DEVELOPMENT AND EVALUATION OF A DOUBLE ROW DISC RIDGER FOR ROOT AND TUBER CROP PRODUCTION

By

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DECLARATION

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree of the Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgment is made in the thesis.

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DEDICATION

Indeed, *"the Lord is righteous in all His ways, Gracious in all His works (Psalm 145:17)."*

This thesis is dedicated to my Lord and my God for His grace upon me.

To the memory of my Father (uncle), Rev. J. K. Wandusim

To my helpmeet, Sukuruman and my lovely kids, Yennube and Yennupang.

To my beloved parents and siblings.

To the Wandusim family.

ABSTRACT

The introduction of mechanical harvesters has been a breakthrough in root and tuber crop cultivation as it has greatly reduced drudgery with a potential increase in global cassava production. However, the use of these equipment requires line or ridgeplanting. While ridging is preferred and can be done manually, empirical evidence suggests that manual ridging is laborious, time-consuming and the quality and standard of ridging cannot be guaranteed. The objective of this study was to develop and test the performance of a double-row disc ridger for root and tuber crop cultivation. Functional analysis (FA) and computer-aided design methodologies (CAD) were applied. The device was fabricated from locally available materials and tools, making it an adaptable, resilient and affordable technology for small-scale farmers. The prototype was tested at varied tractor speed ranging from 1.67 – 2.5 m/s (6 – 9 km/h) and disc angle from 40^{o} - 45^{o} to determine the draught force, fuel consumption, wheel-slip, depth and width of cut. Preliminary results indicate that optimum performance was achieved at disc and tilt angle of 42.5^{o} and 25^{o} and tractor speed of 2.23 m/s (8 km/h). The ridger recorded a field capacity of 1.45 ha/h and average fuel consumption of 6.3 l/ha (9.14 l/h). It was observed that increased tractor speed and disc angle resulted in increased draught force from 1.8 – 2.4 kN, increased fuel consumption from 5.2 – 7.04 l/ha (7.81 – 10.45 l/h) and increased depth and width of cut from 30 – 40 cm and 250 – 280 cm, respectively. A hazard and operability (HAZOP) study established possible deviations, causes, consequences, safeguards, and recommendations for users. Further research is necessary to establish the effect of different moisture content and soil type on the performance of the ridger. Wear and durability test on different agro-ecologies are also recommended.

Key words: Agriculture, Disc Ridger, Development, Evaluation, Prototype.

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CHAPTER ONE INTRODUCTION

1.1 Background

Agriculture is the main driving force behind Ghana's economy, accounting for approximately 42% of the country's gross domestic product (GDP) and employing 54% of its workforce (GIPC, 2018). GDP from agriculture in Ghana increased from GHS 7209.81 million in the third quarter to GHS 8723.60 million in the fourth quarter of 2018 (GGAD, 2019).

Root and tuber crops, including cassava, sweet potato, potato and yam are the most important food crops for direct human consumption in Africa (Wang *et al*., 2016). According to Sanginga (2015), these four crops are grown in varied agroecology and production systems contributing to more than 240 million tonnes annually, covering around 23 million hectares. Research indicates that the aggregate value of yam, cassava, potato and sweet potato exceeds all other African staples, including cereal crops (cereals annually producing on average 169 million tonnes on 108 million ha of land (Bavagnoli, 2019). Like most West African countries, yam and cassava are the major staples produced and consumed in Ghana (Amponsah *et al.*, 2014). The country has since the past decade, ranked third in world yam production and sixth in world cassava production (Dasmani, 2019; Ennin *et al.*, 2009). Cassava and yam contribute 22% and 16% to Ghana's AGDP with an annual production of about 19.14 and 8.25 million metric tonnes respectively (MoFA, 2017). It is estimated that 70% of local farmers are engaged in cassava production (Dasmani, 2019).

Undisputed evidence suggests that every part of the cassava plant has economic value. The root, leaves and stem can be used to produce a large variety of food, non-food products and industrial products (Aponsah *et al*., 2014). Its importance is, therefore, confirmed in terms of cultivation area, total production, contribution to Agricultural GDP and food expenditure shares (MoFA, 2000). Ghana's cassava production rose from

15,989,900 Mt in 2013 to 16,523,660 Mt in 2014 and went up to 19,137,940 Mt in 2017. The annual area harvested to cassava in 2013 was 875,200 Ha while that of 2017 was 925,620 Ha (MoFA, 2017). The increase in production was a factor of the increased area under production, the development and release of higher-yielding varieties by scientific research efforts and, also, favourable government policy (Manu-Aduening, 2005). Research has predicted the growing importance of cassava in Ghana's economic development and stressed its great potential to spur rural industrial development, raise rural incomes and contribute to food security (Manu, 2017).

Yam, on the other hand, constitutes the predominant starchy staple in sub-Saharan Africa where food security for a growing population is a critical issue (Fu *et al*, 2011). The five West African countries namely, Nigeria, Cote d'Ivoire, Ghana, Benin and Togo are in the traditional "Yam Zone" and accounted for 93% of the total yam production of the world in 2008 (Aidoo, 2009). Yam is an extremely important crop for at least 60 million rural poor producers, processors and consumers in West Africa providing multiple opportunities for poverty reduction and nourishment of poor people in the subregion (Osei-adu *et al.*, 2016). In Ghana, yam is the most important food crop in terms of output value (Owusu *et al.*, 2014). It contributes significantly to agricultural gross domestic product as mentioned earlier and plays a key role in guaranteeing household food security (Asante *et al*., 2011). Out of the total agricultural land under cultivation (7,846,551ha), yam cultivation occupies 492,980 ha representing 6.3% (MoFA, 2017). A total of 8,252,940 MT of yam was produced in 2017 which came second to cassava of 19,137,940 MT. Its importance lies in the fact that it serves as both food security and income-generating crop. Its cultivation cuts across the Forest, Coastal Savannah, Forest Transition and the Guinea Savannah agro-ecological zones of Ghana (Amponsah *et al*., 2014).

The importance of root and tuber to the Ghanaian economy can, therefore, not be overemphasized. However, available research holds the view that root and tuber have seen very little improvement in its husbandry practices over the years. According to Robin (2017), the productivity of root and tuber remains almost static, reflecting the agrotechnological and socio-economic constraints to production. Currently, major phases of cultivation are labour-intensive, associated with drudgery, causing the youth to shy away from its cultivation, and limits the scale of production especially tillage (land preparation) as it requires the most energy (Ennin *et al*., 2009; MoFA, 2016).

Generally, root and tuber crops do not produce satisfactory yields on compacted or shallow soils, hence, three objectives of seedbed preparation in root crop generally, are to (i) optimize infiltration, (ii) enhance rooting depth, and (iii) improve soil-water management (FAO, 2000). Currently, mounding is by far the most widespread, and in the West African yam and cassava agro-ecology, mounding used to be almost universal in the past (Ennin *et al*., 2009). Bergh *et al.* (2012), reported that 99% of farmers planted yams in mounds, rather than ridges. While mounding is a very tedious and expensive operation that limits the scale of root crop production, it is also said that mounding and flatland forms impede mechanization (mechanical planting, weeding, and harvesting) of root and tuber production (Amponsah *et al.*, 2014). Ridging, on the other hand, has been shown to result in increased cassava yields by 38% (Ennin *et al*., 2009) over mounding, mainly because of increased plant population density and better weed suppression on ridges. Also, yams grown on ridges have higher yields than yams grown in mounds (Bergh *et al*., 2012). Ridging can be mechanized to reduce drudgery and increase the scale of production of root crops. The question, however, lies in the type of ridging implements most suitable for root and tuber fields. Research by Singh *et al.* (2006), revealed that unlike the mouldboard, the disc ridger enables deep working depths, imposes low draught, has the ability to roll over obstacles and better soil pulverization ability.

1.2 Problem Statement

Studies have shown that challenges regarding manual harvesting of root crops include; postharvest losses, high drudgery, labour intensity, waste of time and limited production scale (Dasmani, 2019; Ennin *et al.*, 2009; Spencer & Ezedinma, 2017). For these reasons, mechanical harvesting has become a major resort. The use of mechanical harvester, however, requires line or row-planting, which has further led to a growing interest in tillage implements such as ridgers. However, existing disc ridgers were not designed for root crop fields in Ghana. Put in another way, disc ridgers are not able to withstand difficult soil conditions (stumpy and stony soils) during operation. Hence, the implement is prone to structural failure (frame breakages), unstable working width adjustment, susceptible to hub-base wear, when subjected to arable soils in Ghana. Imported disc ridgers on the other hand, produce narrow ridges suitable for horticultural crops but are inadequate for mechanized root and tuber production.

1.3 Study Objective

The main objective of this study was to develop and test a fully-mounted double-row disc ridger for root and tuber crop production.

Specific objectives were to;

i. design and fabricate a double-row disc ridger using the method of functional analysis and computer-aided design (CAD). ii. field-test the performance of the ridger with regards to draught, fuel consumption, wheel-slip, depth and width of cut.

iii. determine optimum operational adjustments (disc and tilt angles) that influence the performance.

iv. perform a hazard and operability study (HAZOP).

1.4 Justification for the study

Despite the many advantages disc ridgers have to support small-holder farmers who contribute 90% of Ghana's root and tuber production, there has been inadequate research and development of disc ridgers locally to meet their needs. Among few researches on disc ridging implements include, (i) Ridging a mechanize alternative to mounding and flatland forms (Ennin *et al*., 2009), (ii) Comparison between locally manufactured panel ridge and conventional disc ridge throughout investigating their effects on power-use-efficiency, draught force and actual field productivity (Abdallah & Rahaman, 2019), (iii) performance evaluation of disc ridging tractive effort model (Nkakini, 2015) and (iv) modelling tractive force requirement of wheel tractors for disc ridging in loamy sand soil (Nkakini & Fubara, 2012). Therefore, research advancement around design, development and performance evaluation of disc ridgers to enhance the mechanization of root and tuber crops in Ghana is very necessary.

CHAPTER TWO LITERATURE REVIEW

2.1 Introduction

It is apparent that much research has been carried out on the development and evaluation of tillage implements which has a profound influence on the study. This chapter reviews these studies to provide some baseline information relevant to the study and to serve as a guide for the conduct of the research.

2.1 Root and Tuber Production in Ghana

Root and tuber crops, including cassava, sweet potato, potato and yam are the most important food crops for direct human consumption in Africa (Bavagnoli, 2019). These four crops are grown in varied agro-ecologies and production systems contributing to more than 240 million tonnes annually, covering around 23 million hectares (Osei-adu *et al*., 2016). The aggregate value of yam, cassava, potato and sweet potato exceeds all other African staples, including cereal crops (cereals annually producing on average 169 million tonnes on 108 million ha of land) (Sanginga, 2015). In Ghana, root and tuber are major food crops and industrial raw materials. Cassava and yam contribute 22% and 16% to Ghana's AGDP with an annual production of 19.14 and 8.25 million metric tonnes respectively (MoFA, 2017).

2.1.1 Cassava

Cassava belongs to the family *Euphorbiaceae* and may manifest itself under different species; *Manihot esculenta* Crantz, *Manihot ultissima* Phol or *Manihot aipi* Phol (Oriola & Raji, 2013). For different parts of the world, cassava may be commonly referred to as *Agbeli*, *Bankye*, *Yuca*, *Tapioca*, *Mandioca* or *Manioc* depending on the locality in which it finds itself and its use as food (Amponsah *et al.*, 2014). Cassava farming in Ghana was introduced from its native country Brazil to Ghana in the 16th and 17th centuries and later spread to other West African nations and the Caribbean Islands by the Portuguese (Zindzy, 2019).

Cassava is one of the leading tuber crops that offers the highest production of food energy and is a staple food for millions of households across the globe (MoFA, 2016). Cassava production in Ghana has been successful over the years since many people depend on cassava roots as their main food. This is because cassava has a high starch content and the crop has substantial amounts of various minerals such as dietary fibre, iron, phosphorus, vitamin B6, manganese, calcium, potassium, and vitamin C (Mombo *et al*., 2017). While some researchers have reported a significant decrease in cholesterol levels by cassava consumers (Osei-adu *et al*., 2016), others have indicated its potential to help support the nervous system and assists in alleviating stress, anxiety and bowel syndrome (Manu-Aduening *et al*., 2005). The crop also has numerous benefits since the cassava leaves can be used as a drug that can cure various diseases such as rheumatism, headaches, fever, wounds, diarrhoea, intestinal worms, dysentery, night blindness, and beriberi (Zindzy, 2019).

Among the starchy and cereal staples such as cocoyam, maize, rice, millet, sorghum and plantain, cassava is one of the crops cultivated over a large land space in Ghana. According to Ghana's Agricultural sector report (MoFA, 2017), cassava production has seen a rise over the past five years as shown in Table 2.1. Most farmers are engaged in the cultivation of cassava right from the land preparation, through planting, maintenance, post-harvest processing and marketing. In Ghana, cassava is produced on both small-scale and large scale and the roots are processed and prepared as a subsistence crop for home consumption and for sale (Manu-Aduening *et al*., 2005).

The utilization of cassava has seen numerous improvements. It can be processed into gari, fufu, cassava flour for bread and doughnuts making, 'konkonte', agbelikor (Ewe parlance for cassava, eaten in its cooked state) or ampesi (Akan parlance for cassava eaten in its cooked state). Other uses of cassava include edible starch, tapioca cakes and biscuits (Amponsah *et al.*, 2011). According to Akerele (2016), cassava performs five main roles namely; famine reserve crop, a rural food staple, a cash crop for urban consumption, industrial raw material, and foreign exchange earner. Cassava leaves are consumed as vegetable and the crop itself serves as raw material for industries as well as being a means of alleviating poverty (Akerele, 2016). Related studies in Ghana revealed that cassava wastes such as peel, barks and wastewaters provide feedstock to generate bio-energy (electricity, hot or cold air) by building gasifier and biogas plant (Mensah, 2014). The cultivation and on-farm processing of cassava provide a source of rural employment particularly for women (Spencer & Ezedinma, 2017).

2.1.2 Yam

Yam (*Dioscorea species*) is said to be the predominant starchy staple in sub-Saharan Africa, where food security for a growing population is a critical issue (Fu *et al.*, 2011).

The five West African countries namely, Nigeria, Cote d'Ivoire, Ghana, Benin and Togo are in the traditional "Yam Zone" and accounted for 93% of the total yam production of the world in 2008 (Nweke *et al.*, 2013). Yam is an extremely important crop for at least 60 million rural producers, processors and consumers in West Africa providing multiple opportunities for poverty reduction and nourishment of people in the subregion (Osei-adu *et al.*, 2016).

In Ghana, yam is the most important food crop in terms of output value (Owusu *et al.*, 2014). Its importance lies in the fact that it serves as both food security and incomegenerating crop (Mombo *et al*., 2017). Ghana became the world second-largest producer of yam in terms of quantity in 2010 and has been the second-largest producer in terms of value since 2001 (Zakaria *et al*., 2014). Ghana is currently the leading exporter of yam (36 per cent of world exports) and it ranks second after pineapple among non-traditional exports (Asante *et al*., 2011). Out of the total agricultural land under cultivation (7,846,551 ha), yam cultivation occupies 492,980ha representing 6.3%. A total of 8,252,940 MT of yam was produced in 2017 which came second to cassava of 19,137,940 MT (MoFA, 2017). Its cultivation cuts across the Forest, Coastal Savannah, Forest Transition and the Guinea Savannah agro-ecological zones of Ghana (Zakaria *et al.*, 2014). Table 2.1 presents trends of production and area cultivated to cassava, yam and cocoyam for five recent years.

Table 2.1: Production and Cultivation Trends of Major Root and Tuber Crops ('000Ha)

Year	**Crop yield ('000 MT)**			**Area Cultivated ('000Ha)**		
	Cassava	Yam	Cocoyam	Cassava	Yam	Cocoyam
2013	15,989.90	7,074.60	1,261.50	875.20	421.60	194.00
2014	16,523.66	7,118.89	1,298.97	888.61	428.01	200.40
2015	17,212.76	7,296.12	1,301.19	916.54	430.20	200.49
2016	17,798.22	7,440.35	1,343.73	879.10	427.22	205.86
2017	19,137.94	8,252.94	1,387.29	925.62	492.98	204.24

Source: MoFA (2017)

2.1.3 Production Practices for Root and Tuber

Production practices associated with cassava may include land preparation, planting materials preparation, planting, fertilizer application, farm sanitation and weeding, pest and disease control, harvesting and processing (Kouakou *et al.*, 2016). Figure 2.1 presents an overview of root and tuber production value chain based on research.

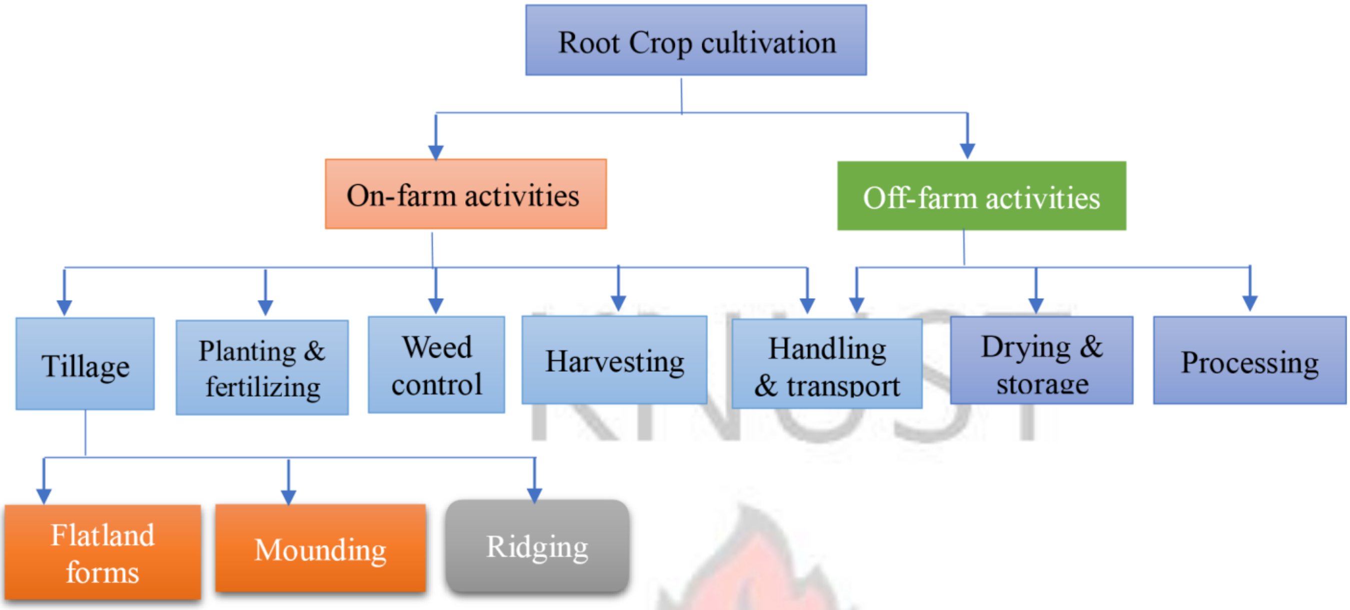


Figure 2.1: an overview of root crop value chain (Auther's own construct, 2019)

2.1.4 Land Preparation for Root Tuber Crop Production

The field is usually prepared after the land has been cleared, by first ploughing followed by harrowing. Cassava could be planted on the flat, on ridges or on mounds. Figure 2.2 presents the various landforms used in cassava planting.

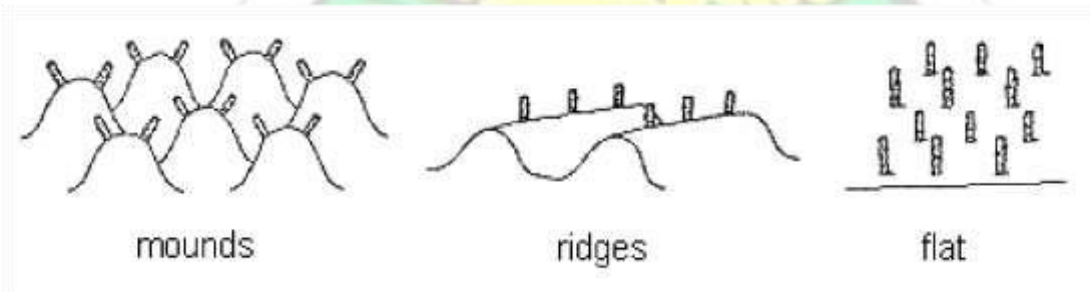


Figure 2.2: Various landforms used for planting cassava (Ekanayake *et al*., 1997)

Where ridges are preferred, they are constructed using a ridger after primary and secondary tillage and may range from 15-30 cm in height and 75-100 cm crest-crest distance (between ridges). Ridging could, however, be done before or after planting and is best suited for areas with drainage problems. Research conducted by Ennin *et* *al.*, (2009) proved that planting cassava on ridges had the advantage of higher cassava root yield coupled with better and easier field management and has the potential for mechanization to further decrease drudgery and increase the scale of production of cassava compared to planting on mounds and on flatland forms. The type of tillage system has a significant effect on root shape of cassava and tuber shape of yam (Muinga & Marechera, 2018). Data available indicate clearly that management of cassava fields is easier on ridges than on mounds (Ekanayake *et al*., 1997).

The evidence above suffices to conclude that ridging is a feasible option for cassava and yam production. Ridging has the potential for mechanization to further decrease drudgery and increase the scale of production of cassava and yam production on the forest-savanna transition, coastal-savanna transition and the forest agro-ecologies of West-Africa.

2.3 Tillage

Tillage is the preparation of seedbed for planting and the process of keeping the soil loose and from weeds during the growth of crops. Soil tillage is an integral part of crop production; the aims of which are to influence the biological, chemical and physical characteristics of the soil to create an optimum environmental condition for plants growth. It involves the use of human, animal or machine energy for physical manipulation of soil to provide conditions favourable for plant growth (Nkakini, 2015; Miransari, 2016).

A considerable amount of literature has been published on tillage and these studies show that the choice of tillage-type depends on physical factors, such as soil properties, rainfall regime, climate, drainage conditions, rooting depth, soil compaction, erosion hazards, cropping systems, and socio-economic factors, including farm size and availability of inputs. Furthermore, the use of correct tillage methods may help to promote higher profits, crop yields, soil improvement and protection, weed control and optimum use of water resources since, tillage has a direct impact on soil and water quality (Manuwa, 2009; Taha & Khalifa, 2018).

2.3.1 Tillage Systems

The intensity of soil disturbance and the number of operations can be used to define a tillage system

Tillage systems may, therefore, be grouped into conservation and conventional tillage, depending on the kind, amount and sequence of soil disturbance (ASGROW, 2016)

2.3.2 Conservation Tillage

Conservation tillage is defined as a tillage system in which at least 30% of crop residues are left in the field and is considered as a significant soil conservation practice especially to reduce water and wind erosion (Morris *et al.*, 2010). In areas where wind erosion is the foremost concern, conservation tillage may also be defined as, any tillage system that maintains at least 1,100 kg ha^{-1} of flat, small grain residue equivalent on the surface all year round (Murrell, 2015).

The objective of conservation tillage, however, is to improve agricultural production by increasing the productivity of farm resources. Conservation tillage has lots of benefits like reduction in soil erosion and greenhouse gas emissions, improvement in water infiltration, labour reduction and energy savings and improves soil biodiversity and profitability. Conservation tillage reduces the number of tillage, therefore herbicides especially glyphosate is the main tool to control the weeds under this tillage system

(Briones & Schmidt, 2017). Some authors have reported better crop performance under conservation tillage (Mitchell, 2012). Tillage systems classified as conservation tillage or included under crop residue management are no-till, ridge-till, mulch-till, and reduced-till, strip or zonal till, reduced or minimum tillage (Murrell, 2015).

Regardless of its potential benefits in terms of energy reduction and soil conservation, conservation tillage has had some challenges. Normally, there is a transition period of 5 – 7 years before a conservation agriculture system reaches equilibrium, yields may be lower in the early years, cost and availability of agrochemicals to control weeds, and insect-pests, farmers may require more initial investments to buy specialized machinery and farmers may also need training and skilled advisory services to adopt conservation agriculture system compared to conventional farming (Mitchell, 2012).

2.3.3 Conventional tillage

Conventional tillage system is based on mechanical soil manipulation and it involves mouldboard or disc ploughing followed by no disc harrowing, one- or two-disc harrowing (Nkakini, 2015). Conventional tillage embraces soil cultivation based on ploughing or soil inversion, secondary cultivation using discs and tertiary, working by cultivators and harrowers (León *et al.*, 2019). These tools are commonly drawn by animals or tractors or by other mechanically powered devices. Conventional tillage systems are to a greater degree aimed at weed-control, residue incorporation and seedbed preparation and include disruption, inversion, pulverization, and mixing of soil in the tilled zone (Shahzad *et al.*, 2016).

On one hand, conventional tillage operations pose some serious concerns internationally, for example, high fuel and time requirements increase the possibility of soil erosion, soil compaction and deterioration in soil structure (Müller *et al*., 2009). On the other hand, conventional tillage systems have been found to improve soil physical properties and increase crop performance (Bangura, 2015). A study conducted by Amin *et al.* (2014), on the effect of different tillage practices on soil physical properties under wheat in a semi-arid environment, revealed better performance with conventional tillage practices than conservation tillage. Further research by EL-Din *et al*. (2008), on the effect of tillage and planting methods on rice yield and milling quality, also reported higher yield and milling quality with conventional tillage compared to conservation tillage. Other authors have also reported better crop performance on conventional tillage compared with conversation tillage practices (Aikins *et al*., 2012).

2.3.4 Classification of Conventional Tillage

a Primary tillage

It constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials and rearrange aggregates. The operations performed to open-up any cultivable land with a view to preparing a seedbed for growing crops is known as primary tillage (Lovarelli *et al*., 2017; Taha & Khalifa, 2018). According to FAO (2000), the depth of primary tillage depends on the tractive force available. Using power from animal traction, the depth is normally between 10 and 20 cm whereas with tractors, particularly in view of the increased power of modern tractors, ploughing is done down to a depth of 40 cm in some countries (FAO, 2000).

a Secondary tillage

Tillage operations following primary tillage are performed to create proper soil tilth for seeding and planting are termed secondary tillage. These are lighter and finer operations, performed on the soil after primary tillage operations. Secondary tillage consists of conditioning the soil to meet the different tillage objectives of the farm. These operations consume less power per unit area compared to primary tillage operations (Gill & Berg, 1966). Table 2.3 presents a summary of commonly used primary and secondary tillage implements for conventional tillage operations.

Table 2.2 Tillage types, their corresponding implements and power source

Tillage	Implement	Power source
Primary tillage	Mouldboard ploughs	Tractor and animaldrawn
	Disc plough	Tractor and animaldrawn
	Chisel plough	Tractor-drawn
	Subsoiler	Tractor-drawn
Secondary tillage	Harrows; disc, spike tooth, chain, spring tooth	Tractor and animaldrawn
	Tine-cultivators; spring-tine, springloaded-tine and rigid tine.	Tractor and animaldrawn
	Rotary cultivator	Tractor and animaldrawn
	Ridgers	Tractor and animaldrawn

Source: Auther’s own construct, 2019

2.4 Disc Implements

Mode of action, forces and adjustments

Essentially all disc implements are described here because they basically have similar operating principles and adjustment and, they are core to the objective of this study. The disc, depending on the angle of approach, also cuts a section of soil and inverts it. However, because of the movement of the disc, the acceleration differs according to the position of the disc and the resultant internal friction. The soil is thus also pulverized and mixed (Rahamtallah & Hassen, 2013).

Whilst the disc does not invert the soil as better as the mouldboard body, it both pulverizes and mixes the soil at the same time (Murrell, 2015). Additionally, disc implements tend to be less susceptible to damage from stones and stumps and therefore are well adapted for less cultivated land (Murrell, 2015). For these reasons, being very universal and robust, disc implements have been very successful in mechanized tropical agriculture. However, within the concept of conservation farming and more careful and managed tillage, disc implements should be considered very critically (FAO, 2000).

The forces acting on the disc can also be subdivided into three components. The longitudinal component which approximately has the same value as that of a mouldboard plough; the lateral component can be very large; and the vertical component acts upwards, which is opposite to a mouldboard plough (Rection *et al*., 1989). These characteristics according to Naim (2014), have the following consequences: ·

- In order to support the lateral forces, disc ploughs need a very strong support wheel. Therefore, disc ridgers and harrows are designed with two sets of discs acting in opposite directions. ·
- The disc only penetrates the soil due to its weight as the vertical force is acting upwards. In the case of heavy soils, one must increase the overall weight of the implement by adding additional ballast weights. For these reasons, disc ploughs tend to be made heavier and are not well suited for use with work animals.

These characteristics of the disc are the reasons for the problems of soil degradation that can often be observed in zones where disc ploughs have been misused (Oduma *et al*., 2015). The pulverizing action of the disc brings about a loss of soil structure, more rapid mineralization, increased erosion and loss of moisture and poor infiltration of the water. The disc enters into the soil due to its weight until such depth that the vertical soil force is equal to the implement weight. This means that the disc supports itself on the soil and can be considered as a roller compactor of the subsoil. Research by Nalavade *et al.* (2013), suggest that in zones where disc harrows are frequently used, one can find very compacted horizons beneath the normal working depth of the implement. These compacted layers inhibit the infiltration of water and thus quickly cause drought conditions to build up and can also contribute to a process of desertification on large areas over the longer term (Coppola *et al*., 2011).

With regards to adjustment, it is important to distinguish between the two types of disc implement: those with individual or one-way discs arrangements such as disc ploughs, or those with the discs mounted on the same shaft but arranged in opposite direction such as disc harrows (ASGROW, 2016).

In the first case, that of the plough, both the vertical and horizontal angles of the disc may be adjusted. These adjustments allow adapting the implement to the type of soil and thereby affecting the degree of soil disturbance and the ease of penetration. In the case of the disc plough, correct adjustment is achieved in just the same way as with the mouldboard plough (Moeenifar *et al.*, 2014). This means that when correctly adjusted, all the lateral forces on the plough are balanced and the plough proceeds in a straight line without the need to adjust the chains on the lower links of the three-point linkage system. In the case of the harrow, one can only adjust the horizontal angle. With this, and by adding additional ballast weights, one may adjust the depth of work and the degree of soil pulverization. (FAO, 2000).

2.4.1 Types of disc implement ·

According to Amponsah *et al.* (2014), very few disc ploughs exist for use with draught animals due to the lateral forces required. The only exception is the disc harrow, which exists in a few countries. None the less, disc implements are probably the most commonly used types of tillage implement in tropical countries. This group of implements can be sub-divided as follows:

i. disc ploughs; disc ploughs exist in various versions as either tractor-mounted or trailed, simple or reversible.
ii. disc harrows; are always made up of gangs of discs of equal number that work in opposite senses to neutralize the lateral forces. There are both mounted and trailed models, tandem and offset models for secondary tillage.
iii. disc ridgers; are increasingly becoming very popular for ridging up the soil, for making furrows and for tied ridges.

2.5 Ridging implements

It is an implement used to form ridges required for sowing row crop seeds and in welltilled soil (Jadhav *et al.*, 2013). The ridger is also used for forming field or channels, earthing up and similar other operations (Nkakini & Fubara-Manuel, 2012). A ridge system is a logical part of a furrow irrigation system. Ridger is also known as ridging plough and double mouldboard plough depending on the type (BHASKAR, 2015).

2.5.1 Types of ridgers

i. Mouldboard type

The mouldboard ridger is basically two opposed mouldboard plough bodies placed back to back with the landside of the conventional mouldboard removed to form concave type bodies so that in operation the concave bodies plough or throw the soil both ways into a ridge leaving a trench. The mouldboard ridger works when the share or shovel of the ridging body penetrates the soil maintaining the attacked angle and the depth control setting. The soil is lifted and transported evenly along the breast and wings on to the shoulders or top of the ridge (Temesgen *et al*., 2009). Plate 2.1 presents a picture of a single-row mouldboard ridger.

Plate 2.1: Single-row mouldboard ridger (Okolle et al., 2016)

ii. Disc ridgers

This generally forms rough but large ridges more suitable for tropical root and tuber crops such as cassava and yam. Disc ridgers consist of large discs assembled in such a way that two adjacent discs have their concave faces facing each other and throwing the soil towards each other to form a ridge (Rahamtallah & Hassen, 2013). Nkakini (2012) postulates that a tillage operation intended for heaping up of tilled soil from two sides to form long stripes of mounds having furrows in between is called ridging. This tillage operation is accomplished with the aid of tillage implement called disc ridger says Nkakini. Mechanised ridging is normally done after ploughing and harrowing operations (Barber *et al*., 2001).

Also known as bund formers, ridgers, either operated by tractor or animals are used to prepare bunds in mechanized farms, make bunds for irrigation purposes and for demarking the fields (Singh *et al*., 2006). Singh *et al*. recorded that, tractor operated bund formers are normally either disc or mouldboard type or forming board type. The research by Singh *et al*. (2006) suggests that up to 21 bunds could be formed in one ha area having a total bund length of around 2050 m.

Nkakini (2014) evaluated the performance of disc ridging tractive force model in loamy sand soil using sensitivity measured parameters. Results from his study revealed that the best tillage speed for disc ridging operation is 2.22 m/s.

Plates 2.2a shows one of the existing models of disc ridgers made in China, India and Brazil. These designs are good and satisfy their intended purpose in most agroecologies. However, like any other technical system, these designs are not without challenges. Alien to most Ghanaian root and tuber agro-ecologies, these designs are susceptible to structural failures, unstable working width adjustments among others. Two possible reasons account for these failures; first, it is probably because the existing disc ridgers are made from lighter material with the notion that they are 2^{nd} level secondary tillage implements and that, the soil must be ploughed and harrowed before ridging (Nkakini, 2015). The second has to do with the obstructed nature of most Ghanaian root crop soils. Plate 2.2b presents a common defect associated with disc ridgers that have found application in a semi-deciduous rainforest zone of Ghana hence, give credence to the argument posed earlier that, such designs are alien to root crop fields in the country.

Plate 2.2: b. Two-row disc ridger made in China, b. Defects associated with disc ridger

2.3.5 Power Requirement of Tillage

A power source in agriculture is one of the determining factors for the level of agricultural development and stage of mechanization (Gill & Berg, 1966). Tillage requires the maximum energy amongst all the agricultural operations and as such, it is described as the most expensive operation in agriculture (Nkakini, 2015). MANUWA (2013) stated that the best criterion for the suitable tillage implement is the power requirement which determines the size of the tractor. Therefore, it is imperative that the implement manufacturer must be aware of the importance of the power requirement of various tillage implements so that implements could be designed and manufactured in accordance with the size of the tractors available in the country (Manuwa, 2009).

2.4 Performance Parameters of Tillage Implements

2.4.1 Wheel slippage

Mamkagh (2019) defined slippage as the relative reduction in movement in the direction of travel at the mutual contact surface of a traction or transport device and the supporting surface. Slippage can also be considered as a reduction in actual vehicle travel speed when compared to the theoretical speed that should be attained from the speed of the tire or track surface (Xiang & Boyou, 2010). According to Tayel *et al.* (2015), factors such as draught force, load, speed, soil condition and type affect slippage. Other studies indicate that, wheel slippage increases with increasing load and that slippage decreases with increase in speed, also slippage increases with increasing draught force and moisture content (Okoko & Olosunde, 2018; Nkakini, 2015).

2.4.2 Fuel consumption

Fuel consumption of tillage operations is an essential parameter for selecting appropriate machines. It is needed for developing strategies for operating machines under various field conditions. Energy used in tillage operations depends on many factors such as soil type, soil condition, depth of tillage, speed of operation and hitch geometry (Nkakini, 2015). Mileusnić *et al.* (2010) observed that light disc harrow consumed the least amount of fuel compared to other tested implements. The light disc harrow consumed 7.5 1/hr. On the other hand, the chisel plough consumed 13.6 1/hr. Nkakini (2015) reported that disc harrow required more fuel per hour due to accelerated engine speed. According to Olatunji and Davies (2009), fuel consumption depends upon many factors, such as machine size and the kind of implement attached, travel speed, and soil conditions. They concluded that an increase in speed was accompanied by an increase in fuel consumption.

2.4.3 Draught measurement

The draught is the horizontal component of pull in the direction of travel. The simplest device for measuring implements pull is the spring-type dynamometer (essentially a heavy spring scale) located between the tractor drawbar and the implement hitch and can read directly. Because of rapid fluctuations in load, such measurements must be repeated. A hydraulic type, transmitting to a gauge calibrated in force units is easier to read than the spring type because force fluctuations can be damped considerably by using viscous fluid having a restriction in the line to the gauge. Some hydraulic dynamometers record the pull on a strip chart driven by a ground wheel. To provide a complete picture of implement draft and power requirements, it is necessary to measure speed and the width and depth of cut in addition to determining the draught. Speed may be determined by timing a measured or automatically recorded travel distance or with a tachometer generator driven from a ground wheel (Nkakini, 2015). According to Oduma (2015), factors that influence draught include depth of cut, working speed, the sharpness of cutting edge, the width of cut, implement type, soil condition and attachments. Mathematically it is expressed as,

$D = P \cos \theta$ [**Equation 2.1**]

Where;

D = draught force (kN) P = pull in (kN) θ = angle between the line of pull and horizontal.

2.4.4 Field capacity

According to Mileusnić *et al.* (2010), calculating field capacity is just part of the overall concept of farm machinery management. The field capacity of a machine is a function of the rated width, the speed of travel and the amount of field time lost during the operation (Naim, 2014). He argued that, with implements such as harrows, field cultivator, mowers and combines, it would be practically impossible to utilize the full width of the machine without occasional skips, which is a function of the speed of travel, ground condition and skill of the operator. The measure of field capacity for agricultural machines is theoretical field capacity, effective field capacity and material capacity. Naim (2014) reported that most agricultural field machines performances are expressed as area per unit time or tonnes per hour. It can be measured in acres or hectares per hour and is used to size machinery and it specifies given the amount of time available to accomplish a specific task (Mileusnić *et al.*, 2010). The field time includes productive time and non-productive time, where productive time is the actual time spent to do a specific field operation (Mamkagh, 2019).

The theoretical field capacity (TFC) is the rating of field coverage that would be obtained if a machine is performing its function 100% of the time at rated forward speed and always covering 100% of the rated width (Gupta & Shukla, 2017). According to Lovarelli *et al*. (2017), it is calculated simply by multiplying the distance travelled in an hour by the effective working width.

$$TFC, ha/h = \frac{w \; x \; s}{10} \qquad \textbf{[Equation 2.2]}$$

Effective field capacity (EFC) is the actual area covered by the implement based on its total time consumed and its width (Naim, 2014). Mathematically, it is expressed as:

$$C = \frac{S \times W}{10} \times \frac{E}{100} \qquad \textbf{[Equation 2.3]}$$

Where:

C = effective field capacity, hectare per hour.

S = speed of travel in km per hour.

W = theoretical width of cut of the machine in metre,

E = field efficiency in percent.

2.4.6 Field efficiency

Field efficiency is defined as the ratio of the effective field capacity to the theoretical field capacity expressed as a percentage. It includes the effect of time lost in the field and failure to utilize the full width of a machine in the fieldwork. Field efficiency is not constant for a machine but varies with the size and shape of the field, the pattern of field operation, crop yield, moisture content and crop condition. Field efficiency is affected by several factors such as the theoretical field capacity of the machine, machine manoeuvrability, field size, shape and pattern, yield (if harvesting operation), soil and crop condition, and system limitation (BHASKAR, 2015).

$$\text{Field Efficiency} = \frac{\text{EFC}}{\text{TFC}} \times 100$$ [**Equation 2.4**]

Other terminologies associated with tillage implements include (Singh & Singh, 2001):

- Centre of power: It is the true point of the hitch of a tractor.
- Centre of resistance: It is the point at which the resultant of all the horizontal and vertical forces act. The centre lies at a distance equal to the 3/4th size of the plough from the share-wing.
- Line of pull: It is an imaginary straight line passing from the centre of resistance through the clevis to the centre of pull (power).
- Pull: It is the total force required to pull an implement.
- Side draught: It is the horizontal component of the pull perpendicular to the direction of motion. This occurs when the centre of resistance is not directly behind the centre of pull.
- Unit draught: It is the draught per unit cross-sectional area of the furrow.
- Horsepower: it is the power an engine produces which is expressed mathematically as:

$$\text{HP} = \frac{\text{Draught(kN) X Speed(m/s)}}{75}$$ [**Equation 2. 5**]

- Soil Inversion

$$\text{Soil inversion} = \frac{\text{No. of weeds before ridging} - \text{No. of weeds after ploughing}}{\text{No. of weeds before ploughing}} \times 100$$

[**Equation 2.6**]

- Soil pulverization; It is the quality of work in terms of soil aggregates and clod size. This is measured by cone penetrometer.

2.5 Effect of Soil Engaging Disc Parameters on Soil Reaction Forces

2.5.1 Definitions

The definitions provided below are according to Singh & Singh (2001):

Disc - It is a circular, concave revolving steel plate used for cutting and inverting the soil.

Disc angle - It is the angle at which the plane of the cutting edge of the disc is inclined to the direction of travel. Usually, the disc angle of good plough varies between 42° to 45°.

Tilt angle - It is the angle at which the plane of the cutting edge of the disc is inclined to a vertical line. The tilt angle varies from 15° to 25° for a good plough.

Concavity - It is the depth measured at the centre of the disc by placing its concave side on a flat surface (Aikins *et al.*, 2012). Figure 2.3 shows the various angles of disc implements.

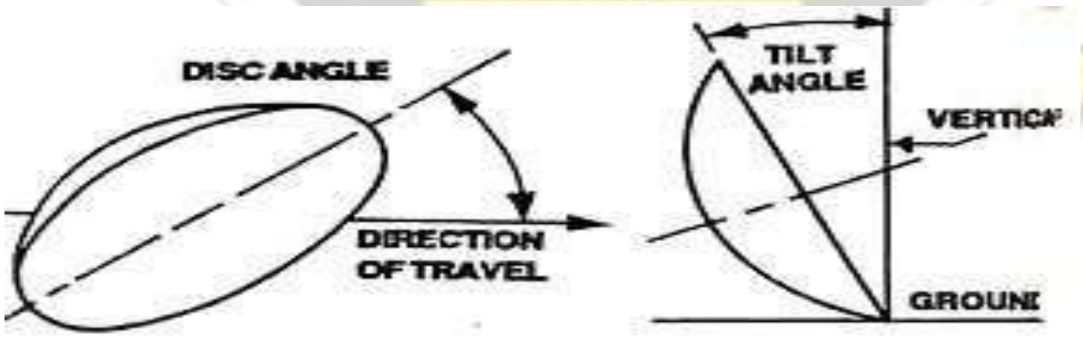


Figure 2.3: Angles of disc plough (Okolle et al., 2016)

2.5.2 Standard disc and tilt angles of discs and its effect on implement performance

The effect of the disc angle on the soil reaction of disc implement may be considered as the most important factor in a given soil condition. It affects some other variables such as the width of cut and the area of contact between the furrow wall and the convex side of the disc. Moreover, the disc angle controls the relationship between the forward and rotational movement of a freely rotating disc (Naim, 2014).

Gordwin (2007) measured the draught, vertical and side force components of the soil reactions on a disc tool at the different disc and inclination angles with constant width and depth of cut 177.8 mm and 152.4 mm respectively. The disc angles ranged from 36° to 51 ° for two specific settings of the angle of inclination 0° and 15°. The diameter and radius of curvature of the disc were 660.4 mm and 568.96 mm respectively. He observed that the draught force on the disc attains a minimum for a disc angle of about 45°, and that above 45° the draught force increases rather sharply. On the other hand, for smaller disc angles there is an increased area of contact between the furrow wall and the convex side of the disc, which consequently increases the draught force. He also noted that when the angle of inclination increased to above 15° a marked increase occurred in the draught force.

From experimental observation with 610mm, 710mm and 810mm disc sizes, Godwin *et al.* (1987) suggested that for an optimum range of operation in terms of draught force, the disc angle would be between 25° and 32°, which is much lower than that recommended by others. Later, Gill *et al.* (1980) studied the spherical and conical disc with a large radius of curvature and confirmed that due to the pressure on the back of the disc, the optimum disc angle ranges between 25° to 32°. He also noted that if the disc is operated below 25° it creates compaction and is non-productive. Keller (2004) in his discussion on the performance of standard agricultural disc plough suggested the range of disc angle for vertical disc from 35° to 55°, commonly 40° to 45° and for the inclined disc from 42° to 45°, with a range of inclination angle of 15° to 25°. They also observed that an increase in inclination within 15° to 25° increases the draught and vertical upward force but decreases the side force. Thus, penetration is better at the smaller tilt angles.

Mamkagh (2009), suggested the optimum disc angle be about 45° as a rule and indicated that up to this angle the penetration tends to increase. He also pointed out that an increase in the angle of inclination from 15° to 25° increases the draught slightly and tends to reduce penetration but assists in turning the furrow slice efficiently.

Al-Ghazal (1989), studied the effect of disc angle, tilt angle, furrow width and speed of operation on the three components of soil reactions. His observation showed that in general, the draught force (L) increases with the disc angle (a). In contrast, the width of cut decreased with the increase in disc angle. There is a simple geometric relationship between the disc angle and the furrow width, and its choice has a great influence on the resistance of the disc plough. The combined effect of these variables is thus most important. Accordingly, draught force would be minimized at a maximum width of cut by using the lowest possible disc angle, subject to inner furrow ridging considerations and possible compaction effects. The draught per unit width showed a marked decrease from minimum to a maximum width of cut.

Alam (1989) also observed that the draught force always increased with the speed, but the power required to operate the plough was not raised proportionately to speed and a tilt angle of about 15° was generally suitable for a draught. Hence, to avoid this effect and to take advantage of a decreasing draught per unit width, he suggested operating the disc plough at greater width for the same rate of work. Taylor found that the minimum side force occurs at high tilt angles, possibly combined with low disc angles. He also noted that the side force increased more than proportionately with furrow width and that it increased with speed by a mean amount of 179.1 N/m/s on lighter soil and 348.3 N/m/s on heavier soil. He also observed that the penetration became increasingly difficult as the plough was opened because the upward soil force on the disc rises sharply at low disc angles and more weight is required to keep the plough in work. Tilt angle interacts with this effect in such a way that low tilt angles mitigate it and high ones accentuate it. He also observed that speed had no effect on vertical force except for a small interaction with tilt angle to give easier penetration at higher speeds with 25° tilt.

Godwin *et al*. (1987) studied with deep spherical and shallow spherical discs of diameter 610 mm, concavity 140 mm and 70 mm respectively with a depth of cut 100 mm and 40 mm. They observed that the minimum draught force occurred at disc angles in the range of 20° to 30° both in 40 mm and 100 mm depth of cut. They noted that the point of minimum draught was ranked according to the clearance angle of the disc. The vertical resistance to penetration decreased rapidly with disc angle up to the clearance angle of the disc, above which the vertical resistance to penetration was relatively insensitive to the disc angle. Based on the observation it was noted that minimum specific resistance occured at similar but marginally larger disc angles than those of minimum draught force, which allowed the disc to cover larger width of cut with the same rate of soil resistance.

The effect of disc angle, tilt angle, speed of operation, disc diameter and concavity were studied by Johnston and Birstwistle (1963). They measured the draught, side and vertical components of the soil reaction forces and presented as a force per unit area of a furrow, based on a cross-sectional area equals wd, where, w is the furrow width, and d is the depth of cut. They reported that the minimum draught force L, may occur over a wide range of disc angles from the usually accepted 45°, depending on furrow width, the manner of edge sharpening and soil type, whereas the inclination angle appeared to have little effect on draught in the 10° to 15° range commonly used for wider furrow widths. The effect of the disc diameter and concavity, furrow width and depth were reported to be insignificant on the draught per unit area. On the other hand, they found a highly significant effect of speed on draught per unit area. Speed also increased side force but not vertical force. They also observed that the side force S per unit area of furrow cross-section increased with the disc angle and the disc diameter. They noted that the effect of concavity was consistently negative since the rear of the disc furnished considerable side support.

Current literature confirms the effort of previous researchers, suggesting optimum ranges of tilt and disc angles as 15° to 25° and 42° to 45° respectively (Ranjbarian & Jannatkhah, 2017). Research on the effect of disc and tilt angles on tractor effective field capacity, wheel slippage, fuel consumption, ploughing depth and width of cut revealed an increased fuel consumption with an increase in disc angle (Abdalla *et al*., 2014). He further revealed that decreasing ploughing depth led to increasing effective field capacity and field efficiency; increasing the disc angle led to increased width of cut and decreasing tilt angle increases ploughing depth.

3 Factors that govern the penetration of disc implements

In general, the weight pushing the disc into the soil is a major element in penetration and its effectiveness is governed by the angle of the line of pull, inclination, diameter, concavity, thickness, sharpness and the method of sharpening the disc cutting edge (Hashemi *et al.*, 2012). In their discussion on disc penetration, they pointed out that weight is the most important factor in disc penetration. On the other hand, the bearing on the convex side of the disc has been found to be an important factor in compaction and resist penetration. Quasi research by Nkakini (2015) showed that if the setting of the disc is such that there is no scrubbing at the rear of the disc, the curvature of the disc causes the soil to move upward along the path across the disc surface producing the suction effect of an inclined plane. He postulated that this penetration action can be increased by setting the disc at an inclination. According to Taha & Khalifa (2018), penetration of the disc can also be increased by cutting notches at the edge of the disc to reduce the circumferential area of the bearing rather than setting the disc at an inclination. They suggest that inclination increases the bearing at the back of the disc at smaller values of the disc angle which may results in compaction (Taha & Khalifa, 2018).

2.6 Draught forces prediction for soil engaging discs

Theoretical models for the prediction of the performance of wide cutting blades have been in existence for some time. These models characterize the soil as a rigid-plastic Mohr-Coulomb material and depend on advanced mathematical techniques developed for the solution of the complex equations of equilibrium of soil elements in twodimensional plane-strain failure (Godwin & O'Dogherty, 2007). Less rigorous techniques have been employed for developing mathematical models for the behaviour of deep narrow tines. In both cases, the soil-implement contact boundary is assumed to be a plane surface of simple geometrical shape (Reaction *et al.*, 1989). The extension of these methods to deal with three-dimensional failure generated by curved loading boundaries is of comparatively recent origin. The soil failure patterns associated with disc soil cutting implements fall into this category (Nkakini, 2015).

Alam (1989) described the development of a mathematical model for predicting the performance of disc implements. His research follows the technique used by Godwin *et al* (1987) for reducing three-dimensional failure into two-dimensional components. Alam's analysis catered for discs implements having both inclination and disc angles. Soil contact in such implements takes place on complex curved surfaces and the geometry of these were analysed by Alam (1989). He explained that these surfaces were approximated by plane elements which were then assumed to generate two-dimensional failure in planes parallel to the direction of translation of the disc. The rupture geometry and the forces acting on these elements were then computed using the Newcastle adaptation of Sokolovski's rigorous solution to soil failure (Sahu & Raheman, 2006). The force acting on the soil contact surface is then obtained by a version of the method of slices used for analyzing slip surfaces. The model developed could predict the quasistatic soil reactions on disc implements from a knowledge of the disc geometry, soil properties and depth of cut (Godwin & O'Dogherty, 2007).

Godwin & O'Dogherty (2007) presented the summations of these force components as given below:

VT = Vp + Vs: (+ve forces oppose penetration), (1)

DT = Dp +Ds (+ve forces oppose direction of travel), (2) ST = Sp -Ss (+ve forces act from concave to convex faces), (3) where VT. DT and ST are the total vertical, draught and side forces arising from the passive (suffix, p) and scrubbing (suffix, s) components. These are based upon the principles of Mohr-Coulomb soil mechanics and application of two theories. The first, two-dimensional cutting theory developed by Hettiaratchi *et al*. (1966) and reviewed by Hettiaratchi & Reece (1974) is used for estimating the passive component. The scrubbing component is compressive in nature and is estimated using the bearing capacity theory developed for angled footings by Meyerhof (1961).

2.7 Analysis of materials for construction of Agricultural equipment

Strength, durability, and services of a farm implement largely depend upon the quality of material used. Selection of proper material for an application is of critical value. Proper treatment of the selected material affects the initial and running cost as well as durability and performance of the machine (Mazumdar, 2001). Implement parts/components should, therefore, be designed to utilize the lowest cost materials which can perform satisfactorily and provide adequate life. Use of high-cost materials and expensive treatments sometimes become unavoidable to make for a deficiency in the original design (Velazquez *et al*., 2017).

2.7.1 Classification of materials

Figure 2.4 presents the classification of materials for the construction of agricultural machinery.

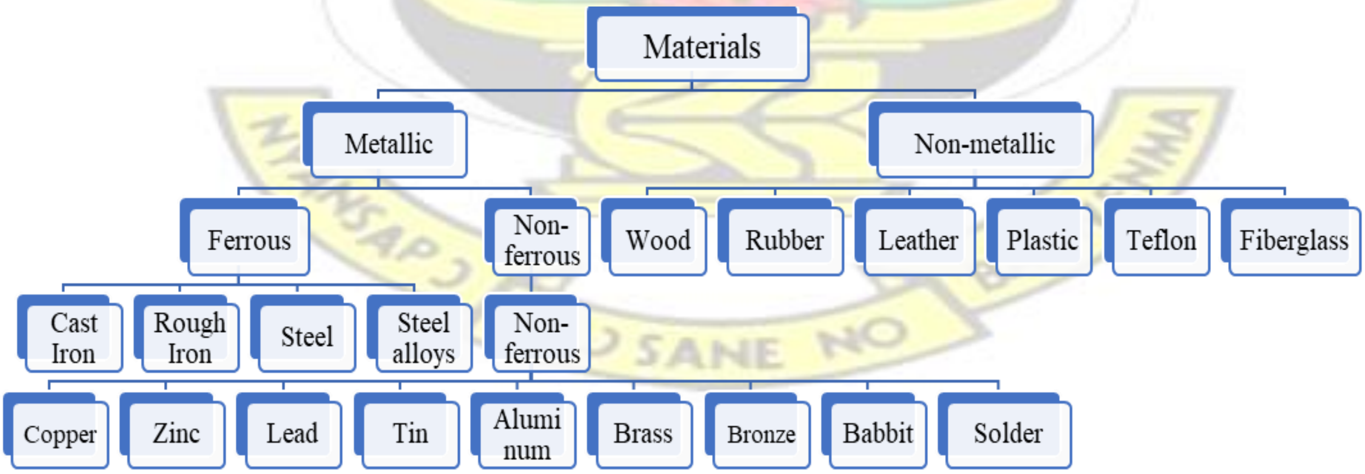


Figure 2.4: Material classification (Groover & Groover, 2012)

Alloys

According to Groover & Groover (2012), an alloy is a substance that has metallic properties and is composed of two or more chemical elements, of which at least one is a metal. There is an infinite number of alloys and are made through a fusion of metals. Common groups of alloys are:

a. Alloy steels using manganese, chrome, nickel, tungsten, etc. as alloying elements.
b. Non-ferrous alloys: Bronze, Brass, Babbit or antimony, solder, and Aluminum alloys

Classification of Steels:

Steel is an alloy of carbon and iron. Steels are classified according to Liang *et al*. (2014)

a) Manufacturing Process: Bessemer Steel, Open Hearth Steel, Electric Steel
b) Carbon Content: Low Carbon (up to 0.25% c) (Easy to bend, forge and shear),

Medium Carbon Steel (0.25% to 0.50% c), High carbon steel (0.50 to 1.2% c)

c) Alloy steel (a mixture of two or more chemical substances one of which is a metal)

d) According to Uses: Structural Steel and Tool steel

e) According to Method of Forming: Rolled Steel, Forged Steel, Cast Steel, and Formed Steel

2.7.2 Application of Steel

According to Joutsenvaara & Vierel (2013), steel finds application in the following:

a) Low carbon steel: Used extensively in the construction of farm machinery. Frames and most of the other members are made from low-carbon steel.

b) Medium carbon steel: Used for greater strength and hardness. Members such as shafts, connecting rods, etc. are made of medium carbon steel.

c) High carbon steel: It is very hard and is used for making tools, ball and roller bearings, cutting tools, etc.

2.8 Analysis of Agricultural Machinery Design methods

The complexity in the design of agricultural machinery lies in the correct choice of a solution based on the diagnosis of needs and the determination of structural options and technologies that satisfy them (Jiandong & Haigen, 2005). Thus, the modelling of a product during the design stage involves the integration of knowledge, skills, creativity and the holistic understanding of the problem to be solved to obtain a product adapted to the needs of the small farmer. For that reason, a system engineering approach can be implemented in the design of agricultural machinery (Al-Suhaibani *et al*., 2010).

According to Bergamo and Romano (2016) in the design of agricultural machinery, several factors affect the design process. Considering the systemic approach, the design of machinery must be analysed as part of the agricultural production system. The analysis is performed according to the supra-system and subsystem that make up the design of agricultural machinery with the objective of identifying its most relevant components and their interaction in a broader context. Therefore, the design of machinery is a complex and open system due to the numerous interactions between the various actors and processes that evolve according to the constraints of the environment (Velazquez-Miranda *et al.*, 2017). According to Velazquez-Miranda *et al.* (2017), it is important to note that as part of a larger system, design of agricultural machinery is influenced by food companies, government and international policies and strategies that govern at the macroeconomy of agricultural production system. Furthermore, it is important to understand the prevailing demographic, cultural and technological conditions of the farmers to design a machine that suits local needs and conditions of small farmers (Gebregziabher *et al*., 2007).

One of the factors is the identification of needs by stakeholders (farmers, manufacturing companies, investors, etc.), which establishes the scope of design. Another factor is the physical context of operation since the proposed design must be functional for the place conceived according to its geographic, climatic and topographic conditions (Abunde & Jiokap, 2017).

Likewise, production processes and practices influence the type of machinery to design, as they can be for precision or conservation agriculture practices (Gupta & Shukla, 2017). Moreover, the dynamics and performance of each concept need to be analyzed regarding its efficiency, reliability, safety, and comfort (Phadnis *et al.*, 2016). These performance factors must satisfy the regulations regarding the construction of agricultural machinery and its quality certification by the National Center for the Standardization of Agricultural Machinery (Bergamo and Romano, 2016).

On the other hand, machinery design must be profitable considering the costs of materials and parts. Concerning the ecological impact, it is necessary to analyse the life cycle of the machinery to visualize the alternatives of the design that are environmentally friendly (Aurich et al., 2006).

2.8.1 Design Theories and Methodologies

Throughout history, mankind has designed a great diversity of artefacts and products that can be changed and redesigned with new materials, manufacturing methods and technologies (Velázquez-Miranda *et al*., 2017).

The importance of the design process is that if an incorrect decision is made in the early stages, later corrections will be more expensive. So, it is necessary to focus on improved methods and design tools to obtain a quality product at a low cost and in less time

(Sadeghi *et al.*, 2016). As a result, a variety of theories and methodologies have been developed over six decades to explain and improve the design process (Tomiyama, 2006).

According to Pahl *et al.* (2007), there are several design methodologies, some of them focus on improving design characteristic, and others are more holistic. Hence there exists different classifications. Newsome *et al.* (2013) proposed that design theories and methodologies should be classified as descriptive or prescriptive model-based representations and methods to support decision making.

Tomiyama *et al*. (2009) considered four classifications of design methodologies and suggested that a design method is:

- concrete and individual when the methodology deals with aspects of design
- concrete and general when it is a systematic process applicable to any product
- abstract and individual when it is based on mathematical models
- abstract and general when the methodology explains the design process in a cognitive way.

Velázquez-Miranda *et al*. (2017), summarized the literature on the evolution of theoretical developments and engineering methodologies as presented in Table 2.3. It is evident from the table that new methodologies have been developed in recent years.

Table 2.3: Design methodologies and theories identified

Period	Methodology/ Theory
1946-1980	Theory of Inventive Problem Taguchi method
	Hansen design methodology
	Waterfall design
	Design decision-making methods
	Quality Function Deployment
	The morphology of design
	Top-down design / Bottom-up design
	Theory of technical systems
	Physically and algorithmically oriented design method
	Systematic approach
	Axiomatic design
1980-1990	General design theory
	Design Structure Matrix
	The design process of Roth
	VDI 2221
	The methodology by Nigel Cross
	Conceptual design for engineers
	Cost-efficient design
	Spiral model design
	An integrated product development model
	Concurrent engineering
1990-2000	Model-based design
	Total design
	The V model
	Ullman design method
	Product design and development
	Whole-system thinking and integrative design
	Universal design theory
2000-2016	Contact and Channel Model
	Adaptable design
	CPM/PDD
	Vision-oriented innovative product design process
	Whole systems design
	The methodology of dynamic linguistic modelling
	Getting design right. A systems approach
	Product-form design model based on genetics algorithms
	Process modelling methodology
	Design methodology for appropriate technology
	Local oriented manufacturing

2.9 Value Analysis (VA) and Value Engineering (VE)

Studies have been published on VE and VA with many referring to Value Management as an umbrella term, which encompasses value engineering and value analysis (Bartolomei & Miller, 2001; Michalakoudis *et al.*, 2017). These studies distinguish between the two methodologies in design and summarize their importance in the manufacturing industry as follows:

- Value Engineering
- Value Analysis

2.9.1 Value Engineering (VE)

According to Wao & Mqsi (2015), VE is a systematic application of recognized techniques that identify the function of a system at the lowest overall cost. He said, it is concerned with new products and applied during product development with the aim of minimizing costs, improving function or both, by way of team-based product evaluation and analysis. This is done before any capital is invested in tooling, plant or equipment. This is very important, because according to many reports, up to 80% of a product's costs (throughout the rest of its life-cycle), are locked in at the design development stage (Abdullah *et al.*, 2010; Miladi & Aminoroayaie, 2018). This is understandable when one considers that the design of any product determines many factors, such as tooling, plant and equipment, labour and skills, training costs, materials, shipping, installation, maintenance, as well as decommissioning and recycling costs.

Value engineering (VE) methodology was reviewed by Wao & Mqsi (2015) with the aim of improving it to achieve better outcomes that are more sustainable. He identified limitations in the conventional VE process and developed solutions to counter the limitations in the respective VE phases. He noted that PerformanceWorth (PW) approach in the function analysis phase, Neuro-Linguistic Programming (NLP) method in the creativity phase and Choosing-By-Advantages (CBA) in the evaluation phase of VE were identified as potential avenues to improve sustainability outcomes. The desired outcomes in a VE job plan would be improved should these methods be integrated into the VE methodology. These new methods would simultaneously include the three facets of VE that focus on achieving project outcomes at optimum cost and at the highest performance and quality levels (Woa & Mqsi, 2015).

The cite studies on VE argue that VE be considered a crucial activity in the product development process and that it is certainly a wise investment, regarding the time it takes. They recommend strongly that VE be built into any new product development process, to make it more robust and for sound commercial reasons.

2.9.2 Value Analysis (VA)

Unlike VE, VA is concerned with existing products. It involves the analysis of a current product and the evaluation of the same by a team, to reduce costs, improve product function or both. VA activity uses a plan which step-by-step, methodically assesses the product in a range of areas that include costs, function, alternative components and design aspects such as ease of manufacture and assembly (Pahl *et al.*, 2007).

According to Mostafaeipour (2016), a significant part of VA is a technique called Functional Analysis, where the product is broken down and reviewed as a number of assemblies. Here, functions are identified and defined for each product assembly. Costs are also assigned to each one. This is assisted by designing and viewing products as assemblies (or modules). As with VE, VA is teamwork that involves brainstorming improvements and alternatives to improve the value of an existing product, particular to the customer (Michalakoudis *et al.*, 2017). Other studies have reported that best performers in the industry often use value analysis, in conjunction with other worldclass manufacturing techniques, such as Lean Manufacturing. By so doing, they reduce costs not only in product development but in all aspects of the business, particularly production (Fantoni *et al*., 2007).

2.9.4 Functional Analysis and Computer-Aided Design

Reusing the engineering know-how in conjunction with Computer-Aided Design (CAD) software has improved product design with higher quality, less cost and short lead-time (Abunde & Jiokap 2017). CAD is essentially based on geometry and focus mainly on 3D shapes along with shape representation, matching, comparison, and retrieval information. Consequently, research on different approaches and categorization of methods has been extensively accomplished (Chakrabarti *et al*., 2011). Disregard to text-based matching, Zehtaban and Roller (2012) citing Iyer *et al*. (2005) have listed seven main categories of methods which decompose a 3D shape into a so-called signature including Graph-based methods, Harmonic- based methods, feature-based methods, etc. They, however, suggest that to have comprehensive knowledge about a designed product, the functional analysis is required.

Tools and techniques for functional analysis

i. Horned beast Diagram

The horned beast diagram permits to question the problem about the product itself, the market, the context of the project and the objectives. The method leans on an interrogative technique by asking three questions: Who or what will this product serve? what does it affect or interact with? and what is the goal? (Abunde & Jiokap, 2017) Essentially, the horned beast diagram is a visual tool to illustrate the functional questions listed above. The horned beast diagram works together with octopus diagram. The horned beast helps to identify functions and elements and then the octopus identifies how the functions relate to each other and the project (Fantoni et al., 2007).

ii. Octopus Diagram

Octopus diagram is applied after analysing the costumer's need where functional analysis determines the functional requirements. The first step is to investigate the connections between the product and the external environment. According to Bartolomei and Miller (2001), these connections are divided into two lists, as illustrated in Fig. 2.5 where:

-*Constraint Requirements (CR):* refers to present adoption or action of the product. It means either the product must be adopted with an element or it acts on an element. -*Functional Requirements (FR):* interaction of the product with elements of the surroundings.

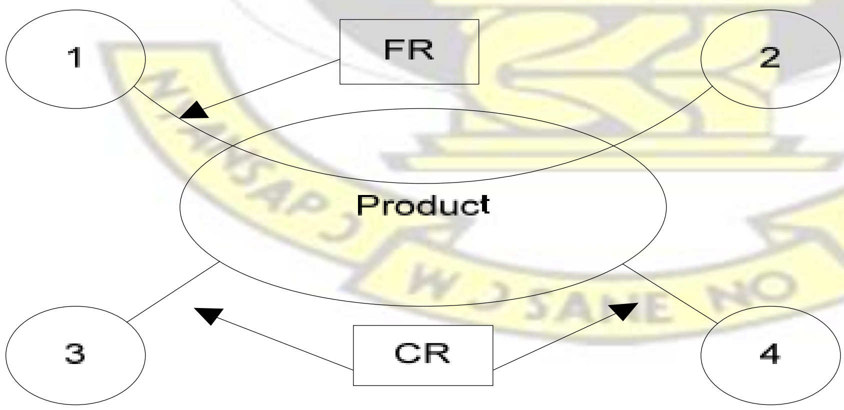


Figure 2.5: FR and CR in Octopus diagram

This method defines the main functions in addition to the constraint functions to have an overview or a global view of the product. However, octopus' diagram does not clarify which functions are received or generated by the main function; it merely expresses the needs of a user.

iii. Functional Analysis Systems Technique

The Functional Analysis Systems Technique (FAST) was introduced by an engineer at Sperry Univac (Unisys) in 1960 called Bytheway (Wixson, 1999). FAST diagram constitutes an essential data set enabling to have a good knowledge of a complex product. The Association of French Normalization (AFNOR) in NF EN 12973 describes the FAST diagram as one of the usual methods of functional analysis. The FAST methodology is based on the decomposition of each basic function of a product and its classification using a logic diagram (Lambert et al., 1999). The logic diagram helps to find and approves alternatives for inventive new model to complete the function. The method has different stages:

Stage 1: Brainstorm all the expected functions from a customer point of view

Stage 2: Select the overall product function

Stage 3: Apply a categorization for functions into basic and secondary

Stage 4: Arrange functions in a critical path as illustrated in Figure 2.6

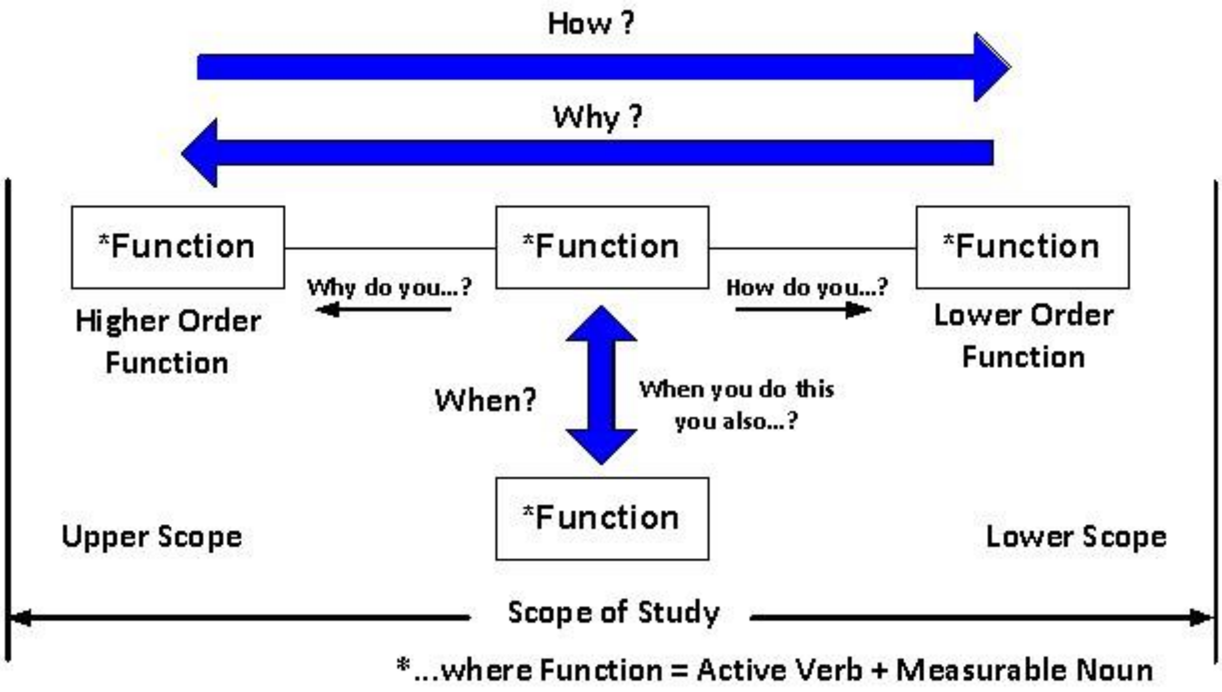


Figure 2.6: FAST diagram (CSVA, 2019)

The method leans on an interrogative technique by asking three questions, regards to Fig. 2.5

HOW is (function) to be accomplished?

WHY is it necessary to (function)?

WHEN (function) occurs, what else happens?

The responses to each mentioned question are neither exclusive nor unique. They can be singular, multiple (using AND connection) or optional (using OR connection) (Zehtaban & Roller 2012).

iv. IDEF0

According to Zehtaban & Roller (2012), Integration Definition for Function Modelling (IDEF0) is a common modelling technique for the analysis, development, reengineering, and integration of information systems; business processes; or software engineering analysis. IDEF0 is a modelling language including rules and techniques to standardize a graphical representation of a system or an enterprise. The target is to support systems integration; accordingly, the model includes structures for system functions (activities, actions processes, and operation), functional relationships and data (information of objects) (Zehtaban & Roller, 2012).

The input for functional analysis in IDEF0 is the output of requirement analysis. The functional analysis comprises of the recognition of the main function (higher-level function) and the decomposition into sub-function (lower-level function). Subsequently, the requirements will be assigned to the functions. In addition, each lower-level function could be decomposed consequently. The two primary modelling components are functions (represented on a diagram by boxes), and data and objects that interrelate those functions (represented by arrows in Figure 2.7) (Lambert *et al.*, 1999).

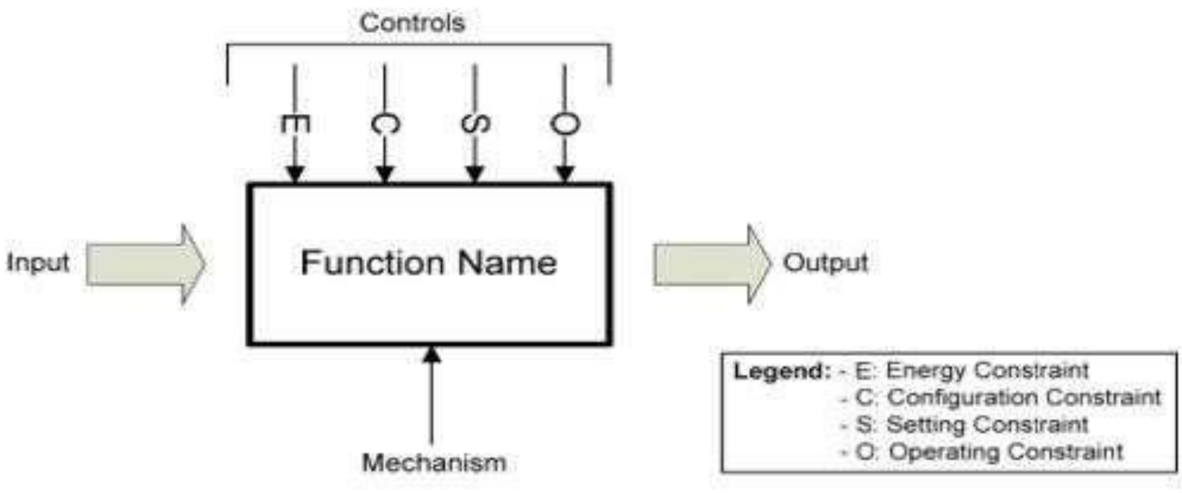


Figure 2.7: Fundamentals if IDEFO Diagram

v. Comparison of FAST, APTE and IDEF0 methods

In the APTE method, the Octopus diagram analyses the requirements and connections of the product with external elements (Michalakoudis *et al*., 2017). According to Michalakoudis, the main function in this method has an individual relationship with each defined element and provide a general overview of the product. However, the method does not inquire how each element with the specified functionality must be implemented (Bartolomei & Miller, 2001). The octopus diagram has been extracted from APTE method to identify all the possible actions from the product surroundings. This identification assists the functional analysis greatly and gives the tool a superior power. In FAST method, the main function is decomposed in technical functions and consequently into the elementary functions in a hierarchy form (Abunde & Jiokap, 2017). Each elementary function is a solution to a technical function. This method presents the elements which compose the product. Therefore, each service function will be represented by one FAST diagram such as constraints functions to ensure the security of the user and the high-quality functioning of the product (Oluwatosin *et al.*, 2016). A disadvantage for FAST refers to the fact that the FAST diagram leads the user to achieve only one solution. Both FAST and Octopus diagram are applied in value engineering. IDEF0 method according to Michalakoudis *et al.* (2017), uses decomposition for functional analysis; though it decomposes only the main function, not the constraint functions. The researchers, however, postulate that certain constraint functions are considered as a sub-function for the main function. They conclude that the method indicates the restriction in implementing the function such as flows, setting and the configuration.

Among all described tools for functional analysis, the horned beast, octopus and FAST diagrams have been adopted for this research because of its comprehensible logic. Nevertheless, all mentioned functional analysis methods are only capable of identifying a single functionality in a product, rather than providing inclusive information about all functions in a product. To fulfil this gap, the functional basis which is considered as a taxonomy-based approach for functional analysis is applied (Wang *et al*., 2016).

2.10 Hazard and Operability (HAZOP) Analysis

HAZOP is an acronym that stands for Hazard and Operability study commonly us as PHA (Process Hazard Analyzer). It is a qualitative risk assessment technique. It is based on the theory that assumes that risk events are caused by deviations from design or operating intentions (Gohad, 2018). The technique uses a systematic process to (1) identify possible deviations from normal operations and (2) ensure that appropriate safeguards are in place to help prevent accidents. HAZOP technique uses special adjectives (such as "more," "less," "no," etc.) combined with process conditions (such as speed, flow, pressure, etc.) to systematically consider all credible deviations from normal conditions. The adjectives called guide words are unique features of HAZOP analysis (Redmill *et al.*, 1997). According to Baybutt (2015), when applied to process design, it indicates potential hazards that may arise from deviations from the intended design conditions. A formal operability study is the systematic study of the design, vessel by vessel, and line by line, using “guide words” to help generate thought about the way deviations from the intended operating conditions can cause hazardous situations. The seven guide words recommended by Abunde & Jiokap (2017) are presented in Table 2.4.

Table 2.4: The seven guide words used in HAZOP and their meanings

Guide words	Meanings	Comments
NO or NOT	The complete negation of these intentions	No part of the intentions is achieved but nothing else happens
MORE LESS	Quantitative increases or decreases	These refer to quantities and properties such as flow rates and temperatures, as well as activities like "HEAT" and "REACT"
AS WELL AS	A qualitative increase	All the design and operating intentions are achieved together with some additional activity
PART OF	A qualitative decrease	Only some of the intentions are achieved; some are not
REVERSE	The logical opposite of the intention	This is mostly applicable to activities, for example reverse flow or chemical reaction. It can also be applied to substances, e.g. "POISON instead of "ANTIDOTE" or "D" instead of "L" optical isomers
OTHER THAN	Complete substitution	No part of the original intention is achieved. Something quite different happens

Source: Abunde & Jiokap (2017)

Other authors have proposed, the following additional guide words or steps in hazard analysis and their precise meanings given in Table 2.5 (Baybutt, 2015; Poulose & Madhu, 2012). According to the researchers, these steps are best when analysing machines and equipment designed for agricultural purposes.

Table 2.5: Additional guide words used in HAZOP study

Guide Word	Meaning
Intention	The intention defines how part of the system was intended to operate; the intention of the designer.
Deviations	These are departures from the designer's intention which are detected by the systematic application of the guide words.
Causes	Reasons why, and how, the deviations could occur. Only if a deviation can be shown to have a real cause is it treated as meaningful.
Consequences	The results that follow from the occurrence of a meaningful deviation.
Hazards	consequences that can cause damage (loss) or injury

Source: (Baybutt, 2015; Poulose & Madhu, 2012)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Background

A Fully-mounted double-row disc ridger was designed, and all CAD models and design simulations were produced with Solidworks. Material for construction was primarily mild steel, which was secured from the open market. The soil engaging parts and others such, as discs, hubs, bearings, category pins and bolts/nuts were also outsourced from the market. The ridger was constructed at the Department of Agricultural and Biosystems Engineering workshop of KNUST. The fabricated ridger was evaluated at the Anwomaso Agricultural Research Station located at latitude 6°41'56.75''N, longitude 1°31'25.85''W and altitude 274 m above sea level.

This chapter of the research is presented in two sections. The first section deals with the material and methods for design, simulation and construction of the disc ridger, while the second section presents how the evaluation was carried out.

Section One: Design Modelling, Simulation and Fabrication

3.2 Resources and Design Methodology

Tools, Software and Hardware Components

Table 3.1 presents the tools and software that were used for the realization of the project. These include both the roles and description of each component that was used in the project.

Table 3.1: Tools and software used in the project including their roles and description

Software and Routines	Role	Description
Software used for Design and Simulation Analyses		
SolidWorks	For 2D and 3D Engineering Drawings	An engineering design and 2019 simulation software
Tools used for the Project		
Tool	Role	Description
FAST Diagram	Presentation of technical solutions for need analysis	Functional Analysis System Technique
OCTOPUS Diagram	Presentation of principal and constraint functions	Project management tool for design engineers
HORN BEAST Diagram	Identification of design functions	Design tool for functional analysis
GANTT	For project planning	This technique provides the GANTT diagram which permits planning using bars.
Hardware Component		
Laptop	Computer simulations	Model DELL, Ch. No. 8184, x 64-bit based processor, 4GB RAM, (Windows 10 operating system)

3.3 Design Methodology

The ridger design was accomplished using a combination of Functional Analysis (FA) and Computer-Aided Design methods as described by Abunde & Jiokap (2017). Figure 3.1 presents a detailed methodology for the realization of the design and fabrication while Figure 3.2 shows an exploded view of the design development.

OVERVIEW OF METHODOLOGY

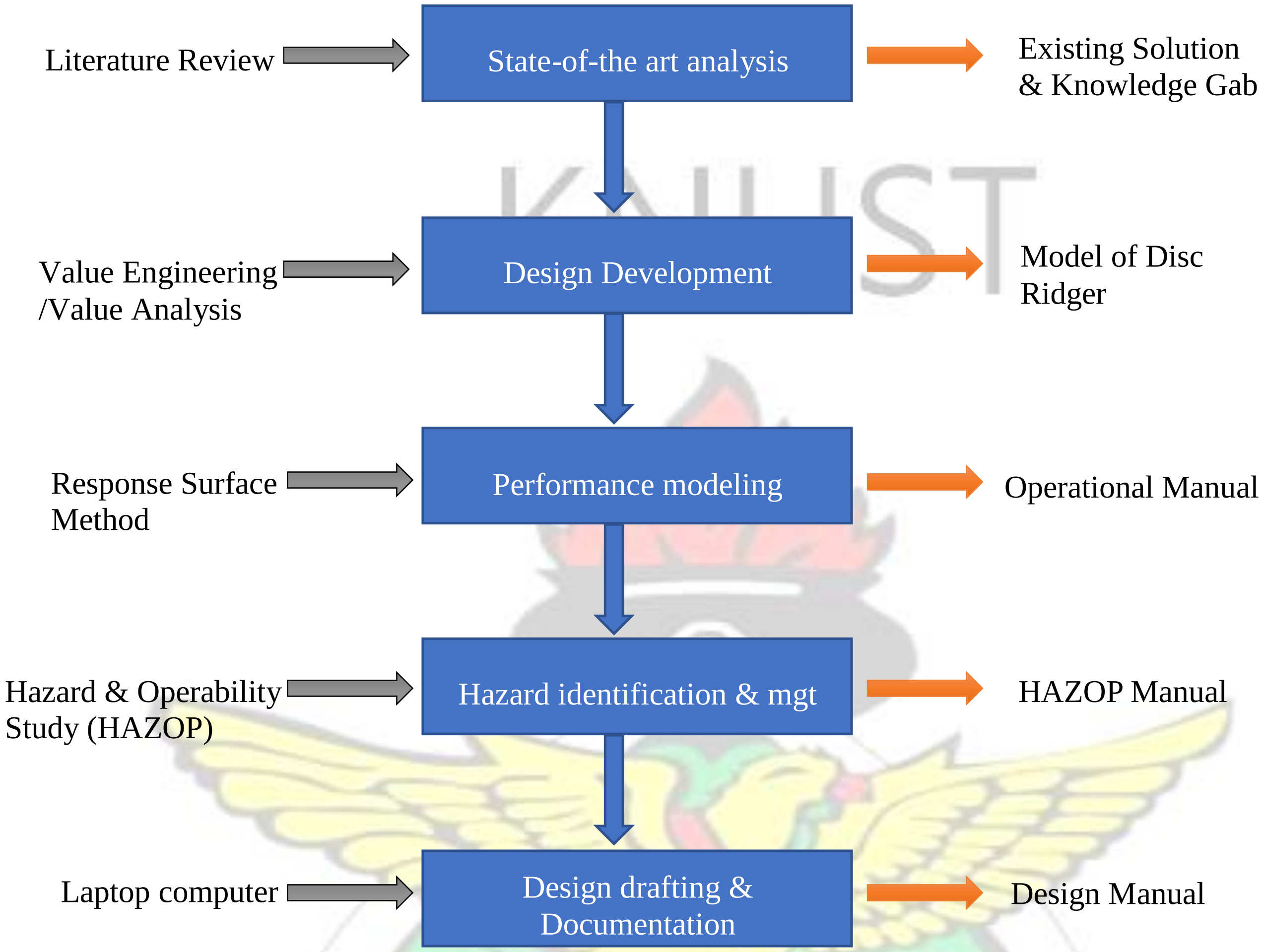


Figure 3.1: Design Methodology adopted from Abunde & Jiokap (2017) OVERVIEW OF DESIGN METHODOLOGY

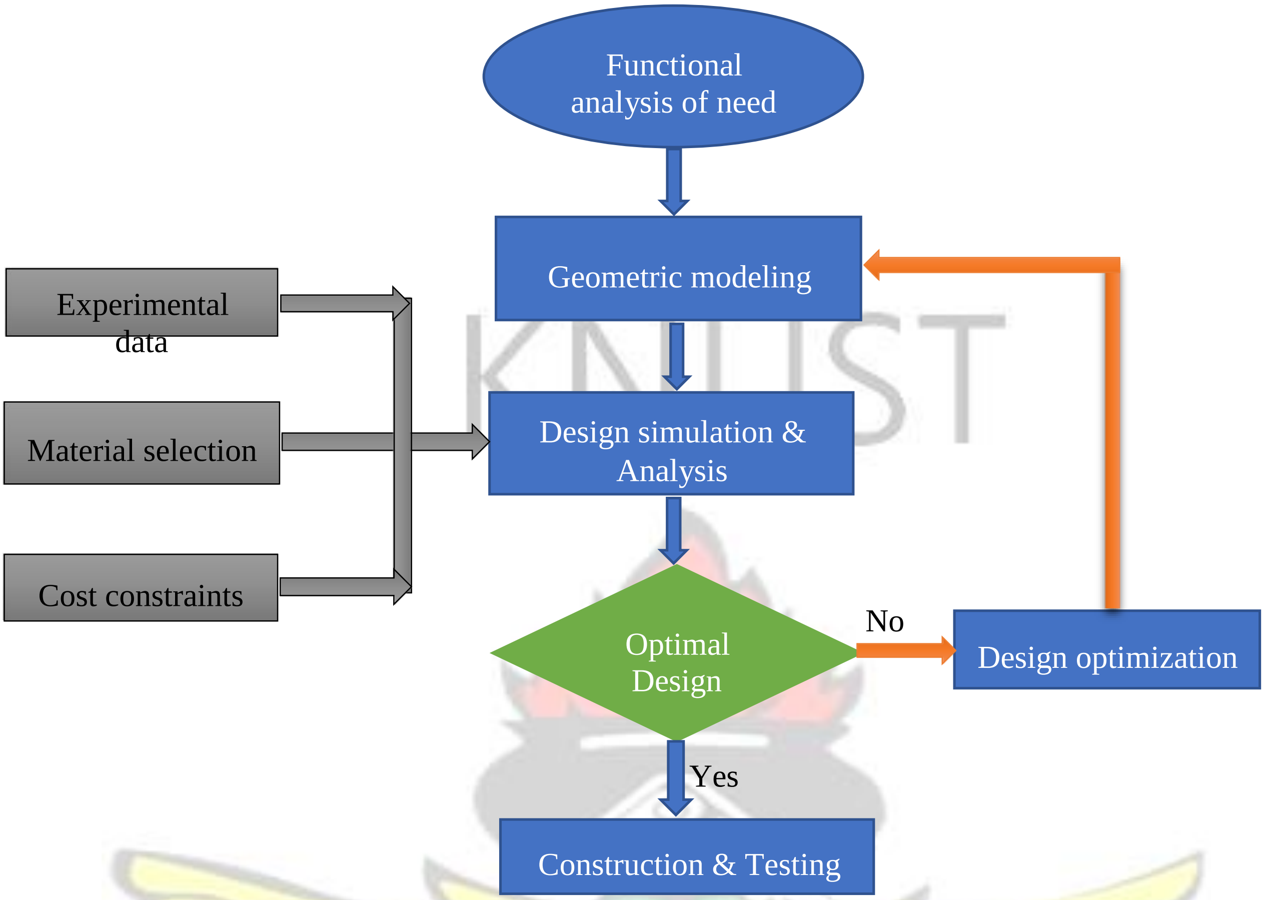


Figure 3.2: Design Development adopted from Abunde & Jiokap (2017)

3.4 Design Principles and Criteria

The purpose of the technical system was to form bunds or ridges wide enough to accommodate root and tuber cultivation machinery. As a fundamental principle postulated by Pahl *et al.* (2007), technical systems whose main flow is energy-based are referred to as machines, those that are material-based as equipment or apparatus, and those whose main flow is signal-based as devices. Hence, the proposed technical system is equipment (implement) since its main flow is material (soil). The main function of the equipment is to make ridges for row cropping as stated above. The subfunctions of the system are to;

i. make bunds for irrigation purposes, ii. make

terraces to check erosion,

The subsidiary flow of the technical system will be energy (i.e. powered by draught power from internal combustion engine-Tractor).

3.5 Factors Considered in the Development of the Ridger

Factors affecting equipment and machinery design may be summarised under the following aspects: need; technical and economic requirements; manufacturing techniques, skills and materials; ergonomic considerations; economic and technical acceptability.

a Need

Functional analysis of need was conducted using modern value analysis methodologies before and during the development of the disc ridger. The results of the functional analysis basically informed the choice of design model adopted in this study.

b Technical and Economic Requirements

The disc ridger was designed to accommodate ridge spacing varying from 60cm for crops such as Soya bean up to 100cm for root and tuber as practised in Ghana. This includes ridge spacing for other crops such as maize which fall within this range. The dimensions were also determined to permit re-ridging and weeding under crops up to knee height. Adjustments were incorporated to allow varying of the disc angles to regulate draught and penetration subject to local conditions. It was also designed as a double-row disc ridger to accomplish two ridges/bonds in one pass so as to increase field capacity and reduce operating cost.

c Manufacturing Techniques, Skills and Materials

Designs requiring machining processes were generally avoided to make the technology accessible to rural artisans and manufacturers. No alloy steels were used, but mild steel, which is locally available. The number of steel sections and types of bolts used was kept to a minimum to make sourcing of materials and replacement of parts as easy as possible.

d Economic and Technical Acceptability

Designs and technologies associated with high tooling costs, particularly machining, were avoided to keep the cost of production down and to make the manufacture of the disc ridger possible by rural artisan/manufacturers. Two standard ball bearings are incorporated in each disc hub. Bolt sizes chosen were generally the same as those used on the fully-mounted disc plough to avoid the acquisition of extra spanners. The ridger was designed to have minimum possible deviations from the farmer's traditional implements and does not require further training to operate.

3.6 Functional Analysis

To adequately analyse the design process, the functional analysis design method was used. As mentioned in the literature, functional analysis was used to define the needs the product must answer and help express the specifications (Zehtaban & Roller, 2012). Figure 3.3 presents the different phases that were used in functional analyses.

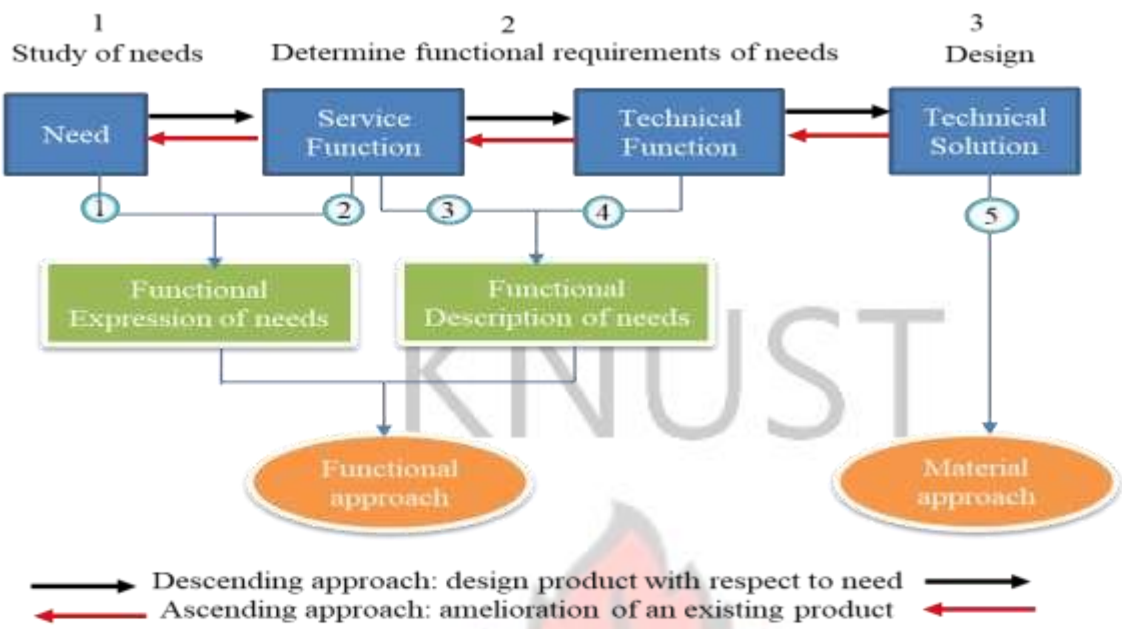


Figure 3.3: Different phases of functional analyses

Some terms used in this method were defined by Abonde & Jiokap (2017) as follows:

- Function: the effect produced by a product or by one of its elements, to satisfy needs.
- Service function: a service function is the awaiting function of a product or the function realized by the product in response to the need of a given user.
- Technical function: an internal action of the product defined by the designer within the framework of a solution to assure the service function.
- Need: something that is necessary or desired by the customer

The different considerations concerning functions of the ridger were obtained by applying the tools of the functional analysis such as the Horned Beast Diagram, Octopus Diagram and Functional Analysis System Technique (FAST) Diagram. The horned beast diagram permitted questioning the problem about the product itself, the market, the context of the project and its objectives. The diagram of interactors also called octopus diagram represented the service functions (Abonde & Jiokap, 2017). The FAST technique aided in thinking about the problem objectively and identifying the project's scope by showing logical relationships between functions. The organization of functions into a function-logic FAST diagram enabled the designer to identify all required functions as shown in the literature review section of this write up (Figure 2.4). It was also used to verify if and illustrate how the proposed solution will achieve the needs of the project. It identified unnecessary, duplicated or missing functions (Bartolomei & Miller, 2001).

3.7 Geometric Modelling of the disc ridger

The various components of the disc ridger were geometrically modelled using standard dimensions and material properties available in literature. The optimal dimensions and material selection were determined after modelling and design simulations which took into consideration the material properties. The modelling was done using SOLIDWORKS 3D modelling software (SOLIDWORKS©2019). The modelling process involved creating a rough two-dimensional sketch of the basic shape of the design, applying/modifying geometric relations and dimensions to the two-dimensional sketch, extruding, revolving, or sweeping the parametric two-dimensional sketch to create the base solid feature of the design, adding additional parametric features by identifying feature relations to complete the design, performing analyses on the computer model and refining the design as needed and finally creating the desired drawing views to document the design.

3.8 Draught force prediction model for disc implements

Knowledge of the horizontal, vertical and lateral components of the passive force that a tillage implement is likely to encounter under field conditions was necessary during the design process to determine the strength of the material for construction. The draught force prediction model developed by Godwin *et al*. (1987) and cited by Godwin *et al*., (2007) available in literature was used to predict the passive force acting on disc implements. The value of the predicted force was applied as the force required during the simulation stage of the design. The results of SOLIDWORKS simulation based on that predicted load then informed the basis for materials (quality and size) selected for the construction of the ridger.

The passive soil reaction force (P) on a disc was calculated as follows, adopting work by Alam (1989). The disc was assumed to translate horizontally at a disc angle as well as an inclination angle.

$$\text{Passive force (P)} = [\Upsilon_i Z^2 K_y + CZK_c + (R - Z)\Upsilon f Z K_q \sin\phi] \times 2(RZ - Z^2)^{0.5}\sin\phi$$

[Equation 3.1]

$$\text{Projected width of cut (W)} = \frac{2\cos\beta}{\cos a}\sqrt{Z\,(D\cos a - Z)}$$ [Equation 3.2]

Where:

DISC PROPERTIES:

R = Disc sphere radius Z

= Depth of cut β

= Disc angle

α = Disc inclination or tilt angle

K = Dimensionless factors

SOIL PROPERTIES:

ϒ = Bulk unit weight:

c = Cohesion: q =

Surcharge:

ϕ = Angle of internal friction:

δ = Angle of soil-metal friction:

3.9 Design Simulation of Double Row Disc Ridger

Solidworks simulation comes in different versions such as Solidworks simulation standard, professional, premium, flow simulation, and sustainability. However, the research made use of the Solidworks simulation professional because of its ability to run stress analysis on static and motion designs. This advanced simulation technique was employed to optimize performance while designing to cut down on costly prototypes, eliminate rework and delays, and save time and development costs. With the intuitive and powerful applications found in the SOLIDWORKS Simulation suite, different physical situations were applied to the 3D CAD model of the ridger frame to gain insight about its mechanical resistance or stress distribution across the beam (Chang, 2019).

3.10 Material Selection and Cost Estimation

3.10.1 Material Selection

Strength, durability, and services of a farm implement largely depend upon the quality of material used. Selection of proper material for the application was of critical value. Proper treatment of the selected material affects the initial cost and running cost as well as the durability and performance of the machine. Implement parts/components should be designed to utilize the lowest cost materials which can perform satisfactorily and provide adequate life. Use of high-cost materials and expensive treatments sometimes become unavoidable to make for a deficiency in the original design. The factors considered in the selection of suitable materials in the design of the ridger are:

- Manufacturability
- Static, fatigue, and fracture characteristics

- ❑ Availability
- ❑ Cost
- ❑ Environmental effects

The most economical materials that satisfied both process and mechanical requirements were selected.

3.10.2 Cost Estimation

This was carried out to estimate the total cost of realization and operation of the disc ridger. The cost estimation was divided into the following sections

- ❑ Cost of supplying construction materials
- ❑ Cost of construction
- ❑ Cost of operation and maintenance

3.10.3 Economic and Financial Analysis of the Double-Row Disc Ridger

For calculation of the cost of owning and operating the ridger, a simple annual cost model was used. The useful life of tillage implement was based on the ASABE (2000) standard.

a. Descriptive Facts, Constants, And Prices

i. Average purchase price (excluding VAT), P

ii. The expected life of the item (in hours or kilometres), N iii. Expected average annual usage of the item (in hours or kilometres), n iv. Salvage percentage, S

v. The percentage used to determine the combined licence and insurance cost, LI vi. Percentages used to determine the repair and

maintenance costs, RM vii. Interest percentage, I viii. Fuel and

oil consumption rates, FO ix. Fuel and oil prices, FP

b. Fixed Costs

i. Depreciation cost ii.

Interest cost iii.

Insurance cost iv. Licence

cost (actual Rand value)

v. In some instances, the Insurance and Licence costs are combined

(percentage) vi. Total fixed cost, including

and excluding interest

c. Variable Costs

i. Repair and maintenance costs

ii. Fuel cost iii. Lubricant (oil)

cost

iv. Total variable cost

d. Total Costs

i. Total cost, including interest ii.

Total cost, excluding interest

All the costs originate from the item's life period and the annual usage, the average purchase price of the item, the salvage percentage, and the average investment of the item. The purchase price and the salvage percentage determine the average

investment.

e. The relevant formulae are

i. Salvage value = P x S [Equation 3.3]

ii. Average investment = (P + S) ÷ 2 [Equation 3.4] iii.

Depreciation cost = (P - S) ÷ N [Equation 3.5] iv. Lic. and Insurance cost = [(LI%) x AI] ÷ n [Equation 3.6] v. Interest cost = (I x AI) ÷ n [Equation 3.7] vi. Repair and maintenance costs = (RM x P) ÷ N [Equation 3.8]

vii. The fuel cost will depend on the fuel consumption and the fuel price.

viii. The oil cost will depend on the oil consumption and the oil price. ix. The oil consumption is generally a percentage of the fuel consumption.

Taking interest rate to be 16%, inflation rate of 18%, the useful life of disc ridger in hours as 2500 (5-years) according to ASABE (2000) standard, average number of working hours per year as 500, cost of hiring per hour of 48.2 US$, RM as 2.5% of capital cost, the ridging cost per hectare was calculated. The annual net income was computed based on the number of hectares ridged per year and the unit cost of one hectare. Breakeven analysis was performed on the ridger.

3.11 Construction of the Implement

The implement was constructed at the Agricultural and Biosystems Engineering Workshop of KNUST in Ghana. Work on the construction began on the 14th of

January 2019 and was completed on 15th February 2019. Figure 3.5 presents the manufacturing processes that led to the construction of the ridger.

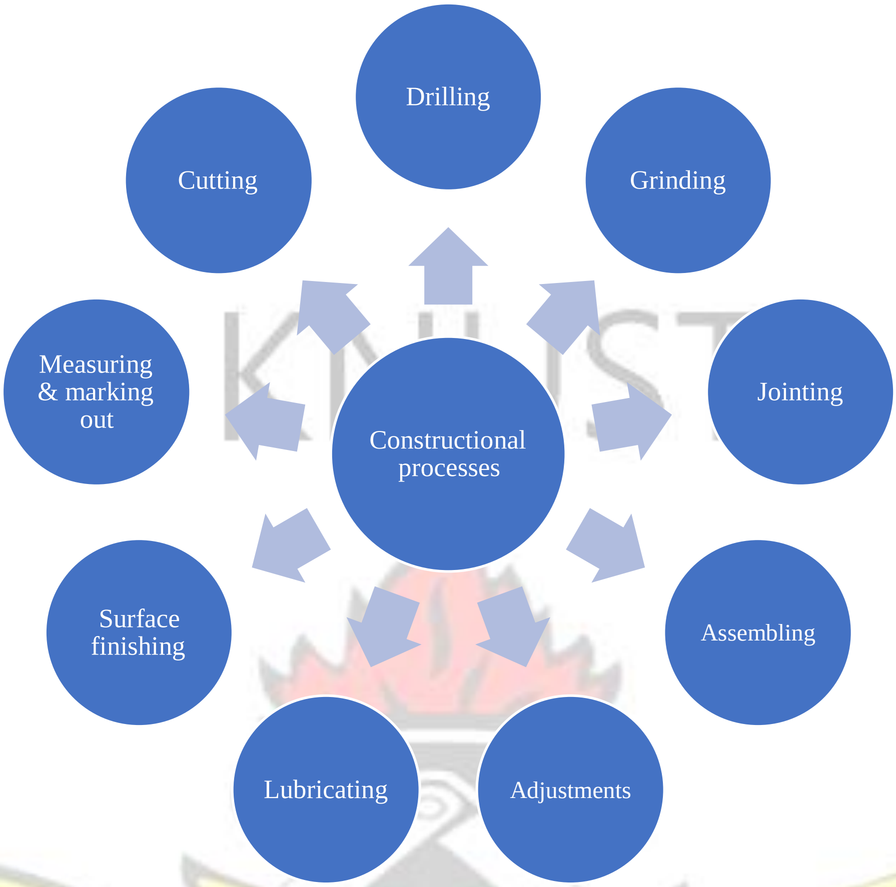


Figure 3.4: Flowchart of the manufacturing processes

The disc ridger was built in five stages. The first was the construction of the support frame to carry the soil working members, the second was the hitching system to allow the implement to be hitched to the tractor for easy transport and operation, the third was the shanks/standard which connects the ridger bottom to the frame and fourth was the hub and discs assembly. The hub and discs assembly are subassembly which consists of the discs, flanges, hubs, bearings (these parts were outsourced from implement dealers) and hub-wear protectors. The final part of the construction was assembling the components together to form the two-row disc ridger.

3.11.1 Support Frame

The support frame was constructed by using 100 x 100 x 6 mm tubular pipe made of mild steel. It was first marked into five parts of lengths presented in Table 3.2.

Table 3.2: Dimensions of parts used to construct the mainframe

Sno.	Part	Unit	Dimension (mm)
1	Main bar	1	3500
2	Lead/front bar	1	2000
3	End/back bar	1	1300
4	Connecting/link bar	4	600

A full length of square pipe was cut into the seven pieces listed above. Three holes of 30 mm diameter (each) were drilled along both ends of the main bar 1090 mm from the centre of the 3500 mm bar. These holes were spaced 210 mm apart to allow for working width adjustment. Two holes of the same diameter were drilled 310 mm from the centre main bar, one each on the front and back bars of the frame to enable connection of the shanks to the frame. The parts were assembled and welded together to form the mainframe of the ridger as shown in Figure 3.5. The frame was re-enforced using a 6 mm mild steel plate split 100 x 180 mm (12 pieces) and bend at 90 degrees angles. The angular plates were attached to all 12 corners of the mainframe through a permanent jointing technique (welding). The square holes left at the ends of the frame assembly were covered by welding 100 x 100 x 4 mm mild steel plates welded to each hole. The welded parts of the frame were neatly dressed using a power grinding machine.

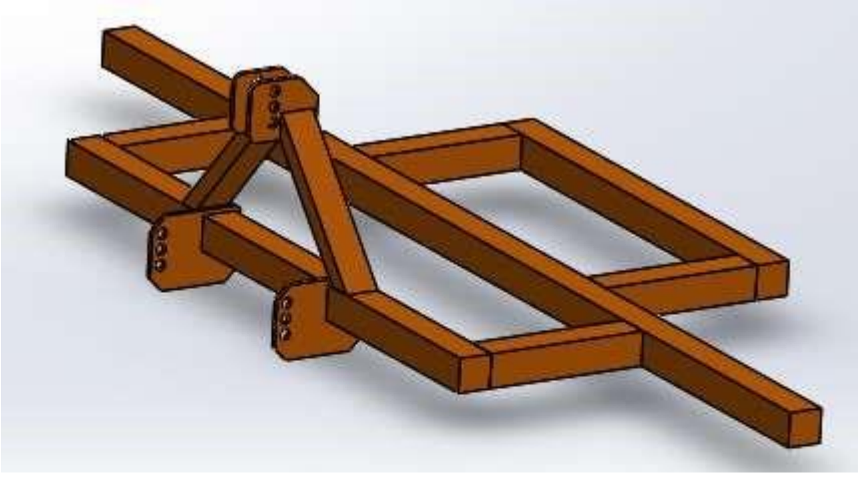
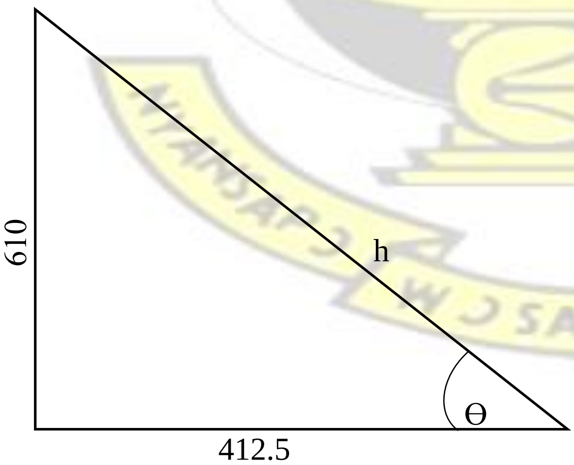


Figure 3.5: 3D view of the support frame

3.11.2 Three-point linkage hitch system

A category 2 hitch system (82 mm wide and 610 mm high) was constructed considering the power available on most farms to pull the implement. The length of the triangle was determined using trigonometrical calculations as shown in Figure 3.6. Detailed dimensions of the three-point hitch system is given in Figure 3.7.



Note:

SOH; Sin θ = Opposite/Hypotenuse

CAH; Cos θ = Adjacent/Hypotenuse

TOA; Tan θ = Opposite/ Adjacent

The angle θ is calculate as follows;

$\tan\theta = \frac{Opposit}{Adjacent} \Rightarrow \tan\theta = \frac{610}{412.5}$

$\theta = tan^{-}(1.478) = \underline{56^{0}}$

Therefore;

$\cos\theta = \frac{Adjacent}{Adjacent} \Rightarrow \cos 56 = \frac{412.5}{h}$

$h = Cos^{-}(56)$ x 412.5 = $\underline{737.67\text{mm}}$

Figure 3.6: Trigonometrical calculation for the three-point linkage

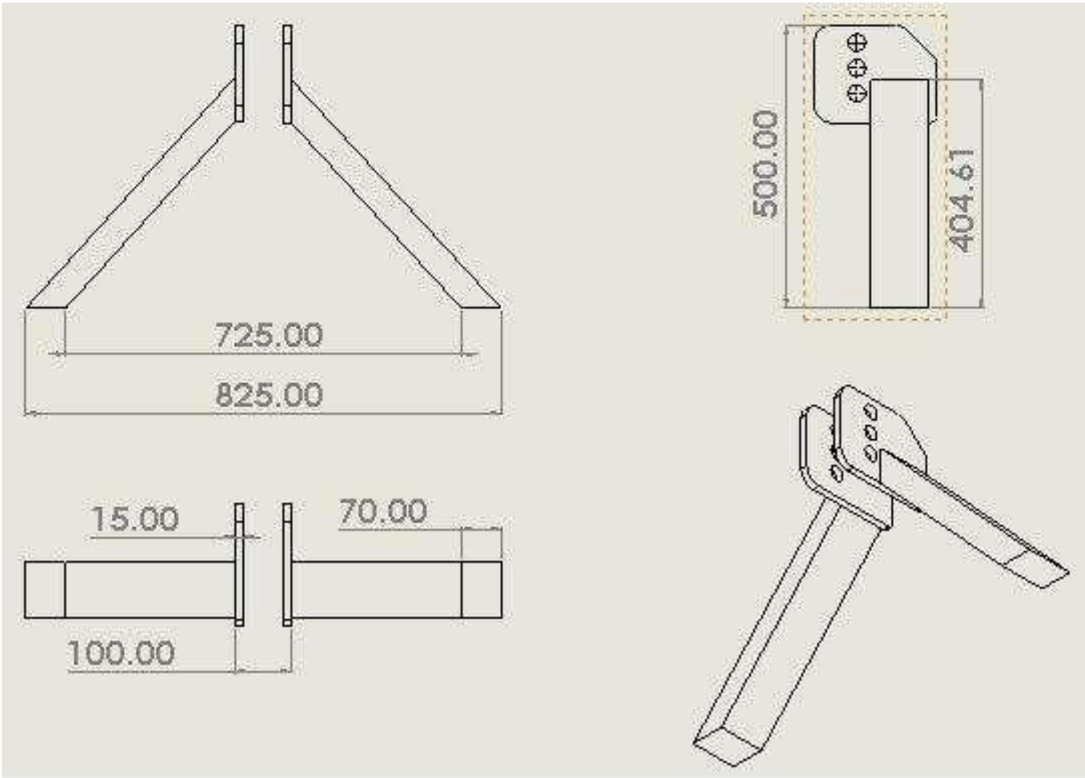


Figure 3.7: Orthographic view of three-point linkage

One full length of 100 x 50 x 6 mm mild steel hollow pipe and pieces of 16 mm mild steel plates were used to construct the 3-point linkage hitch system. Two pieces of the 50 x 100 mm pipe were cut to the length calculated above and welded to form a triangle with the front side of the mainframe. Six pieces of 16 mm plate were cut to form 100 x 175 mm right angle and chamfered at the ends. These plates were welded in two pairs, spaced at 100 mm attached to the ends of the triangle to form the three-point linkage system, providing one top and two lower link hitch points. The front bar of the mainframe completed the triangle of the linkage. A stay of wedge 270 x 200 mm was cut out of the 50 x 100 mm pipe and welded to connect the top-link hitch point to the main bar for the stability of the hitch system. Three holes of diameter 30 mm were drilled on each plate to accommodate hitch pins. The mainframe of the ridger was then completed as shown in Figure 3.5.

3.11.3 Shanks

The shanks (four pieces) were constructed with a 100 × 40 mm mild steel bar, chamfered at the bottom end with a chamfer distance of 170 mm as shown in Figure 3.8. Triangular plates (Four pieces) of 300 × 240 mm were cut out of 16 mm mild steel plate and placed on top of each shank with holes drilled through them to enable connection to the mainframe and adjustment of the disc angles. Figure 3.8 presents the 3D view of the shank.

Figure 3.8: 3D Views of Shank

3.11.4 Ridger Bottom Sub-assembly

The bottom sub-assembly consists of the shank, disc, hub (flange, bearing, bearing cup, seal, and grease) and hub-wear protectors. One of the principles that governed the design process was simplicity. The Design had minimum deviations as possible from farmers' traditional tillage implements and components were made compatible with parts of traditional implements. In other words, modifications were made only where necessary. For purposes of replacement, the disc, hub and bearing design were made compatible with other disc implements, and therefore these parts were outsourced from "Same" plough dealer. Also, these parts were outsourced for economic reasons since it was cheaper to buy than produce. The diameter of the hub was measured, and semicircular wear protectors cut (200 mm length, 90 mm wide and 16 mm thickness), rolled and welded to the base of the hubs to prevent wear, due to inevitably deep working depths during operation on undulated fields. The various components of the subassembly were joint together by bolts and nuts. Figure 3.9 gives exploded view of the sub-assembly while Figure 3.10 presents a 3D view of the assembled bottom. Part list of the ridger bottom sub-assembly is given in Table 3.3.

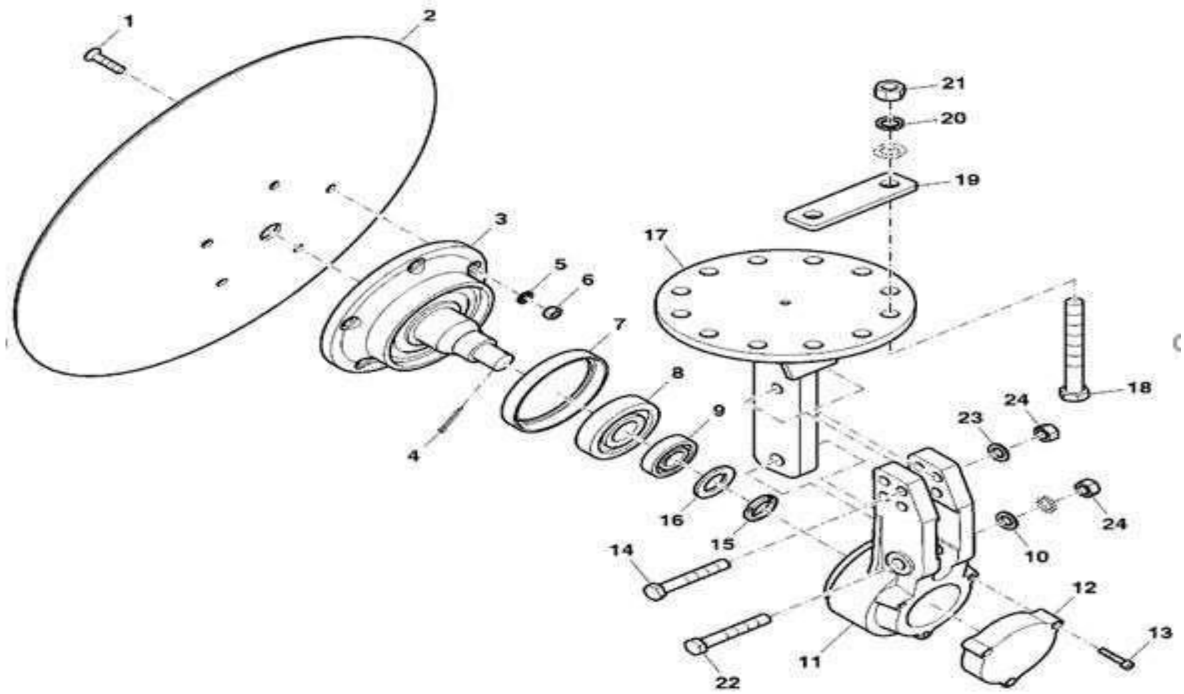


Figure 3.9: Exploded view of ridger bottom

Table 3.3: Parts identification list of ridger bottom

SNO.	Part	SNO.	Part
1	Bolt	13	Bolt for hub cover
2	Concave disc	14	Hub-shank connecting bolt

3	Flange	15	Castellated nut
4	Lock pin	16	Washer
5	Washer	17	Disc angle adjustment plate
6	Nut	18	Bolt
7	Bearing case	19	Brace
8	Big end bearing	20	washer
9	Small end bearing	21	Nut
10	Washer	22	Bolt
11	Hub case	23	washer
12	Hub cover	24	Nut

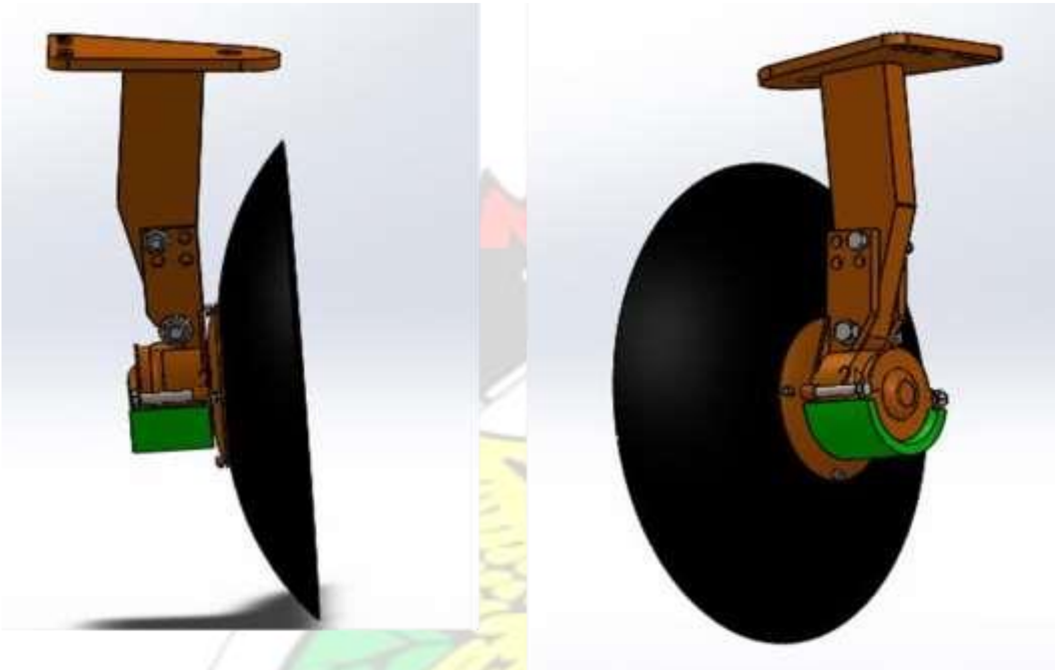


Figure 3.10: 3D views of the ridger bottom sub-assembly

3.11.5 Ridger assembly

The four sets of bottoms were assembled to the mainframe (using bolts and nuts) to form the complete implement as shown in Figure 3.11.

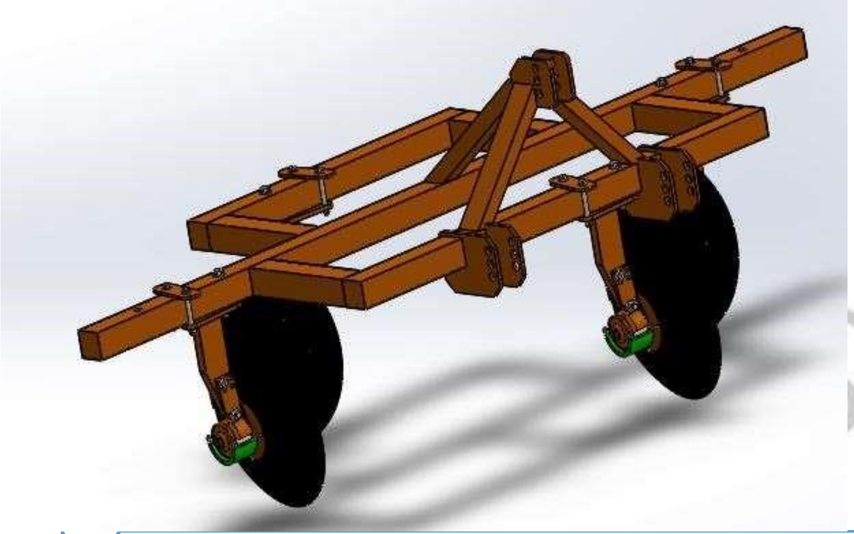


Figure 3.11: 3D view of complete 2-row ridger assembly

3.12.1 HAZOP Study

Hazard and operability study was conducted on the ridger using the procedure in Figure 3.12

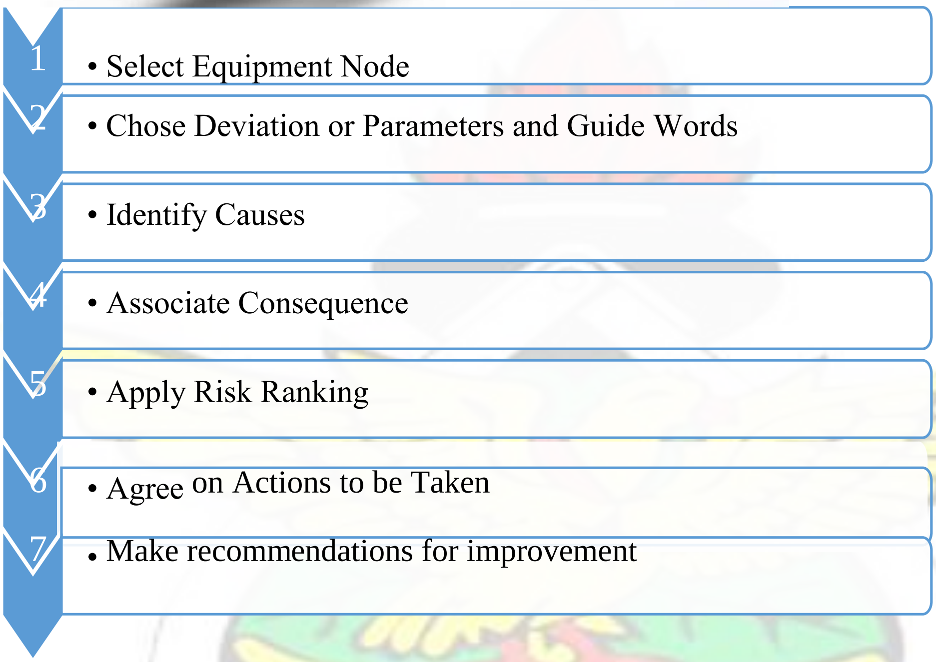


Figure 3.12: Simplified sequence of Hazard and Operability study adopted from Poulose & Madhu (2012)

Section Two

3.12.2 Materials/Equipment

Soil samples from the location were taken from depth (0 -30) cm by an auger. The soil at the experimental site was generally clay-loam. Other materials used include: i

Measuring tape: An iron 50-meter measuring tape was used for measuring dimensions and distances, to calculate areas and speeds.

ii Steel poles: Used for marking the distances during the experiment. iii Stopwatch: Used to determine the tractor speed and recording time.

iv Measuring cylinder: One-litter capacity graduated cylinder was used to refill the auxiliary tank for determination of fuel consumption. v Fuel jerry can: It was used for transporting fuel to the field.

vi Steel pipe with hooks at both sides: Used for pulling the tested tractor by the auxiliary one.

vii Dynamometer: Dynamometer with 3000kg was used for direct draft measurement.

viii Notes Recording the data and drawing the map of work.

3.12.2 Equipment

Two tractors were employed to carry out the evaluation of the implement. The tractors used for the experiment were VALTRA (shown in Plate 3.1) and New Holland, both with 50 kW engine power rating. The specifications of the tractors are shown in Table 3.6.

Table 3.4: Specification of Tractors

Specification	Tractor (1)	Tractor (2)
Model	Valtra 795	New Holland 290
Make	4WD	4WD
Engine type	Diesel	Diesel
No. of cylinders	4	4
Cooling system	Water-cooled	Water-cooled
Engine power	75hp	75hp

Plate 3.1: Experimental Tractor

3.13 Method for evaluation

3.13.1 Experimental design

The central composite design (CCD, expert 6.0.10) method was used to determine the number of experiments to be evaluated for the optimization of the variables and responses. The design consisted of two factors at three-factor levels each. The measured responses were; implement draught, fuel consumption, tractor wheel slip, depth and width of cut. The two independent variables were set at high, centre, and low levels, chosen as +1, 0, and -1, respectively. This is illustrated in Table 2.5. The design was established and analysed with the help of MATLAB software @ 19. A rotatable experimental matrix consisting of 13 runs was generated by equation 3.9:

$$N = K^2 + 2K + C \qquad \text{[Equation 3.9]}$$

Where;

N = Number of runs

K = Number of factors

C = Centre points or replicates (which can be set between 2 to 6)

The experimental ranges for the two independent variables were adopted from the preliminary experiments conducted on the effects of disc angle and speed on the performance of disc implement (Nkakini, 2015). The choice of speed was also, based on the normal tractor field operational speed range of 0.8 – 4.2 m/s (3 – 15 km/h) according to Mamkagh (2019).

Table 3.5: Experimental Design for Optimization of the Response Factors

Factor	Symbol	Level		
		Low (	Middle (0)	High (+1)
Disc angle	X_1	40	42.5	45
Tractor speed	X_2	1.67 m/s	2.23 m/s	2.5 m/s

The test factors were coded to develop the regression equation in accordance with Equation 3.10

$$X_i = \frac{x_i - x_{io}}{\Delta x_{io}} \quad \text{[Equation 3.10]}$$

Where;

X_i is the coded value of the i^th^ independent variable

x_i the neutral value of the i^th^ independent variable

x_{io} is the neutral value of the i^th^ independent variable at the centre point

Δx_{io} is the step change value.

The mathematical relationship of responses $y_{1 ...5}$ on all two independent variables were fitted to a second-order polynomial regression model:

$$y_{1....5} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1{}^2 + \beta_{22} x_2{}^2 + \beta_{12} x_1 x_2 + \beta_{122} x_1 x_2{}^2 + \beta_{112} x_1{}^2 x_2$$

[Equation 3.11] Where;

$\boldsymbol{y_1}$ = response of draught force

$\boldsymbol{y_2}$ = fuel consumption

$\boldsymbol{y_3}$ = wheel-slip

$\boldsymbol{y_4}$ = cutting width

y_5 = response of cutting depth.

x_1 *and* x_2 correspond to two independent variables

β_0 represents constant β_1 *and* β_2 are linear coefficients β_{11}*and* β_{22} are quadratic coefficients β_{12}*and* β_{21} are cross product coefficients.

P-values were used to determine the significance of each coefficient in the quadratic equation.

3.13.2 Experimental area preparation

An area of 5775 m^2 (165 × 35 m) equivalent to 0.58 hectares of land was used for this field evaluation. The site was first cleared (of top-growth), ploughed and harrowed before ridging experiment began.

3.14 Measurements

3.14.1 Implement Draught Measurement

Implement draught was determined for each run of ridging using the 10-tonne RON 2125 Dynamometer (Plate 3.2). The instrument is equipped with a datalogger which stores the force (kN) required to pull each implement making it possible to download stored data onto the computer for analysis using popular spreadsheet programs. The instrument was linked to a towing bar placed between two tractors. The instrumented tractor had the implement hitched to it and is set to a neutral gear and pulled by another tractor. Load and no-load draught forces were obtained for runs in working and transport positions respectively.

Plate 3.2: RON 2125 Dynamometer

Plate 3.3 shows the implement draught measurement procedure with one tractor pulling the other with the ridger hitched to it and the force required for the pulling being logged onto the RON 2125 Dynamometer.

Step-by-step procedure for measuring implement-draught

1. A RON 2125 type dynamometer was linked to the front of the tested tractor to which the implement was linked.
2. An auxiliary tractor was linked to the tested one through the dynamometer with a steel chain.
3. The draught force (kN) was recorded for a measured distance of 165 m at No-load.
4. Then the implement was put in tillage position (loaded) and the rear tractor was pulled to record the draught force.
5. The difference between the two readings gives the value of the draught required to pull the implement.

6. The draught force (kN) was calculated using equation 3.12:

$$P = P_2 - P_1 \qquad \text{[Equation 3.12]}$$

Where;

P = draught force

P_1 = the force required to pull the implement in transportation position

P_2 = the force required to pull the implement during tillage operation.

Specific draught (N/m^2) to pull the implement is the Actual draught/Area ploughed. Mathematically expressed by Equation 3.13:

$$\text{Specific draught (n)} = \frac{P}{A} \qquad \text{[Equation 3.13]}$$

Where;

P = Actual Draught (N)

A = Area ploughed (m^2)

In other words, the average drawbar-pull (Draught to pull the implement) is the difference between the towing force, while in neutral gear without implement in tillage operation and the towing force while the implement is in tillage operation respectively.

Plate 3.3: Tractors–dynamometer, implement mounted in tillage operation.

3.14.2 Measurement of Depth of Cut and Width

These parameters were determined by setting the level that controls the lifting mechanism at a level corresponding to the required depth of cut and driven at a predetermined speed (1.67 – 2.23 m/s). The depths of cut (height of ridge) were measured with a steel tape, from the bottom of the furrow to the surface level of the soil at randomly selected points.

3.14.3 Measuring of rear-wheel Slippage

The rear-wheel slippage was determined as follows:

1. The un-worked flat area was chosen to represent normal working conditions.
2. The rear wheel was marked by a piece of chalk at position tangent to the ground surface.

3. A distance covered by five revolutions of the wheel when the tractor was unloaded was measured.

4. Another distance covered by the same number of revolutions was measured when the tractor was loaded with the implement.

5. The wheel slippage was calculated as follows:

a $$\text{Wheel} - \text{slippage}\ (\%) = \frac{UnloadedAdvance\ (m) - LoadedAdvance\ (m)}{UnloadedAdvance\ (m)} \times 100$$

[Equation 3.14]

b $$\text{Slippage}\ (\%) = \frac{Revolutions\ with\ load\ (m) - Revolutions\ without\ load\ (m)}{Revolutions\ with\ load\ (m)} \times 100$$

[Equation 3.15]

3.14.4 Measurement of field capacities and efficiencies

1. A distance of 165m was measured on the plot.
2. Ridging started at the required speed.
3. Using the measuring tape, the width of cut was measured.
4. Time (sec) for each operation was recorded using a stopwatch.
5. Time for turning was also measured for the plot.
6. Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE) were calculated by equation 3.16:

   a. TFC (ha/hr) = $\frac{S \times W}{C}$ [Equation 3.16]

   b. EFC (ha/hr) = TFC × FE or EFC = $\frac{A}{t}$ [Equation 3.17]

   c. FE = $\frac{EFC}{TFC} \times 100$ [Equation 3.18]

Where:

FE = Field Efficiency (%)

S = Average Speed (km/hr)

W = Average Width of Cut

C = Constant (8.83 or 10) (Naim, 2014) t = Average working time (hr) (time includes non-productive time)

A = Area Covered (ha)

3.14.5 Measurement of Fuel Consumption

1. The tractor started working the plot with a full tank capacity.
2. After finishing the operation, the tank was refilled by a measuring cylinder and the amount of the fuel used to refill the tank was recorded, also the time to finish the plot was recorded.
3. The fuel consumption rates were calculated in litre/ha and litre/hr as follows:

a. Consumption rate (l/ha) = $\frac{Reading\ of\ Cylinder\ (ml)}{Area\ of\ Plot\ (Ha)\times 1000}$ [Equation 3.19]

b. Consumption rate (l/hr) = $\frac{Reading\ of\ Cylinder\ (ml)}{Time\ to\ cover\ Plot\ (hr)\times 1000}$ [Equation 3.20]

3.14.6 Determination of Soil Moisture Content

Prior to the field test, soil samples were collected at depth of 0–30 cm 30–50 cm and 50–70 cm with the aid of soil auger at three replications per sample points for determination of soil parameters. Field test samples were randomly selected for the determination of soil moisture content using the oven-dry method (gravimetric). The moisture content of the soil was obtained using equation 1.

Moisture Content (%) = $\frac{Ww - W_D}{W_D} x100$ [Equation 3.21]

Where; W_w = weight of wet soil sample, g, W_D = weight of dry soil sample, g

3.14.7 Measurement of Cone Index

The soil cone index (CI) was measured to ascertain the soil strength profile, using cone penetrometer having an enclosed angle of 30^0, with a base area of 3.23 m^2 (323 mm^2) mounted on a shaft of 0.203 cm (20.27 mm) marked with respect to depths on the shaft.

At three different depths (0–100, 100–150, and 150−200) mm, soil resistance (cone index) to the penetration of implements were obtained before tillage operation. Cone penetrometer testing involves pushing a cone into the soil at a steady rate and recording the resisting force exerted by the soil on the penetrometer. The force recorded by the dial is divided by the base area of the cone to provide a "pressure" measurement, referred to as cone index in KN/m^2 (Kilo Pascal) in SI unit.

3.14.8 Volume of soil disturbed

The volume of soil disturbed was calculated by multiplying the effective field capacity with the depth of cut. E.g. $V = 10000 \times CD$ [Equation 3.22]

Where:

V = Volume of soil disturbed

C = Field Capacity

D = Depth of cut

3.14.9 Heart Rate Measurements

Polar heart rate sensing devices (RS 800 CX) were used to obtain the heart rate for the tractor operators during ridging. The Polar heart rate sensor is an instrument that measures the heartbeat rate during every physical activity. It has a strap that is worn around the chest area and a watch (monitor) with a sensor which reads the heart rate and logs it per pre-determined interval in seconds. Data stored was downloaded later onto a computer for analysis. Figure 3.13 shows the Polar heart rate (RS 800 CX) watch and how the chest strap (with heartbeat sensor) should be worn before an activity. Before and after any field activity, the person is allowed some time, say ten (10) minutes period of rest so that heart rate could be stabilized and are referred to as the rest and recovery periods, respectively. The period between the rest and recovery is the work period. This instrument can also calculate how much calories are burnt during any physical activity. This gives an idea of the amount of energy used or the drudgery involved in carrying out any physical work. Heart rate recordings were obtained for tractor operators before, during and after ridging with the implement.

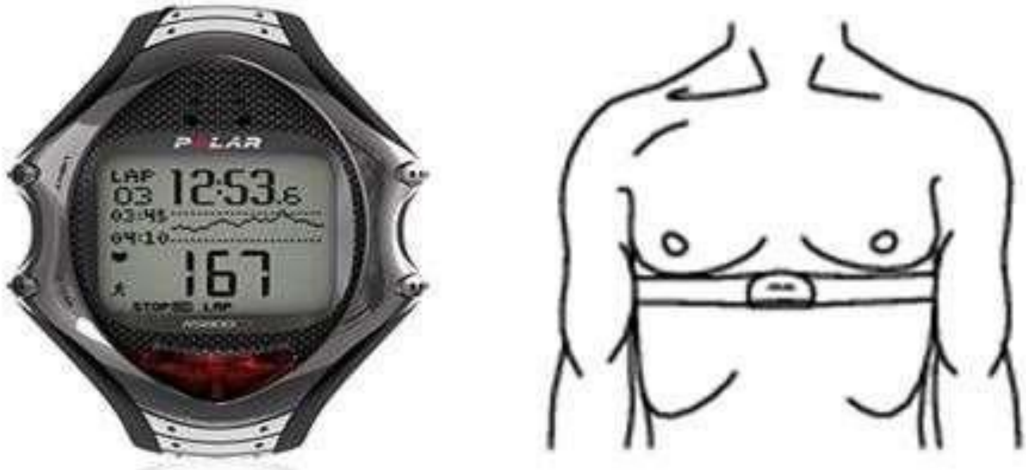


Figure 3.13: The Polar (RS 800 CX) watch and chest strap as worn by a person

Knowledge of how much energy is used for carrying out physical work is useful in determining the rest period (min/hr) required by a person after work using Equation 3.23.

Tr = $60\left(1 - \frac{250}{P}\right)$ [Equation 3.23] Where;

Tr = Total rest period (min/hr)

P = Gross energy consumption (Watts)

Using the mean heart rate obtained for a field activity to trace for a corresponding energy consumption value on the Heart rate - Energy conversion chart, the Gross energy consumption (Watts) was determined.

3.15 Data Analysis

The data recorded in the experiment were subjected to analysis of variance (ANOVA) using MATLAB statistical software (Version 2019). Least significant differences (LSD) were calculated from standard errors of the difference of the means. Statistical significance was set at $p<0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The object of this project was to develop and test a fully-mounted double-row disc ridger for root and tuber production. As presented in the materials and methods, this chapter is presented in two sections. The first section consists of results and discussion on functional analysis, design modelling, simulation and construction of the ridger. Evaluation results and performance modelling are presented and discussed in the second section. Moisture content and penetration resistance of the soil were established prior to the evaluation which results are also presented in this chapter.

Section One: Design Modelling, Simulation and Construction

4.2 Functional Analyses of Need

Figure 4.1 presents a horned beast diagram that clarified the fundamental requirement that justified the design of the double row disc ridger. The diagram is a design project management tool that uses the head of an animal with horns and a protruded tong to illustrate the need to which the system answered. The head of the animal represented the designed product, the two horns answered the design questions ‘who is the beneficiary of the product?’, and ‘what interactors are concerned?’ and the tongue defined what the goal of the product was (Michalakoudis *et al*., 2017b). As indicated in the diagram, the goal of the ridger was to form ridges on arable soil for mechanization of root and tuber cultivation.

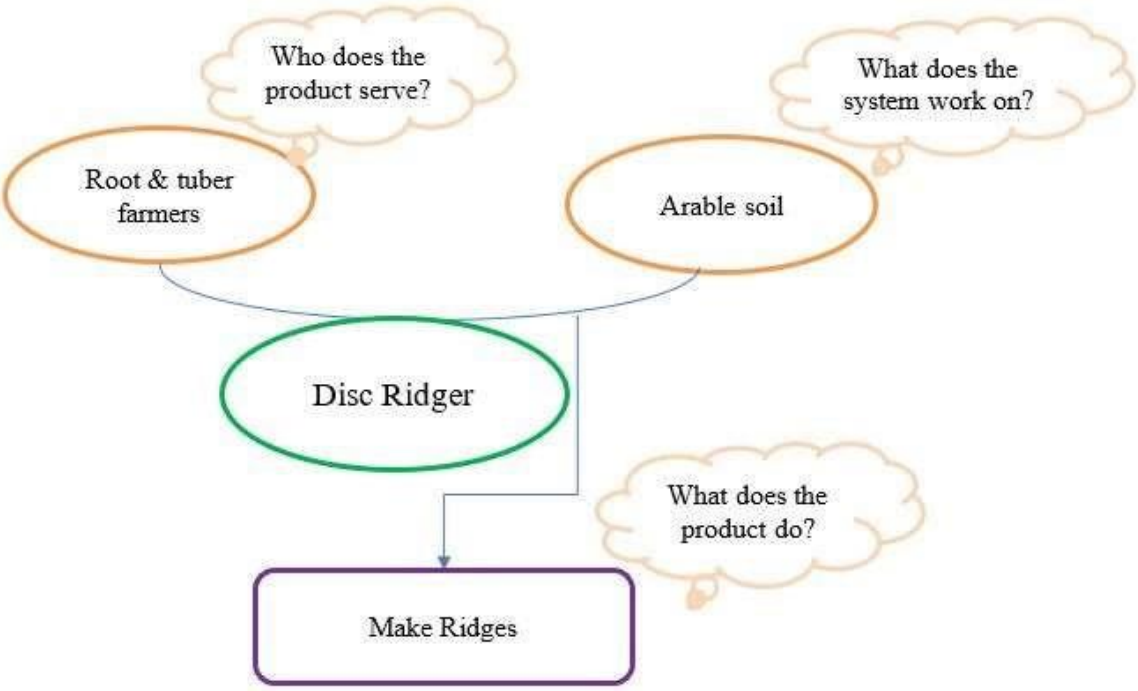


Figure 4.1: Horn beast diagram showing functional analysis of the need

4.2.1 Identification of Functions (Octopus Diagram)

Figure 4.2 presents an Octopus diagram which comprises the designed product and the different components of its external medium as earlier mentioned above in materials and methods. Unlike the horned beast diagram which defines the need, the octopus diagram defines the functions that satisfy the need. The functions are broken into principal and constraint functions as showed in Table 4.1. The designed product is in the centre of the diagram, and the external elements (EE) of the environment are positioned around. While the interaction or principal function links to external elements through the product, a constraint or adaptation function links directly an external element to the product (Useful Engineeing, 2018). The functions involved in the octopus diagram in Figure 4.2 are enumerated in Table 4.1 below.

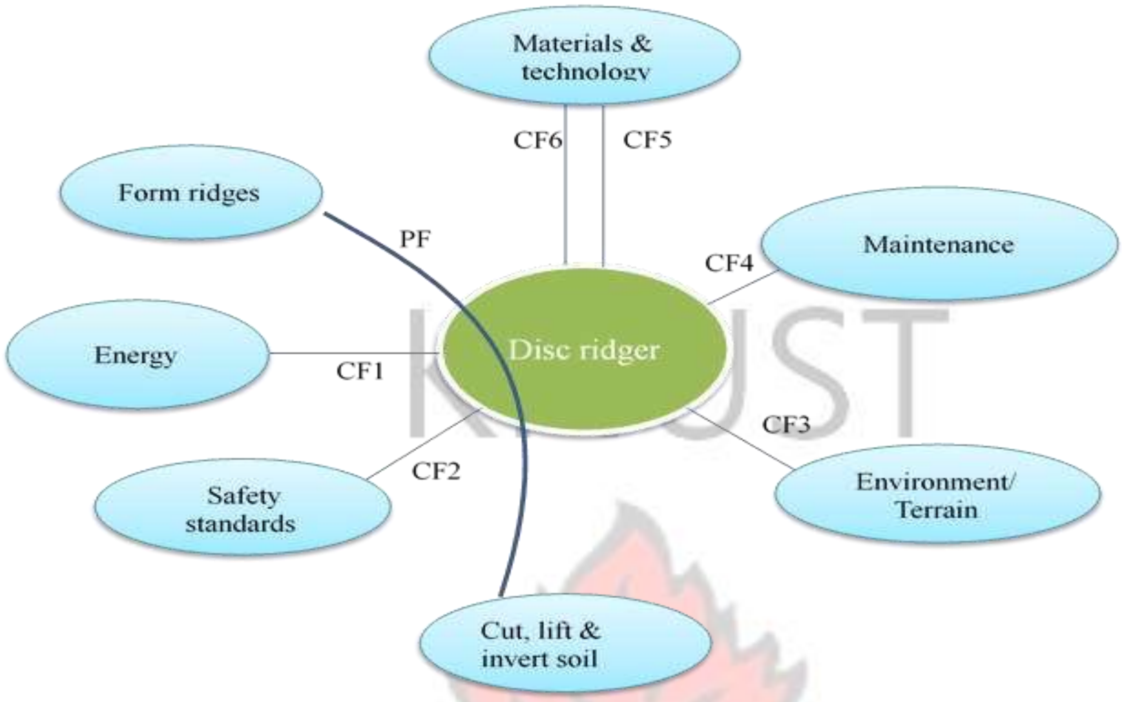


Figure 4.2: Octopus diagram showing the relationship between system and external medium

Table 4.1: The principal and constraint functions together with their descriptions

Principal Function (PF)	
PF	Make bonds/ridges
Constraint Functions (CF)	
CF1	Use draught power from tractor
CF2	Design should respect safety standards
CF3	Design should respect quality standards and minimize losses from accidents
CF4	Strong enough to work in difficult soil conditions
CF5	Maintenance should be simple and easy to carryout
CF6	Easily constructed with local material and technology
CF7	Materials for construction should be of good quality, locally available and cost-effective

4.2.2 Functional Analyses System Technique (FAST Diagram)

A FAST diagram in Figure 4.3 presents the technological solutions that permit the satisfaction of the principal and constraint functions. The diagram is a graphical representation of the logical relationships between the functions of the ridger. It illustrates how functions are expanded in “How” and “Why” directions as shown by the

blue arrowheads.

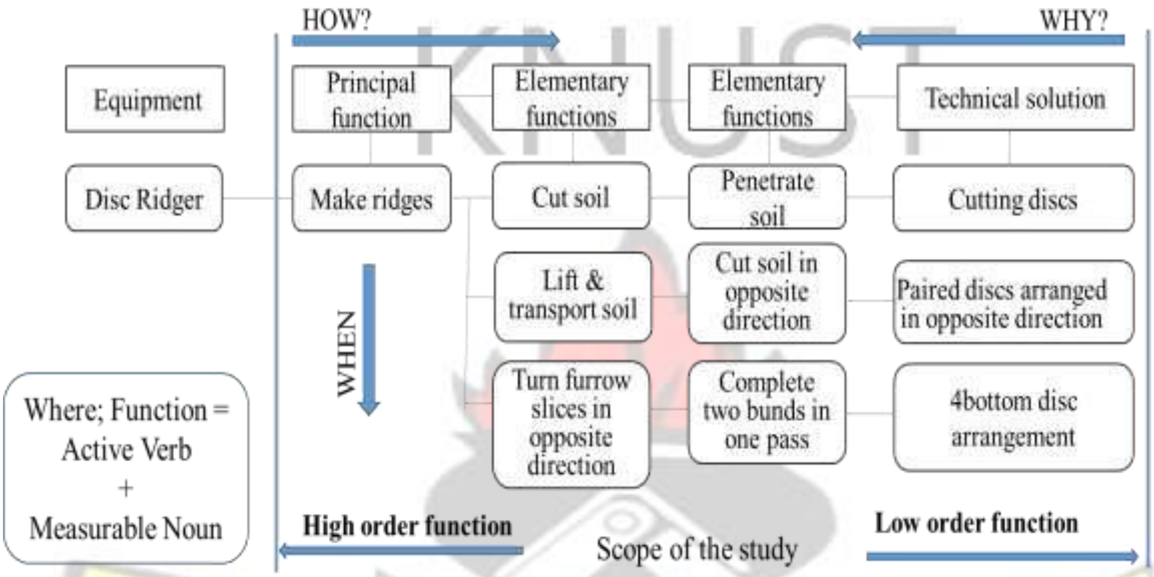


Figure 4.3: FAST diagram showing functions and their corresponding technical solutions

Table 4.2: Design Specification Document for the ridger

Sn.	Service Function	Characteristics		Constraints
		Parameter	Specification	
1	Pull ridger through the soil	Power required (HP)	75-110	Use drawbar power from a tractor
2	Hold ridger assembly & allow mounting/dismounting	Frame & 3point linkage construction	Heavy-duty box Frame 100×100×6mm	Operate in tough conditions without structural defects.
3	Penetrate, Cut, lift, transport & invert soil to form bunds	Type & Size of cutting discs	Plain Concave Disc 660×6mm	Rollover obstacles, ensure smooth operation & impose less draught.
		Weight	435kg (Approx.)	Penetrate soil by its own weight
4		Type of Hubs & bearings	High quality (SAE 52100)	Ensure smooth operation & minimal load on a tractor
5	Vary working width & depth	Disc angle	40, 43, 45deg.	Should be easily adjustable
		Spacing between disc	0.5, 0.7, 1m	

		Tilt angle	15, 20 & 25deg.	

Table 4.3: Technical Specification of the Ridger

S.N.	**Parameter**	**Specification**
1	Type of ridger	Double row disc ridger
2	Frame construction	Square tubular rigid frame
3	3-point linkage construction	610 x 825mmTriangular frame
4	3-point linkage materials	100 x 50mm mild steel tubular bar
5	Frame materials	100 x 100 x 6mm mild steel frame;
6	Number of bottom/discs	4
7	Size of disc	660 x 4mm
8	Type of disc	Plain circular concave revolving disc
9	Number of bearing hubs	4
10	Type of bearing	Ball-bearing
11	Bearing size outer	60 x 130mm (6312)
12	Bearing size inner	45 x 85mm (62092)
13	Disc angle	Adjustable
14	Tilt angle	Adjustable
15	Size of shanks	40 x 20mm solid rectangular bar
16	Number of shanks	4
17	Maximum width of cut	3500mm
18	Working depth	330mm

4.3 CAD Modelling

Figure 4.4 presents the orthographic views of the ridger obtained with the Solidworks (Professional @ 19) drawing software. These include the plan, front and end elevations, respectively. Figure 4.5 gives a well-labelled assembled view of the ridger and Table 4.4 shows the part list of the ridger.

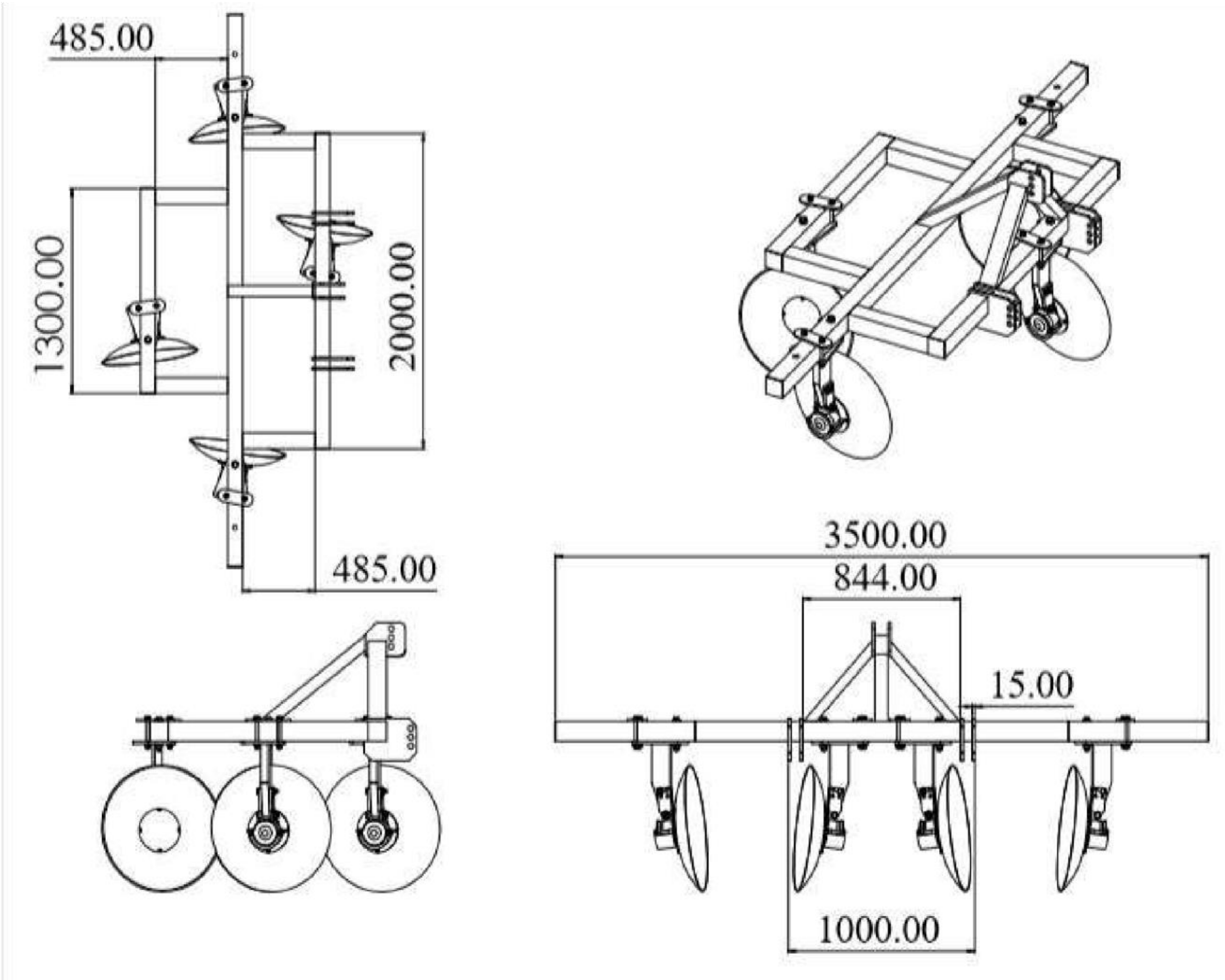


Figure 4.4: Orthographic view of disc ridger

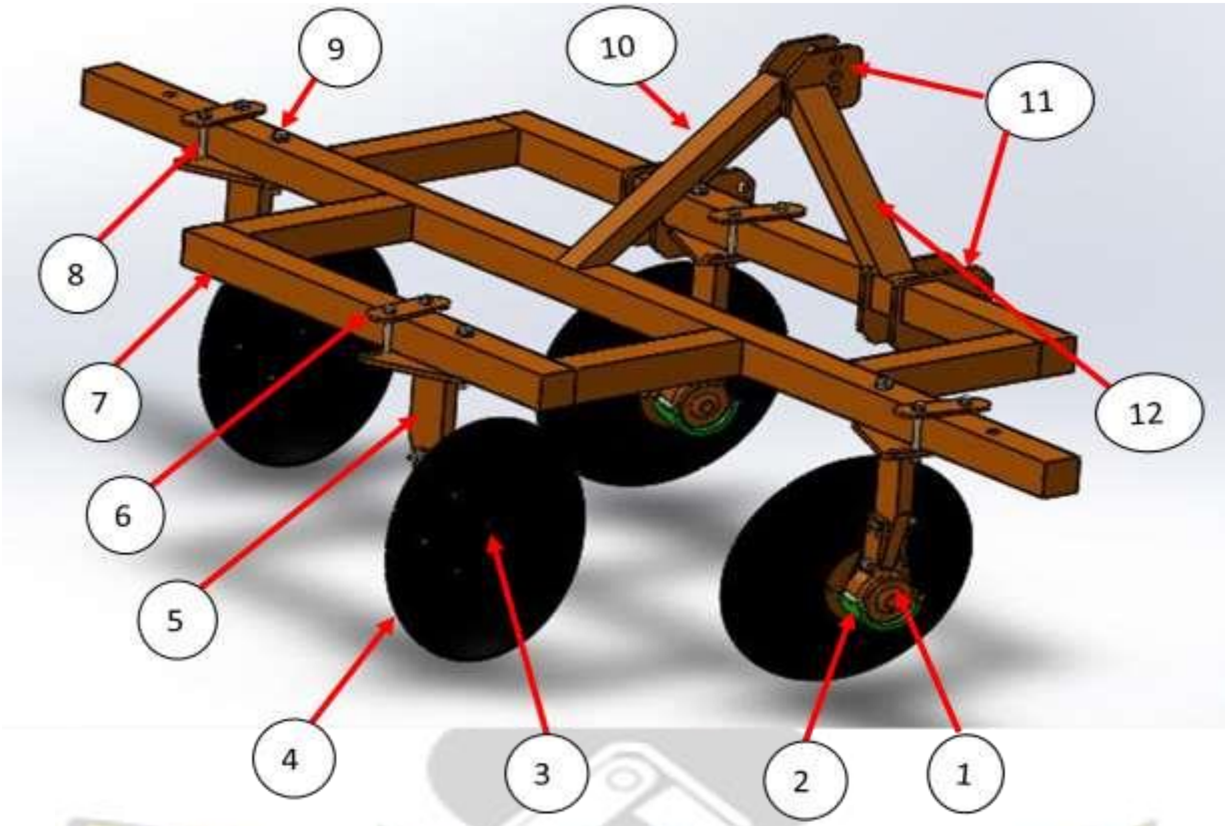


Figure 4.5: 3D Labeled Assembled View of 2-Row Disc Ridger

Table 4.4: 3D Labeled Assembled View of 2-Row Disc Ridger

ITEM NO.	PART NAME	MATERIAL	QTY
1	Hub & bearing	Chrome Steel	4
2	Hub wear protector	Mild steel	4
3	Disc bolt	Carbon steel	16
4	Concave disc	Boron steel	4
5	Shank	Mild steel	4
6	Bracket	Mild steel	4
7	Mainframe	Mild steel	1
8	Shank bolt	Carbon steel	8
9	Central bolt	Carbon steel	4
10	3-point linkage stay	Mild steel	1

11	3-point link plate	Mild steel	6
12	3-point link frame	Mild steel	2

4.4 Design Simulation

The disc ridger in Figure 4.5 consists of the mainframe on which all the parts are mounted, including a hitch system that enables mounting and dismounting of the implement to the tractor for easy transport and operation, and shanks that allow connection of the ridger bottom or soil working members. The ridger bottom consists of the discs, hubs, bearings, flanges and the standards or shanks. Hub-wear protectors were incorporated in the ridger bottom sub-assembly to prevent hub base wear. The final part of the construction was assembling the components together to form the tworow disc ridger. Parts of the hub and disc sub-assembly were procured from implement dealers in the open market to meet heavy-duty primary tillage implement standard. The design simulation was therefore conducted on sub-assemblies of the mainframe and three-point linkage of the ridger to determine materials selected for its fabrication.

Figure 4.6 presents Von Mises stresses obtained from the finite element analysis. The minimum and maximum stresses obtained were 1.867e-02 N/m^2 and 5.141e+06 N/m^2, and the yield strength of the material was 6.204e+08 N/m^2, respectively. This result proved that the prototype design was valid and safe and that the design could withstand the stresses from predicted field conditions. This conclusion was drawn because, the design met the requirement of Von Mises yield criterion which states that, if the Von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension, then the material will yield (Capecchi and Ruta, 2015).

The result obtained in the experimental tests also validated the design of the ridger since the measured draught force of 1.8 – 2.4 kN was lower than the 3.75 kN predicted force that was applied during the design simulation. The method of simulating the performance of the implement by introducing static loads on the mainframe was appropriate because the numerical results were well correlated to those obtained from the experimental tests.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.867e-02 N/m^2 Node: 10190	5.141e+06 N/m^2 Node: 12511

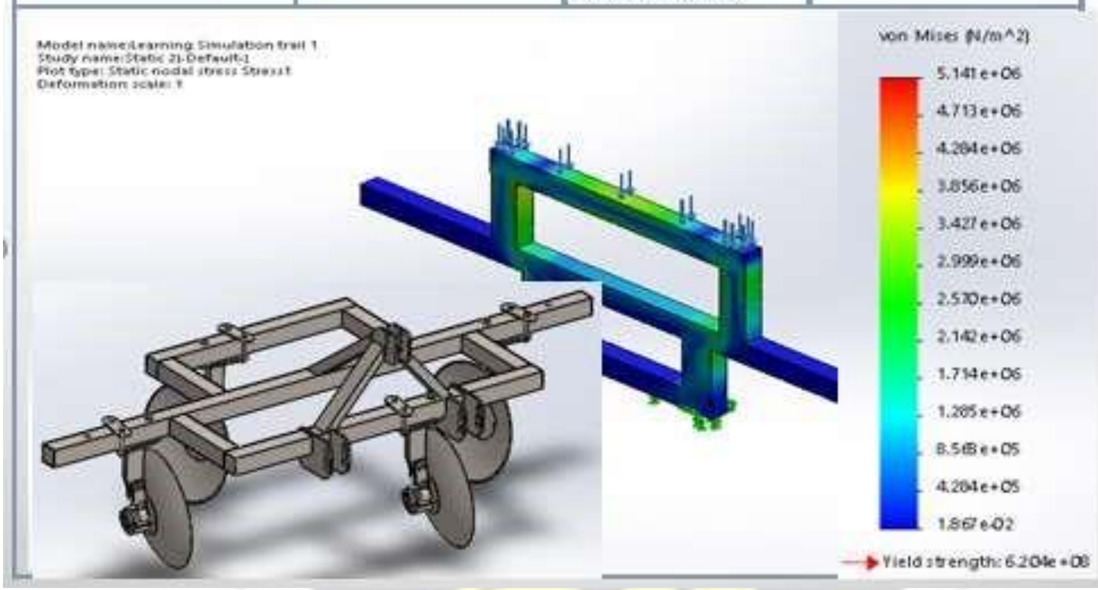


Figure 4.6: Solidworks Simulation Study Results

4.5 Construction of the Disc Ridger

The constructional procedure laid down in Figure 3.4 was followed to realise the implement. Plate 4.1 presents the fully finished view of the fabricated double row disc ridger. Details of construction are shown in appendix 2.

Plate 4.1: The fabricated fully-mounted double row disc ridger ready for testing

4.6 Hazard and Operability Study

Table 4.5 presents the HAZOP manual developed to explain the possible operational hazards that could result from the operation of the disc ridger.

Table 4.5: HAZOP manual for the disc ridger

HAZOP Review of the Double Row Disc Ridger					
Equipment Node 1: Hitching system					
Item	**Deviation**	**Causes**	**Consequences**	**Safeguards**	**Recommendations**
1	Implement dismount during operation	Unsecured hitching of implement	1. Potential to injure nearby personnel 2. Can cause broken hitch links and pins 3. Potential to disrupt operations	Ensure hitch pins are properly secured	Use lynch pins
Equipment Node-2: Hub Assembly					
2	Broken bearings	Irregular lubrication of bearings	1. Disc not cutting soil effectively 2. High draught imposed on a tractor 3. Disrupt operation	1. Lubricate bearings after each field operation 2. Replace chocked and missing grease nipples	Use recommended grease for heavy-duty implements
Equipment Node-3: Disc Assembly					
3	Abrupt removal of disc from its flange	• Loose bolts and nuts • Shared bolts	• Potential to injure nearby personnel • Can disrupt operation • Potential to increase operational cost	1. Fasten loose bolts and nuts 2. Replace broken bolts and nuts	Use quality bolts and nuts Check to be sure all nuts are tightened before each field operation
Equipment Node-4: Transport unit					
4	Transportation difficulty	Excess width of implement (3.5m)	1. Potential to injure nearby personnel. 2. Potential to obstruct or cause damage to other traffic	1. Drive carefully when transporting ridger 2. Do not overtake traffic with ridger hitched to a tractor	Observe all road safety regulations for transporting agricultural machines

4.7 Economic Analyses and Financial Appraisal

The implement consists of four major cost components of the Discs, shanks, frame and the three-point linkage system. The materials used in the fabrication were mainly mild steel with details shown in the design specification manual (Table 4.2). The bill of construction materials is given in Table 4.6.

4.7.1 Cost Analysis

Table 4.6 presents the total cost of materials purchased to build the implement. Considering a 25% profit margin on manufacturing as proposed by Schuler & Frank (1991), the cost of selling the implement was calculated as follows;

Selling price (P) = $12{,}004.5 + (12{,}004.5 \times 0.25)$

P = 12,004.5 + 3,001.13

P = GHs 15,005.63 or US$ 2,753.33

This calculation was done when the US dollar rate in Ghana stood at five Ghana cedi, fortyfive pesewas (GHs 5.45).

Table 4.6: Itemized and total cost of materials

SNO.	ITEM	UNIT	COST/UNIT (GHS)	TOTAL (GHS)
1	4-bottom 'same' plough shanks & hubs	4	900.00	3600.00
2	Modification of hubs (machining, thread cutting)	4	70.00	280.00
3	Bearings (6312) 130 x 60 mm	4	80.00	320.00
4	Bearings (6209z) 85 x 45 mm	4	40.00	160.00
5	Bearing caps	4	10.00	40.00

6	Hub wear protectors	4	25.00	100.00
7	Bolt & nut set	1	220.00	220.00
8	Washer set	2	44.00	88.00
9	Hollow square pipe 6mm (100 x 100 mm)	2	700.00	1400.00
10	Hollow square pipe 5mm (100 x 50 mm)	1	500.00	500.00
11	Concave disc (600 mm diameter)	4	355.00	1420.00
12	Design modelling	1	500.00	500.00
13	Conveyance & transport of shanks & hubs	1	250.00	250.00
14	Transportation	1	320.00	320.00
15	Cutting disc	10	18.00	180.00
16	Grinding disc	3	20.00	60.00
17	Power saw blade	2	90.00	180.00
18	Hand-gloves for work	4	10.00	40.00
19	Welding electrode	5	35.00	175.00
20	Plough pins	3	20.00	60.00
21	Manufacturing cost	1	1,130.00	1,130.00
23	Spraying	1	200.00	200.00
24	Cost of evaluation	1	781.50	781.50
			TOTAL	**12,004.50**

4.7.2 Breakeven analysis

Figure 4.7 presents the breakeven analysis of the ridger. With a useful life of 5 years (2500 h) for most tillage implements, annual average working hours of 450, operational cost of US$9.03 per hour (Sopegno *et al.*, 2016), the breakeven point (in hours) for owning and operating the ridger was calculated as 244 hours which translate into 366 ha since the field capacity was established as 1.5 ha/h. This means that, if all things being equal, a farmer decides to own and operate the ridger at the cost of 48.2 US$/h, he/she stands a chance of making profit after 30 days of engaging the implement, assuming eight (8) working hours per day.

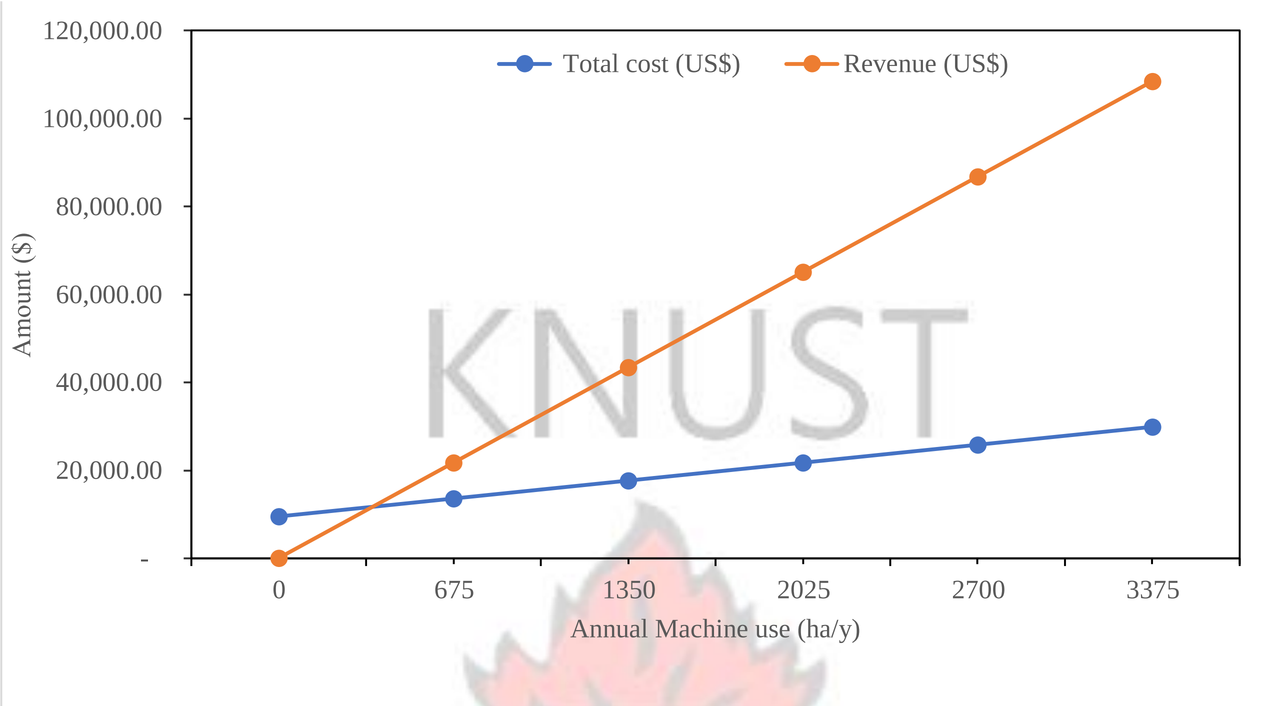


Figure 4.7: Graph showing a breakeven point of owning and operating the ridger

Section Two: Field Evaluation and Performance Modelling of the Ridger

4.8 Soil moisture content

Figure 4.8 shows the moisture content of the selected site prior to the field test. It was observed that the moisture content increased steadily with depth from 0 to 12 cm and decreased sharply from 12 to 30 cm deep. The highest moisture content of the soil was recorded at 10 cm depth. The average moisture content of 13% was recorded prior to the field test. This moisture content was within acceptable limits for tillage if the assertion of Kumi (2011) is anything to go by. Kumi reported that it is advisable to till the land at a low moisture content at the beginning of rains when the moisture content is usually between 5% and 15%.

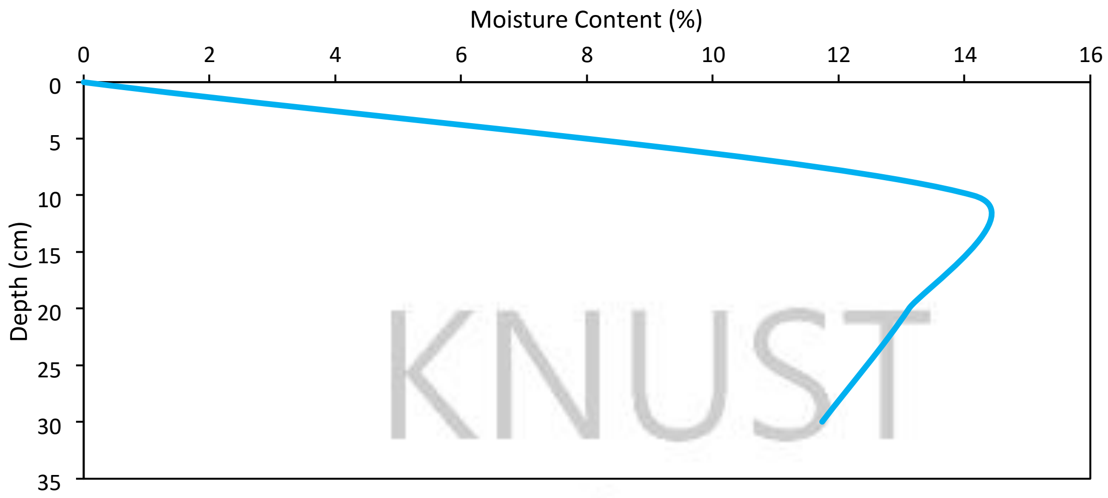


Figure 4.8: **Moisture content of the field prior to evaluation.**

4.9 Soil Penetration Resistance Before and After Ridging

Figure 4.9 presents the soil penetration resistance before and after ridging. The results indicate a trend of increasing resistance with probing depth. In other words, as the depth of probe increased, so did resistance to penetration as shown on the graph. This observation means, the deeper the ridger will engage the soil, the more resistance it will encounter which influence draught force imposed on the tractor-implement, wheel-slip, and fuel consumption. Highest resistance of 155 kN was observed at a depth of 25 cm before ridging operation and reduced sharply from 155 to 140 kN at probing depths of 26 to 30 cm. A similar trend was observed after the ridging. However, a reduction in soil penetration resistance was recorded after the ridging operation, the highest resistance being 145.6 kN at 25 cm depth of probe. What is worth noting here is that the ridging operation caused further disintegration or loosening of the soil which, accounts for the 10 kN reduction in penetration resistance recorded by the cone penetrometer.

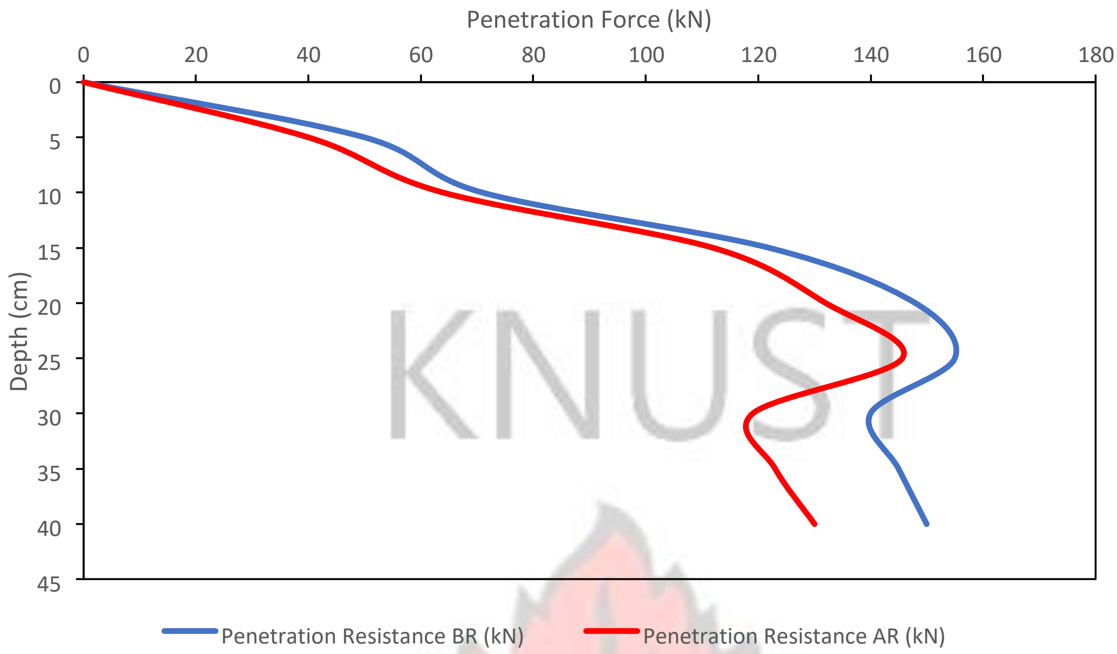


Figure 4.9: Soil Penetration Resistance before and after Ridging

4.10 Measured performance during field testing

Figure 4.10 presents the profiles of load and no-load draught forces recorded during field testing of the ridger. The no-load draught force was recorded with the implement in transport position and the load-draught force was taken when the ridger engaged the soil (during ridging). An average net draught force of 2.2 kN was recorded.

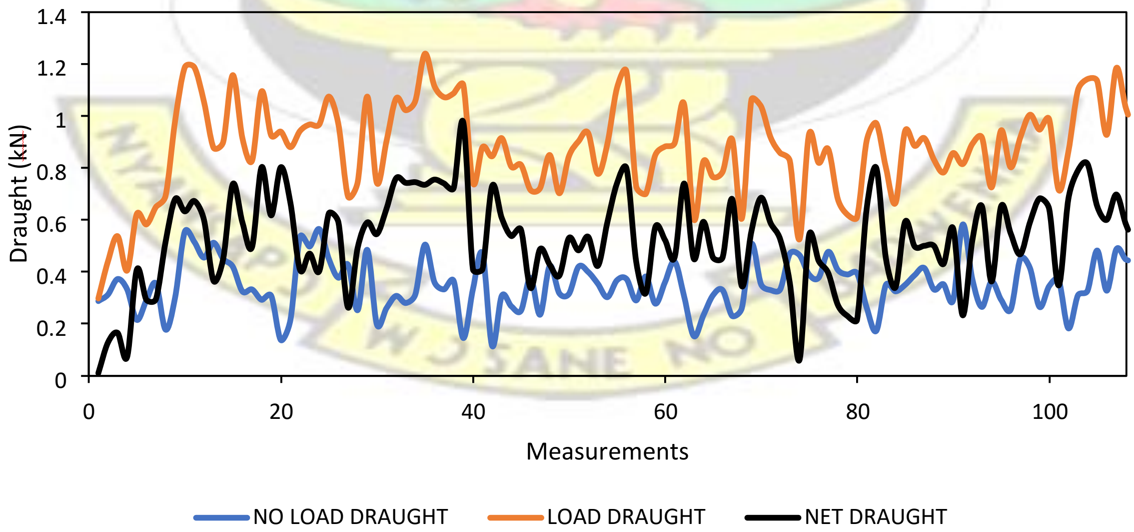


Figure 4.10: Profile of load and no-load draught forces recorded during field testing.

4.11 Effect of tractor speed on ridger performance

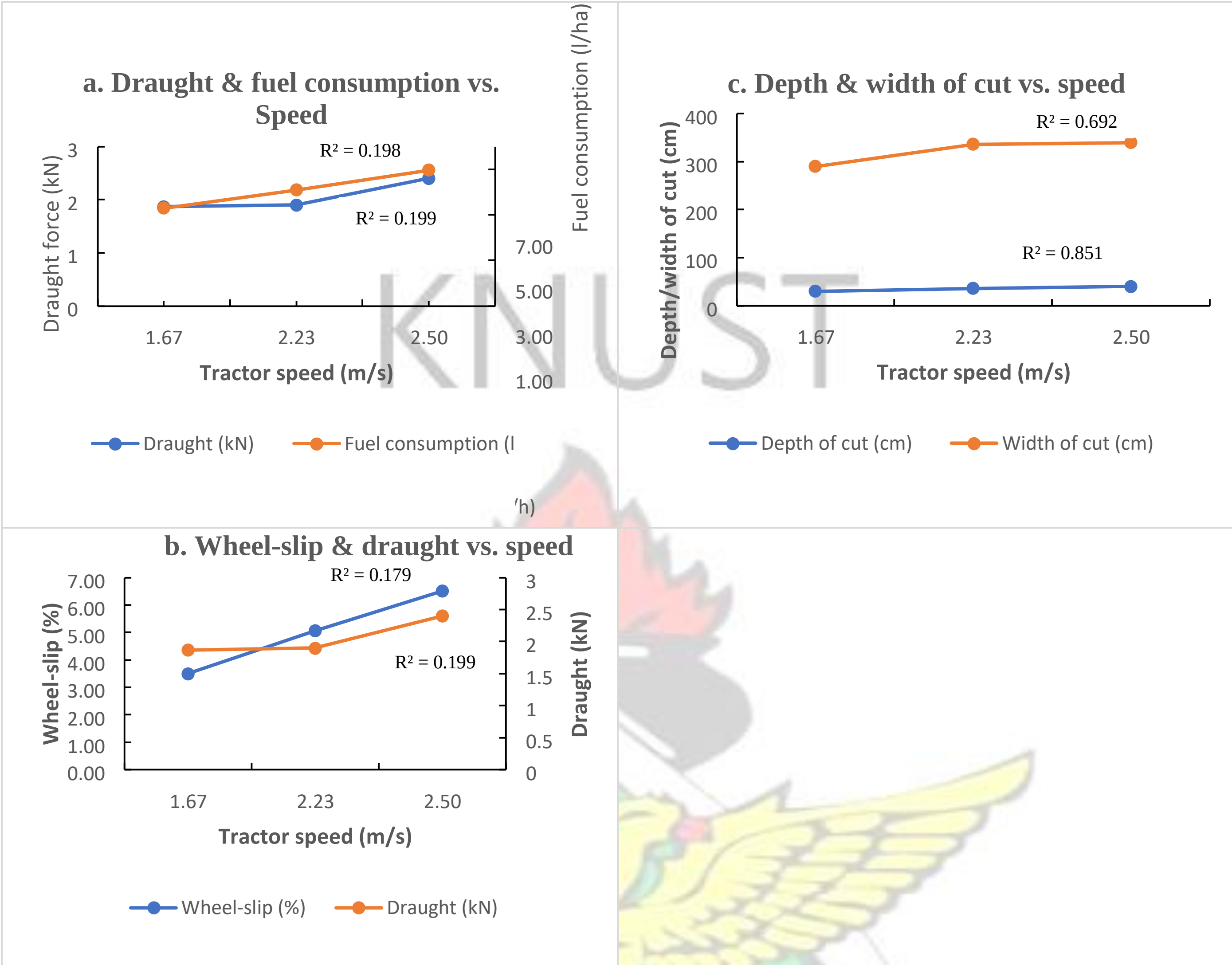
Figure 4.11 presents the effect of tractor speed on draught force (kN), fuel consumption (l/ha), wheel-slip (%), depth and width of cut (cm). A minimum and maximum draught force of 1.8 and 2.4 kN, respectively were recorded at varied ridging speed from 1.67 – 2.5 m/s (6 – 9 km/h). These figures indicate optimum performance as they fall within the predicted and measured draught force for disc implements computed by the ASABE (2000). The results revealed a slight increase in draught force (1.8 – 2.4 kN) as speed increased. It is intriguing to note that the minimum draught force was recorded at 2.23 m/s tractor speed. This means that high draught force is required when ridging at speeds below 2.23 m/s and above 2.5 m/s. Regardless of the slight increase in the draught, the field tests recorded an R^2 of 0.199 indicating less significance of the effect of speed on draught force which totally agrees with findings by Taylor (1967) as indicated in the literature review section this of work. This may be attributed to the rotation of the discs which absorbs part of the soil forces at a certain speed.

Average fuel consumption recorded was 6.35 l/ha (9.2 l/h). The highest fuel consumption of 7.04 l/ha (10.56 l/h) was recorded at tractor speed of 2.5 m/s and lowest of 5.41 l/ha (7.85 l/h) at 2.23 m/s tractor speed. It is apparent from the graph that increasing speed resulted in increased fuel consumption but very little. These measured fuel consumption figures agree with the American Society of Agricultural Engineers (ASABE, 2000) standard of 9 l/h of average fuel consumption for disc implements. While these results agree with literature suggesting that increased speed results in increased fuel consumption (Nkakini, 2015; Mamkagh, 2019), the effect was not so significant given an R^2 of 0.1992.

The minimum and maximum wheel-slip of 5.5 and 5.7% were recorded at tractor speed of 1.67 – 2.5 m/s respectively. This is not as significant as the 15% stated in some literature. However, the results agree with the 5.7% wheel-slip recorded by Niam (2014) in his research on disc implements.

Depth and width of cut rather saw a significant increase with an increase in tractor speed given an R^2 of 0.85 and 0.70 respectively. The observed increase in depth of cut as a function of speed indicates that at high forward speed, better and conical ridges are formed. In other words, heaping is best at high speed than at low speed. While it is yet unclear what might have accounted for the increase in width of cut at increased speed, the possible explanation is that there is a clear demarcation of furrows at high speed.

Figure 4.11: Effect of tractor speed on ridger performance



4.12 Effect of Disc Angle on ridger performance

Contrary to the observations made in Figure 4.11, Figure 4.12 presents a rather significant effect of disc angle on draught force (kN), fuel consumption (l/ha), wheel-slip (%), depth and width of cut (cm). The results revealed an R^2 of 0.98 for draught, 0.90 for fuel consumption and 0.912 for wheel-slip indicating a significant effect of disc angle on these performance parameters. This agrees with research by Joshnton and Birtwistle (1963) and Niam (2014), stating that increased disc angle results in an increase in draught force, wheel-slip and fuel consumption.

Also, R^2 of 0.81 and 0.85 were also recorded for depth and width of cut, respectively. This apparently shows that depth and width of cut increased significantly as disc angle increased. As explained earlier, an increase in depth of cut indicates that as disc angle increased, better and conical ridges are formed, and that clear demarcation of furrows are observed. These findings are also in line with the body of literature suggesting that an increase in disc angle results in increased depth and width of cut respectively (Abdalla *et al.*, 2017; Askari & Khalifahamzehghasem, 2013; Moeenifar *et al*., 2014). This was mainly because a huge volume of soil was conveyed by the disc when the disc angle increased and vice-versa.

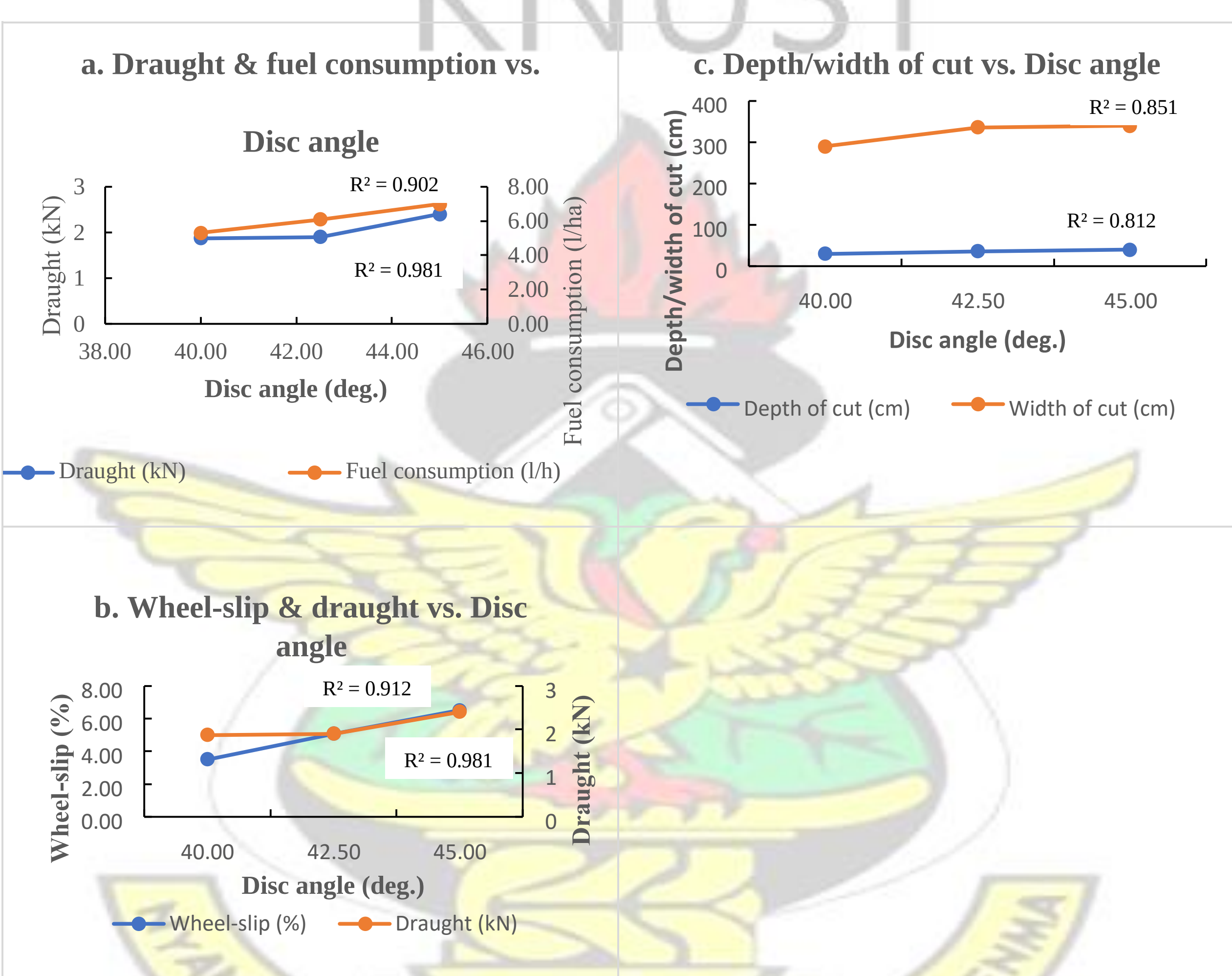


Figure 4.5: Effect of Disc Angle on ridger performance

Figure 4.13 presents a dendrogram of similarities and correlation between variables. The order of the leaf nodes in the dendrogram plot corresponds - from left to right - to the permutation in leaf order. It was observed that tractor speed as an independent variable is correlated with two clusters of dependent variables. The first cluster constitutes variables that are inherent to the performance of the tractor and the second are those variables inherent to the performance of the disc ridger.

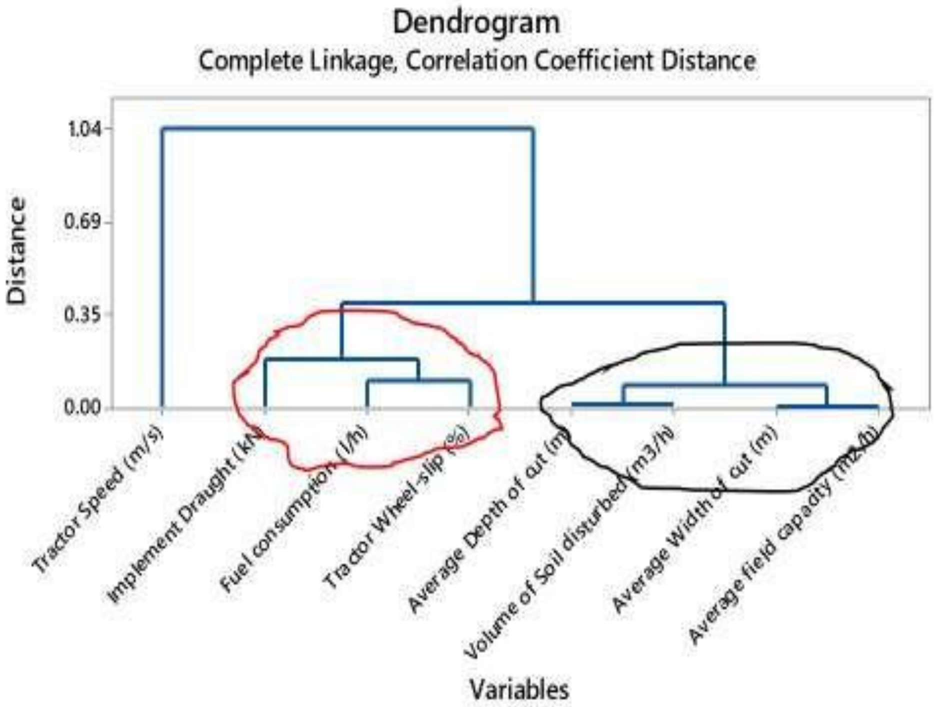


Figure 4.13: Dendrogram plot of similarities among performance parameters

4.13 Performance modelling of the disc ridger

Multiple linear regression models were created as discussed in the previous chapter to describe the relationship between x and y by finding the slope and the y-intercept that defines the line of regression that best fit the experimental data. This regression equation was used to model the relationship between tractor-ridger performance parameters such as; implement draught (y_1), fuel consumption (y_2), tractor wheel-slip (y_3), depth (y_4) and width (y_5) of cut, and how these parameters respond to change in tractor forward speed (x_1) and disc angle (x_2) of the ridger. Based on the p-values obtained in Table 4.7, it can be said that the combined effect of disc angle and tractor speed was statistically significant. This means that the developed models best fit the data and that as disc angle and tractor speed increased, all responses (performance parameters) also increase as indicated earlier.

Regression models and diagnostics

The y-intercept, linear and quadratic coefficients of $\boldsymbol{x_1}$ *and* $\boldsymbol{x_2}$ are listed below;

$$y_1 = 14.311 + 23.383x_1 + 22.168x_2 + 9.5671x_1^2 + 9.6121x_2^2 + 36.66x_1x_2 + 12.389x_1x_2^2 + 10.501x_1^2x_2$$

$$y_2 = 72.548 + 115.52x_1 + 115.87x_2 + 50.957x_1^2 + 38.891x_2^2 + 195.58x_1x_2 + 40.624x_1x_2^2 + 78.918x_1^2x_2$$

$$y_3 = 33.316 + 102.4x_1 + 79.621x_1^2 - 50.113x_2^2 + 96.016x_1x_2 - 59.359x_1x_2^2 + 114.04x_1^2x_2$$

$$y_4 = 1.6794 + 1.6433x_1 + 3.248x_2 - 0.19331x_1^2 + 2.0532x_2^2 + 4.4127x_1x_2 + 2.789x_1x_2^2 + 0.00668x_1^2x_2$$

$$y_5 = 15.04 + 17.552x_1 + 28.541x_2 + 1.2596x_1^2 + 18.038x_2^2 + 38.869x_1x_2 + 24.559x_1x_2^2 + 0.0665x_1^2x_2$$

Table 4.7: Fitting characteristics of the regression model

Regression model	**Fitting characteristics**			
	RMSE	$\boldsymbol{R^2}$	$\boldsymbol{AdjR^2}$	**P-value**
Implement draught ($\boldsymbol{y_1}$)	0.0072	0.998	0.994	2.96e-0.6 ***
Fuel consumption ($\boldsymbol{y_2}$)	0.304	0.943	0.863	0.0076 **
Wheel slip ($\boldsymbol{y_3}$)	0.342	0.937	0.873	0.00231 **
Cutting depth ($\boldsymbol{y_4}$)	0.00318	0.997	0.992	6.77e-0.6 ***
Cutting width ($\boldsymbol{y_5}$)	0.0317	0.975	0.939	0.00107 ***

NB: **:(p<0.01), very significant; ***: (p<0.001), highly significant

Kernel density plots

The fitting of the linear regression models was done using the least-squares method. An assumption of the least square estimation is that the errors are random and normally distributed.

If error terms are not normal, then the standard errors of ordinary least squares estimates won't be reliable, which means the confidence intervals would be too wide or narrow. The randomness of the error was assessed using the heteroscedastic plots while the normally distributed nature was assessed using kernel density plots. The kernel density estimate of the residual vector was obtained using the Kernel smoothing function estimate, *ksdensity* of Matlab (Mathworks Natick, NA) for univariate and bivariate data. If the kernel density plots show a bow shape, then the errors are not normally distributed, and in such cases, it is worthwhile to check for linearity assumption again if this assumption fails. Similarly, if the heteroscedastic plots show a trend, it reveals the errors are not random. However, it clear from the plots in appendix 4a and b that, the errors are random and normally distributed.

4.13.1 Relationship between Disc Angle and Travel Speed on measured responses Figure 4.14a presents the effect of disc angle and tractor speed on implement draught force. It was observed that the implement draught force increased with an increase in disc angle (40° - 45°) and tractor speed (1.67 – 2.23 m/s). What is interesting in this data is that, at a disc angle of 42.5° and forward speed of 2.23 m/s, the draught force recorded was 1.85 kN, representing the optimum predicted draught force for disc implements reviewed in the literature (Godwin & O'Dogherty, 2007; Sahu & Raheman, 2006). This also agrees with the empirical evidence of 1.8 kN draught force requirement for disc implements reported by Nkakini (2015). Contrary to the above, the implement recorded the highest draught force of 2.4 kN at a disc angle of 45° and forward speed of 2.23 m/s respectively.

Figure 4. 14b. provides the effect of disc angle and tractor speed on fuel consumption. It is apparent from that plot that, fuel consumption increased with increase in disc angle and tractor

speed. What is more intriguing was that the fuel consumption decreased at high (9 km/h) tractor forward speed and lesser implement disc angle (42.5). This was probably due to the revolving effect of the disc, absorbing part of the load exerted by the soil forces on the tractor through the implement.

Figure 4. 14c shows the effect of disc angle and tractor speed on tractor wheel-slip. The plot indicates that an increase in tractor speed and disc angle resulted in an increase in tractor rear wheel slippage. This agrees with Bukhari et al., (2018) who stated that an increase in disc angle led to an increase in wheel-slip.

Figure 4. 14d provides the effect of disc angle and tractor speed on cutting depth. The combined effect of disc angle and tractor speed on cutting depth was significant (6.77e-0.6 P-value). It was observed that high speed (2.23 m/s and above) resulted in pyramid seedbeds or ridges thereby increasing the depth of cut. Also, an increase in disc angle revealed a significant increase in cutting depth (30 – 40cm).

Figure 4. 14e shows also, the effect of disc angle and tractor speed on cutting width. Unlike cutting depth, the width of cut was influenced significantly by disc angle. The combined effect was positive as observed on the plot. However, it was deduced during the analysis that tractor forward speed independently did not have any significant effect on cutting width as shown in the response surface plot.

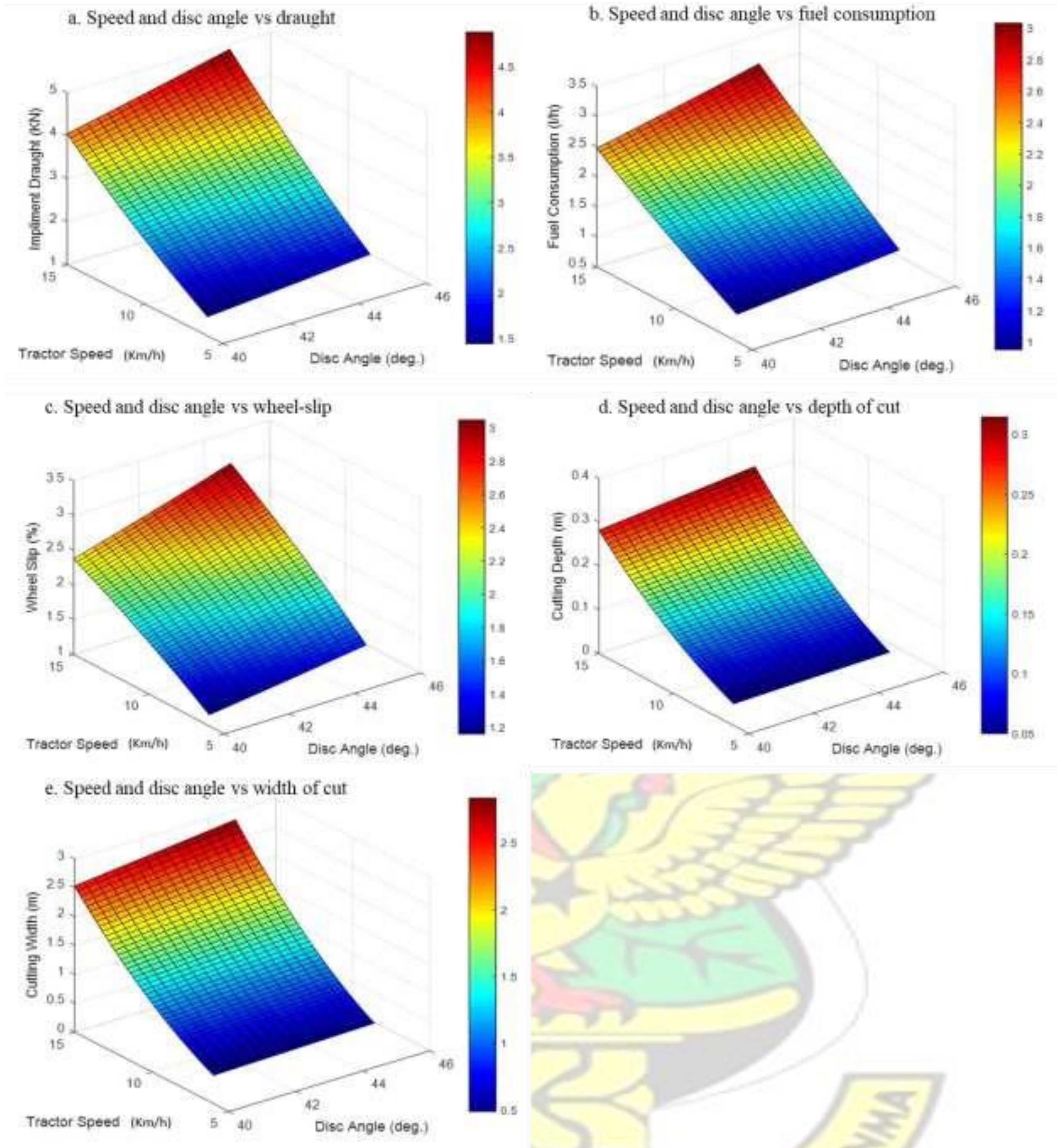


Figure 4.14: Response surface plots showing relationship between dependent and independent variables

4.13.2 Drudgery measurement

In this study, working heart rate (bpm) was taken as a proxy for drudgery. Table 4.8 presents the mean heart rate (bpm), gross energy consumption (Watt) and total rest period (min/h) obtained for a tractor operator at Anwomaso during ridging. The preliminary result was the heart rates of the author when testing the ridger in the field to access its performance. The preliminary drudgery result, which is not conclusive, suggests that for every hour of work (ridging), the operator requires approximately 35 minutes of rest to recover. This is not a true reflection of the drudgery level of an operator in a ridging operation. The high rest period was recorded because the researcher was running up and down the field doing other stuff.

However, knowledge of the total rest period required after ridging activity was necessary in order to determine the effective working hours for the tractor operator (Researcher) as shown in five and six. If there are eight (8) hours allocated for work each day, the operator would have an effective working time of 3 hours, 21 minutes and the remaining used as recovery time. It could be seen from the calculations in appendix five (5) that the energy consumption is directly proportional to the total rest period., it implies that the more the energy consumed during an activity, the longer the rest (recovery) period required to compensate for the lost energy. While this is not conclusive it shows that the operator would have to exert a great deal of effort in order to control the tractor so as to carry out the ridging operation as expected.

Table 4.8: Mean Heart Rate, Gross Energy Consumption and Total Rest Period

Study site	Mean Heart Rate (bpm)	Gross Energy Consumption (Watt)	Rest Period (min/h)
Anwomaso	106.51	597.40	34.89

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A fully-mounted double-row disc ridger has been developed and tested. The study applied functional analysis methodology in the design of the tillage implement for local application. A key advantage of this methodology is that it aligns the specification of the device to the requirements of the users thereby streamlining wasteful functionalities and hence reducing the cost of manufacturing. The device was fabricated from locally available materials and tools, making it an adaptable, resilient and affordable technology for local artisans and small-scale farmers who contribute 90% of root and tuber crops in Ghana. Preliminary field tests were conducted to determine the response of the implement to performance parameters such as draught, wheel slip, fuel consumption, depth and width of cut, and drudgery imposed on operators. The following additional conclusions can be drawn:

- The design meets the requirement of its service function with a field capacity of 1.45 ha/h and fuel consumption of 6.3 l/ha.
- Optimum performance of the disc ridger was achieved at a disc angle of 42.5° and tractor speed of 2.23 m/s (8 km/h) with tilt angle set at 25°.
- Increase in disc angle (40° - 45°) and tractor speed from 1.67 – 2.5 m/s resulted in increased draught force from 1.8 – 2.4 kN. However, tractor speed had no significant effect on draught as an R^2 of 0.199 was recorded, indicating less variation.
- Fuel consumption increased from 5.23 – 7.04 l/ha (7.85 – 10.56 l/h) with an increase in disc angle and tractor speed.
- Depth and width of cut increased from 30 – 40 cm and 240 – 280cm, respectively with a corresponding increase in tractor speed and disc angle.
- Finally, a hazard and operability (HAZOP) manual was developed that explains the possible operational hazards that could result from using the ridger. The HAZOP analysis established possible deviations, causes, consequences, safeguards, and recommendations for users of the implement.

5.2 Recommendations

- Further research is necessary to establish the effect of different moisture contents and soil type on the performance of the ridger.

- Comparative evaluation is needed to establish the technical and economic performance of the locally developed disc ridger and other soil engaging implements.
- Wear and durability of the ridger in different agro-ecologies are necessary.
- A further field test is required to establish the drudgery imposed on an operator using the ridger compared to other tillage implements.
- Finally, since, the current design is meant to ease constraints associated with mechanical harvesting, an interesting progression of the study should focus on assessing the extent to which such ridges accommodate mechanical harvesting.

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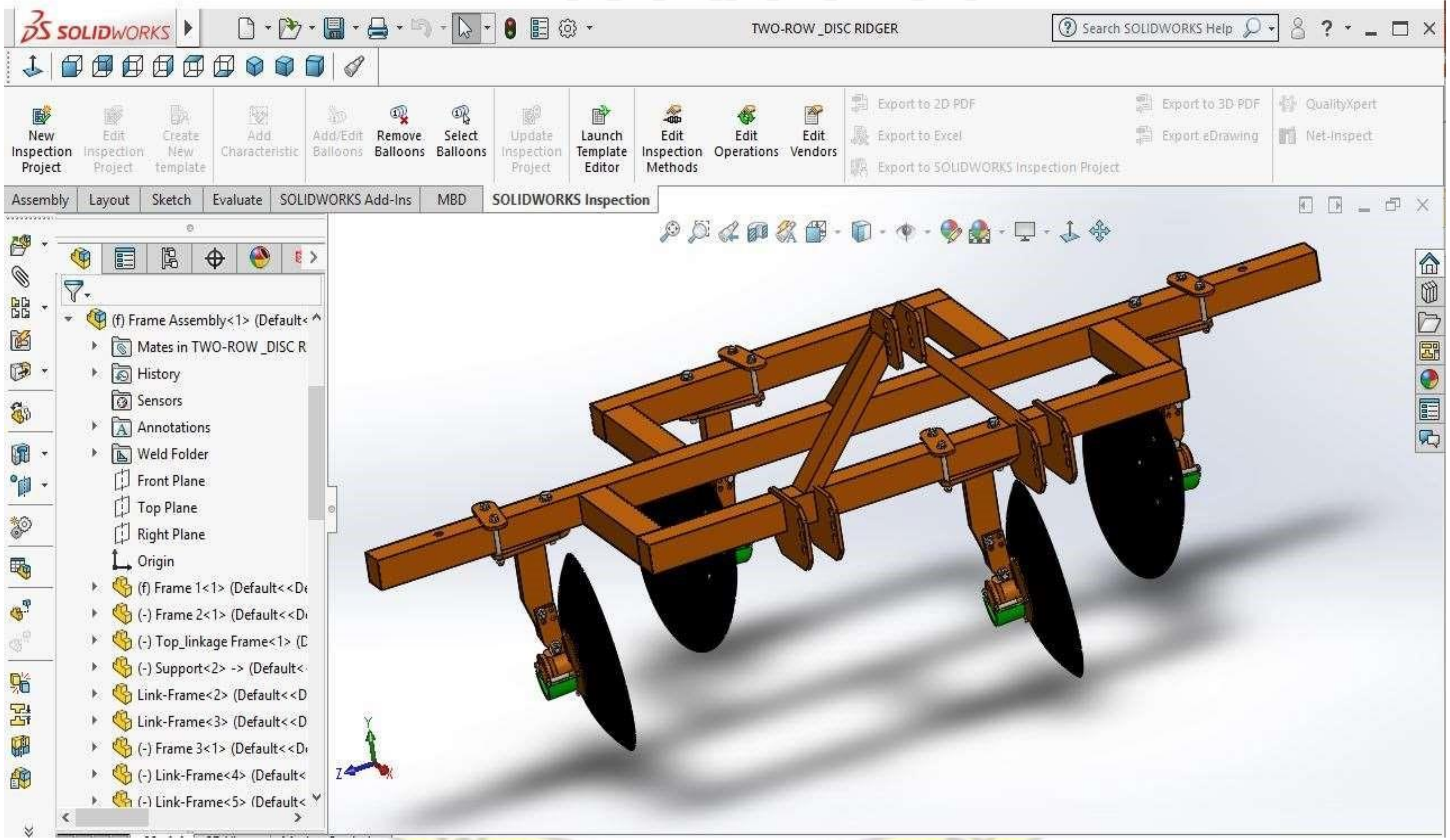
APPENDICES Appendix 1 Stale picture showing design development of the disc ridger in Solidworks software

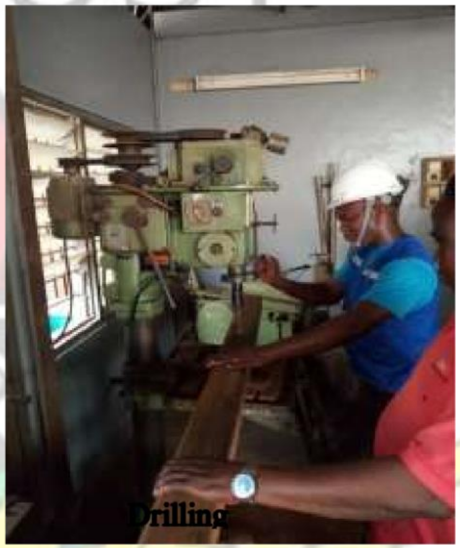


Appendix 2

Stale pictures showing fabrication processes of the disc ridger

Marking

Cutting



Drilling

Setting-up frame for welding

Welding of frame

Surface

Development of shanks

Assembling of ridger

Appendix 3
Stale pictures showing field evaluation processes of the disc ridger

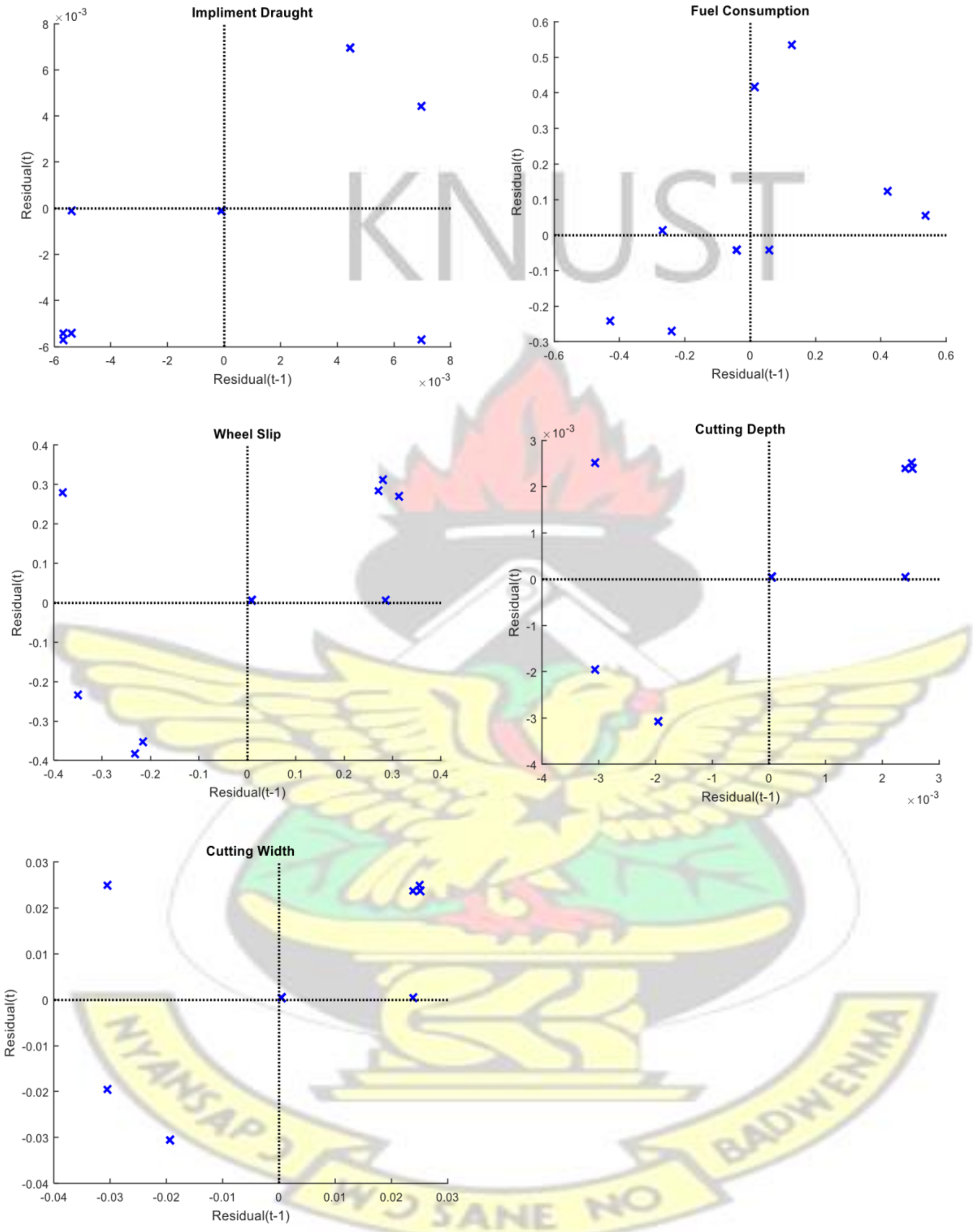
Measurement of draught with ridger in tillage position

Measurement of wheel-slip with ridger in tillage position

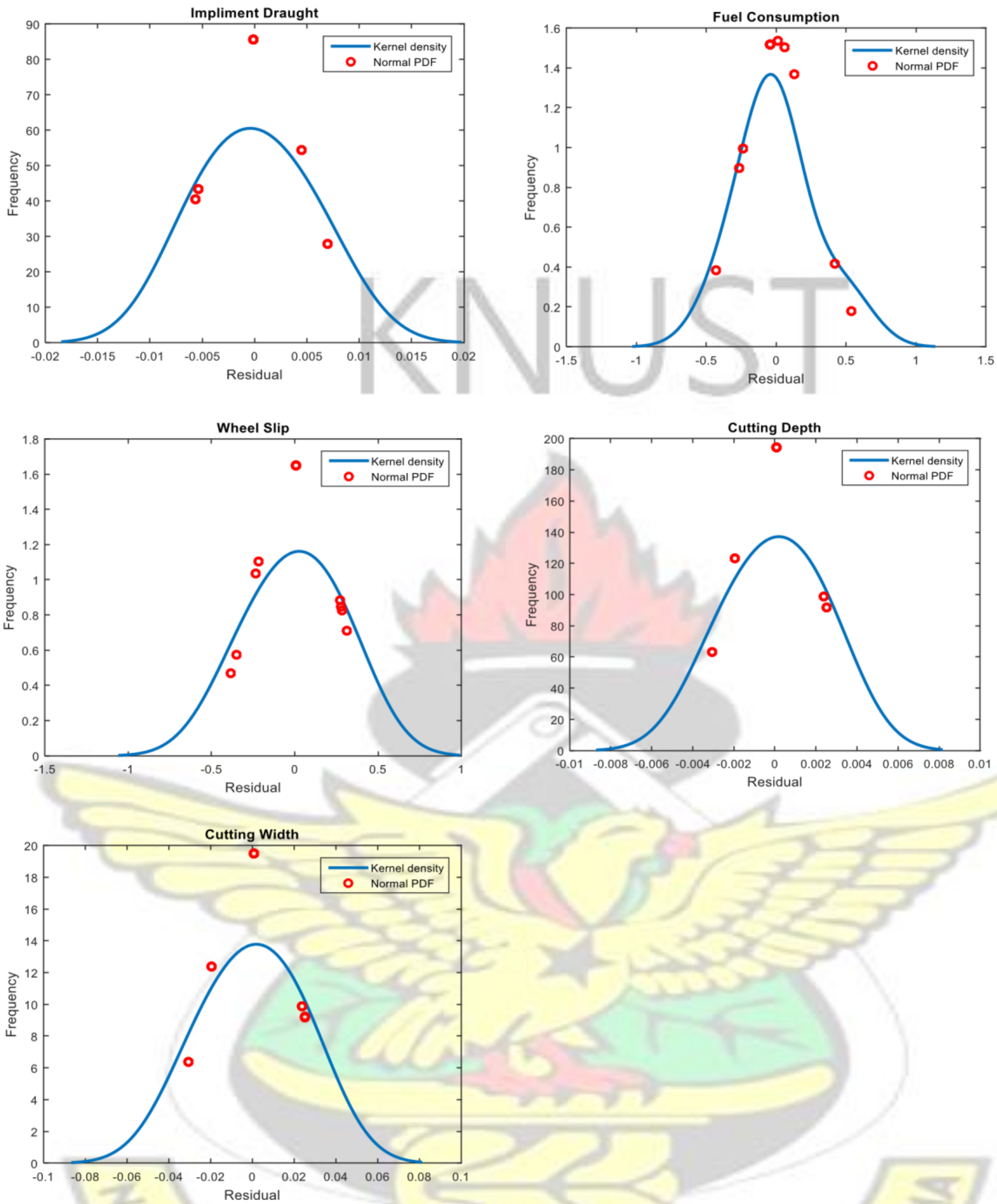
Measurement of fuel consumption

Measurement of soil penetration resistance after ridging

Appendix 4a
Heteroscedastic plots showing a normal distribution of errors

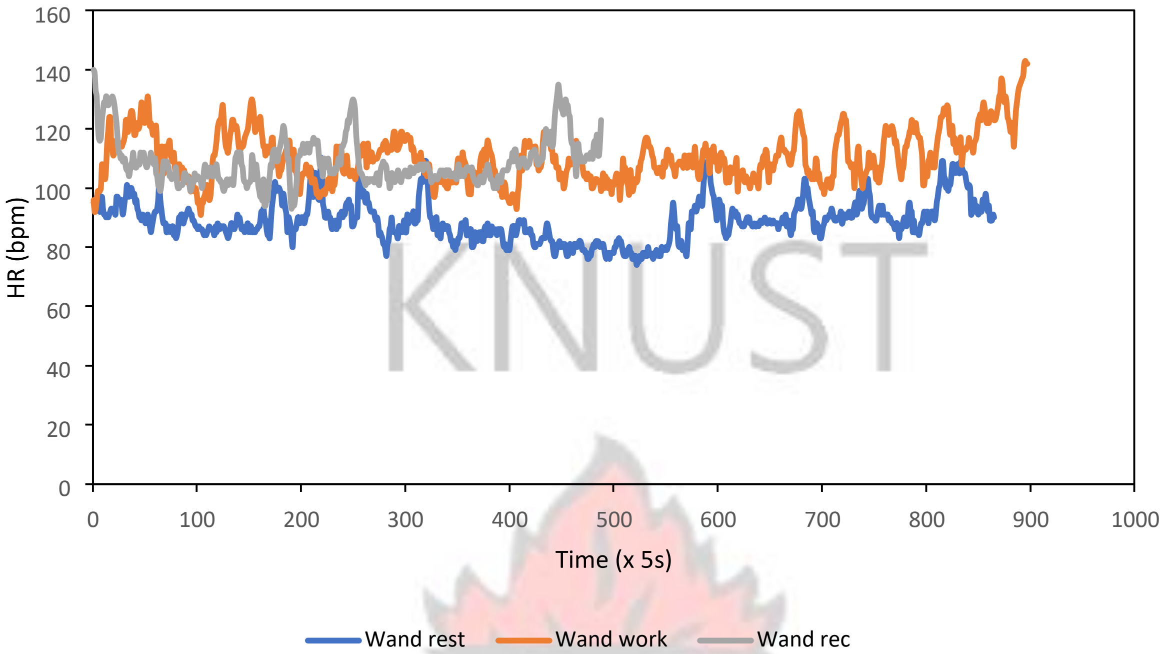


Appendix 4b
Kernel density plots showing the random distribution of errors

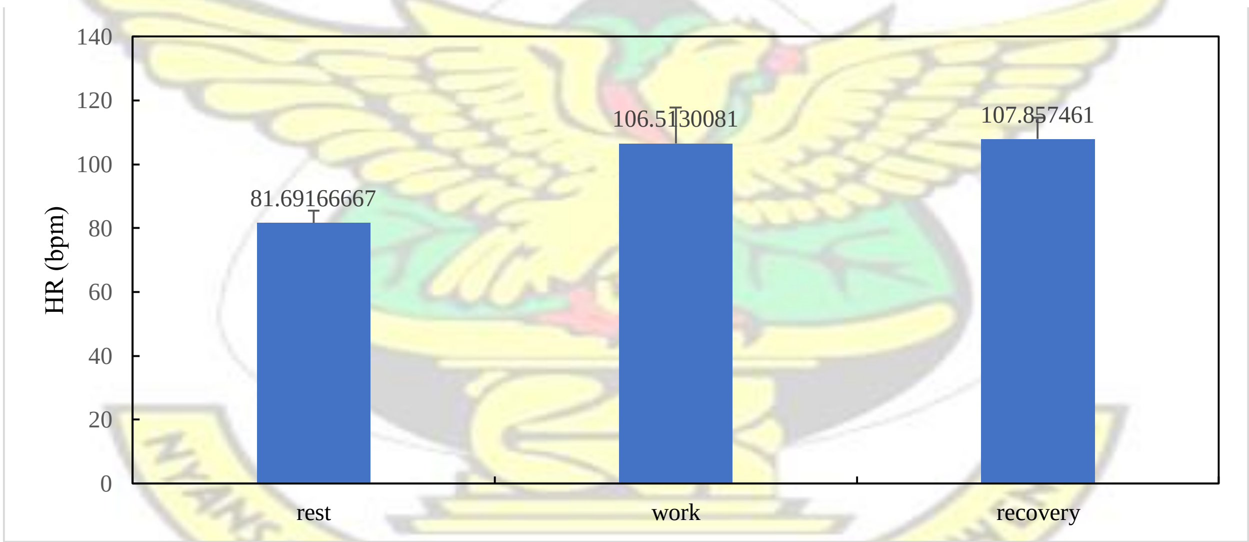

Impliment Draught
Fuel Consumption
Wheel Slip
Cutting Depth
Cutting Width
Kernel density
Normal PDF
Frequency
Residual

APPENDIX 5

a. **Profile of the operator's heart rate during ridging operation**



b. Mean rest, work and recovery periods of operator's heart rate during ridging



APPENDIX 5

Example of drudgery calculations

Rest Period (Tr) calculation:

The operator's heart rate during ridging activity was recorded as 106.51, corresponding to 597.40 Watts of gross energy consumed (P).

Therefore, using Equation 3.2, Tr = $60\left(1 - \frac{250}{P}\right)$, the rest period (Tr) required by the operator per every one hour was calculated as follows;

Tr = $60\left(1 - \frac{250}{597.4}\right)$ min/h

= 60 (1 - 0.4185)

= 60 × 0.4206

= 34.89 mins/hour

APPENDIX 6

Heart Rate - Energy Conversion Chart

Heart Rate (bpm)	Energy (watt)	Heart Rate (bpm)	Energy (watt)
72	210	120	751.68
76	255	121	763.28
80	300	122	773.72
84	346	123	785.32

88	390	124	796.92
90	408.32	125	808.52
91	419.92	126	820.12
92	431.52	127	831.72
93	443.12	128	843.32
94	454.72	129	854.92
95	466.32	130	866.52
96	477.92	131	875.8
97	489.52	132	886.26
98	501.12	133	895.52
99	512.72	134	905.96
100	523.16	135	922.2
101	534.76	136	915.24
102	546.36	137	926.84
103	557.96	138	937.28
104	569.96	139	948.88
105	580	140	960.48
106	591.6	141	972.08
107	609.2	142	982.52
108	614.8	143	994.12
109	626.4	144	1009.4
110	638	145	1016.16
111	648.44	146	1027.76
112	660.04	147	1038.2
113	671.64	148	1049.8
114	683.24	149	1061.4
115	694.84	150	1071.84
116	706.44	151	1083.44
117	716.88	152	1095.04
118	728.48	153	1105.48
119	740.08	154	1117.08