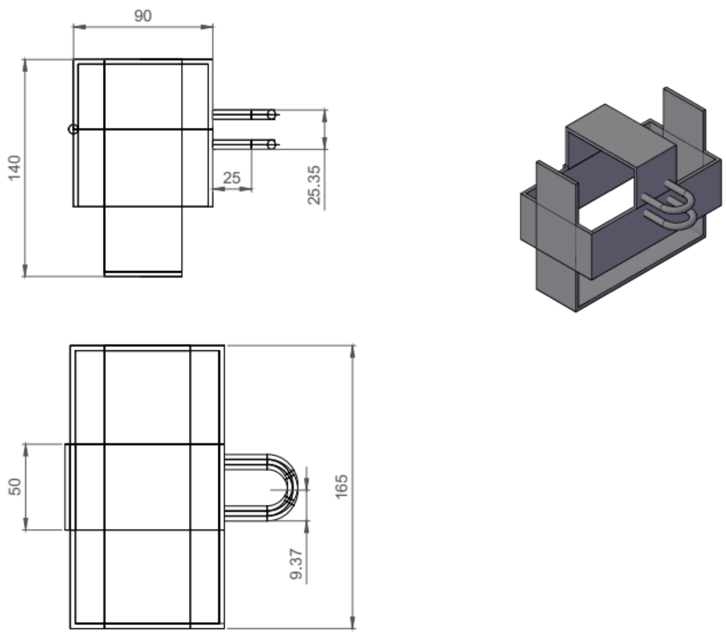
Appendix A12: The Chain Drive System



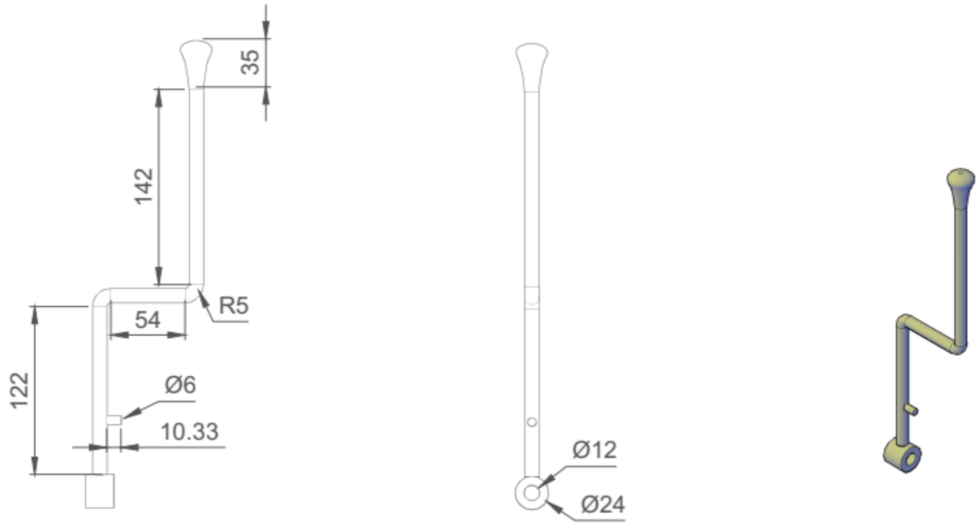
Appendix A13: The Front Balance Wheel



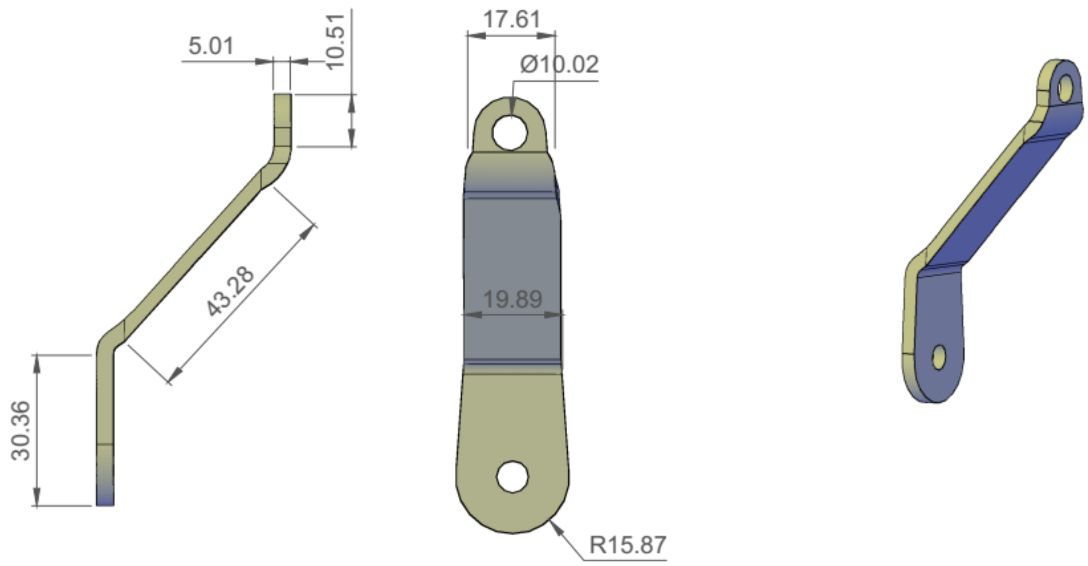
Appendix A14: Battery Housing



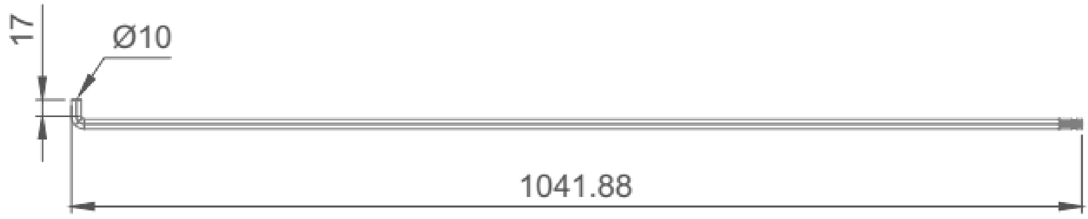
Appendix A15: Gear Lever

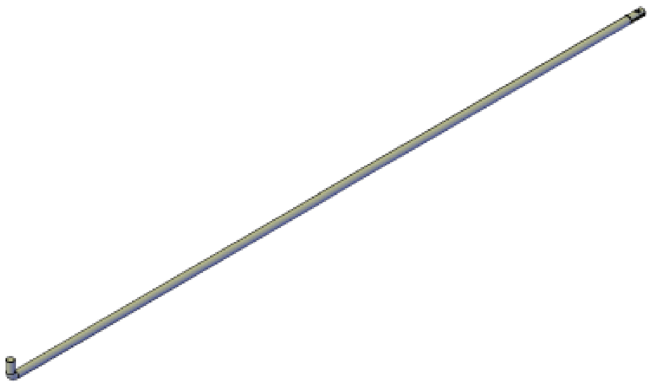


Appendix A16: Gear Selector

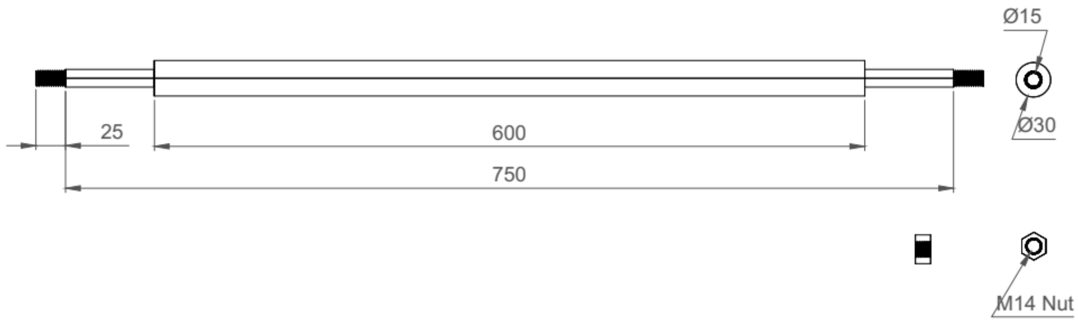


Appendix A17: Gear Selector Linkage

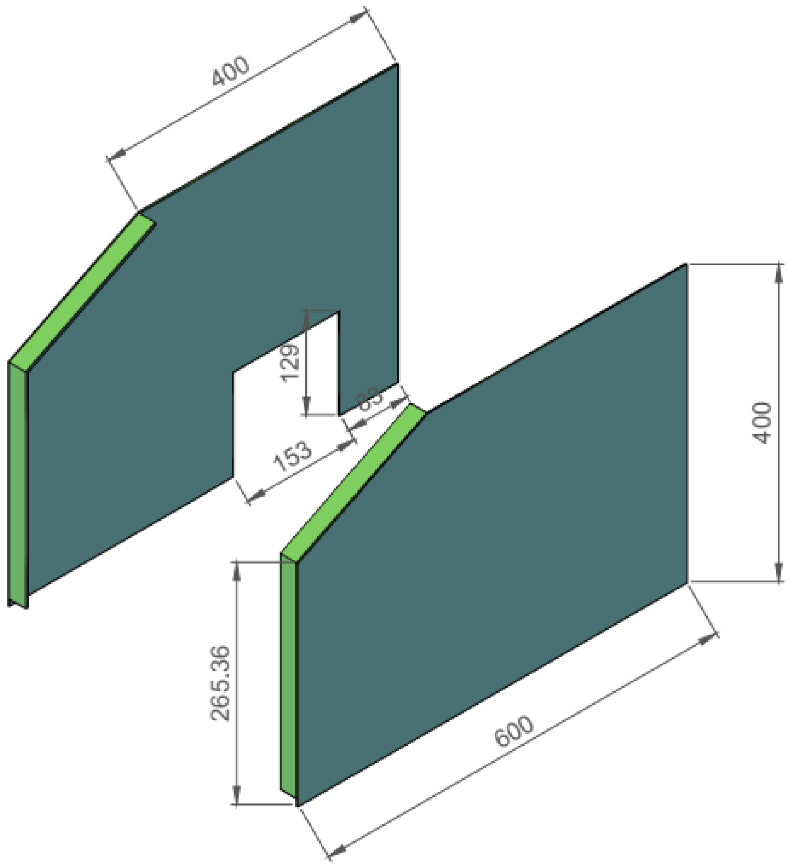




Appendix A18: Driving wheel Shaft



Appendix A19: Side Covers



APPENDIX B: DETAILS OF DESIGN AND EVALUATION CALCULATIONS

Appendix B1: Calculation of the Length of Belt

$L = 2C + 1.57(D + d) + (D - d)^2/4C$ ………………………….. (3.4)

Where:

C = centre distance = 580 mm

D = diameter of large pulley = 123 mm

d = diameter of small pulley =70 mm

Belt drive speed ratio = 1:1.75

$L = 2 \text{ X } 580 + 1.57(123 + 70) + (123 - 70)^2/4 \times 580$

L = 1,160 +303.01 + 2809 / 2320

L = 1160 +303.01+1.2108

L = 1464.2208mm

Appendix B2: Cost-Benefits Analysis

$Depreciation = \frac{Purchase\ price - Salvage\ Value}{Economic\ life}$ ……………… Equation 3.11

$$\frac{7{,}285.2 - 2{,}914.08}{10}$$

= 437.112

Appendix B3: Parameters determined after the tilling unit evaluation

Wheel slip for speed 1 (0.278 m/s)

$S = \frac{N_l - N_u}{N_u} \times 100\ \%$ ………………………………….……… (3.6)

$S = \frac{12.08 - 11.5}{11.5}\ X\ 100$

S = 5.03 %

Wheel slip for speed 2 (0.556)

$$\boldsymbol{S = \frac{12.75-11.5}{11.5} \times 100}$$

S = 10.64 %

Wheel slip for speed 3 (0.833 m/s)

$$S = \frac{13-11.5}{11.5} \times 100$$

S = 13.04 %

Appendix B4: Theoretical field capacity (C_{th})

$$C_{th} = \frac{v.w}{10}$$

$$C_{th} = \frac{0.56 \times 15.89}{10}$$

C_{th} = 0.889 ha/h

Appendix B5: Effective Field Capacity for tilling

$$Effective\ field\ capacity\ = \frac{(Area\ covered, ha)}{Total\ time\ taken, h}$$

$Area\ covered = 19 \times 14$ = 266 m^2 or 0.027 ha

$Total\ time\ taken$ = 56 + 47.36 + 43.36 = 146.72 s or 0.04 h

Therefore,

$$Effective\ field\ capacity\ = \frac{0.027}{0.04}$$

$Effective\ field\ capacity$ *0.7 ha/h*

Field Efficiency for tilling

$$Field\ Efficiency = \frac{Effective\ field\ capacity}{theoritical\ field\ capacity}$$

$Field\ Efficiency = \frac{0.7}{0.889}$

$Field\ Efficiency = 0.7874\ 0r\ 78.74\ \%$

Effective Field Capacity for Irrigation

Area covered in square meters = $A = \pi r^2$

$A = \pi(11)^2$= 380.182 m^2

$EFC = \frac{area\ (m^2) \times time(\text{min})}{60}$

$EFC = \frac{380.182 \times 16}{60}$ =1425.6825 m^2/h

EFC = $\frac{1425.6825}{10000}$ = 0.143 ha/h

Area covered per year = $6\ h\ \times 100\ days\ \times 0.143 \frac{ha}{h}$ = 85.8 ha

Appendix B6: Parameters determined during the irrigation system evaluation

Sprinkler Discharge Rate

$Q_s = \frac{volume\ of\ water\ discharged\ (L)}{time\ (s)}$

$= \frac{90}{80}$

= 1.125 L/s

Appendix B7: Average Sprinkler Application Rate

$I_t = 1000 \frac{Q\ 360}{\pi\ (0.9R)^2\ \alpha_{sr}}$ ………………………… (3.9)

$I_t = 1000 \times \frac{1.125 \times 360}{\pi\ (0.9 \times 10)^2 \times 360}$

$I_t = 4.42\ mm/h$

Appendix B8: Coefficient of Uniformity

$X_{av} = \frac{\sum Xi}{\sum i} = \frac{1310}{16} = 81.875$

$CU = \left[1 - \left(\frac{\sum[\text{xi} - \text{Xav}]}{\sum i \times X_{av}}\right)\right] \times 100$

$= \left[1 - \frac{302.25}{16 \times 81.875}\right] \times 100$

$= 76.93\ \%$

APPENDIX C: TABLES OF RESULTS

Appendix C1: Coefficient of Uniformity

S/No	Distance (m)	Volume X_i (ml)	Deviation from the average volume $[X_i - X_{av}]$
1	3	105	23.125
2	3	115	33.125
3	3	95	13.125
4	3	100	18.125
5	7	105	23.125
6	7	85	3.125
7	7	95	13.125
8	7	98	16.125
9	7	90	8.125
10	11	65	16.875
11	11	60	21.875
12	11	60	21.875
13	11	58	23.875
14	11	62	19.875
15	11	57	24.875
16	11	60	21.875
Total		1310	302.25

$X_{av} = 81.875$ $\sum i = 16$ $\sum x_i = 1310$ $\sum[x_i - X_{av}] = 302.25$

Appendix C2: Average volume for the various distances.

Distance (m)	Volume (ml)
3	103.8
7	94.6
11	60.3

Appendix C3: Water Distribution Efficiency

$= (1 - \frac{d}{D}) \text{ x } 100$

Where,

d = Average of absolute values of deviations from the mean

D = Mean volume of water collected during irrigation

Mean volume $= \frac{1310}{16} = 81.875$

Mean deviation $= \frac{302.25}{16} = 18.891$

$$\frac{18.891}{81.975} \text{ x } 100 = 76.9 \text{ \%}$$

Appendix C4: Plough Material Properties and Force Applied

Material(s)

Name	Steel, High Strength, Low Alloy	
General	Mass Density	7.85 g/cm^3
	Yield Strength	275.8 MPa
	Ultimate Tensile Strength	448 MPa
Stress	Young's Modulus	200 GPa
	Poisson's Ratio	0.287 ul
	Shear Modulus	77.7001 GPa
Part Name(s)	plough ffff1.ipt	

Result Summary of the Mould Board FEA

Name	Minimum	Maximum

Volume	1946370 mm^3	
Mass	15.279 kg	
Von Mises Stress	0.000272762 MPa	220.727 MPa
1st Principal Stress	-23.8222 MPa	178.719 MPa
3rd Principal Stress	-145.972 MPa	15.3181 MPa
Displacement	0 mm	0.284135 mm
Safety Factor	1.24951 ul	15 ul

Force:

Load Type	Force
Magnitude	707.107 N
Vector X	0.000 N
Vector Y	500.000 N
Vector Z	500.000 N

Appendix C5: Shaft material properties and force applied

material(s)

Name	Steel, Mild	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0.275 ul
	Shear Modulus	86.2745 GPa
Part Name(s)	Driving wheel shaft without thread1.ipt	

Moment:

Load Type	Moment
Magnitude	8090.000 N mm
Vector X	8090.000 N mm
Vector Y	0.000 N mm
Vector Z	0.000 N mm

Result Summary of the Driving wheel shaft

Name	**Minimum**	**Maximum**
Volume	450622 mm^3	
Mass	3.53738 kg	
Von Mises Stress	0.0240704 MPa	74.8531 MPa
1st Principal Stress	-5.86302 MPa	78.489 MPa
3rd Principal Stress	-83.2412 MPa	5.98696 MPa
Displacement	0 mm	0.089977 mm
Safety Factor	2.76542 ul	15 ul

Force:

Load Type	Force
Magnitude	550.000 N
Vector X	0.000 N
Vector Y	-550.000 N
Vector Z	0.000 N

Appendix C6: Frame material properties and force applied

Material(s)

Name	Steel, Mild	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0.275 ul
	Shear Modulus	86.2745 GPa
Part Name(s)	Frame union1.ipt	

Summary of results for Frame FEA

Name	**Minimum**	**Maximum**
Volume	2407420 mm^3	
Mass	18.8982 kg	
Von Mises Stress	0.0000144079 MPa	17.3815 MPa
1st Principal Stress	-1.34991 MPa	15.6227 MPa
3rd Principal Stress	-19.7014 MPa	1.38881 MPa
Displacement	0 mm	0.0112926 mm
Safety Factor	11.9092 ul	15 ul

Force:

Load Type	Force
Magnitude	450.000 N
Vector X	0.000 N

Vector Y	0.000 N
Vector Z	-450.000 N

Appendix C7: Control Bars Material Properties and Force Applied

Material(s)

Name	Steel, Mild	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0.275 ul
	Shear Modulus	86.2745 GPa
Part Name(s)	Control Bars Separated1.ipt	

Result Summary of the Control Bars

Name	**Minimum**	**Maximum**
Volume	973316 mm^3	
Mass	7.64053 kg	
Von Mises Stress	0 MPa	0.0909601 MPa
1st Principal Stress	-0.0551032 MPa	0.138225 MPa
3rd Principal Stress	-0.139721 MPa	0.0469922 MPa
Displacement	0 mm	0.151546 mm
Safety Factor	15 ul	15 ul

Force:1

Load Type	Force
Magnitude	157.500 N
Vector X	-157.500 N

Vector Y	0.000 N
Vector Z	0.000 N

Appendix C8: Back Engine Seat Material Properties and Force Applied

Material(s)

Name	Steel, Mild	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0.275 ul
	Shear Modulus	86.2745 GPa
Part Name(s)	Engine Back seat separated1.ipt	

Result Summary of the engine back seat

Name	**Minimum**	**Maximum**
Volume	152352 mm^3	
Mass	1.19596 kg	
Von Mises Stress	0 MPa	13.656 MPa
1st Principal Stress	-2.52687 MPa	12.7728 MPa
3rd Principal Stress	-10.598 MPa	2.19186 MPa
Displacement	0 mm	6.08×10^{-5} mm
Safety Factor	15 ul	15 ul

Force:

Load Type	Force
Magnitude	305.000 N

Vector X	-305.000 N
Vector Y	0.000 N
Vector Z	0.000 N

Appendix C9: Front Engine Seat Material Properties and Force Applied

Material(s)

Name	Steel, Mild	
General	Mass Density	7.85 g/cm^3
	Yield Strength	207 MPa
	Ultimate Tensile Strength	345 MPa
Stress	Young's Modulus	220 GPa
	Poisson's Ratio	0.275 ul
	Shear Modulus	86.2745 GPa
Part Name(s)	Front engine seat Separated1.ipt	

Summary of results for Front engine seat FEA

Name	**Minimum**	**Maximum**
Volume	182068 mm^3	
Mass	1.42924 kg	
Von Mises Stress	0.000000283352 MPa	1.67239 MPa
1st Principal Stress	-0.125177 MPa	0.517791 MPa
3rd Principal Stress	-1.52659 MPa	0.0369072 MPa
Displacement	0 mm	0.0000680383 mm
Safety Factor	15 ul	15 ul

Force:

Load Type	Force
Magnitude	305.000 N

Vector X	-305.000 N
Vector Y	0.000 N
Vector Z	0.000 N

Appendix D Cost-Benefits Analysis

Table 1: Raw Material Cost

S/N	Raw material	Specification	Unit cost (GH¢)	Amount of material used (%)	Usable material quantity	Cost per usable material quantity (GH¢)
1	Structural steel round bar	Dia. 16 mm, 24 meters	70	100	24 meters long	70
2	MS sheet metal	1200×2400×2 mm	300	60	720×2400×2 mm	180
3	MS plate	1200x2400x4 mm	400	50	600×692 mm and 162×1776 mm	200
4	MS Round bar	Dia. 30 mm 30 and 2300 mm long	80	80	Dia.30 and 1840 mm long	80
5	Angle iron	50×5×6000 mm	120	90	45 mm long	108
6	Flat iron	40x3x6000 mm	40	20	1200 mm long	8
7	Paint	Green color (1liter)	120	100	1 liter	275
		Black color (1liter)	120	100	1 liter	
		Thinner (0.5 liter)	50	70	0.35 liter	
Total						**921.00**

Table 1: Component cost

S/N	Component	Specification	Quantity	Unit cost (GH¢)	Total cost (GH¢)
1	V Belts	12.5x1450 La	1	40	40
2	Bearings	P205	2	40	80
3	Pulley	Single V grooved; B type; Dia. 127 mm,	1	70	70

		Small dia. 70 mm	1	35	35
4	Sprocket big And small	428-36T	1	50	80
		428-14T	1	30	
5	Chain	428-30L	1	45	45
6	Bolts and nuts	3F-8.8 (8 bolt & Nuts)	16	0.5	79
		YZ-4.8 (13 bolts & nuts)	8	1.5	
		ZX-8.8 (19 bolts & nuts)	14	2.5	
		TY-8.8 (17 bolts & nuts)	8	2	
		Komax-8.8 (14 bolts & nuts)	2	1.5	
		FY-4.8 (10 bolts & nuts)	5	1	
7	Engine	Apsonic Ap125-8	1	2100	2100
8	Water pump	Mouvex Triplex plunger Water Pump	1	900	900
9	Water hose	15 mm inlet & 16 mm outlet Dia. Pipe.	1	600	600
10	Wheels	2.75-18	3	200	600
11	Battery	12N9 AP	1	80	80
12	Sprinkler stand		1	200	200
13	Sprinkler head & nozzles	Brass impact sprinkler.	1	200	200
Total					**5109**

Table 2: Manufacturing process utilities

S/N	Utility	Specification	Quantity	Unit cost (GH¢)	Total cost (GH¢)
1	Grinding disc	180x6.0x22.2	2	24	48
2	Grinder cutting disc	180x6.0x22.2	5	24	120
3	Electrode	Dia. 2.5	3 packages	54	257

		Dia. 3.2	1 package	95	
4	HSS Drill bits	Dia. 8	1	25	130
		Dia. 10	1	45	
		Dia. 12	1	60	
Total					**555.00**

Table 5.3: Cost of the manufacturing process

S/N	Parts manufactured	Number of parts produced	Necessary operations	Average time needed per unit (hr)	Total time used (hr)	Average cost per hour (GH¢)	Total cost (GH¢)
1	Frame	1	Cutting, drilling, welding	2	2	40	80
2	Handle and its adjustment	1	Cutting, grinding, drilling,	2	1.5	40	60
3	Moldboard holder	1	Cutting, drilling welding	2	2.5	40	100
4	Belt tensioner	1	Cutting, drilling, welding	1.5	1	40	40
5	Real	1	Cutting, machining, welding	3	2.5	40	100
6	Shaft: Turning, facing, drilling	1	Turning, facing, drilling	5	3.5	40	140
7	Final assembly	1	Fitting, welding	3	3	40	120
8	Finishing the assembly	1	Tapping Painting	1.5	1.5	40	60
9	Petrol fuel (1L 425ml)						20.67
Total							**7,285.2**

Ownership Cost

The cost of owning the PTIS was estimated as presented in Table 5.6

Table 5.6: Ownership Cost

Item	Assumption	Cost GH¢
The purchase price	120 % of the manufacturing cost	8,742.24
The salvage value of the PTIS	40% of the purchase price (Lazarus, 2009)	3,496.89
The Bank of Ghana's interest rate	28.84% 06 Sept. 2024	2,521.26
Taxes on agricultural machinery in Ghana	Tax-free	
Insurance cost	0.25% of the purchase price (Srivastava, Goering, Rohrbach, and Buckmaster, 1993)	21.86
Cost of housing	0.75% of its purchase price (Srivastava et al., 1993)	65.57
Annual usage	100 days per year, and 6 hours per day	
Total		**14,847.82**

Operating cost for tilling

Table 5.7: Operating Cost for tilling

Item	Assumption	**Cost GH¢**
The repair and maintenance cost	15 % of the purchase price (Aikins, 2018)	1, 311.34
Cost of Fuel	GH¢13.25 (as of Sept. 2024) 6 h × 100 days x 0.7 ha/h × 25.75	276,361.9
The cost of lubrication	15 % of the fuel cost (Ajit K. Srivastava et al., 2013)	41,454.29
The operator's labour cost	6 hours per day x GH¢ 17.00/hr x 100 days/year	10,200.00
Total		**329,327.53**

Operating cost for Irrigation

Table 5.8: Operating Cost for Irrigation

Item	Assumption	**Cost GH¢**
The repair and maintenance cost	15 % of the purchase price (Aikins, 2018)	1,092.78
Cost of Fuel	GH¢13.25 (as of Sept. 2024) 6 h x 100 days x 0.0005 ha/h x 19.46 litres	173,426.55
The cost of lubrication	15 % of the fuel cost (Ajit K. Srivastava et al., 2013)	41,454.29
The operator's labour cost	6 hours per day x GH¢ 10.00/hr x 100 days/year	6000
Cost of water	GHc8.33(1000L or 1 m^3) × 7,396 m^3/ha (Tuyến et al., 2016) x 85.8 ha ha for 100 days	4,472,790.17
Total		**4,694,763.79**

5.2.4. Total Cost

Table 5.9: Total Cost

Cost component	**Amount (GH¢)**
Ownership Cost	14,847.82
operating cost for tilling	329,327.53
Operating cost for irrigation	4,694,763.79
Grand Total	**5,038,939.14**

Benefits of the Machine

The benefits of the PTIS were estimated using chili pepper production. The average chili pepper (capsicum annuum) yield per hectare in Ghana is 8.30 Mt/ha or 8,300 according to Asravor et al. (2015). The selling price of the crop is GH¢ 10.22 per Kg (Wamucii, 2024).

Total benefit per year for tilling = Area covered per year x Crop yield per hectare x crop selling price.

Area covered for tilling per year = 6 h x 100 days x 0.7 ha/h = 420 ha

Benefits for tilling per year GH¢ = 420 X 2075 X 10.22

= 8,906,730

Total benefit for irrigation per year = Area irrigated per year x Crop yield per hectare x Selling price of the crop

Area irrigated per year = 6 h x 100 days x 0.143 ha/h = 85.8 ha

Benefits for irrigation per year GH¢ = 85.8 X 2075 X 10.22

= 1,819,517.7

Total Benefits of the PPISGIS per year GH¢ = 8,906,730+ 1,819,517.7

= 10,726,247.7

Comparing the costs to the Benefits

Benefit-cost ratio (B/C ratio) is the ratio of benefits to costs (expressed either in present or annual worth). It is a simple ratio of benefit and cost of investment. In the current study, the cost ratio of farm machines was calculated using the following formula:

$$\frac{B}{C} ratio = \sum_{t=1}^{t} \frac{Bt}{(1+r)^t} / \sum_{t=1}^{t} Ct/\,(1+r)^t$$

Where:

Bt = Discounted benefit from the machine = 10,726,247.7

Ct = Discounted cost incurred = 5,038,939.14

t = time (years) = 10

r = discount rate (assumed 28.99% based on the Bank of Ghana's rates as at September 18, 2024).

When r = 28.99%

$$\frac{B}{C} ratio = \sum_{t=1}^{10} \frac{10{,}726{,}247.7}{(1+0.02899)^{10}} / \sum_{t=1}^{10} \frac{5{,}038{,}939.14}{(1+0.0.2899)^{10}}$$

$$\frac{B}{C} ratio = 2.13$$

The calculated $\frac{B}{C} ratio$ is greater than 1 (2.13 > 1)