EFFECTS OF TILLAGE DEPTH AND SPEED ON DRAWBAR POWER AND PERFORMANCE OF DISC AND MOULDBORAD PLOUGHS IN SILT LOAM SOIL

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and to the best of my knowledge it has not been presented for an award of a degree or diploma in this or any other university.

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Recommendations

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DEDICATION

I wish to dedicate this study to my beloved parents and my dear wife Jemima, for the love, patience, support and encouragement continuously received from them and to our lovely daughter Alie Ylst and son Bevon Wavula who have remained to be a source of inspiration and strength. Thank you and may God continue to bless you all.

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ABSTRACT

A research was carried out at the Ngongongeri Farm Kenya to determine effects of tillage depth and speed on drawbar power and performance of disc and mouldboard ploughs so as to develop a mathematical model that would assist farmers, machinery managers and policy makers to properly match implements to tractors and the size of tractors to import based on soil types and conditions. The implements used were a standard 2-bottom mouldboard plough and a 3-bottom disc plough. Tillage depths used were 6.5 cm, 12.5 cm and 22.5 cm while the forward speeds were 1.3 km/h, 2.3 km/h and 3.0 km/h with the width of both implements fixed at 80 cm. Preliminary field studies of soil parameters were conducted and the analysis of parameters showed homogeneity hence a completely randomized design was used. Two tractors were used with a digital pull dynamometer located in between the tractors to take the readings of draught at various depths and speeds of tillage. The measured draught was used to calculate the drawbar power and specific power. The results showed increase in drawbar power with increase in tillage depth and forward speed at all the levels of the parameters tested for both the ploughs used with mouldboard plough having higher values of power requirement at all levels of the parameters investigated. The specific drawbar power increased with increase in forward speed and decreased with tillage depth for the implements used. Mathematical models were developed to predict specific drawbar power given by; $Y_s = -0.27X_1 + X_2 + 0.13X_3$ and $Y_s = -0.41X_1 + 3.43X_2 + 0.15X_3$ for disc and mouldboard ploughs respectively based on depth (X_1), speed (X_2) and width of cut (X_3). The predicted values from the models fitted well to the measured values with some minimal residuals, hence can be used in matching of these implements to tractors in silt loam soils. Soil pulverization ratio increased with increase in speed while trench specific resistance decreased with increase in tillage depth. Mouldboard plough had better soil inversion at all levels of interaction between speed and depth of tillage as compared to disc plough. The results of the study showed that the mouldboard plough had better performance in terms of soil slice inversion and pulverization as compared to the disc plough at all levels of the factors tested. Therefore, based on the tillage power and specific power disc ploughs should be encouraged to minimize the cost of tillage. While looking at the field in terms of performance in primary tillage then shallow mouldboard tillage should be encouraged to take advantage of good inversion properties.

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ABBREVIATIONS AND ACRONYMS

ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
CI	Confidence Interval
D	Ploughing depth
Db	Dry basis
DBP	Drawbar power
Df	Furrow depth
F	Draught
G	Grams
Hr	Height of ridge
Hv	Heating value of fuel
KALRO	Kenya Agricultural and Livestock Research Organization
Km	Kilometres
kN	Kilonewton
kPa	Kilopascal
kW	Kilowatt
N	Newton
P	Power
RRD	Ridge to ridge distance
S	Speed of tillage
MC	Soil moisture content
TCA	Trench cross section area
TDW	Maximum with of soil throw
USA	United States of America
V_w	Volume of water
W	Width of implement
W_d	Weight of dry soil
Wfs	Maximum width of soil cut
W_w	Weight of water in soil
W_s	Weight of soils solids

SYMBOLS

ρ	Soil bulk density
ϕ'	Angle of shearing resistance
c'	Apparent cohesion of soil
τ_f	Shearing stress at soil failure
σ'_n	Normal stress at soil failure
S_r	Degree of moisture saturation of soil

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Soil tillage may be defined as the mechanical manipulation of soil in order to improve soil conditions for crop production. It represents the most costly single operation to famers and the most tasking to the tractors (Abdallah, 2015). The objectives of tillage include; production of a suitable soil tilth, control of soil moisture, destruction of weeds and pests, and burying of organic material to add humus to the soil. Methods of tillage can broadly be classified as conventional and conservation tillage. Conventional tillage method involves ploughing followed by harrowing and tertiary operations in the preparation of a seed bed and further cultivation after emergence of plants. Conservation tillage includes among other operations; minimum tillage, no-till or direct seeding and strip till. These are majorly practiced in order to reduce soil loss and preserve soil moisture (Aina, 2011). Minimum tillage reduces the number of tillage operations done on the field during seedbed preparation and cultivation. In direct seeding planting is done in a narrow (usually 15 cm or less) seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. A press-wheel follows to provide firm soil-seed contact. Strip tilling is when a farmer only cultivates thin strips in their field where seeds will be planted. The strips are located where the rows of crops are located. Each year, the strips will shift roughly fifteen centimeters in one direction.

In areas prone to wind soil erosion, it is preferable that plant residue be left on the soil surface to prevent or minimize soil erosion by wind. Under such field conditions tillage operations that burry plant residues are discouraged. Also, it is advisable to avoid primary tillage operation on heavy soils prone to compaction, especially when the soil is wet. Under such circumstances where ploughing is discouraged, weed control is primarily accomplished by use of herbicides. Conservation tillage systems often require some other changes to be made both on the method and equipment. For example, planter changes are needed to provide for cutting through the plant residue left on the surface, for it to be able to place the seeds. This is usually accomplished by adding fluted or serrated/notched disc coulters ahead of the furrow openers. But even with such modifications done on tillage implements and methods, there is need to properly select and match the implements to available power units based on field and operating conditions.

Proper selection and matching of implements to tractors is a major factor in reducing power consumption and breakages that occur on implements and tractors due to under loading or overloading. According to Alcock (2012) and Grevis-James (1979) tractor and implement matching involves balancing implement load characteristics with tractor output characteristics to obtain the best output from the combination. When tractors were first introduced, matching them with implements was simple; most tractors were designated by the number of horses they replaced or the size of implement they pulled. Today matching tractors and implements is far from simple owing to the changes in types of equipment, the rapid changes in the size of equipment and the range of alternatives. Until quite recently little engineering has been applied to the problem of matching. The use of agricultural machinery is considered the main factor in the total power inputs in agricultural system during tillage, planting, spraying or harvesting. Among all these field operations tillage has been reported to be the highest consumer of power. According to Olatunji and Davies (2009), there are three things that are involved in tillage that is source of power, soil and implement. Conditions of the soil at tillage time such as bulk density, moisture content and texture, implement size and tractor size have to be understood before selection and matching for a particular task.

It is recognized by farmers, decision makers and machinery managers that application of power-saving methods can make effective contributions to economy. This is possible by choosing economical and effective field operation methods in all agricultural areas (Bayhan *et al.*, 2006). As fuel costs continue to rise, farmers must become more efficient fuel users. No single solution or practice will achieve this goal. Shelton and Rider (2014) outlined the following practices that can be used to reduce fuel consumption without adversely affecting production levels: reducing tillage trips over the field, ballasting tractors, proper matching of tractors and implements, selecting travel and engine speeds, and maintaining engines and implements in optimum operation conditions.

Tillage operations are conducted to prepare a seedbed and or control weeds. The number of tractor trips required to perform these operations depend on soil type and condition, weather conditions, type of tillage system utilized and size of seed to be planted. Excessive tillage operations increase fuel consumption, operating costs, and labour requirements. The number of trips over the field can be reduced by: eliminating one or more tillage operations, or combining tillage operations into one pass over the field (Baker & Saxton, 2007; Koller & El Titi, 2003). The power savings depend on changes made which would require that the best tillage implement is selected based on its performance to reduce the number of subsequent operations.

A major management decision facing many farmers is matching implements with tractors; proper sizing of implements and power unit will minimize labour requirements while maintaining efficient field operations within the available time for land preparation. Tillage cannot be done indefinitely since there is limitation in time available after harvest of previous crop and planting for the next season. If the tractor is oversized for the implement fuel consumption and costs will be higher than necessary for the work done. If the implements are too large for the tractor, overloading will occur reducing both field capacity and quality of work as well as increasing chances of breakages (Shelton & Rider, 2014). This also causes excessive wear of implements and tractors, which increase downtime and maintenance cost. Selecting an implement to match the tractor depends majorly on tractor size, soil type and condition, field speed and power requirement by the implement.

In the selection of farm tillage machinery the most considered factor is its size. Width of cut and ground speed information has been used to match the size of implement to the farming activity. It is however, important to consider power requirement of the machinery in selection to be able to tie it to the available power unit. The optimal use of the power unit is attained when the tillage machinery is correctly matched with the tractor's available drawbar power.

Factors that affect drawbar power requirement by implements include type and condition of soil and tractor-implements characteristics. Tillage depth, texture and moisture content of soil are important parameters that have effect on power. Working width, geometry and leveling of implements and forward speed are parameters which also have effect on power (Al-Janobi *et al.*, 2010).

1.2 Statement of the problem

Increase in agricultural mechanization in the country has caused varied imports of implements and sizes of tractors though they have not been based on data on power requirement that is matched to our soils and field conditions. Even after buying these machineries, at farm level implements are paired to tractors without considering the power output from the tractor and power demand by implements based on speed, depth, and width of tillage and soil conditions leading to overloading or under loading of the tractor. Overloading and under loading lead to breakages of implement and tractor parts resulting into high maintenance and repair costs, poor performance of the implements, wastage of power and increasing downtime. Farm machinery managers, farmers, consultants and policy makers need to rely on power requirements and performance data while selecting tillage implements for tillage operation. Availability of tillage implement power requirements for different soils and conditions, and performance data is important for efficient farm machinery management. Therefore, there is need to develop a tool for selection and matching of implements and tractors for local soils and conditions that would help farmers and mangers to avoid cases of overloading and under loading of tractors and implements. One way of achieving this important data is by carrying out tests for different soils and soil conditions with common tillage implements. This study aims at generating documented information and data on disc plough and mouldboard plough power requirements and performance in silt loam soils of Kenya, which was the predominant soil within the test field.

1.3 Objectives

1.3.1 Broad objective

The broad objective was to develop a mathematical model based on local soil conditions that would help farmers, managers and policy makers to properly match the implements and tractors

1.3.2 Specific objectives

i. To determine the effects of tillage depth, forward speed and width on drawbar power requirements for disc and mouldboard ploughs in silt loam soils and develop a mathematical model for matching of tractors and implements.

ii. To determine the effects of tillage depth, forward speed and width on performance of disc and mouldboard ploughs in silt loam soils.

1.4 Research Questions

i. How do tillage depth, forward speed and width affect drawbar power requirements for disc and mouldboard ploughs in silt loam soils and performance of mathematical model developed?

ii. How do tillage depth, forward speed and width affect performance of disc and mouldboard ploughs in silt loam soils?

1.5 Justification of the Study

Tillage implement power requirements and performance data in different soil types and conditions are an important factor in matching tractors with implements. Tillage implements' drawbar power requirements and performance data is not well documented for Kenyan soils thus forcing farmers and managers to use the American Society of Agricultural

Engineers (ASAE) Standards data which are based on United States of America (U.S.A) and European soil types and conditions (Manuwa & Ademosun, 2007). This study will help generate this important data which would go a long way in reducing the cost of production to the farmers and hence increase productivity leading to improved livelihoods and poverty reduction as envisaged in the Kenyan vision 2030. It will also aid in guiding the farmers, managers and decision makers on the size of implements and tractor to buy for their field conditions.

1.6 Scope and Limitation

The research studied the effect of tillage depth and speed on drawbar power requirement, specific power and performance of a three bottom disc plough with a total width of 80 cm and a two bottom standard mouldboard plough also having a width of 80 cm on silt loam soil. The depths used were 6.5 cm, 12.5 cm and 22.5 cm with speeds of 1.3 km/h, 2.3km/h and 3 km/h. Although, other sizes and types of ploughs are available for use within the country, they were not considered in the study. The study did not consider other soils.

CHAPTER TWO: LITERATURE REVIEW

2.1 Background

Tillage is an alteration of soil structural conditions by mechanical forces such as shearing or compressing, or tearing. Kepner *et al.* (1982) defined tillage as the manipulation of soil in order to; develop a desirable soil structure for a seedbed or root bed - granular structure is desirable to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil, and to minimize resistance to root penetration. It is also carried out to control weeds and remove unwanted plants (thinning). It could help in minimizing soil erosion by following certain practices such as contour tillage and managed plant residues. A good seedbed is generally considered to imply fine particles and greater firmness in the vicinity of seeds. According to K'Owino (2010) about 80% of the Kenyan population live in rural areas and derive their livelihood from agriculture. Even for the urban poor, a majority of them make a living on agricultural related activities. The sector is therefore the main source of national income and employment creation for over 80% of the population and contributes to poverty reduction and food security. Small-scale farmers, mainly in the high potential areas, dominate Kenya's agriculture. He further established in his study about the adoption of conservation agriculture that use of quality inputs and equipment such as hybrid seed, fertilizers and pesticides and machinery by the sub-sector is very low. Therefore to increase and or sustain productivity in the sub sector, there is need for enhanced efforts to encourage farmers to adopt modern farming practices that entail sustainable land development for food security.

It is recognized that application of power saving methods can make effective contributions to economy (Sessiz *et al.*, 2010), hence the need to do proper matching of implements and operation at optimal depths and speeds of tillage.

2.2 Tillage Methods

Tillage can be classified broadly as; primary and secondary tillage. The former is the initial operation intended to reduce soil strength, cover crop residues and rearrange soil aggregates while the latter is intended to create refined soil conditions (Jantalia *et al.*, 2007). In most cases the difference between the two is not clear cut as stated by Kepner *et al.* (1982), but generally, primary tillage is the initial opening of virgin land or first tillage after harvesting for crop establishment while secondary tillage is any subsequent operation on the same field before and after crop establishment and before harvesting. In the Kenyan situation most farmers use disc and mouldboard ploughs and disc harrows for the two tillage methods. Immediately after harvest of previous crops, a farmer can choose to use either a disc plough or disc harrow depending on the condition of the field or availability of the implement. Due to changes in soil properties and the climate conditions there has been adoption of other systems of tillage like conventional and conservation tillage systems. According to Samarajeewa *et al.* (2006) conservation tillage is practiced in order to reduce soil loss and preserve soil moisture. The need for sustainable farming methods and increasing fuel prices compel farmers to change the farming methods and find alternative economic tillage methods. Minimum tillage and direct seed drilling are some of the methods that farmers apply recently for a long term erosion free farming at lower fuel cost (Ansari, 2008), but these methods have had low adaptability by Kenyan farmers.

2.2.1 Mouldboard plough

Mouldboard ploughs are the most widespread used tillage equipment in the world as well as the biggest consumer of power in tillage. During tillage mouldboard ploughs leave almost no untilled land and result to better pulverization. For this purpose, most researchers have endeavored to carry out numerous studies to optimize the performance of the mouldboard plough either through trial and error method or through semi- theoretical approaches (Sahu & Raheman, 2006).

Figure 2.1 shows a pictorial presentation of a traditional animal drawn mouldboard plough. The parts of a mouldboard plough broadly include: the plough body, hitch, wheel and handle beam assembly. The plough body which comprises of the plough, landside, share and the frog is our area of interest. The depth of the furrow slice can be altered by adjusting the height of the furrow wheels. At the end of the furrow the ox-man lifts the share clear of the soil using the handles and guides the plough in the correct line

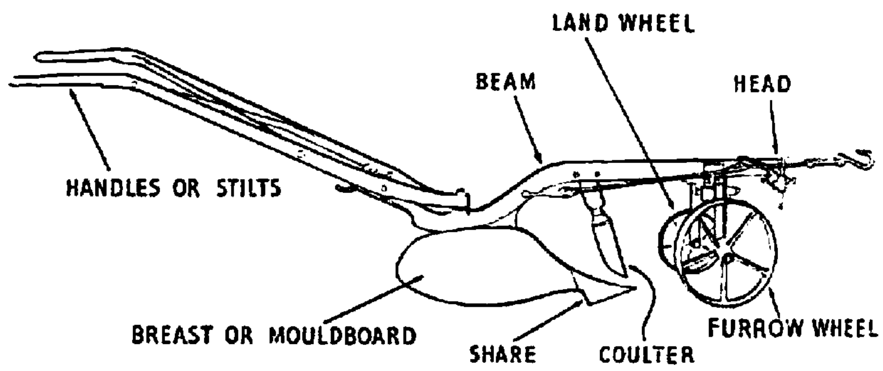


Figure 2.1: Oxen drawn mouldboard Plough (adapted from National Ploughing Association- 2012)

2.2.2. Mode of Operation of the Mouldboard Plough

Mouldboard ploughs are designed to slice the soil, loosen the soil, lift the furrow, fracture it and also invert. By doing so, they bury the plant residues and loosen the soil. The front edge of the mouldboard cuts the soil vertically and the curvature lifts the soil hence inverting the soil. The front edge is called the shin and it easily wears out. If the mouldboard is adjusted, it can flip a furrow slice to 180 degrees (Okoko, 2018).

The share usually points downwards and must always be kept sharp to allow suction. They are attached to the frog by two bolts. Once it faces downwards it can then run in the ground hence suction. There two types of shares; the flat and the upset. In rough conditions the share type used is the upset. Shares can be sharpened if blunt or even replaced if they are worn out. The share cuts the furrow bottom and the shin in turn cuts the furrow wall.

The landside serves as a stabilizer and then holds the plough horizontally as it moves forward. Landsides are adjusted to alter the landside pressure on the furrow wall. They are also adjusted to the frog by bolts. There two types of landsides; plain and the heel type which is not commonly found. If the landside is not replaced after wearing out, it becomes increasing hard to control the plough. The working of the plough can be summarized as in Figure 2.2. Where; at position 1 no shearing is taking place but as the furrow slice is lifted shearing then occurs which is shown in position 2. At position 3 the furrow slice is now bending which then allows the mouldboard to break the soil and invert it (Finner & Straub, 1985)

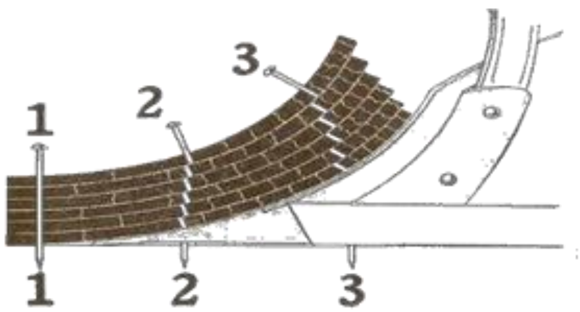


Figure 2.2: Working of the mouldboard Plough: adapted from Finner and Straub (1985)

2.2.3 Disc plough

It is a plough, which cuts, turns and in some cases breaks furrow slices by means of separately mounted large steel discs. A disc plough is designed with a view of reducing friction by making a rolling plough bottom instead of sliding plough bottom. A disc plough works well in the conditions where mouldboard plough does not work satisfactorily (Singh, 2016). There are two types of disc ploughs namely; Standard disc plough and Vertical disc plough.

The standard disc plough consists of steel disc of 60 to 90 cm diameter, set at a certain angle to the direction of travel as shown in Figure 2.3. Each disc revolves on a stub axle in a thrust bearing, carried at the lower end of a strong stand which is bolted to the plough beam. The angle of the disc to the vertical and to the furrow wall is adjustable. In action, the disc cuts the soil, breaks it and pushes it sideways (Singh, 2016; Srivastava *et al.*, 2006). The vertical disc plough combines the principle of regular disc plough and disc harrow and is used for shallow working in the soil.

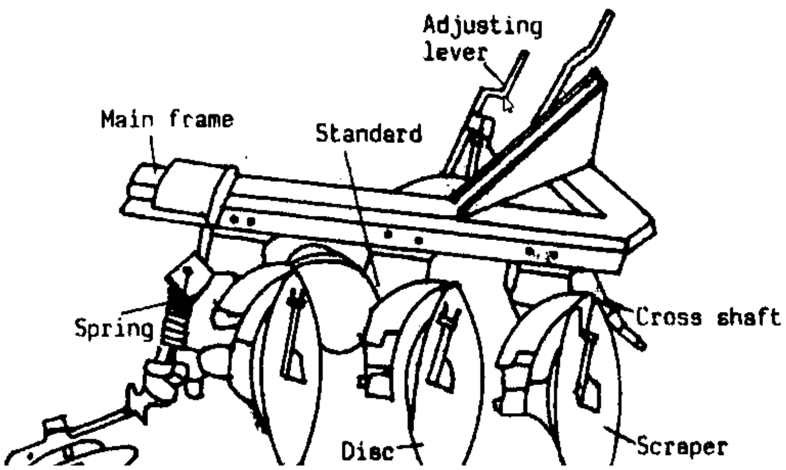


Figure2.3: Standard Disc Plough*:* adapted from Singh (2016)

2.2.4. Mode of Operation of the Disc Plough

A disc plough consists of a series of individually mounted, inclined disk blades on a frame supported by furrow wheel. A tractor –mounted disc plough has only a rear furrow wheel. Disc ploughs are most suitable for conditions under which mouldboard ploughs do not work satisfactory, such as in hard, dry soils, in sticky soils where a mouldboard plough will not scour, and in loose, push-type soils such as peat lands. A mouldboard ploughs, in soils and moisture conditions where it works properly, does a better job than a disk plow and has a lower specific draft (Singh, 2016; Srivastava *et al.*, 2006).

2.3 Factors Affecting Draught and Tilth

The draught of a tillage tool is affected by the soil properties, tool design and operational parameters (Foereid *et al.*, 2015; Naderloo *et al.*, 2009). Soil properties include bulk density, soil strength (compaction), water content, soil texture and structure. Tool design parameters consist of tillage tool rake angle, shape and curvature, aspect ratio, attachments and soil-metal sliding friction. Tillage depth, travel speed and width of cut of implement are the operational parameters. Rashidi *et al.* (2013), stated that depth of tillage and speed of operation have the greatest influence on the draught force requirement with most common tillage tools. Soil compaction is a major factor affecting the draught of most tillage implements hence increasing the cost of tillage operations (Sahu & Raheman, 2006). According to Karlen *et al.* (1997) soil tilth is defined as the physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its promotion of seedling emergence and root penetration. In relation to tillage is the structure of freshly tilled soil defined by the size and shape distribution, spatial arrangement, and internal structure of soil fragments produced by tillage. For a given soil and tillage implement, the tilth obtained depends primarily on soil moisture content at time of tillage (Hillel & Hatfield, 2005)

2.3.1 Effect of Soil Properties on Draught and Performance

2.3.1.1 Effect of Soil Moisture Content on Draught and Performance

Manuwa and Ademosun (2007), conducted investigations to study the influence of moisture content and cone index, on draught force and soil disturbance of some tillage tools including tillage tines. They observed that draught increased at a decreasing rate as soil moisture content increased from 11% to 22.5%. In the first case, the rake angle and depth were held constant at 45^0 and 150mm respectively and speed at 1.0m/s. In the second case, rake angle depth and speed were held constant at 90^0, 150 mm and 1.0 m/s respectively and the cone index was held constant at a mean of 400 kPa. The moisture content varied from 6.0 to 17.5%, the range of moisture content being in the moist or friable soil consistency typical of when tillage operations in loamy soils are undertaken.

Raper and Sharma (2004), observed that decreased moisture content contributed to increased soil disruption above the ground surface as shown on Table 2.1. Very dry soil condition at moisture content of 6.1% had the most disturbed soil cross sectional area with a value of $40.9\times10^{-3}m^2$. Dry condition at moisture content of 8.3% had a cross sectional area of $35.4\times10^{-3}m^2$, moist condition at 13.3% moisture content had $33.6\times10^{-3}m^2$ and wet condition at 16.3% moisture content had $25.2\times10^{-3}m^2$ disturbed soil cross sectional area. Decreased soil moisture also contributed to the enlargement of the trench cross-sectional area.

Table 2. 1: Spoils and trench areas for straight and minimum tillage shanks at different moisture levels. Numbers in parenthesis indicate standard deviation

Moisture level	Disturbed Area $\times10^{-3}\left(m^2\right)$			Trench Area $\times10^{-3}\left(m^2\right)$s		
	Straight	**Min-Till**	**Avg**	**Straight**	**Min-Till**	**Avg**
Wet	27.3 (2.3)	23.1 (2.3)	25.2	74.1(8.3)	69.5 (9.0)	71.8
Moist	35.8 (2.9)	31.3(1.6)	33.6	72.8 (8.2)	68.3 (3.3)	70.6
Dry	37.6(5.9)	33.1 (3.7)	35.4	80.7 (9.8)	73.7 (4.2)	77.2
Very dry	43.8 (7.7)	38.0 (2.9)	40.9	90.7 (9.6)	92.6 (23.3)	91.6
Average	**36.1**	**31.4**	**33.8**	**79.6**	**76.0**	**77.8**

Source: Raper and Sharma (2004)

Manuwa and Ademosun (2007), showed that draught increased with increasing moisture content when tine harrow was used to till the land. Their findings agree with those of Gupta and Surendranath (1989), for a clay soil. However the rate of increase decreased as the moisture content increased and this could be explained by the cohesion of the soil that was weakened by increased moisture content. A decrease in draught with increased moisture content was reported by Ademosun (1990) for a sandy loam soil, this occurred in the region where maximum cohesion of the soil had been overcome by water molecules (Manuwa & Ademosun, 2007).

The effect of soil moisture content on soil disturbance (performance) is shown by Manuwa and Ademosun (2007) in Table 2.2. The parameters of soil disturbance include: maximum width of soil throw (TDW) maximum width of the soil cut (Wfs); also known as width of crescent; the ridge-to-ridge distance (RRD), the height of the ridge (hr); after plough furrow depth (df); and the tool width (W). The tines they used were rectangular in cross-section and the widths were 1.0 cm (T1), 5.1 cm (T5) and 20.0 cm (T20).

Methods used for soil moisture measurement include gravimetric, electrical-resistance, heat-diffusion, absorption, tensiometric, penetration and Neutron probe moisture meters. Gravimetric method involves collecting a soil sample from the field, weighing it before and after drying it at the required temperature. The moisture removed is then calculated as outlined by Javadi and Hajiahmad (2006). This method is the oldest (other than the ancient method of feeling the soil) but still continues to be the most widely used method for obtaining data on soil moisture. It is required for calibrating the equipment used in the other methods because it is the only direct way of measuring soil moisture. Its major shortcoming is in the time and effort required to obtain data. It is time consuming to collect samples from deep the ground, weighing and drying soil samples from the experimental plots or fields (Johnson, 1992).

Table 2.2: Effect of moisture content on soil disturbance for 90^0 rake angle, 150mm depth and 1.0 m/s speed

Parameters of soil disturbance (cm)	T1			T5			T20		
	Moisture Content (%)			Moisture Content (%)			Moisture Content (%)		
	6.0	11.5	17.5	6.0	11.5	17.5	6.0	11.5	17.5
RRD	11.4	9	8	19	16.5	15.5	30.5	30	29
Wfs	12	10.5	9.5	22.5	19.5	18	32.5	31.5	30.5
TDW	14.5	12	10.5	25.5	23	20.5	35	33.5	32
d_f	5.5	6.5	7.0	6.5	7.2	7.8	4.0	4.5	5.5
h_r	2.0	3.5	4.4	3.5	5.5	6.5	5.0	6.0	6.5
Draught, N	150	180	210	450	510	563	1005	1160	1125
* Specific Draught,	12.5	17.1	22.1	20	26.8	31.3	36.2	36.8	36.9

* Specific draught= Draught/disturbed width

Source: Manuwa and Ademosun (2007)

Electrical resistance method uses plots which work on the principle that resistance to electrical flow between the terminals of the plot buried in the soil will depend on the moisture content (Johnson, 1992). The plots are made of porous material which easily absorbs moisture when buried in the soil or gives it out so that the moisture of the plot balances with the soil. This method is fairly faster and the plots are durable however, it is not very accurate especially at higher moisture contents of the soil.

Heat diffusion method is based the principle that the heat conductivity of soil varies with moisture content within the soil. According to Johnson (1992), the temperature rise used by an electrical activated heat source installed in the soil is measured a sensitive device and then correlated with soil moisture content. This method has challenges which includes;

i. Unsatisfactory results when used in soils at moisture content above field capacity
ii. In some cases the correlation between moisture content and all measurements cannot be obtained
iii. They are not available for commercial sources

Absorption method uses porous points or plots that absorb moisture from the adjacent area when installed in the soil. Moisture content is then estimated by change in weigh of the points or plots. This method is more qualitative than quantitative and has considerable inherent errors which have limited its use.

Tensiometric method uses tensiometer which consists of porous point or cap which is filled with water. This water comes into balance with the moisture content of the soil. Water flows out of the point as the soil dries and creates a greater tension, or back into the point as the soil becomes wetter and has less tension. These changes on tension are recorded using the device and data is then correlated to moisture content of the soil. The meters are easy to install and read however the method is limited at lower moisture content and affected by both temperature and soil salinity

Neutron probe moisture meters involve the detection of soil moisture using radioactive element (americium 241). A probe is fed deep into the soil and connected to power supply, microcontroller, display and keypad via wire. The probe contains a source and detector. The fast neutrons are emitted by the source and the detector detects the neutrons that come back after collision and absorption with nuclei of soil and water (Nwogwu *et al.*, 2018). The number of neutrons that come back to probe depends upon the hydrogen and oxygen atoms present in the soil. When a neutron comes into contact with the hydrogen atom, it loses power. So this collision slows down the emitted neutrons, some loses power to such extent that they cannot come back to the detector. Boron trifluoride gas is used in the detector. Gas emit photons when it absorbs the neutrons, so the number of neutrons that come back can be calculated by using an electronic circuit that counts the photons emitted by Boron trifluoride .

Neutron probe method gives fast and reliable measurement. Repeated measurements can be taken at any depth of soil and at any location. The major disadvantage of neutron moisture meter is involvement of radioactive element. This radioactive element requires extensive care to handle and licensed, efficiently trained operator. The equipment is of very high cost and extensive calibration is required. The presence of salts also affects the readings of meter. There are small soil moisture meters which are affordable and overcome the challenge of cost.

Based on the discussions of the methods gravimetric and soil meter methods were chosen for moisture measurement for this study. This is because of at the accuracy of the first method and ease of use of the second method since a lot of data was involved.

2.3.1.2. Influence of Soil Compaction on Draught and Performance of Tillage Tool

Compaction of soil is defined as the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water. According to McKenzie (2010) human-induced compaction of agricultural soil can be the result of using tillage equipment during soil cultivation or result from the heavy weight of field equipment. It is usually measured by use of a cone penetrometer which utilizes a 60^0 right circular cone attached to a smaller shaft. Soil resistance to penetration is measured by an optically indicating dynamometer (Probing ring) as the instrument is pressed into the soil and the resistance is expressed in units of stress (kPa) (Donaldson, 1986).

Mouazen and Ramon (2002) reported that draught increased at an increasing rate as the cone index increased. This agrees with the findings of Manuwa and Ademosun (2007) which showed that draught increased at an increasing rate as the cone index increased from about 200 to 850 kPa. This is because the soil strength (cohesion) increased with increased cone index.

Raper and Reeves (2007) used a cone penetrometer to record the cone index forces at every 3 mm of depth and then reduced the data by averaging the data in 50 mm increments. Cone index value used was taken as the average penetrometer reading that indicates the soil strength or the state of soil compaction.

2.3.1.3. Effect of Bulk Density on Draught and Performance of Tillage Tool

Bulk density is the weight of soil in a given volume. According to Karlen *et al.* (1997) soils with a bulk density higher than 1.6 g/cm^3 tend to restrict root growth and it increases with compaction and tends to increase with depth. Table 2.3 show values of soil bulk density for various soil types and Heiskary and Wilson (2005), classified bulk densities into three categories.

Nkakini and Vurasi (2015), reported increase in power requirenment with increase in soil bulk density using disc plough which shows higher forces to be overcome in ploughing as the bulk density increase. Manuwa and Ademosun (2007), also found a 15 to 35% increase in draught when the soil bulk density of a fine sandy loam was changed from 1680 kg/m^3 to 1830 kg/m^3.

Table 2.3: General relationship of soil bulk density to root growth based on soil texture.

Soil Texture	Ideal bulk densities for plant growth	Bulk densities that affect root growth	Bulk densities that restrict root growth
Sands, loamy sands	<1.60	1.69	> 1.80
Sandy loams, loams	< 1.40	1.63	> 1.80
Sandy clay loams, clay	< 1.40	1.60	> 1.75
Silts, silt loams	< 1.40	1.60	> 1.75
Silt loams, silty clay	< 1.40	1.55	> 1.65
Sandy clays, silty clays,	< 1.10	1.49	> 1.58
Clays (> 45% clay)	< 1.10	1.39	> 1.47

2.3.1.4. Effect of Soil Particle Size on Draught and Performance of Tillage Tool

Particle size refers to the diameter of individual grains of sediment and it is used as the basis for identification and classification of soil into various classes. According to Tagar *et al.* (2014) soil particle size affect failure pattern soil and draught of tillage tools. Soil particle size distributions in a sample determine its texture which affects mechanical behavior and strength of soil. Soils at same mechanical and environmental conditions but different texture behave differently. This further affects soil disruption and pulverization during tillage since it affects cohesion of particles at different moisture content levels (Bashar & Zhou, 2015).

2.3.2 Effect of tillage tool operational parameters on draught

2.3.2.1 Effect of depth on draught

The literature reviewed showed that draught of tillage implements generally increases with depth. Mamman and Oni (2005), observed that draught of tillage tine increased at all levels of tillage depth and rake angle. For 10^0 rake angle, draught increased from 104.02 to 128.44 N at tillage depths of 2.5 and 10 cm, respectively. At a tillage depth of 2.5 cm, draught increased from 104.02 to 125.91 N at rake angles of 10^0 and 30^0 respectively. They reported that for a rake angle of 30^0, draught increased from 125.9 to 158.18 N at tillage depths of 2.5 and 10 cm respectively. For a tillage depth of 7.5 cm, draught against depth curves indicates a sharp increase in draught for all levels of tine rake angle studied.

This consistent increase in draught with depth could be attributed to the increased weight of soil on the tine. The influence of tillage depth on draught at different levels of rake angle was represented by polynomial equations of the second-degree. Desbiolles *et al.*

(1997) had a similar observation as above for disc plough, curved blade, chisel tine and low rake angle tillage tools however, Summers *et al.* (1986) found a linear relationship between draught and depth for mouldboard plough, chisel tine and the low rake angle tillage tools e.g. chisel tines and plough shares. Research findings for low rake angle tillage tools conducted by Desbiolles *et al.* (1997) and those conducted by Summers *et al*. (1986) do not agree, and more studies are required with low rake angle tillage tools.

Mamman and Oni (2005), reported that ploughing using model chisel furrowers in a soil bin at a 20 cm depth, draught was 11.5 kN as compared to ploughing the same field at 30 cm depth which required a tillage tool draught of 17.2 kN. Ploughing the same field at 40cm depth required a tillage tool draught of 33.7 kN. There was a sharp increase in tillage tool draught between 30 cm and 40 cm depths. They reported a linear regression of draught force on measured depth for three tillage tools.

2.3.2.2. Effect of tillage tool speed on draught

The draught requirements of tillage tools as a function of operating speed is an important method for evaluating tillage tool implements either by field or laboratory experiments. Kushwaha and Linke (1996), conducted field experiments with five different tillage tool blades operated vertically in sand, loam and clay soil types up to speeds of 18 m/s to determine the relationship between draught and speed. Three experiments with 18 mm flat tool at an operating depth of 50 mm showed that draught increased sharply as the speed increased from 5 m/s and then increased at a decreasing rate to about the speed of 15 m/s. The experimental results showed that the draught increased less above a critical speed range of 3 to 5 m/s. This critical speed range was compared with the propagation (transmission) speed of a longitudinal pressure wave in the soil, the speed of the soil particles caused by this pressure wave in the soil, and the speed of disruption of the soil. These speeds are related to the observed critical speed range.

Experiments on effects of speed by Upadhyaya *et al.* (1984) showed that the draught of mouldboard and disc ploughs increased as the square of speed, while the increase of draught of many other tillage implement was linear. These relationships were apparently intended only for typical field speeds, which are generally under 4 m/s, above which the relations are different. Kushwaha and Linke (1996) and Sahu and Raheman (2006) reported that the relationship between the draught of plane tillage tools and speed as linear, second-order polynomial, parabolic and exponential. These differences in the findings were noted by other investigators which could be caused by inertia required to accelerate the soil, the effect of shear strength of soil and the effect of shear rate on soil-metal friction, all of which vary with soil types and condition.

Experiments by Mamman and Oni (2005) showed increase in draught with increase in tool speed. Their investigations show that at all levels of speed, draught increased with increase in rake angle. Mean values of draught at 10^0 rake angle increased from 97.91 to 132.35 N at tool speeds of 0.02 m/s and 0.15 m/s, respectively. There were steady increases in draught at a tool speed of 0.02 m/s from 97.91 to 124.84 N at rake angles of 10 to 30^0 respectively. For 30^0 rake angle, draught increased from 124.84 to 160.14 N at tool speeds of 0.02 and 0.15 m/s respectively. The relationship between tool speed and draught of the tools used in the experiments at different rake angles was defined by polynomial equations of the second-degree (Mamman & Oni, 2005).

Summers *et al.* (1986) found a linear relationship between draught and speed for chisel ploughs and disc ploughs; and a quadratic function of speed for mouldboard ploughs. Onwualu and Watts (1998) and Gupta and Surendranath (1989) reported a relationship between draught and speed to be linear, second-order polynomial, parabolic and exponential. A number of reports on the effect of speed on draught have not been consistent. These results may be inconsistent because of different soil conditions during experiments. More investigations need to be conducted on the effect of speed on draught.

2.3.2.3. Influence of tillage implements speed and depth on performance

Tillage implement speed affects the performance in that it tends to produce more pulverized soil (small soil aggregates) at higher speeds than at lower speeds. Higher speeds also increase tillage tool draught (Raper, 2007).

The depth of tillage was found to have an effect on the trench (furrow) width by Raper and Reeves (2007) who reported that tillage at a depth of 20 cm resulted in a trench width of 0.66 m which higher than trench widths at tillage depths of 30 cm and 40 cm which were 0.52 m and 0.44 m respectively. Increased depth of tillage resulted in decreased trench widths which were contrary to popular belief that increased ploughing depth results in wider trench widths. The soil used for this experiment could be partially responsible for this finding with severe compaction near the surface resulting in narrower trench widths when ploughing depth was increased. More research is recommended in different soil types and conditions.

Manuwa and Ademosun (2007) examined the soil failure pattern and soil disturbance ahead and behind the tillage tool shank. The cross-section of the disturbed soil is carefully excavated, leaving undisturbed boundary and examined. The soil disturbance is recorded by laying a steel rule across the disturbances and measuring the vertical distances from the rule to the disturbed boundary (Manuwa & Ademosun, 2007).

The parameters of soil disturbance represented on Figure 2.4 showing furrow cross section include maximum width of soil throw, maximum width of the soil cut also known as width of crescent, the ridge-to-ridge distance, the height of the ridge ; after plough furrow depth, and the tool width.

From the knowledge of the soil disturbance and the draught, equation 2.1 was given for calculation of specific draught (specific resistance) (Manuwa & Ademosun, 2007; Raper & Sharma, 2004).

$$T = \frac{D}{A} \tag{2.1}$$

Where T = Trench Specific Resistance / specific draught, kN/cm^2

D = Draught (kN)

A = Trench Cross-sectional area, cm^2

It is advantageous for resistance to be small because this would indicate small values of draught coupled with large values of below-ground soil disruption.

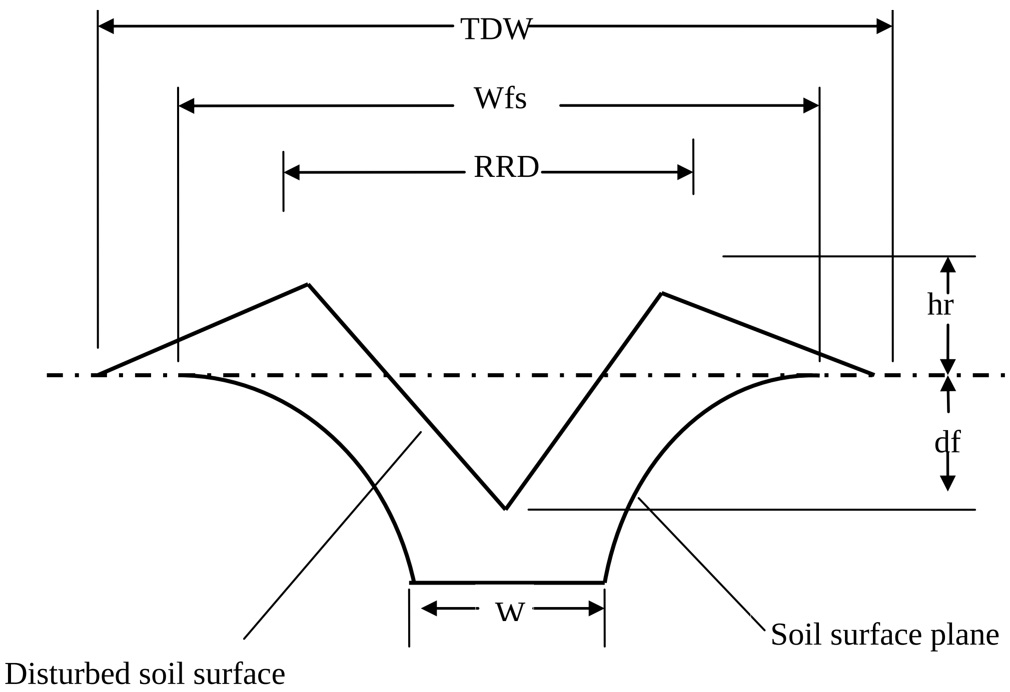


Figure 2.4: Parameters used to define soil disturbance of a tillage tool shank (Manuwa & Ademosun, 2007)

Key: TDW = maximum width of soil throw, Wfs = maximum width of the soil cut/ width of crescent, RRD = the ridge-to-ridge distance, hr = the height of the ridge, df = after plough furrow depth, and W = tool width

2.3.3 Effect of tool design parameters on draught

The width of the cutting blade of a tillage tool affects its draught and overall performance, the draught in the soil increases with increasing width of blade. Attachments to the tillage tool shank will also increase tillage tool draught.

The effect of tillage tool rake angle on draught according to Godwin (1997) is shown Figure 2.5., which indicates that draught of a tillage tool increased at a slow rate up to rake angles of about 45^0. As the rake angle increases further, draught increases at a faster rate. At a rake angle of 90^0, the draught of the tillage tool is doubled and continues to increase sharply at rake angles greater than 90^0.

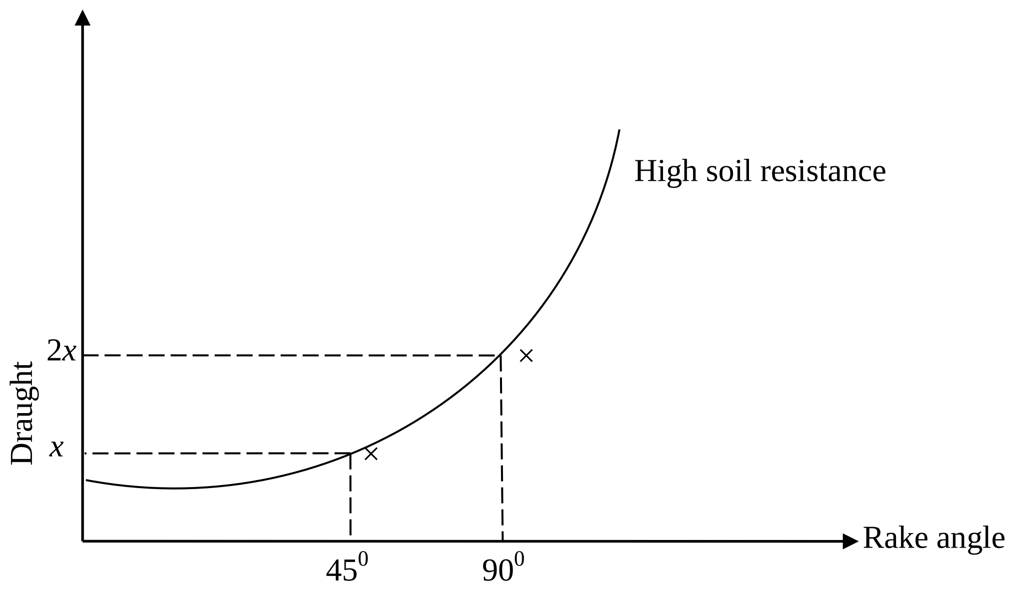


Figure 2.5: Tillage tool draught versus rake angle (Godwin, 1997)

For large rake angles, the tillage tool experiences a large upward soil force. At rake angles of 50^0 to 60^0, the vertical force is zero as shown on Figure 2.6. At smaller rake angles the soil vertical force is negative, but at very small rake angles, the tillage tool penetration into the soil is a problem (Godwin, 1997).

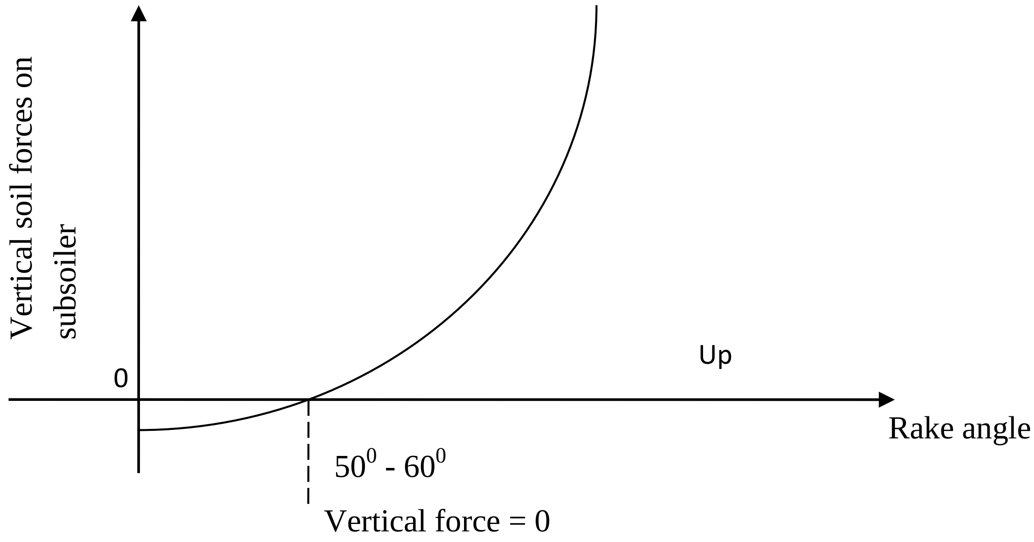


Figure 2. 6: Tillage tool rake angle versus vertical force (Godwin, 1997)

2.4 Tillage power requirement

Power is defined as the rate of doing work. It is the amount of work accomplished per unit of time. In equation form, power (P) is defined as follows:

$$P = F \times \left[\frac{x}{t}\right] \tag{2.4}$$

where x is distance travelled by force (F) in time (t).

Therefore for the tractor the power requirement during tillage was directly calculated from the measured draught force and the speed of travel according to Goering (1992) who gave a formula for calculation of linear power as;

$$P = \frac{F \times S}{K_{LP}} \tag{2.5}$$

Where P= linear power in kW

F= force in kN

S= speed in km/h

K_{LP}= units constant = 3.6 and subscript LP refers to Linear power

The author further described a formula based on the amount of fuel consumed by the tractor and called it fuel equivalent power which can be computed from the product of fuel consumption rate and the heating value of the fuel;

$$P_{fe} = \frac{HV \times M_f}{K_{fe}} \tag{2.6}$$

Where P_{fe}= fuel equivalent power in kW

HV= heating value of fuel in kJ/kg

M_f= fuel consumption rate in kg/h

K_{fe}= units constant = 3600 and subscript *fe* refers to fuel equivalent

In the current research equation 2.5 was used to determine the draught power requirement for the implements used.

2.5 Models for implement tractor matching

Awulu *et al*. (2016) developed a computer program for the purpose of matching tractors and tillage implements with the aim of reducing chances of overloading or under loading of tractors. The program was majorly based on American Society for Agricultural and Biological Engineers (ASABE) standard equations for predicting draught power requirement. The program was developed using visual C++.

Similar works was also done by Grisso and Perumpral (2014) who demonstrated the use of a spreadsheet for matching of tractors and tillage implements. The spreadsheet was based on the Brixius model and American Society of Agricultural Engineers (ASAE) standards D497.5 to predict tractor performance and implement draught respectively. The cases they considered were; three tractors of different power levels and configuration, three different implements and three soil types. Al-Janobi *et al.* (2010) also developed an excel spreadsheet to estimate performance parameters for chisel plough-tractor combination during tillage process based on artificial neural network.

2.6 Summary of literature review

Reducing the number of tillage operations has been found to reduce the amount of fuel used with no significant change in production according to studies by Abdallah (2015), Thiagalngam *et al*. (1996) and Sessiz *et al.* (2010). Rashidi *et al.* (2013) stated that depth of tillage and speed of operation has the greatest influence on the draught force for most common tillage tools. There is a general increase in draught hence power required for tillage with increase in soil moisture content according to studies by Manuwa and Ademosun (2007) and Gupta and Surendranath (1989).

A number of findings on the effect of speed on draught have not been consistent. These results may be different because of the conditions of the experiments. More investigations need to be conducted on the effect of speed on draught. The influence of tillage depth on draught at different levels of rake angle was represented by polynomial equations of the second-degree. There was a sharp increase in tillage tool draught between 30 cm and 40 cm depths. Mamman and Oni (2005) reported a linear regression of draught force on measured depth for three tillage implements. Both the speed of operation and depth of tillage are found to have an effect of performance as reported by Raper and Reeves (2007) and Manuwa and Ademosun (2007). Farm managers use the draught and power requirements data of tillage equipment in the specific soil type to determine the size of the tractor and tillage equipment required. The draught requirements are mainly a function of: soil properties, tool geometry, working depth and speed (Saunders *et al.,* 2007).

Soil moisture content and compaction are conditions that have been found to affect draught power, specific power and performance of tillage implements. This study did not study these effects but the results will be based on the in-situ moisture and bulk density of the soil at the time of experiment.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Study Area

Field experiments were conducted at Ngongongeri farm, Egerton University, Njoro, located 25 km west of Nakuru town, Kenya. The climate in Njoro area is characterized by tri-modal precipitation pattern with long rains occurring from March – May and an additional small peak occurring in August, and another in October – November. Mean annual rainfall measured at Kenya Agricultural and Livestock Research Institute (KALRO) Njoro between the years 1990 1nd 2013 is 1200 mm as shown in Figure 5 in appendices. Average annual minimum and maximum temperatures for the area are 9° and 24° respectively. The elevation of the area is about 2300 m above mean sea level. The study site has a gentle slope of less than five percent and vast agricultural land.

3.2 Preliminary Studies

The area of land required for study was determined based the number of variables and replications which was found to be 1.8 Hectares. The land was further divided into 18 plots and pegs placed at the start and end of every plot. The length and width of each plot was 30 m with inter plot space of 10 m to allow for turning of the tractor as shown in Figure 3.1. Soil samples were collected randomly from each of the plots for laboratory analysis before field studies. Collected sol samples were put in moisture cans and labeled with reference to plot number and depth. Moisture content of soil was measured in situ using a moisture meter. Samples were then taken to a laboratory for determination of gravimetric moisture content, bulk density and soil texture.

3.2.1 Soil Bulk Density Determination

Tests were carried out to determine soil bulk density within the plot before the experiment was carried out in each experimental plot and the chosen depths of tillage. During soil ample collection for bulk density determination a soil core ring was driven into the soil at the required depth and then carefully dug out as shown in Plate 3.1.every plot to improve on the accuracy of the data. The dug out core ring and the soil sample was taken and soils protruding at both ends were carefully trimmed using a knife as shown on Plate 3.2. The sample was then kept in polythene paper to avoid any moisture losses and taken to the laboratory for analysis. The soil sample in the ring was weighed and put in the oven for drying for 24 hours at a temperature of 105 ºC.

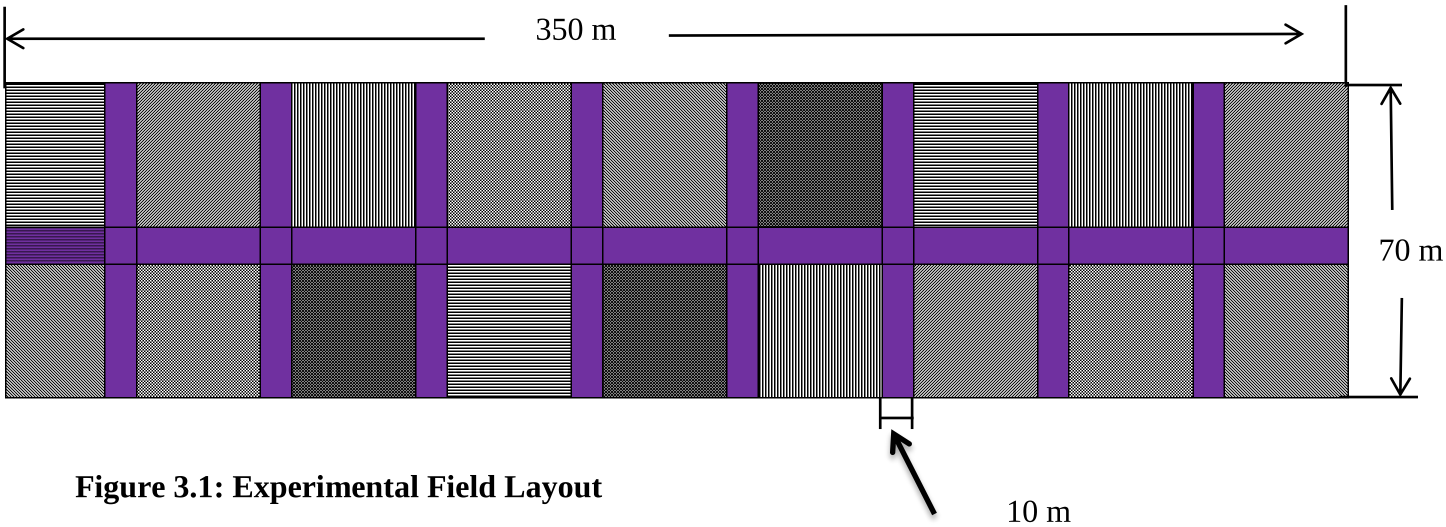
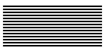
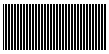
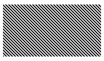


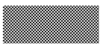
Figure 3.1: Experimental Field Layout

Key

Disc plough

Hatch	Acronyms	Meaning
	$D_1S_1S_2S_3$	combination of depth 1 and speeds 1,2 and 3
	$D_2S_1S_2S_3$	combination of depth 2 and speeds 1,2 and 3
	$D_3S_1S_2S_3$	combination of depth 3 and speeds 1,2 and 3

Mouldboard plough

	$D_1S_1 S_2S_3$	combination of depth 1 and speeds 1,2 and 3
	$D_2S_1 S_2S_3$	combination of depth 2 and speeds 1,2 and 3
	$D_3S_1 S_2S_3$	combination of depth 3 and speeds 1,2 and 3
		Interplot space for turning, 10 m

The weight of the dry samples was then taken and recorded, dry soil sample was then removed and the weight of the ring taken. The height and diameter of each ring was also measured and recorded and the respective volume calculated. This procedure was repeated for all samples and bulk density calculated using equation 3.1

Plate 3. 1: Driving the core ring to required depth

.

Plate 3. 2: Removing excess soil from the ends of core ring

Equation 3.1 was used to determine the soil bulk density for the samples collected from the plots

$$\rho = W_d \div V \qquad (3.1)$$

Where;

ρ is bulk density in g/cm^3

W_d is dry weight of soil sample (g)

V is volume of soil core ring (cm^3)

Weight of sample was determined using equation 3.2 below;

$$W_d = \frac{w_{dc} - w_c}{1 + mc} \qquad (3.2)$$

Where;

w_{dc} is weight of field moist soil plus can (g)

w_c is weight of can (g)

mc is soil moisture content

3.2.2 Soil Moisture Content Determination

The soil moisture content was determined by gravimetric method as discussed above and direct measurement using soil moisture meter (model VG-METER-200) whose specifications are given in Table 3.1 and reading taken as shown in plate 3.3. The gravimetric method was taken as the control and the data from it used to calibrate the soil moisture meter which was used for most measurements because it was less time consuming.

Table 3.1: Soil Moisture Meter Specifications

VG-METER-200	
Batteries	2 AA
Dimensions	Enclosure: 2.5cm x 6.4cm x 94 cm (1in x 2.5in x 3.7in)
Operational Temperature	-20ºC to 85ºC
Baud Rate	9600, 8 bits, No Parity, 1 stop bits
Sample output rate (USB version)	1 sample/second
Cable Length	1.2 meters (4 ft)

This meter uses VH400 soil moisture sensor, and presents soil moisture results as a simple percentage (VWC).

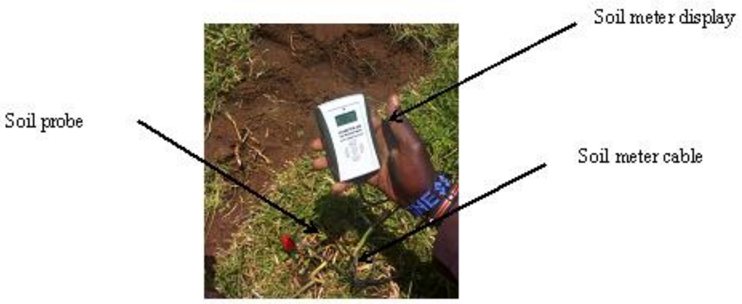


Plate 3.3: Taking of moisture reading using a moisture meter

3.2.3 Soil Texture Determination

The soil particle size distribution was determined using hydrometer method. In this method the first stages was to oven dry the soil sample and then disperse the soil into the individual particles. This method relies on the effects of particle size on the differential settling velocities within a water column. After the soil was dispersed into smaller particles the sample was passed through a 2 mm sieve and the soils of diameters < 2 mm collected. A 50 g of the collected sample was weighed out and the weighed sample saturated with distilled water and 100 ml of 10% calgon solution added to it. The sample was allowed to settle for 10 minutes then transferred to a dispersing cup and topped to the mark using distilled water. The suspension was mixed using an electric stirrer for 2 minutes and then transferred into a graduated cylinder. The cylinder was then covered with a tight-fitting rubber stopper and the suspension mixed by inverting the cylinder carefully ten (10) times. Two drops of amyl alcohol was added to the sample in order to remove froth and the hydrometer gently placed into the column. The hydrometer and temperature readings were taken after 40 minutes and 2 hours. The readings were then used to calculate soil particle distribution as percent sand, percent silt and percent clay. The calculated percentages were used together with textural triangle to establish the class of the soils in the field. Using the soil texture triangle, scientists have created classes which break the distribution of particle sizes into 12 categories: clay, sandy clay, silty clay, sandy clay loam, clay loam, silty clay loam, sand, loamy sand, sandy loam, loam, silt loam and silt.

After 40 seconds, the sand has settled and the hydrometer reading reflects the amount of silt and clay in 1 litre of the suspension. The percentage of sand was determined using equation 3.3:

$$\%sand = \frac{50 - x}{50} \times 100 \tag{3.3}$$

Where;

x is the hydrometer reading after 40 seconds (grams per litre).

50 is the weight of soil sample that was saturated in 1 litre of water

After 2 hours, the silt would have settled. The hydrometer reading now reflected the clay content of the original suspension and percentage clay was determined using equation 3.4;

$$\%clay = \frac{y}{50} \times 1000 \tag{3.4}$$

Where;

y is the hydrometer reading after 2 hours (g/l).

The silt content was calculated according to equation 3.5

$$\%silt = 100\% - (\%sand + \%clay) \tag{3.5}$$

These percentages were then used in the soil textural triangle shown in Figure 3.1 to classify the soil.

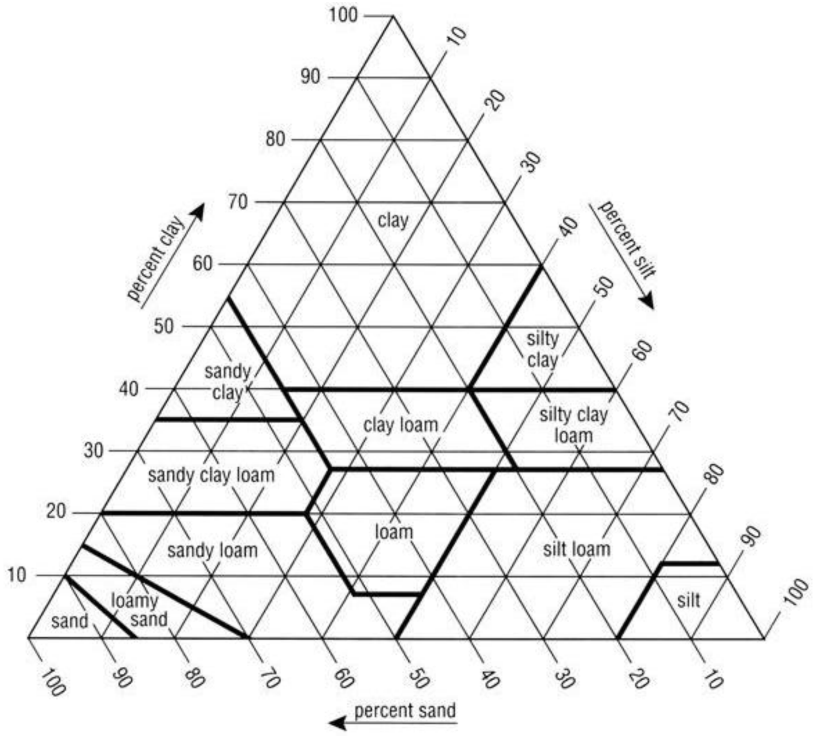


Figure 3.2: Soil textural triangle used for soil classification

Analysis of soils in the experimental site showed that percentages of sand, silt and clay were obtained as 37%, 51% and 12% respectively and the soil classified as silt loam using the textural triangle. Moisture contents were 27% at 6.5 cm and 26% at 12.5 cm and 22.5 cm depths. Bulk densities were 1.30 g/cm^3, 1.40 g/cm^3 and 1.36 g/cm^3 at corresponding depths. These results showed that the soil conditions were homogenous hence treatments were completely randomized within the plots as shown in Figure 3.1 so as to be able to have replications.

3.3 Experimental Setup

The numbers of variables were two; tillage depth and speed, using disc and mouldboard ploughs. The various depths that were used were denoted as D1, D2 & D3, which were 6.5 cm, 12.5 cm and 22.5 cm respectively; this was because the study was intended for normal tillage depths. Speeds were denoted as S1, S2, & S3 and whose values were 1.3 km/h, 2.3 km/h and 3.0 km/h; these speeds were chosen and used since they were easily attainable on the tractor used and were within the typical tillage speeds. For both the ploughs the width of cut was 80 cm. There were three replications for every level combination on three separate plots as depicted by same shading in Figure 3.1, and three runs within each plot.

Two tractors were used for the field experiments and the set-up was as shown in Figure 3.3 and Plate 3.4. Tillage implement was hitched on the three-point hitch system of tractor *B* so that the depth of tillage was controlled using the tractor hydraulics. Tractor A was used to pull tractor B which was on neutral gear position during operation and tillage implement through the dynamometer during operations.

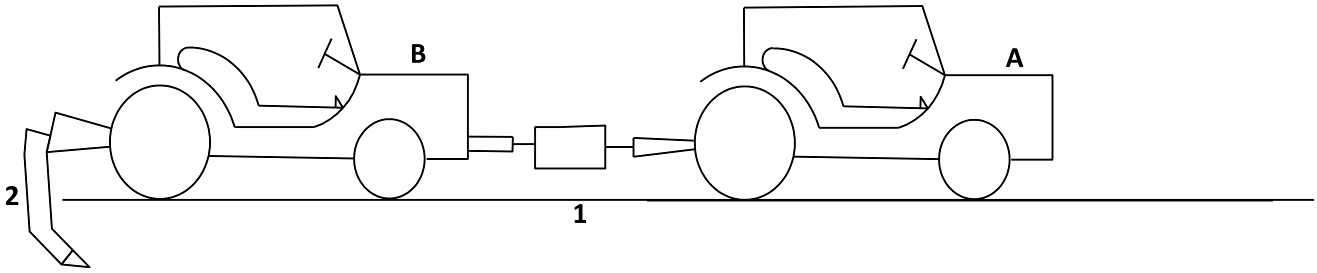


Figure 3. 3: Experimental set-up comprising of two tractors and load cell

A - Tractive tractor
B - Tractor hitched with the tillage tool
1 - Dynamometer
2 - Tillage tool

Plate 3. 4: Field set-up comprising of two tractors and load cell

The draught readings were taken by a digital dynamometer which was remotely connected to a display that was in turn connected to the computer to allow for automatic recording and saving of data obtained. The operator of the display system and the computer was located at the midway of the land clear of any obstacles as shown on Plate 3.5.

Plate 3.5: Dyna-Link 2 tension dynamometer set-up

The digital dynamometer uses disposable cells as the source of power with the display unit having in-built rechargeable battery and shackles at both ends to allow for mounting between the two tractors. The display section is well reinforced to prevent breakage while in use. Calibration was done to change: units of the draught values, the accuracy level and how the draught values were recorded. The Dyna-Link 2 was calibrated using standard precision test weights. During calibration weights of known value were suspended on the dynamometer which was hanged on hoist within the workshop. The weights were increased from 50 kg to 500 kg varying by 50 kg.

Units inbuilt in the system are: pounds (lbf), kilograms (kgf), kilo Newton (kN) and Tonnes (T); for this experiment the values were recorded in kilo Newton (kN). The accuracy levels were given to two decimal places. The dynamometer was then connected remotely to a display which showed actual values on the dynamometer which were then transferred to the computer through a universal serial bus (USB) cable for automatic saving. However, an interface was required to allow compatibility of the display system to a computer. The manufacturer of the dynamometer provided interface software called Tera Term as shown on Plate 3.3. After the software was installed into the computer the recorded values were saved in a tera term window in a version of a note pad which was later saved in Microsoft excel for analysis.

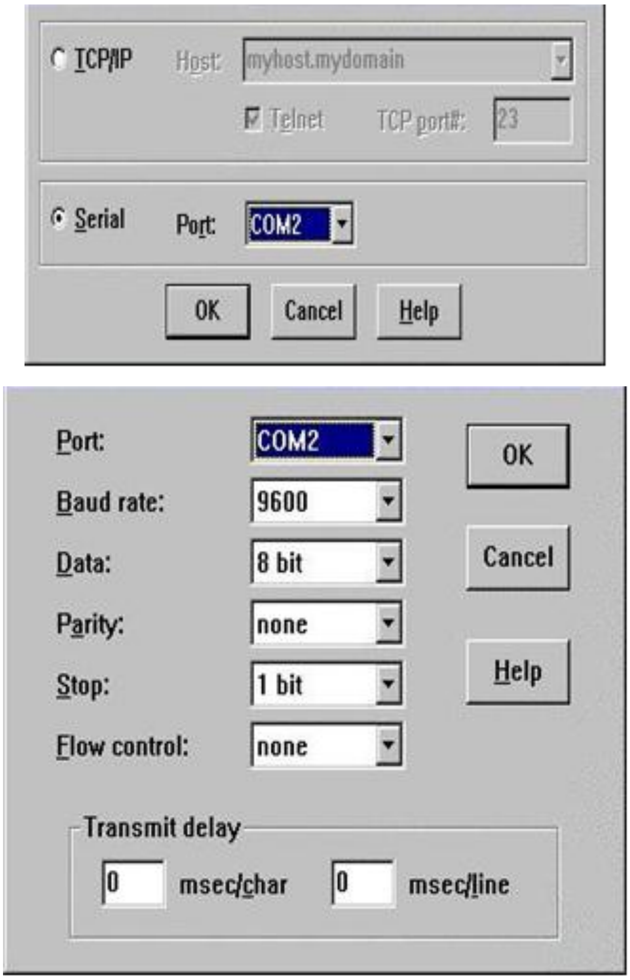


Plate 3.5: Tera Term Iinterface Extract

3.4 Determination of Drawbar Power Requirements

Towed force was determined for each plot and at each speed which was later subtracted from gross drawbar force to get net force using equation 3.6. The drawbar forces were measured while ploughing at various depths and speeds for both the disc and mouldboard plough and recorded as gross force (Figure 3.3 and Plate 3.4)

$$F_n(kN) = F_g - F_t \quad (3.6)$$

Where;

F_n is the net force

F_g is gross force which is the total force measured when the rear tractor has the tillage implement lowered into the ground to the required depth and moved at the required speed

F_t is towed force which is the total force measured when the rear tractor has the tillage implement raised from the ground and moved at the required speed.

The net force was then multiplied with the speed of operation to give the power requirement at each level of the experiment using equation 3.7.

$$DBP = F_n \times V \quad (3.7)$$

Where;

DBP is drawbar power, kW

V is forward speed, m/s

Average value of drawbar power was used at each depth and speed for analysis using excel software since there were several values of draught recorded by the dynamometer at each depth and speed during experimentation.

The drawbar power required to plough a unit volume of soil referred to as specific drawbar power was calculated by dividing the total power by the ploughed soil volume at each depth of tillage and forward speed by using equation 3.8.

$$\text{specific power} = \frac{\text{drawbar power (kW)}}{\text{ploughed soil volume}(\text{m}^3)} \ \text{kW.m}^{-3} \quad (3.8)$$

The ploughed volume was determined using equation 3.9;

$$\text{V} = \text{LWD} \ (\text{m}^3) \quad (3.9)$$

Where:

D is the ploughing depth, m

L is length covered in one second, m

W is the width of cut, which was fixed for the two implements, m

3.5 Measurement of performance of disc and mouldboard ploughs

Performance was evaluated based on pulverization ratio and soil inversion, trench formed and resulting specific resistance. Soil samples were taken from the field after tillage from each plot and passed through a sieve of 25 mm diameter and the weights of the soil passing the sieve measured. Pulverization ratio was determined as percentage of the weight of soil fraction which is less than 25 mm diameters to the total weight of clods produced during ploughing.

Soil inversion was evaluated based on the amount of vegetation cover before and after tillage and the level of cut soil slice turning in reference to un-ploughed ground level. An area of 1 m^2 was marked out within the plots and number of weeds before and after ploughing counted and recorded. Soil inversion was calculated as a percentage of the number of buried weeds to total number of weeds using equation 3.10 given as;

$$SI = \frac{NW_i - NW_f}{NW_i} \times 100 \qquad 3.10$$

Where;

NW_i is number of weeds before ploughing

NW_f is number of weeds after ploughing

The surface soil disturbance or spoil is a measurement of the amount of soil crown above the original soil surface by the tillage process and subsurface soil disruption or trench, is the area that is disrupted below the soil surface (Shinde *et al.,* 2011). In this study the trench formed was studied for both the disc and mouldboard ploughs at various speeds and depths of tillage. Dimensions of the trench were measured with the help of an improvised system having a ruler, plumb bob, spirit level and a straight edge. The straight edge was fixed across the trench and a 30 cm ruler was moved with knobs and spirit level to keep it horizontally leveled. With the help of plum bob the vertical depth of the soil surface was determined at every 2 cm horizontal distance on the main scale. Three replications of soil disruption were recorded for each of the tillage tools. The performance of tillage implements were compared on the basis geometric parameters of spoil and trench profiles and their areas of disruption (Shinde *et al.*, 2011; Zhang *et al.*, 2007), as discussed in literature review.

3.6 Data Analysis

Experimental data were subjected to statistical analysis based on a completely randomized design (CRD) with a factorial of 2x3, to determine the effects of forward speed and tillage depth on drawbar power, specific drawbar power and performance using Excel programme. Analysis of Variance (ANOVA) tests were carried to investigate effects speed and depth. Regression analysis was also carried out to develop mathematical models for the relationships between specific drawbar power, speed and tillage depth. Results were recorded and discussed in Chapter Four.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Preliminary Studies and Dynamometer Calibration

The soils in the experimental site were sampled and tested for soil texture, moisture content and bulk density. The percentages of sand, silt and clay were obtained as 37%, 51% and 12% respectively and the soil classified as silt loam using the textural triangle. Moisture contents at the time of experiments were 27% at 6.5 cm and 26% at 12.5 cm and 22.5 cm depths. Bulk densities were 1.30 g/cm^3, 1.40 g/cm^3 and 1.36 g/cm^3 at corresponding depths.

4.2 Effects of Depth and Speed on Power Requirement for Disc and Mouldboard Ploughs

Effects of depth and speed of operation on drawbar power for disc and mouldboard ploughs are as shown in Table 4.1.

Table 4.1 Drawbar Power in kW for disc and mouldboard ploughs

Implement		**Speed (km/h)**		
Disc plough	Depth(cm)	1.3	2.3	3.0
	6.5	1.84 ± 0.045	3.46 ± 0.170	4.73 ± 0.025
	15.0	3.09 ± 0.146	5.60 ±0 .265	7.49 ± 0.249
	22.5	3.80 ± 0.354	6.49 ± 0.500	8.93 ± 0.228
Mouldboard plough	6.5	2.30 ± 0.159	4.04 ± 0.103	6.91 ± 0.426
	15.0	3.31 ± 0.165	6.25 ± 0.147	8.61 ± 0.350
	22.5	3.84 ± 0.285	7.40 ± 0.375	9.85 ± 0.524

4.2.1 Effects of Depth of Ploughing on Power Requirement at various speeds for Disc Plough

The drawbar power increased with increasing depths as shown on Table 4.1 and represented in Figure 4.1 for the disc plough. These results concur with the observations made by Mamman and Oni (2005) who observed that power increased at all levels of depth when experiments were carried out at 2.5 cm, 5.0 cm, 7.5 cm and 10.0 cm while Abdallah (2015), reported similar results for plough depths of 10 cm, 15 cm and 20 cm the disc plough.

When the speed of tillage was 1.3 km/h (0.36 m/s) as shown on Table 4.1 and Figure 4.1, power increased from 1.844 kW to 3. 798 kW when the depth was varied from 6.5 cm to 22.5 cm. This translates to an increase of 0.122 kW per centimeter increase in tillage depth. At a speed of 2.3 km/h and with depth of tillage varied at similar range, power increased from 3.463 kW to 6.489 kW giving 0.189 kW increase per centimeter change in tillage depth. Similarly, at 3.0 km/h power increased from 4.725 kW to 8.926 kW which is equivalent to 0.263 kW increase per centimeter.

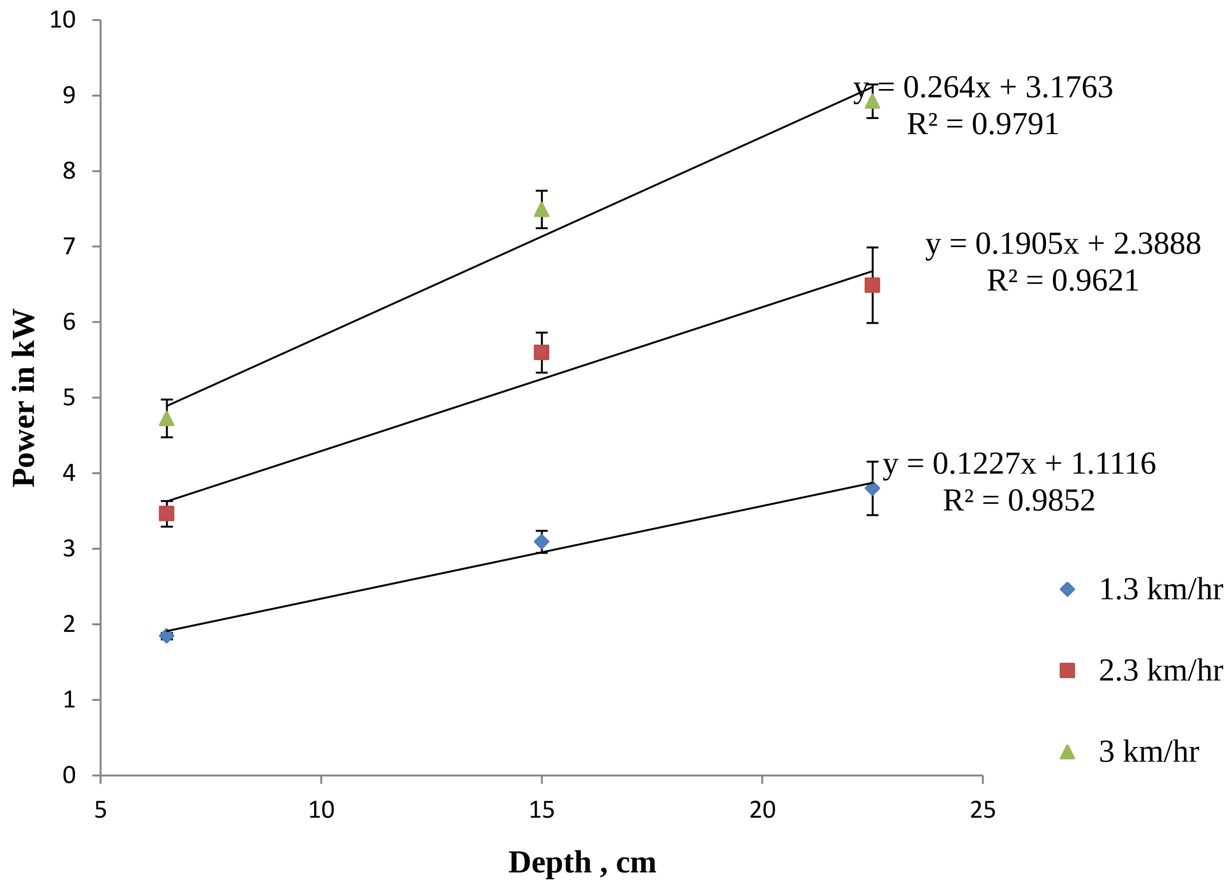


Figure 4.1: Drawbar power with depth for disc plough at different speeds

4.2.2 Effect of Ploughing Depth on Power Requirement for Mouldboard Plough

Results for mouldboard plough presented on Table 4.1 Figure 4.2 shows that power increased with increase in tillage depth, which is also in agreement with earlier studies ((Abdallah, 2015; Kushwaha & Linke, 1996; Mamman & Oni, 2005; Naderloo *et al.*, 2009; Ranjbarian *et al.*, 2017). At a speed of 1.3 km/h power increased from 2.299 kW to 3.842 kW which is equivalent to 0.053 kW per centimeter increase in depth. While operating at 2.3 km/h power increased from 4.031 kW to 7.395 kW resulting to a change of 0.210 kW per centimeter. The highest was at 3 km/h when power increased from 6.910 kW to 9.851 kW which is corresponding to an increase of 0.184 kW per centimeter.

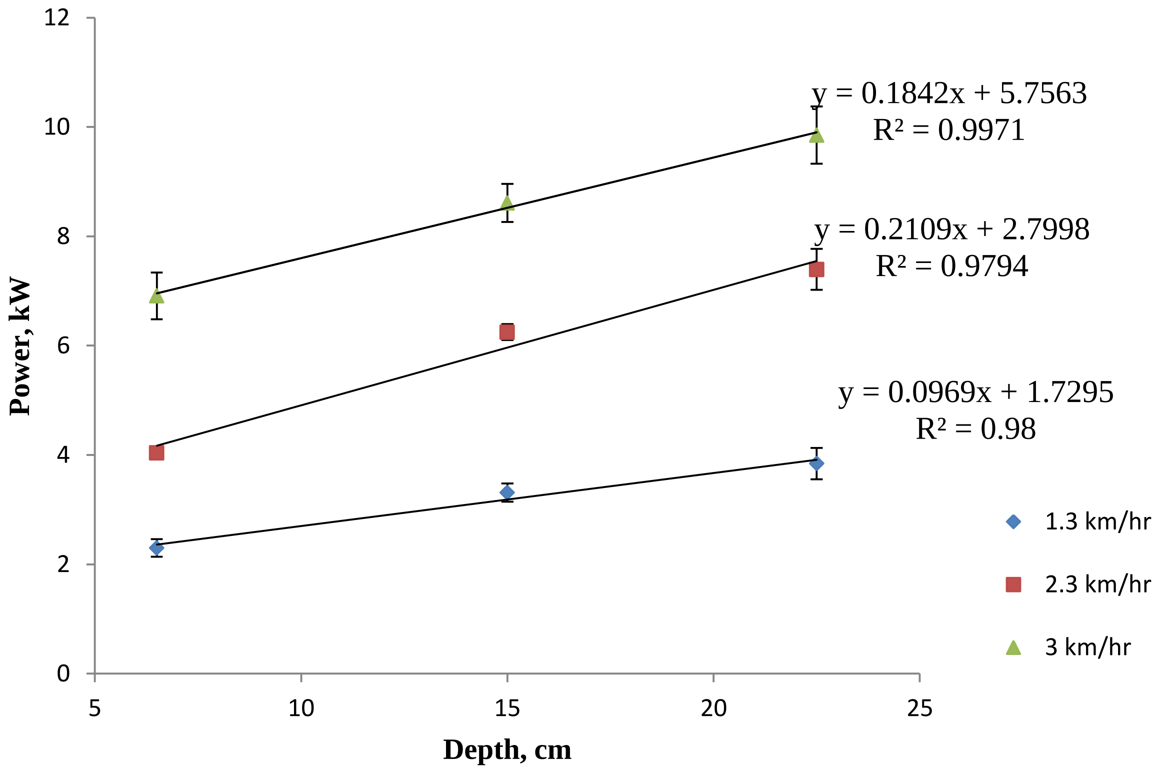


Figure 4.2: Power against depth for mouldboard plough

Comparison of the effect of depth on power by the two primary tillage implements showed that at all levels of depths, mouldboard plough had higher power requirement as compared to the disc plough as shown in Table 4.2 and Figure 4.3.

Results on Table 4.2 are represented graphically on Figure 4.3 showing relationship between depth of tillage and draught power given for mouldboard plough and disc plough. Mathematical models predicting the relationships are given by equations 4.1 and 4.2 for mouldboard and disc ploughs respectively.

Table 4.2: Power in kW at various depths for the disc and mouldboard ploughs

Parameter	Implement	
Depth (cm)	Disc	Mouldboard
6.5	3.344	4.416
12.5	5.393	6.056
22.5	6.404	7.029

y_m = 0.16x+3.23; R^2=0.99 (4.1)

y_d= 0.19x+2.23; R^2=0.98 (4.2)

Where; y is power in kW

Subscripts d and m refers to disc and mouldboard ploughs respectively.

x is depth of tillage in centimeters, cm.

Coefficient of determination, R^2 values show a strong relationship between the factors tested. Power requirement for mouldboard plough changed from 4.416 kW to 7.029 kW when tillage depth was varied from 6.5 cm to 22.5 cm. This results into an increase of 0.163 kW per unit change in depth of tillage. For the case of disc plough it increased from 3.344 kW to 6.404 kW which is equivalent to an increase of 0.191 kW. This indicates slightly higher increase rate for the disc as compared to mouldboard plough even though the later had higher power requirements. This observation concurs with among others, Naderloo *et al.* (2009) who carried out a similar study on clay loam soils at depths of 10, 17 and 22 cm.

Increase in draught power at different tillage depths can be attributed to the increased volume of the mass of soil being supported, moved forward and inverted by the plough bottom. This phenomenon is more in the mouldboard because of the geometry of its bottom which consist of a rigid assembly while the disc plough has a rotating circular disc which reduces the dragging effect hence less resistance.

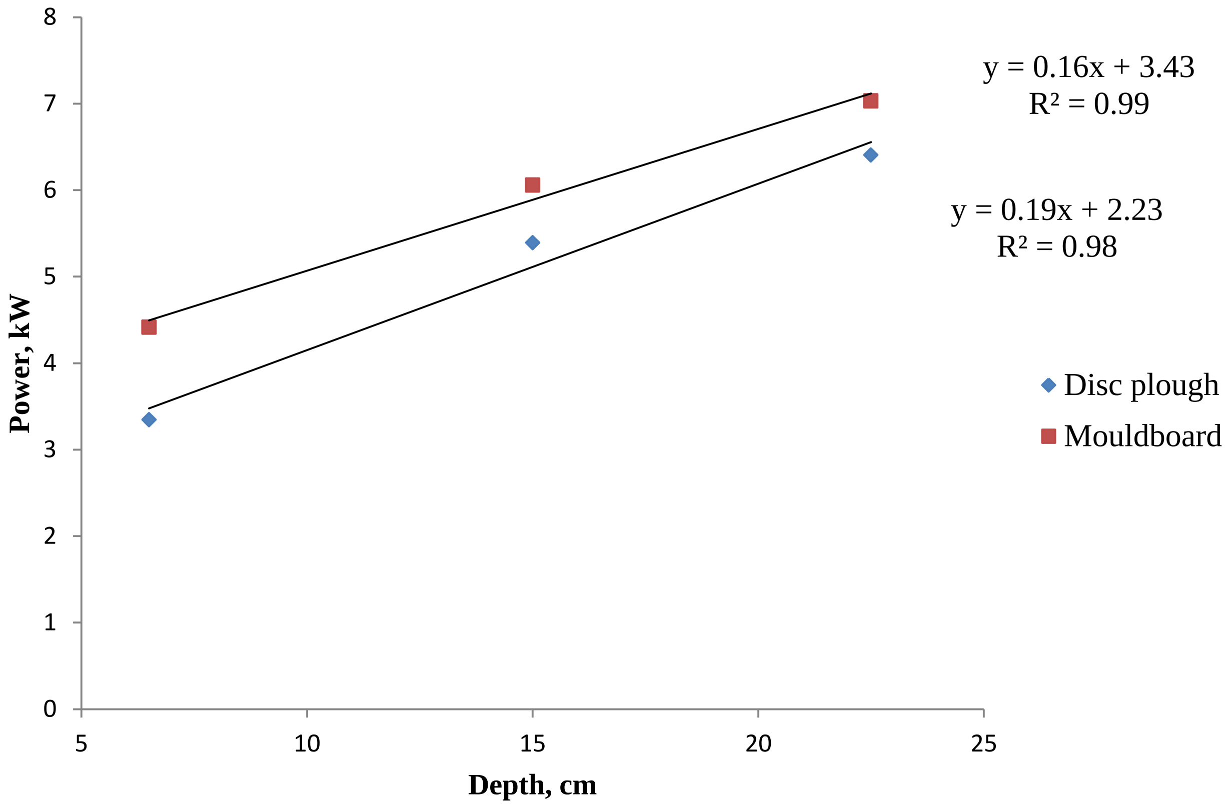


Figure 4.3 Power against Depth for disc and mouldboard plough

4.2.3 Effects of Speed of Ploughing on Power Requirement at Various Depths

Table 4.1 and Figure 4.4 show the relationship of power and speed of tillage for disc plough at various depths of tillage. Power was found to increase with increase in speed of tillage. The value increased from 1.844 kW to 8.926 kW while the speed was increased from 0.36 m/s to 0.833 m/s. This agrees with studies by Kushwaha and Linke (1996) which showed that power increased linearly with speeds below 3 m/s but less above speed range of 3 to 5 m/s. This increase in power with increase in speed can be as a result of the high acceleration of the cut soil slices as they are displaced and turned by the plough bottom. Similar results are shown on Figure 4.5 for mouldboard plough. A. Al-Janobi and Al-Suhaibani (1998) concluded that speed significantly affected power requirement by tillage implements when they conducted their study in sandy loam soils.

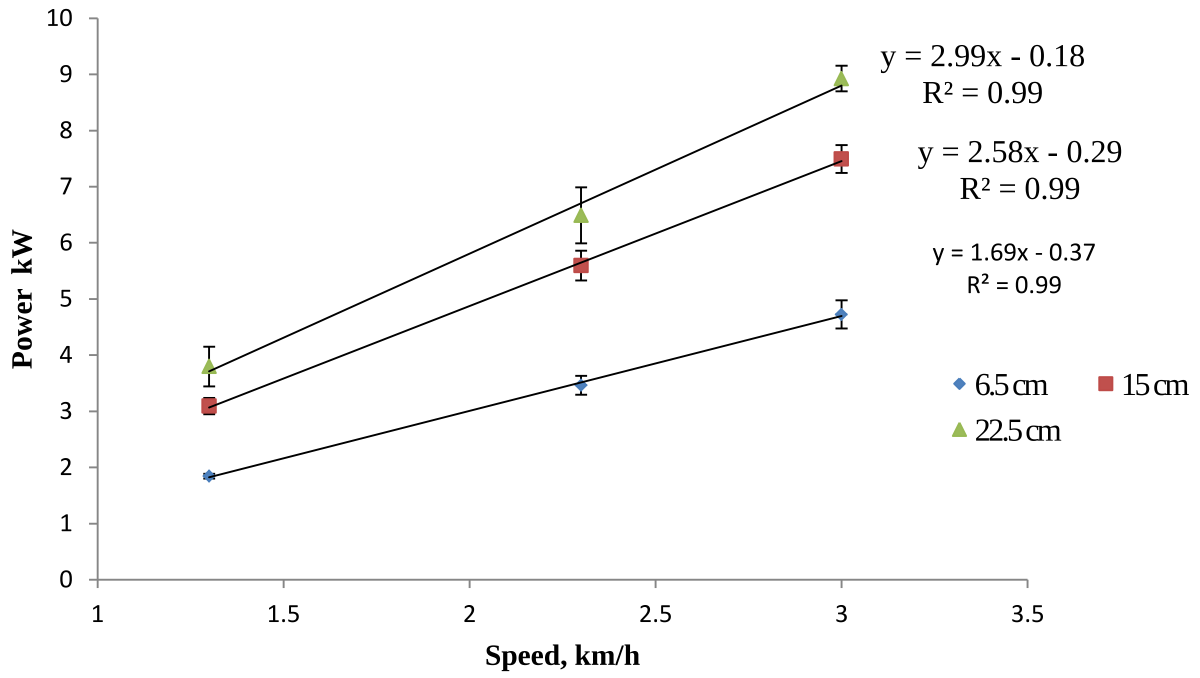


Figure 4.4: Variation of drawbar power with speed for disc plough

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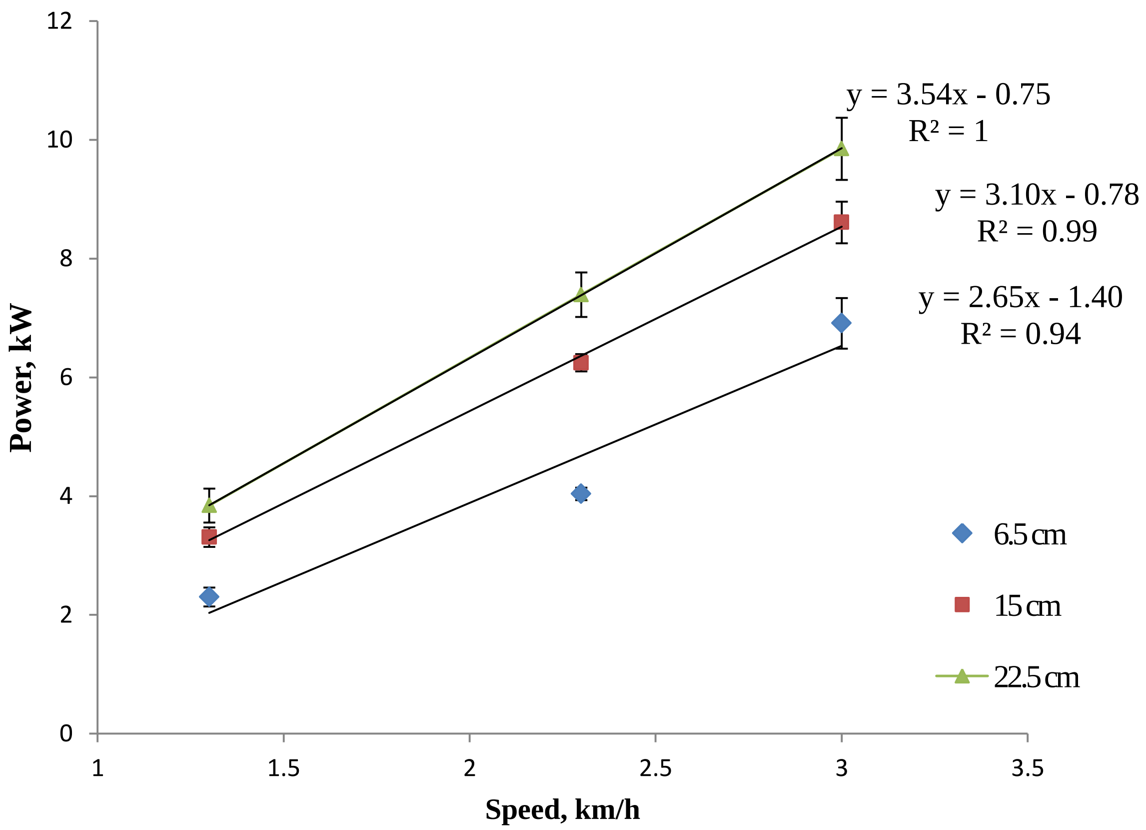

Figure 4.5: Changes in drawbar Power with speed for mouldboard plough

Figure 4.6 gives comparison of the effect of forward speed on power requirement by the disc and mouldboard plough. From the data presented mathematical models for predicting power requirement based on speed of tillage are given by equations 4.3 and 4.4 for mouldboard and disc ploughs respectively.

$$y_m = 3.10s - 0.98; R^2 = 0.99 \quad (4.3)$$

$$y_d = 2.42s - 0.28; R^2 = 0.99 \quad (4.4)$$

Where, s is the speed of tillage and must be greater than Zero.

Ranjbarian *et al.* (2017) in their studies found similar draw bar power prediction equations given by $y = 3.68x - 2.14$, $R^2 = 0.98$ for mouldboard and $y = 3.83x - 2.75$, $R^2 = 0.98$ for disc plough. From their findings it implies power requirement at zero speed will be -2.14 and -2.75 kW for the respective ploughs which is not physical. In both cases there is increase in power requirement with the mouldboard plough having the highest increase in power. When speed was increased from 1.3 km/h. to 3 km/h. for disc plough, the power requirement increased from 2.911 kW to 7.048 kW resulting into an average change of 2.434 kW for the corresponding change in speed. While for the mouldboard plough the change was 3.12 kW within the same range. This shows that the mouldboard plough is more sensitive to changes in speed as compared to the disc plough and this can be attributed to fixed nature of the mouldboard bottom which leads to dragging of the soil and any other material forward at these high speeds.

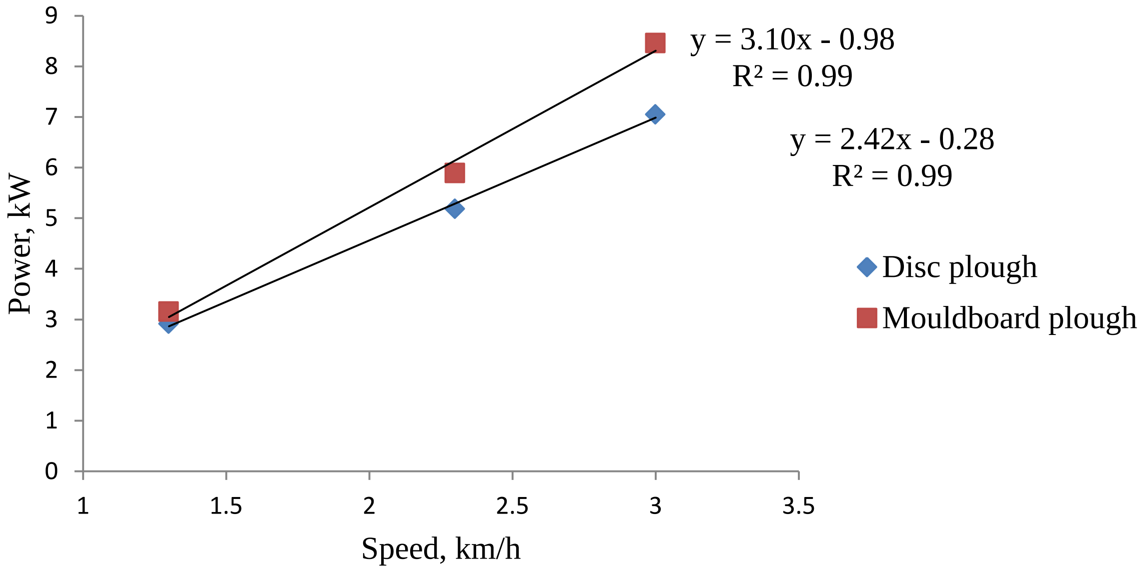

Figure 4.6: Comparison of drawbar Power based on speed

MS-Excel software was used to run statistical analysis on data to investigate the effect of depth and speed on power requirements. At 95% confidence level ($P<0.05$) the p-values were found to be less than 0.05 for all the parameters and implements used in this study. This shows that depth of tillage and speed significantly affect power requirement by disc and mouldboard plough.

Tables 4.3 and 4.4 gives an analysis of variance on the effects of depth and speed on power requirement by disc and mouldboard plough respectively.

Table 4.3: ANOVA table showing effects of parameters on power for disc plough

Source of Variation	SS	df	MS	F	P-value	F crit
depth	14.58545	2	7.292727	21.99963	0.006945	6.944272
speed	25.75471	2	12.87735	38.84652	0.002397	6.944272
Error	1.325972	4	0.331493			

Table 4.4: Effects of parameters on power requirement by mouldboard plough ANOVA

Source of Variation	SS	df	MS	F_{cal}	P-value	F crit
depth	8.014361	2	4.00718	19.43691	0.008704	6.944272
speed	42.40844	2	21.20422	102.8515	0.000364	6.944272
Error	0.824654	4	0.206163			

4.3 Development of Mathematical Model for Matching of Tractors and Implements Based on Drawbar Power and Specific Power

To be able to match implements and tractors based on power requirement a study of behavior of drawbar power requirement in cutting a unit volume of soil slice for the two implements was evaluated and a regression analysis carried out to develop a model for matching both disc and mouldboard ploughs to a tractor in silt loam soil based on depth and speed and fixed width of 80 cm.

4.3.1 Effects of Tillage Depth and Forward Speed on Specific Power by Disc and Mouldboard Ploughs

Table 4.5 shows mean values of specific drawbar power derived from drawbar power in Section 4.2 in kW/cm^3 as affected by tillage depth and speed.

Table 4.5: Mean specific drawbar power for disc and mouldboard ploughs

Implement		**Speed (km/h)**		
	Depth (cm)	1.3	2.3	3
Disc plough	6.5	92.70	97.93	102.66
	15	67.33	68.57	70.54
	22.5	55.16	53.01	56.03
Mouldboard plough	6.5	115.61	114.20	150.15
	15	72.13	76.54	81.07
	22.5	55.80	60.42	64.10

Table 4.5 shows values specific power which is represented graphically in Figures 4.7 and 4.8 for disc and mouldboard ploughs respectively. The data show a decrease in specific power with increase in tillage depth for both disc and mouldboard ploughs at a given speed of tillage. For the disc plough, specific power decreased from; 92.70 kW/m^3 to 55.16 kW/m^3, 97.93 kW/m^3 to 53.01 kW/m^3, and 102.66 kW/m^3 to 56.03 kW/m^3 as the depth was varied from 6.5 cm to 22.5 cm. Similar observations were made for the mouldboard plough where specific power decreased from; 115.61 to 55.80, 114.20 to 60.42, and 150.15 to 64.10 kJ/m^3 for the same depths. Muhsin (2017), studied effects of depth on specific power in silt loam soils and observed a decrease in specific power with increase in tillage depth using a chisel plough. He observed that by increasing ploughing depth from 10 to 20 and 30 cm, the specific power significantly decreased ($p=0.05$) from 158.60 to 135.28 and118.10 kW/m^3 respectively. Studies by Khadr (2008) also presented values that showed decrease in specific power with increase in depth of tillage for all the implements used. Since the specific power refers to the power required to cut and pulverize a unit volume of soil, the decrease could be

attributed to the increased useful work done as the depth is increased due to higher volume of soil cut and moved.

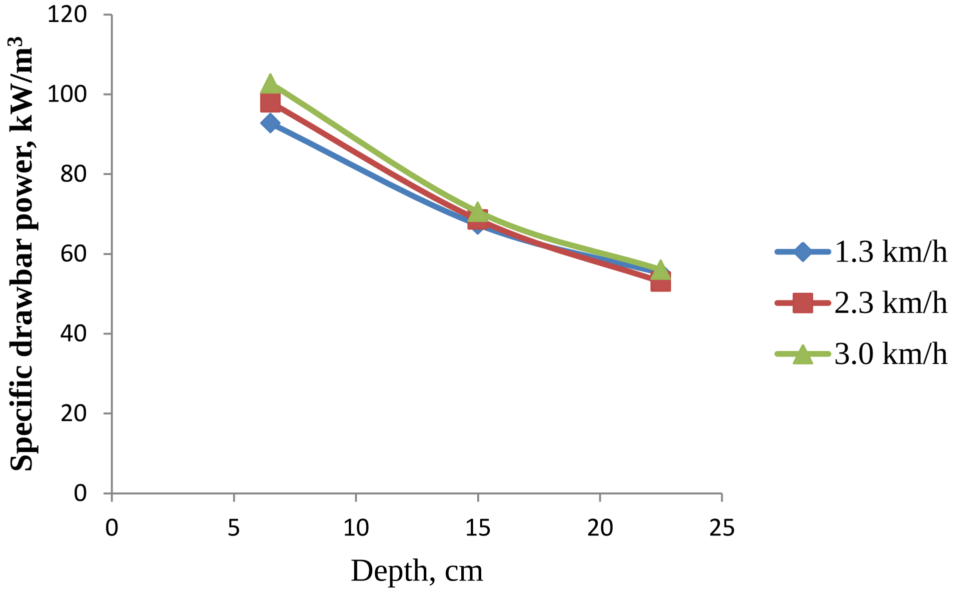

Figure 4.7: Variation of Specific power with depth of tillage for disc plough

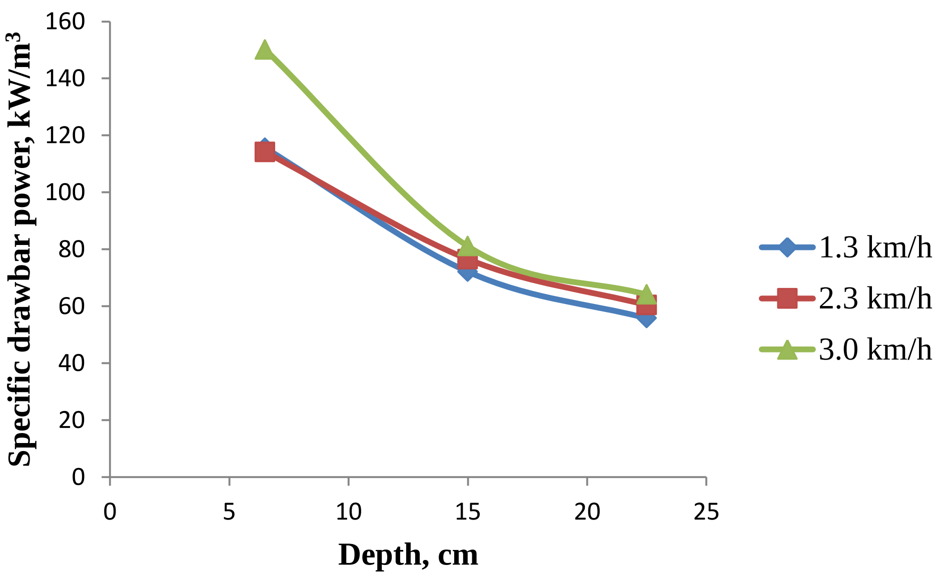

Figure 4.8: Specific power against depth of tillage for mouldboard plough

Generally specific power for soil volume was higher for mouldboard plough at all levels of the depths tested as shown on Table 4.5 and Figure 4.9. The higher values resulting from mouldboard plough can be tied to the greater power requirements at these depths as compared to the disc plough. This is directly attributed to higher drawbar power requirement by the mouldboard plough as discussed in Section 4.2.

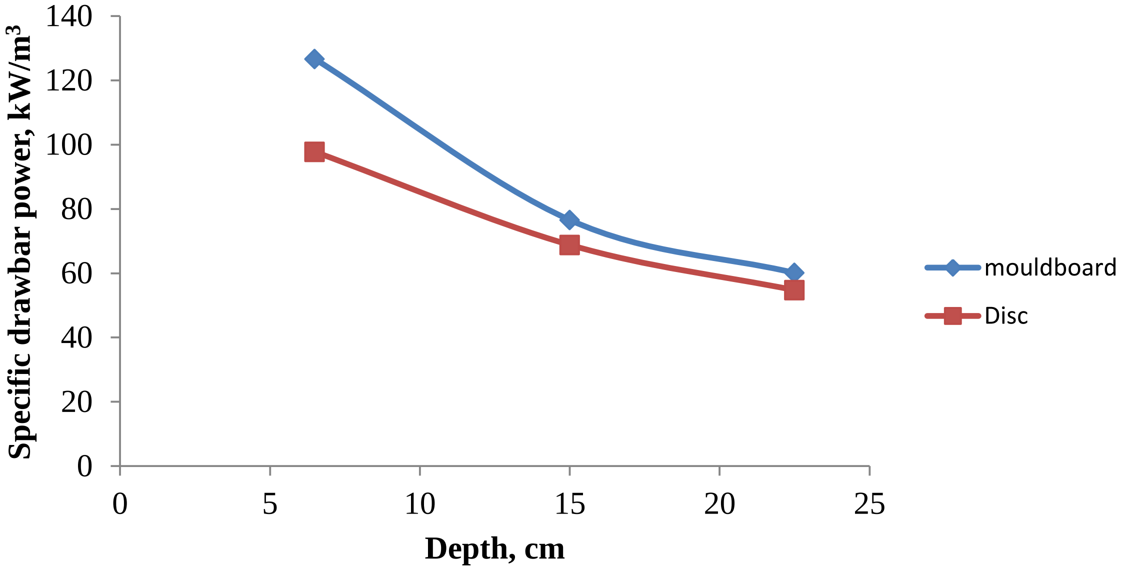

Figure 4.9: Comparison of Specific power for disc and mouldboard plough

4.3.2 Effect of speed of tillage on specific drawbar power

Table 4.5 and Figures 4.10 and 4.11 show changes in specific power with change in speed for the disc plough and mouldboard plough. Specific drawbar power increased with increase in speed from 92.70 kW/m^3 to 102.66 kW/m^3, 67.33 kW/m^3 to 70.54 kW/m^3 and 55.16 kW/m^3 to 56.03 kW/m^3 when speed was varied from 1.3 km/h to 3.0 km/h for disc plough at depths of 6.5 cm. 12.5 cm and 22.5 cm respectively. Similarly specific drawbar power increased for mouldboard plough increased from 110.61 kW/m^3 to 125.34 kW/m^3, 72.13 kW/m^3 to 81.07 kW/m^3 and 55.80 kW/m^3 to 64.10 kW/m^3 at similar depths and speed range. These results concur with studies by Muhsin (2017) and Khadr (2008) who observed increase in specific power as the speed of tillage was increased. Khadr (2008), observed an increase from 102.3 kW/m3 to 135.5 kW/m^3 and from 57.7 kW/m^{3}to 71.6 kW/m^3 as speed was increased from 3 to 6 km/h and from 4 to 7 km/h using mouldboard plough and disc harrow respectively. This increase in specific drawbar power can be attributed increased resistance to motion as the tillage implement is forced forward through the soil. Soil inertia tends to offer resistance to the cutting force of the implement, therefore higher power is required to cut and displace soil slices as speed of tillage is increased.

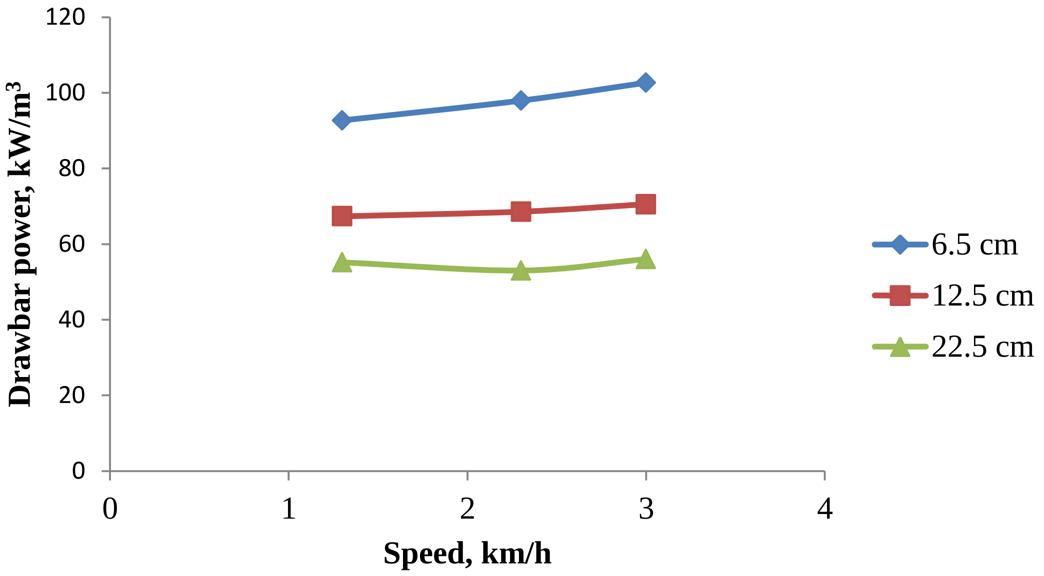

Figure 4.10: Specific power against speed for disc plough

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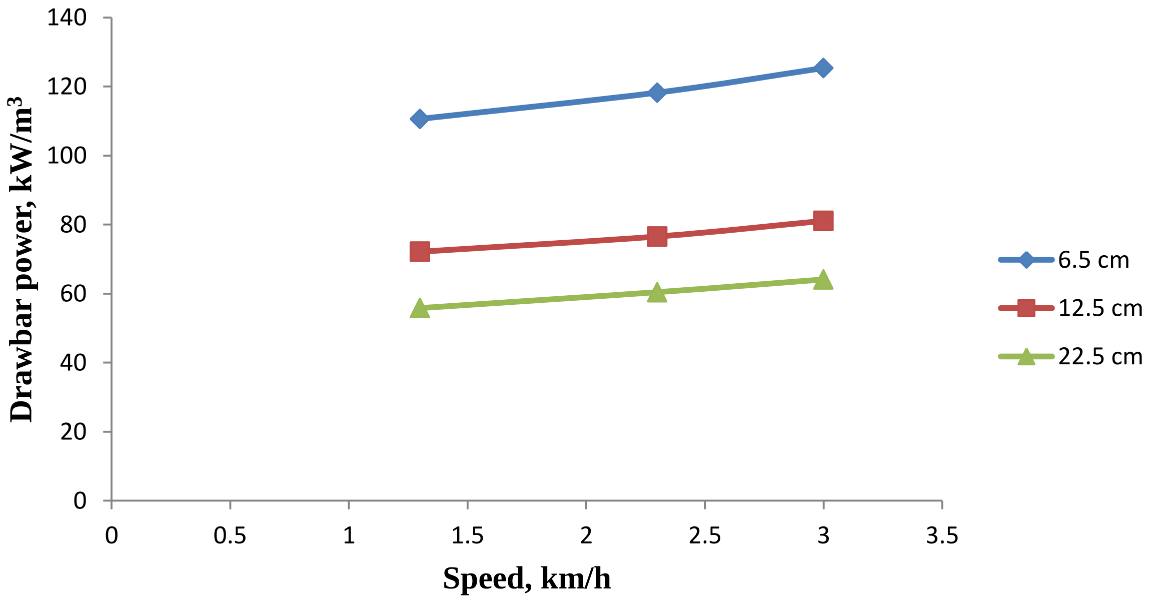

Figure 4.11: Effect of speed on Specific drawbar power for mouldboard plough

A comparison of average values of specific drawbar power for disc and mouldboard ploughs as affected by speed showed that for disc plough produced 71.73 kW/m^3, 73.17 kW/m^3 and 76.41 kW/m^3 at speeds of 1.3 km/h, 2.3 km/h and 3.0 km/h respectively. Mouldboard plough produced 79.51 kW/m^3, 85.06 kW/m^3 and 90.17 kW/m^3 at similar speeds. As shown on Figure 4.12 at all levels of speed, mouldboard plough produced higher values of specific drawbar power as compared to disc plough. Khadr (2008)and Muhsin (2017) made similar observations and found higher specific power requirements for mouldboard plough than other implements used.

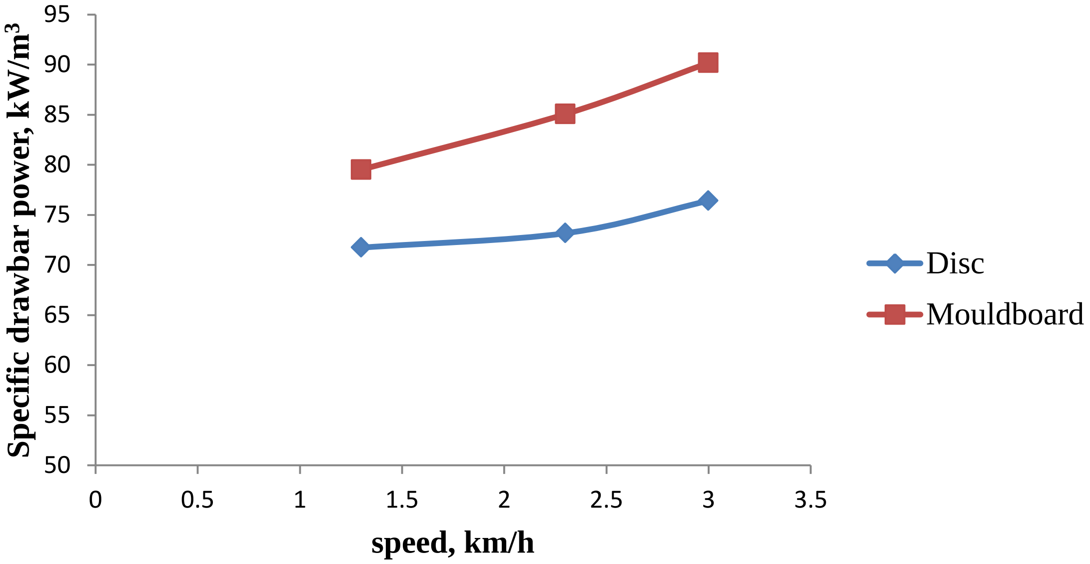

Figure 4.12: Comparison of specific power the implements based on speed

In order to develop a model for matching of the implements to tractors, regression analysis was carried out to establish a combined effect of speed and depth on power requirement and for disc plough and mouldboard plough within the speeds, depths tested and width of tillage. For the case disc plough Tables 4.6 and 4.7 give the results of the regression.

Table 4.6 Regression values on effect of depth and speed on power requirement for disc plough

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1115.56	688.52	-1.62	0.149	-2743.66	512.538	-2743.66	512.54
Depth (X_1)	149.82	39.24	3.82	0.007	57.03	242.603	57.03	242.603
Speed (X_2)	6692.45	1148.02	5.83	0.001	3977.80	9407.09	3977.80	9407.09

Tillage power equation can generally be given in the form of;

$$Y = a + bX_1 + cX_2 \qquad (4.5)$$

Where;

Y is power in Watts

a is a constant; intercept

X_1 is variable one in this case depth in cm

X_2 is variable two; speed in m/s

b and c are coefficients of the variables

From Table 4.5 intercept is found to be -1115.56 with a p-value of 0.149 which is greater than 0.05, hence it is not significant for the prediction equation. To confirm whether it is actually equal to zero a confidence interval is determined using equation 4.6;

$$CI = \bar{X} \pm t^{*}_{df, \alpha/2} \times SE \qquad (4.6)$$

From table 4.6, the error is 688.52, t-value from table is 2.365. Therefore CI is;

$CI = -1115.56 \pm 2.365 \times 688.52$ = 512.79 or -2743.91

There the intercept can be taken to be Zero because it lies between -2743.91 and 512.79 which includes zero. Values of b and c 149.82 and 6692.45 respectively, p-values are all less than 0.05 which means all the factors are significant and can be used in the equation, therefore the model for predicting drawbar power requirement for a disc plough working in silt loam soil is given by equation 4.7;

$$Y = 149.82X_1 + 6692.45X_2 \qquad (4.7)$$

Using the developed model in equation 4.7, predicted values of power for the depths and speeds were determined and compared with measured values with their residuals in Table 4.7 at various levels of combination of depth and speed and Figure 4.13 .

From Table 4.7 it can be seen that the model developed for disc plough predicts well the relationship between power of tillage as affected by depth and speed. The highest residual is 1095.87 with the lowest being -49.49 and from Figure 4.13 the model has a R^2 value of 0.89, hence the resulting model can be recommended for use to predict power requirement in silt loam soils when using disc plough at speeds between 1 km/h to 3 km/h and depths 6.5 cm to 22.5 cm.

Table 4.7 Model predicted values of power for disc plough with resulting residuals

Observation	Measured Y	Predicted Y	Residuals
1	1844	2267.53	-423.53
2	3090	3540.97	-450.97
3	3798	4664.60	-866.60
4	3463	4141.42	-678.42
5	5595	5414.86	180.14
6	6489	6538.49	-49.49
7	4725	5433.06	-708.06
8	7492	6706.50	785.50
9	8926	7830.13	1,095.87

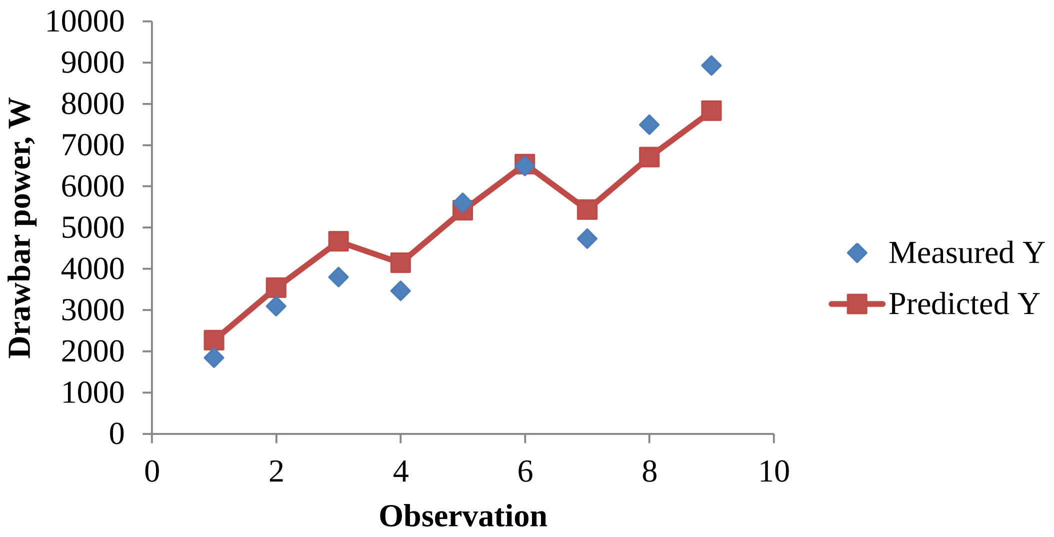

Figure 4.13: Comparison of measured and predicted drawbar power for disc plough

In the case of the mouldboard plough Table 4.8 shows the result of regression analysis giving the values of the constant and coefficients for the model. Intercept is found to be -1157.68 which lies between -2854.56 and 539.19, with a p-value of 0.151 which is greater than 0.05, it therefore taken to be zero, b is 115.75 and c is 9033.75, p-values are all less than 0.05 which means all the factors can be used in the equation, therefore the model for predicting power requirement for a mouldboard plough working in silt loam soil is given by equation 4.8;

Table 4.8 Regression values on effect of depth and speed on drawbar power for mouldboard plough

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1157.68	717.61	-1.61	0.151	-2854.56	539.19	-2854.56	539.19
Depth (X_1)	115.75	41.34	2.80	0.027	17.98	213.51	17.98	213.51
Speed (X_2)	9033.75	1195.01	7.56	0.000	6207.99	11859.51	6207.99	11859.51

$$Y = 115.75X_1 + 9033.75X_2 \quad (4.8)$$

Where; X_1, X_2 and Y are as defined before.

Using the developed model in equation 4.8, predicted values of power for the depths and speeds were determined and compared with dynamometer derived values with their residuals in Table 4.9

Table 4.9 Measured and predicted values of power for mouldboard plough

Observation	Measured Y	Predicted Y	Residual
1	2300	2846.81	-546.81
2	3310	3541.28	-231.28
3	3840	4698.73	-858.73
4	4040	5376.26	-1336.26
5	6250	6070.73	179.27
6	7400	7228.18	171.82
7	6910	7119.77	-209.77
8	8610	7814.24	795.76
9	9850	8971.69	878.31

From Table 4.9 it can be seen that the model predicts well the relationship between power of tillage as affected by depth and speed for the mouldboard plough. The highest residual is -1336.26 with the lowest being 171.82 and from Fig 4.14 showing graphical presentation of the data R^2 value is 0.98, hence the resulting model can be recommended for use to predict power requirement in silt loam soils when using mouldboard plough at speeds between 1 km/h to 3 km/h. and depths 6.5 cm to 22.5 cm.

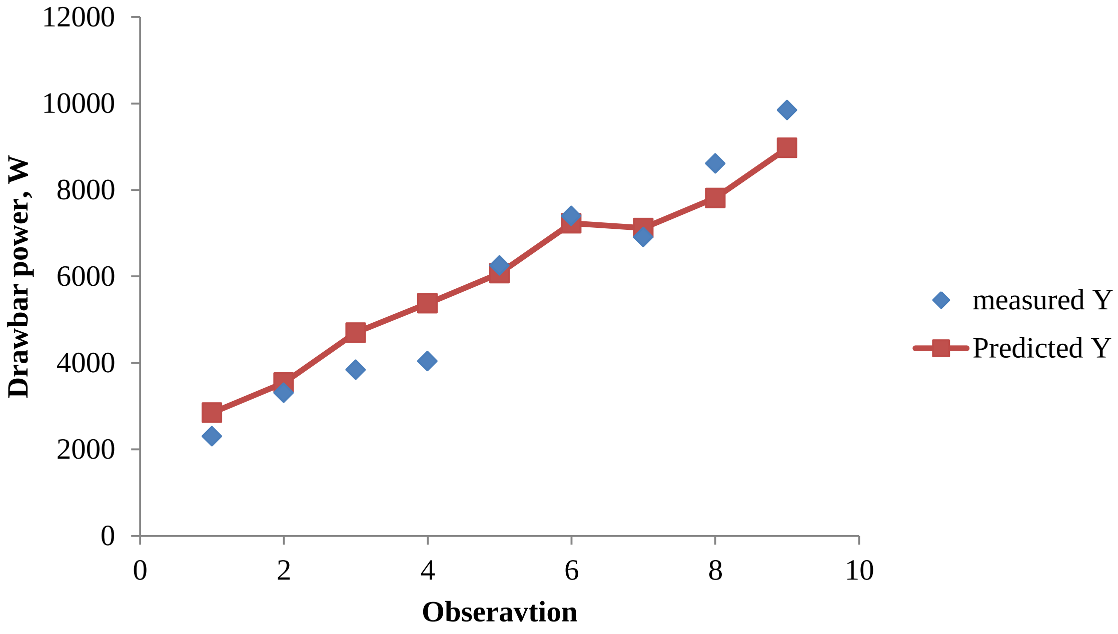

Figure 4.14: Comparison of measured and predicted drawbar power for mouldboard plough

To be able to find models that can be applied for other disc and mouldboard ploughs with varied widths working at other speeds and depth, we considered specific drawbar power. Models developed can be used to determine specific drawbar power given depth, speed and width of implement, which can then be used to know the size of tractor for that condition. Similar regressions procedure was undertaken as in determining models based on drawbar power.

For disc plough Table 4.10 shows results of regression with zero intercept and the coefficients of the independent variables. All p-values are less than the significance level of 0.05 which means they all affect specific drawbar power .Using these coefficients a model for predicting specific drawbar power can be developed as shown in equation 4.8;

$$Y_s = X_2 + 0.13X_3 - 0.27X_1 \quad (4.9)$$

Where;

Y_s is specific drawbar power in kW/cm^3

X_3 is width of implement in cm,

X_1 and X_2 are as defined before.

Table 4.10 Specific drawbar power regression values for disc plough

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth (X_1)	-0.27	0.01	-23.97	0.00	-0.30	-0.24	-0.30	-0.24
Speed (X_2)	1.00	0.38	2.61	0.04	0.06	1.94	0.06	1.94
Width (X_3)	0.13	0.00	37.71	0.00	0.12	0.14	0.12	0.14

Using equation 4.9 developed, values of specific drawbar power were generated at the levels of variables and compared with calculated values and resulting residuals also given as shown in Table 4.11 and Figure 4.15. It shows a highest residual value of -0.29 and a lower value of 0.05, the model can therefore be used to give a rough estimate of size of tractor required given a width of disc plough, depth of tillage and speed of operation in silt loam soil.

Table 4.11 Predicted and calculated values of specific drawbar power for disc plough

Observation	Measured Y	Predicted Y	Residuals
1	10.27	10.04	0.23
2	9.79	9.84	-0.05
3	9.27	9.56	-0.29
4	8.46	8.42	0.05
5	8.23	8.22	0.00
6	8.08	7.94	0.13
7	5.60	5.72	-0.12
8	5.30	5.53	-0.22
9	5.52	5.25	0.27

The model developed for disc plough shows decrease in specific drawbar power as depth is increased as shown on Figure 4.15. It decrease steeply at lower depths and starts to stabilize at 22.5 cm, since the unit increase in volume of soil cut is now almost the same as the increase in drawbar power. At lower depths the unit volume of soil increases much more than the increase in power as depth is varied. The model developed shows that about 94% of specific drawbar power can be explained by the variables, the R^2 value is 0.94.

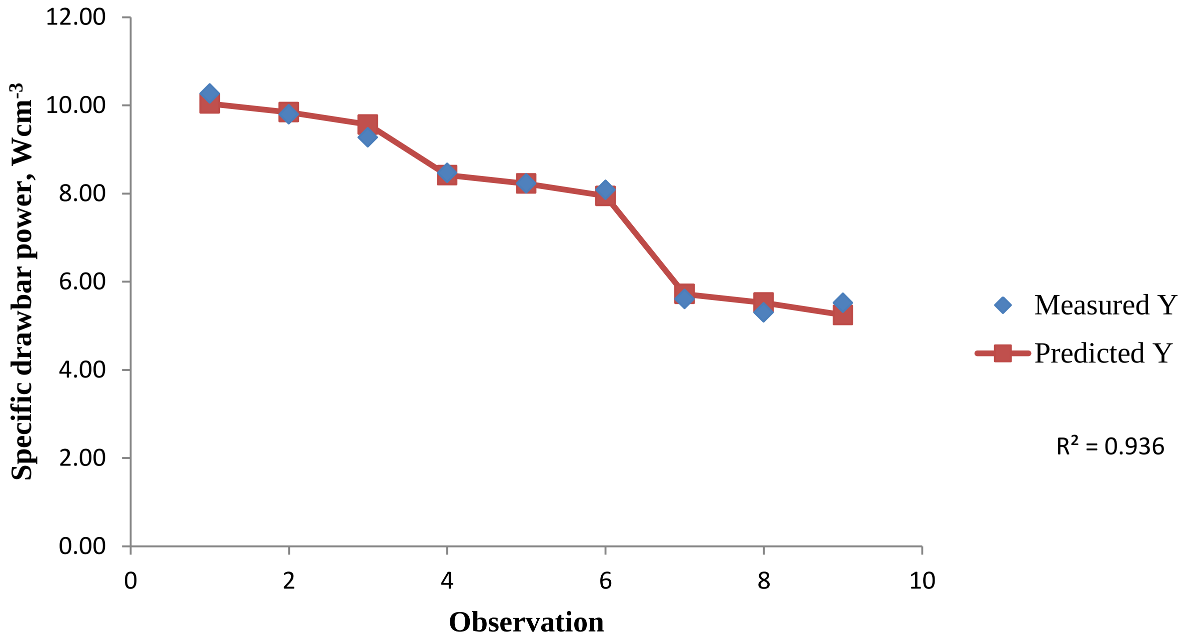

Figure 4.15: Measured and predicted specific drawbar power for disc plough

Considering disc ploughs of varied widths working at various depths and speeds, then machinery managers, farmers and decision makers can use this model to check the drawbar power required to pull the implement on similar soil under similar soil conditions. For instance, a 90 cm wide disc plough working at a depth of 30 cm and speed of 8 km/h, then the size of tractor can be determined as follows;

The first step is to determine volume of soil cut;

$$V = DWS = 90 \times 30 \times 2.22 = 5940 \text{ cm}^3$$

Then specific power is calculated using the model;

$$Y_s = 2.22 + 0.13x\ 90 - 0.27x\ 30 = 5.82 \text{ W/cm}^3$$

Then we multiply the specific drawbar power by volume of soil cut to get drawbar power (DBP) required;

$$DBP = 5.82 \text{ W/cm}^3 \text{ x } 5940 \text{ cm}^3 = 34855.08 \text{ W} = 34.89 \text{ kW (46.7 Hp)}$$

Determine the PTO power required: The final step is to determine the power that your machine should have at the power-take-off point (PTO) so that it can achieve the required power at the drawbar. This is calculated using a rule-of-thumb multiplying factor, which takes into account the type of soil condition you will experience as presented in Table 4.12.

Table 4.12: PTO power multiplication factors for different soil conditions. From (Sumner & Williams, 2007).

Soil condition	Multiply drawbar kW by
Firm, untilled soil	1.5
Previously tilled soil	1.8
Soft or sandy soil	2.1

For mouldboard plough Table 4.13 shows results of regression with zero intercept and the coefficients of the independent variables. All p-values are less than the significance level of 0.05 which means they all affect specific drawbar power .Using these coefficients a model for predicting specific drawbar power can be developed as shown in equation 4.10;

$$Y_s = 3.43X_2 + 0.15X_3 - 0.41X_1 \quad (4.10)$$

Table 4.13 Specific drawbar power regression values for mouldboard plough

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth (X_1)	-0.41	0.05	-7.61	0.00	-0.54	-0.28	-0.54	-0.28
Speed (X_2)	3.43	1.83	1.87	0.01	-1.06	7.92	-1.06	7.92
Width (X_3)	0.15	0.02	9.23	0.00	0.11	0.19	0.11	0.19

The coefficients of variables show that increase in speed and width both lead to increase in specific drawbar power while increase in depth of tillage lead to reduction in specific drawbar power. This concurs with the discussions on effects of speed and depth on specific drawbar power. For both disc and mouldboard plough per unit change in depth has the highest effect on the predicted value of specific power.

A model represented by equation 4.10 was used to generate values of specific drawbar power at the levels of variables and compared with calculated values and their resulting residuals also given as shown in Table 4.14 and presented graphically on Figure 4.16. It shows a high residual value of 1.98 and a lower value of 0.14, the model can therefore be used to give an estimate of size of tractor required given a width of mouldboard plough, depth of tillage and speed of operation in silt loam soil. The coefficient of determination (R^2) of the model is 0.97 which shows the data are 97% fitted to the regression line.

Table 4.14 Predicted and calculated values of specific drawbar power for mouldboard plough

Observation	Measured Y_s	Predicted Y_s	Residuals
1	15.01	13.04	1.98
2	11.42	12.38	-0.96
3	11.56	11.42	0.14
4	9.73	10.57	-0.84
5	9.19	9.91	-0.73
6	8.66	8.95	-0.29
7	6.18	6.46	-0.28
8	6.04	5.80	0.24
9	5.58	4.84	0.74

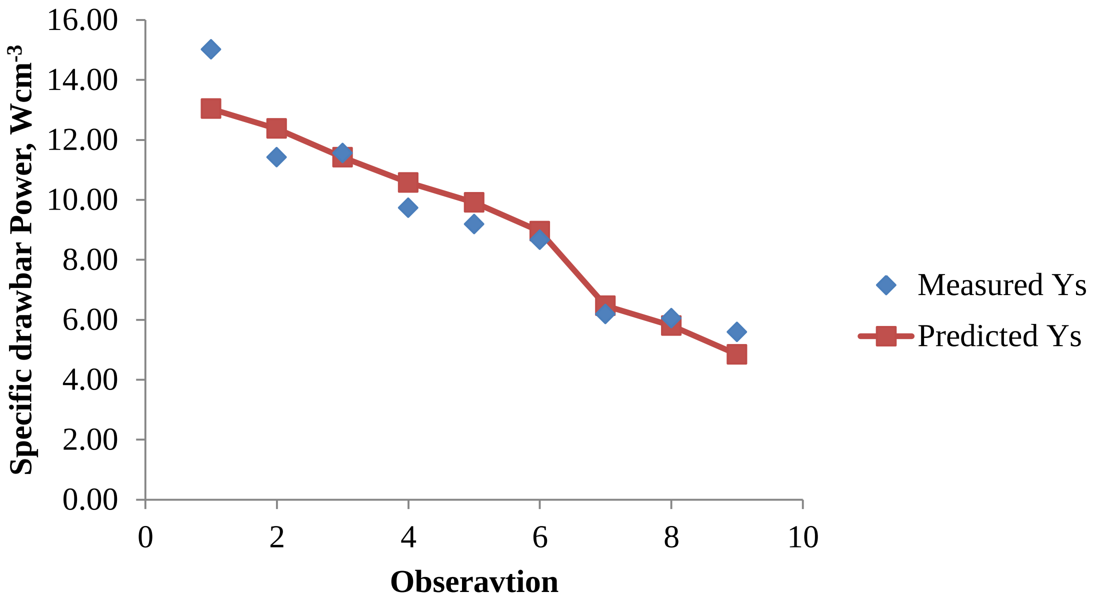

Figure 4.16: Measured and predicted specific drawbar power for mouldboard plough

Taking a similar case study as with the disc plough, then the size of tractor required to pull a 90 cm mouldboard plough in silt loam soil working at a depth of 30 cm at a speed of 8 km/h is determined using the model in equation 4.10 as follows;

The first step is to determine volume of soil cut;

$V = DWS = 90 \times 30 \times 2.22 = 5940 \text{ cm}^3$

Then specific power is calculated using the model;

$Y_s = 3.43 \times 2.22 + 0.15 \times 90 - 0.41 \times 30 = 8.81 \text{W/cm}^3$

Then we multiply the specific drawbar power by volume of soil cut to get drawbar power (DBP) required;

DBP = 8.81 W/cm^3 x 5940 cm^3 = 52358.72 W = 52.36 kW (70.2 Hp)

4.4 Effects of depth and speed on performance of mouldboard and disc plough.

4.4.1 Effects of speed on performance of tillage implements

This was evaluated based on pulverization ratio and inversion of soil, trench formed and resulting specific resistance. Pulverization and soil inversion were better in mouldboard plough than in disc plough as shown in Figure 4.17. The level of soil inversion and pulverization for both the implements increased with speed which can be attributed to increased vibration as the plough bottom advances forward. This is in agreement with studies by (Ahaneku and Ogunjirin (2005)) who observed increased pulverization with speed.

The soil pulverization ratio is defined as percentage of the weight of soil fraction which is less than 25 mm diameters to the total weight of clods produced during ploughing. The data on effect of forward speed on the soil pulverization ratio is presented in Table 4.15 and Figure 4.18. The soil pulverization ratio significantly increased ($P \leq 0.05$) as the forward speed increased. It increased from 0.23 to 0.28 and 0.36 and from 0.26 to 0.34 and to 0.42 when the forward speed increased from 1.3 to 2.3 and 3.0 km/h, for disc and mouldboard ploughs respectively. According to Muhsin (2017) increased soil clods acceleration and movement when speed is increase causes an increase in collision of the soil plots, hence causing the soil plots to break up into smaller pieces resulting.

Generally the mouldboard plough had high pulverization ratio at every level of tillage speed as compared to the disc plough. The geometry of the mouldboard plough bottom is such that it has a wide area of contact between the tool and soil slice which increases the vibration and hence particle breakdown. The rolling bottom of the disc plough reduces the contact time of the cut soil slice with the plough bottom.

Table 4.15: Pulverization Ratios at various speeds

Speed (Km/h)	Pulverization ratio	
	Disc plough	Mouldboard plough
1.3	0.23	0.26
2.3	0.28	0.36
3	0.36	0.42

Figure 4.17: soil inversion by disc (A) and mouldboard (B) ploughs at a speed of 1.3km/h. and depth 12.5cm

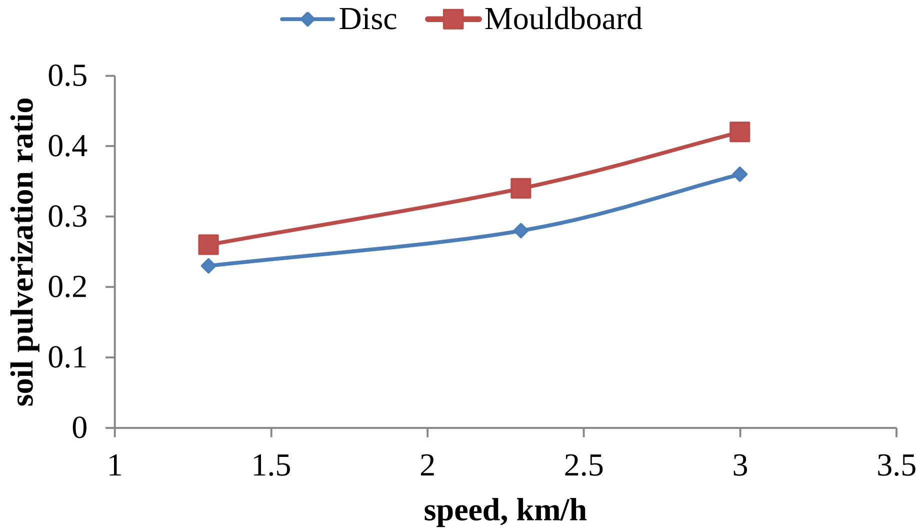

Figure 4.18 Soil pulverization ratio against speed for disc and mouldboard ploughs

4.4.2 Effects of depth on performance of tillage implements

Results of furrow cross-section and total draught were used to compute specific resistance of the soil as affected by tillage depth for the two implements used and results represented in Table 4.16. Trench specific resistance was slightly lower for mouldboard plough than disc plough at all levels of depths tested. Specific resistance decreased as the depth of tillage was increased. This could be due to increased disturbed area of soil as we move deeper into the soil more than the increase in draught. Reducing the magnitude of the specific resistance (draught force/disturbance) is a better indicator of overall tillage efficiency

Table 4.16: specific resistance as affected by depth of tillage for disc and mouldboard plough

	Depth (cm)	Total draught (kN)	Disturbed area (m^2)	Specific resistance (kN/m^2)
Disc plough	6.5	9.29	0.200	46.45
	12.5	14.98	0.32	44.06
	22.5	17.79	0.42	42.36
Mouldboard plough	6.5	12.27	0.28	43.81
	12.5	16.82	0.39	43.13
	22.5	19.525	0.48	40.69

It was also observed that as the depth of tillage was increased inversion of the slices cut were not fully achieved at low speeds instead the cut slices fell back onto the furrows.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study was undertaken with the aim of establishing the effects of tillage depth and forward speed on drawbar power requirement and performance of disc and mouldboard ploughs in silt loam soil and to develop a mathematical model to help in matching tillage implements to tractors. Results of soil tests in preliminary study showed that it was homogeneous and in good soil working conditions. Based on the objectives of the study, results and discussions herein, the following conclusions may be derived;

1. Increasing tillage depth and forward speed both led to increase in drawbar power requirement for the implements. The mouldboard plough had highest values of power requirement at all levels of the parameters investigated
2. Specific drawbar power was found to increase with increase in speed while it reduced as the tillage depth was increased at a given constant speed.
3. The mathematical models developed based on specific drawbar power for the implements both predicted had minimal residual values and fitted well onto the measured data.
4. For both implements soil pulverization ratio increased with increase in speed while trench specific resistance decreased with increase in tillage depth. Mouldboard plough had better soil inversion at all levels of speed and depth of tillage tested as compared to disc plough.

5.2 Recommendations

Based on the findings of this study the following recommendations can be made;

1. From the findings on the effect of speed on power requirement by both the implements studied, there seemed to be steady increase in power beyond the speeds tested hence more studies could be carried out at higher speeds to check the trend.
2. This study has established a decrease in specific power with increasing tillage depth however more studies should be carried to investigate the influence of tillage depth on specific power for various tillage implements and soil types.
3. More studies are recommended under similar conditions to verify the models developed in this research.
4. The observations of the study revealed that at a depth of 22.5 cm and speeds of tillage used, there was partial inversion of slices cut and low pulverization of the soil, therefore,

more studies are needed to investigate effects of increasing speed on soil slice inversion and pulverization for different soils at similar depths.

Therefore, based on the tillage power and specific power disc ploughs should be encouraged to minimize the cost of tillage. While looking at the field in terms of soil particle inversion and pulverization in primary tillage then shallow mouldboard tillage should be encouraged to take advantage of good inversion properties which leads to increased organic matter decomposition in the field and this would further reduce the cost of secondary tillage.

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APPENDICES

APPENDIX A: Sample data sheets

Table A.1: Sample excel output data on calculated draught power from the measured force

Gross force KN	Towed force KN	Net Force	Speed m/s	Draught Power KW
plot 15(0-10)s1				
7	1.56	5.44	0.36	1.96
6	1.56	4.44	0.36	1.96
6	1.56	4.44	0.36	1.96
7.68	1.56	6.12	0.36	2.20
8	1.56	6.44	0.36	2.32
7	1.56	5.44	0.36	1.96
5.7	1.56	4.14	0.36	1.49
6	1.56	4.44	0.36	1.96
7.46	1.56	5.9	0.36	2.12
7	1.56	5.44	0.36	1.96
7.88	1.56	6.32	0.36	2.28
8	1.56	6.44	0.36	2.32
8	1.56	6.44	0.36	2.32
6.62	1.56	5.06	0.36	1.82
6	1.56	4.44	0.36	1.60
7	1.56	5.44	0.36	1.96
8	1.56	6.44	0.36	2.32
8.04	1.56	6.48	0.36	2.33
7.02	1.56	5.46	0.36	1.97
7.34	1.56	5.78	0.36	2.08

Table A.2: Standard deviation and Error on draught power for mouldboard plough

		mouldboard plough						
						Average	Std. Deviation	Standard error
		Trials	P1	P15	P7			
S1	d1	1	1.60	1.99	1.82			
		2	2.08	1.85	1.72			
			1.84	1.92	1.77	1.84	0.07	0.04
	d2	1	3.46	3.07	3.28			
		2	3.22	2.60	2.96			
			3.34	2.84	3.10	3.09	0.25	0.15
	d3	1	3.85	2.67	3.79			
		2	4.08	3.58	1.75			
			3.96	3.12	2.77	3.29	0.61	0.35
			p8	p3	p13			
S2	d1	1	3.80	3.74	3.14			
		2	0.00	2.78	3.51			
			3.80	3.26	3.33	3.46	0.29	0.17
	d2	1	6.39	5.19	5.48			
		2	5.78	5.16	5.58			
			6.09	5.17	5.53	5.60	0.46	0.27
	d3	1	6.95	5.45	5.96			
		2	7.36	5.52	5.90			
			7.16	5.48	5.93	6.19	0.87	0.50
S3	d1	1	5.68	5.05	4.56			
		2	4.66	4.36	4.05			
			5.17	4.70	4.30	4.73	0.43]	0.25
	d2	1	7.51	7.16	7.39			
		2	8.15	6.86	7.89			
			7.83	7.01	7.64	7.49	0.43	0.25
	d3	1	8.54	7.99	9.44			
		2	7.90	8.01	8.05			
			8.22	8.00	8.75	8.32	0.39	0.22

Table A.3: Sample excel data on field bulk density

Bulk Densities								
Plot 1			Plot 7			Plot 8		
Mass (g)	Volume (cm^3)	Density (g/cm^3)	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Mass(g)	Volume (cm^3)	Density (g/cm^3)
108	85.46	1.26	118	85.46	1.38	120	85.46	1.40
123	85.46	1.44	104	85.46	1.22	138	85.46	1.62
105	85.46	1.23	111	85.46	1.30	97	85.46	1.14
112	**85.46**	**1.31**	**111**	**85.46**	**1.30**	**118.33**	**85.46**	**1.39**

N/B: Bolded values represent the averages used.

APPENDIX B: Sample field operation photos

Figure B.1: Pegging for plots demarcation

Figure B. 2: Setup of the two tractors and dynamometer system

Figure B.3: Sample output image on slices inversion by disc plough and mouldboard plough from left to right respectively

Figure B.4: A 3- Bottom disc plough attached to the three point hitch system of the tractor

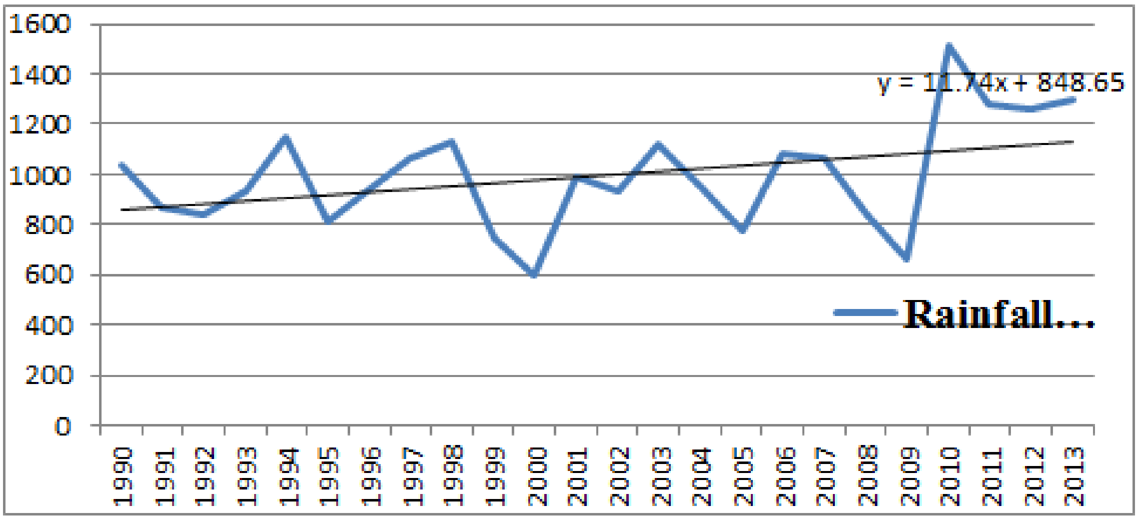
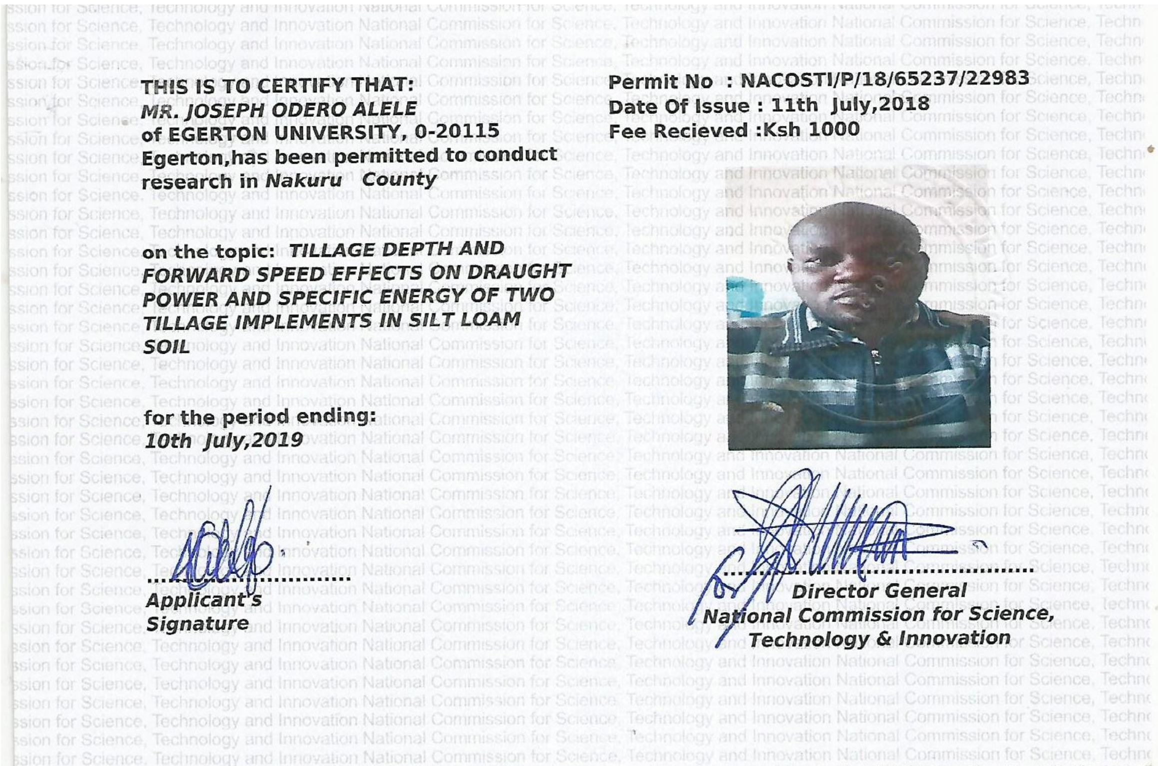


Figure B5**: Rainfall data for Njoro: 1990-2013 – Source, KALRO Njoro**

APPENDIX C: NACOSTI Authorization documents



THIS IS TO CERTIFY THAT:
MR. JOSEPH ODERO ALELE
of EGERTON UNIVERSITY, 0-20115
Egerton,has been permitted to conduct
research in *Nakuru County*

on the topic: *TILLAGE DEPTH AND FORWARD SPEED EFFECTS ON DRAUGHT POWER AND SPECIFIC ENERGY OF TWO TILLAGE IMPLEMENTS IN SILT LOAM SOIL*

for the period ending:
10th July,2019

Permit No : NACOSTI/P/18/65237/22983
Date Of Issue : 11th July,2018
Fee Recieved :Ksh 1000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

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Ref: No. **NACOSTI/P/18/65237/22983**

Date: **11th July, 2018**

Joseph Odero Alele
Egerton University
P.O. Box 536-20115
NJORO

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Tillage depth and forward speed effects on draught power and specific energy of two tillage implements in silt loam soil"*** I am pleased to inform you that you have been authorized to undertake research in **Nakuru County** for the period ending **10th July, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Nakuru County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

DR. STEPHEN K. KIBIRU, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Nakuru County.

The County Director of Education
Nakuru County.

APPENDIX D: Publication Abstract

Effects of tillage depth and forward speed on draught power of primary tillage implements were studied using a pull dynamometer in silt loam soil. The implements used were a standard 2-bottom mouldboard plough and a 3-bottom disc plough. Tillage depths of 6.5 cm, 12.5 cm and 22.5 cm and speeds of 1.3 m/s, 2.3 m/s and 3.0 m/s were used. The effects of the treatments were studied using randomized blocks. There was significant increase in draught power with increase in tillage depth and forward speed at all the levels of the treatments tested for both the ploughs used. It was also noted that the draught power for mouldboard plough was higher than that in the disc plough at all levels of the parameters tested. Power requirement for mouldboard plough changed from 4.416 kW to 7.029 kW when tillage depth was varied from 6.5 cm to 22.5 cm. This results into an increase of 0.163 kW per unit change in depth of tillage. For the case of disc plough it increased from 3.344 kW to 6.404 kW which is equivalent to an increase of 0.191 kW. When speed was increased from 1.3 km/h. to 3 km/h. for disc plough power requirement increased from 2.911 kW to 7.048 kW resulting into an average change of 2.434 kW for the corresponding change in speed. While for the mouldboard plough the change was 3.12 kW within the same range.